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Requirements for the safe management of radioactive waste

*Proceedings of a seminar
held in Vienna, 28–31 August 1995*



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Radiation Safety Section
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FOREWORD

This publication contains the proceedings of the Seminar on Requirements for the Safe Management of Radioactive Waste held from 28 to 31 August 1995 in Vienna.

Human activities and practices, particularly those related to industrial processes, generate waste. The production of nuclear energy and the use of radioactive materials in industrial applications, research and medicine generate radioactive waste. The importance of safe management of radioactive waste for the protection of human health and the environment has long been recognized and considerable experience has been gained in this field.

Sufficient progress has to be achieved in managing all types of radioactive waste to assure protection of human health and the environment now and in the future if nuclear energy is to be considered as a generally acceptable source of electricity generation.

The IAEA is regularly requested to assist Member States in providing evidence that radioactive waste can be managed safely and to help demonstrate that there is harmonization of approach at the international level by promulgating radioactive waste management standards.

More than forty publications have been issued by the IAEA on the subject of radioactive waste management. Moreover, the IAEA is promoting the Radioactive Waste Safety Standards (RADWASS) Programme that establishes, in a coherent and comprehensive manner, the basic safety philosophy for radioactive waste management and the steps necessary to assure its implementation. It is intended that the RADWASS publications will reflect the existing international consensus in the approaches and methodologies for safe radioactive waste management and will provide assistance to Member States in the derivation or implementation of national criteria, standards and practices.

Furthermore, the IAEA General Conference in 1993 adopted a resolution calling for the preparation of a Convention on the Safe Management of Radioactive Waste as soon as the ongoing process of developing waste management Safety Fundamentals had resulted in broad international agreement. The RADWASS Safety Fundamentals document was approved and published in 1995 and preparations for the Convention on the Safe Management of Radioactive Waste are in progress.

The Seminar summarizes the experience gained up to date in the safe management of radioactive waste. The papers were presented by outstanding invited speakers from Member States. It is expected that the outcome of the presentations and discussions of the broad set of issues on radioactive waste management included in this publication will be used in the preparation process of the Convention on the Safe Management of Radioactive Waste.

The information provided in this publication has been arranged as follows: The first part includes the opening statement and three topical presentations in the opening session and the paper on radioactive waste management as part of the environmental protection. The second, third and fourth parts include papers dealing with planning for safety, experience in the safe management of radioactive waste and radioactive waste management issues, respectively. The fifth part contains the summaries of the three sessions, including the respective panel discussions, provided by the chairmen of each session. Finally, the sixth part incorporates statements by panelists and is a summary of the panel discussions provided by the respective chairmen on three topics: "Implications of Treating Spent Fuel as High Level Waste", "Residues from Past Activities and Accidents" and "Exclusion, Exemption and Clearance of Materials from Nuclear Regulatory Control".

The IAEA wishes to thank the Bundesamt für Strahlenschutz for hosting and sponsoring the preparatory meeting for the Seminar.

EDITORIAL NOTE

In preparing this publication for press, staff of the IAEA have made up the pages from the original manuscripts as submitted by the authors. The views expressed do not necessarily reflect those of the governments of the nominating Member States or of the nominating organizations.

Throughout the text names of Member States are retained as they were when the text was compiled.

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SUMMARY

Radioactive waste arises from the generation of nuclear power and the use of radioactive materials in industry, research and medicine. The importance of the safe management of such waste has long been recognized and considerable experience has been gained in this field.

The IAEA initiated the Radioactive Waste Safety Standards (RADWASS) programme which is aiming at establishing a coherent and comprehensive set of principles and standards for the safe management of radioactive waste within a consistent set of documents that reflect an international consensus. Furthermore, the IAEA General Conference adopted a resolution calling for the preparation of a Convention on the Safe Management of Radioactive Waste. The process for drafting the waste safety convention has been initiated.

The Seminar on Requirements for the Safe Management of Radioactive Waste was organized to serve multiple purposes. It was intended to provide results obtained in the RADWASS programme; to summarize achievements of Member States on the safe management of radioactive waste; and to provide background material that could be used by the drafters of the above mentioned convention. The Seminar was held in Vienna from 28 to 31 August 1995 in Vienna. More than 160 experts from 52 Member States and international organizations attended.

After the opening session and the keynote address on "Radioactive Waste Management as Part of Environmental Protection" the papers presented during the Seminar covered the following areas: "Planning for Safety"; "Experience in the Safe Management of Radioactive Waste"; and "Radioactive Waste Management Issues" which included "Management Strategies"; "Safety of Repositories"; and "Regulation and Compliance". The Seminar included also three panel discussions on the "Status of International Consensus" and panel discussions on "Implication of Treating Spent Fuel as High Level Waste"; "Residues from Past Activities and Accidents"; and "Exclusion, Exemption and Clearance of Materials from Nuclear Regulatory Control". During the meeting in July 1995 it became obvious that these three topics were of particular importance for the waste safety convention. The Seminar comprised invited presentations only which were given by senior international experts in the field of radioactive waste management.

The Seminar showed that it is important in radioactive waste management to have the foresight to consider the impacts of our actions on people and the environment far into the future. Although it is true that archaeologists are delighted in finding our ancestor's trash, radioactive waste can most assuredly not be left for archaeologists to stumble across many years from now. Most importantly, the foresight is necessary to recognize and manage the uncertainties associated with safe management of radioactive waste, in particular as these uncertainties increase in the far future. Although it is not possible to fully understand the implications of present day activities for the far future, the objective should be to provide the level of protection that is acceptable today for future generations, on the basis of current knowledge.

The foresight to enable the safe management of radioactive waste should have been available for decades but its wisdom has in several cases only been recognized in recent years. Lessons have to be learned from the past and restorations of past practices have to be carried out today. The foresight to avoid new mistakes in the future is an essential component of radioactive waste management activities.

It was acknowledged in the Seminar that a milestone on the path to international consensus on radioactive waste management was reached with the publication of the RADWASS Safety Fundamentals and the Safety Standard S-1 on the national radioactive waste management system. The nine principles established in the Fundamentals document provide a sound basis for safe radioactive waste management. The principles developed and the recognition of the need for an international waste safety convention provide the kind of vision needed in order to meet the responsibility to manage radioactive waste safely now and in the future.

OPENING SESSION

Chairmen

F. L. PARKER
United States of America

A.C. LACOSTE
France

OPENING STATEMENT

B.A. Semenov
International Atomic Energy Agency,
Vienna

Management of radioactive wastes generated from the production of nuclear energy and from the use of radioactive materials in industrial applications, research and medicine has always been recognized by the Agency as an issue of utmost importance for the protection of human health and the environment now and in the future. It is also an important issue for the future use of nuclear energy.

At the request of Member States, the IAEA has established RADWASS, the Radioactive Waste Safety Standards Programme to provide evidence that radioactive waste can be managed safely and to help demonstrate a harmonization of approaches to waste management at an international level. Essential progress in achieving international consensus has been made with the approval of the two top ranking documents, the Safety Fundamentals "The Principles of Radioactive Waste Management" and the Safety Standard on "Establishing a National System for Radioactive Waste Management", by the Board of Governors in March 1995. It is my hope that it will be possible to have these two documents printed before the General Conference, that would mean by the middle of September. Also this Seminar can be a forum for enhancing international consensus and I would be highly interested to hear, at the end of the meeting, to what degree consensus on waste management issues has been achieved.

Such consensus is important for the "Convention on the Safety of Radioactive Waste Management" which has been initiated, as a first step, with a preparatory discussion in February 1995 and then with a first meeting of an open-ended group of experts in July 1995. As a consequence of the latter meeting three panel discussions have been added to the programme of the Seminar in order to provide a forum for the discussion of the following issues which turned out to be important for the convention:

- Implications of treating spent fuel as high level waste;
- Residues from past activities and accidents; and
- Exclusion, exemption and clearance of materials from nuclear regulatory control.

The outcome of these panel discussions and of the whole Seminar will provide material which may be used by Member States to provide impetus into the waste management safety convention. The papers presented at the Seminar and reports of the respective chairmen on the panel discussions will be published as an IAEA-TECDOC which will be available as a reference document.

The preparation for the Seminar has already been initiated in November 1993. The Agency was assisted in the development of the concept, contents, programme and organization of the Seminar by a Sub-group of the International Radioactive Waste Management Advisory Committee (INWAC). It was proposed to organize the Seminar in such a way that the papers will be presented in invited lectures by senior experts from Member States and the IAEA. The further preparation of the Seminar was carried out by a steering committee and with the involvement of INWAC or later the extended INWAC.

A preparatory meeting, hosted and sponsored by the Bundesamt für Strahlenschutz, was held in April 1995 in Salzgitter, Germany in order to finalize the programme of the Seminar, to harmonize the papers in order to avoid unnecessary overlaps and to provide, as necessary, additional input into the papers.

THE SAFETY STANDARDS PREPARATION AND REVIEW PROCESS

A. Carnino
International Atomic Energy Agency,
Vienna

1. BACKGROUND

In 1974, the Agency launched the Nuclear Safety Standards (NUSS) programme for the purpose of establishing internationally agreed safety standards for land-based thermal-neutron power reactors; the resulting codes and guides were published in the Safety Series.

In addition, over the years the Agency published a considerable number of other documents in the Safety Series, including successive editions of its "Regulations for the Safe Transport of Radioactive Materials".

In 1989, following a major expansion of the Agency's safety-related activities, the Secretariat introduced a hierarchical structure for Safety Series publications, which are now divided into:

- *Fundamentals*, stating basic objectives, concepts and principles;
- *Standards*, stating basic requirements which must be fulfilled in the case of particular activities or applications;
- *Guides*, containing recommendations related to the fulfilment of the basic requirements stated in the Standards; and
- *Practices*, giving examples and detailed descriptions of methods which can be applied in implementing both the Standards and the Guides.

Fundamentals and Standards require the approval of the Board of Governors. Guides and Practices are issued under the authority of the Director General.

The Agency's Safety Series currently contains over 200 publications covering nuclear safety, radiation protection, radioactive waste management, radioactive materials transport, the safety of fuel cycle facilities and quality assurance.

2. RESPONSIBILITY FOR PREPARATION AND REVIEW

As of 1 January 1996, the Deputy Director General of the Department of Nuclear Safety - which is to be created with effect from that date - will have responsibility for the preparation and review of the Agency's Safety Series publications, although, for programmatic reasons, Safety Series publications relating to the safety of fuel cycle facilities and to quality assurance will be prepared outside that Department.¹

3. THE PREPARATION AND REVIEW PROCESS

In the past, there have been different processes for the preparation and review of Safety Series publications in the different safety-related areas in which the Agency is involved, with a resulting lack

¹During the second half of 1995, the preparation and review of safety standards documents are being carried out under the authority of the Director of the Division of Nuclear Safety in order to ensure that the documents are properly harmonized and to avoid undue delays.

of compatibility between some Safety Series publications. The Secretariat is therefore introducing a uniform preparation and review process covering all areas.² To this end, it has been decided to:

- create a set of advisory bodies with harmonized terms of reference to assist the Secretariat in preparing and reviewing all documents;
- assign a Scientific Secretary from the Agency's staff to each of these bodies; and
- appoint a Technical Officer from the Agency's staff for the preparation of each document.

The preparation and review process will involve:

- organizing expert group meetings whenever necessary;
- arranging at different document preparation stages for an internal review of each draft text by the Safety Series Review Committee;
- submitting documents to the relevant advisory committees for review;
- submitting draft texts to the Agency's Member States for comment;
- obtaining the Publications Committee's approval of each document in order to ensure compliance with the Agency's publication policy;
- submitting the Fundamentals and Standards to the Board of Governors for approval after endorsement by the Advisory Commission for Safety Standards (ACSS); and
- submitting the Guides and Practices to the Director General for approval.

The Technical Officers will be responsible for ensuring that documents are prepared or reviewed expeditiously and that they are technically sound. They will also be responsible for ensuring that all documents requiring approval by the Board of Governors are circulated to Member States for comment at an early stage of preparation or review.

The Safety Series Review Committee, an internal Secretariat body, will be responsible for ensuring the consistency of all documents and for monitoring the implementation of the safety standards development programme. Chaired by the head of the organizational unit responsible for co-ordination in the new Department of Nuclear Safety, it will be composed of the Scientific Secretaries of the above-mentioned advisory bodies, the Agency's Chief Editor and the Technical Officer responsible for the document being considered.

4. THE ADVISORY BODIES

The following set of advisory bodies with harmonized terms of reference is being created: the Advisory Commission for Safety Standards, and an Advisory Committee in the areas of Nuclear Safety, Radiation Safety, Transport Safety and Waste Safety. In this paper the functions of the waste safety advisory committee specifically addressed but similar functions are attributed to the other Committees.

²The process is illustrated in the Attachment.

4.1. Advisory Commission for Safety Standards (ACSS)

The Advisory Commission for Safety Standards (ACSS) is a standing body of senior government officials holding national responsibilities for establishing standards and other regulatory documents relevant to nuclear, radiation, waste and transport safety.

The ACSS has a special overview role with regard to the Agency's safety standards and provides advice to the Director General on the overall safety-standards-related programme.

The functions of the ACSS are:

- to provide guidance on the approach and strategy for establishing the Agency's safety standards, particularly in order to ensure coherence and consistency between them;
- to resolve outstanding issues referred to it by any advisory committee involved in the Agency's safety standards preparation and review process;
- to endorse, in accordance with the Agency's safety standards preparation and review process, the texts of the Fundamentals and Standards to be submitted to the Board of Governors for approval and determine the suitability of Guides and Practices to be issued under the responsibility of the Director General; and
- to provide general advice and guidance on safety standards issues, relevant regulatory issues and the Agency's safety standards activities and related programmes, including those for promoting the worldwide application of the standards.

4.2. Waste Safety Standards Advisory Committee (WASSAC - formerly the "extended INWAC")

The Waste Safety Standards Advisory Committee (WASSAC) is a standing body of senior regulatory officials with technical expertise in radioactive waste safety.

WASSAC provides advice to the Secretariat on the overall radioactive waste safety programme and has the primary role in the development and revision of the Agency's radioactive waste safety standards.

The functions of WASSAC are:

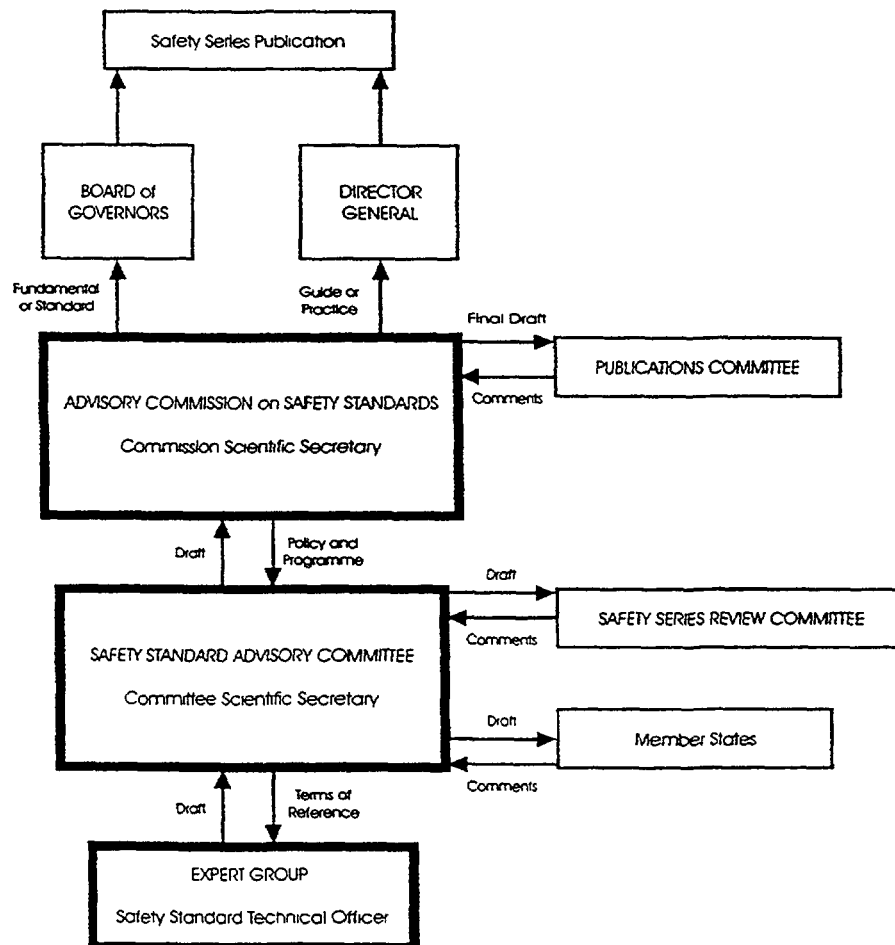
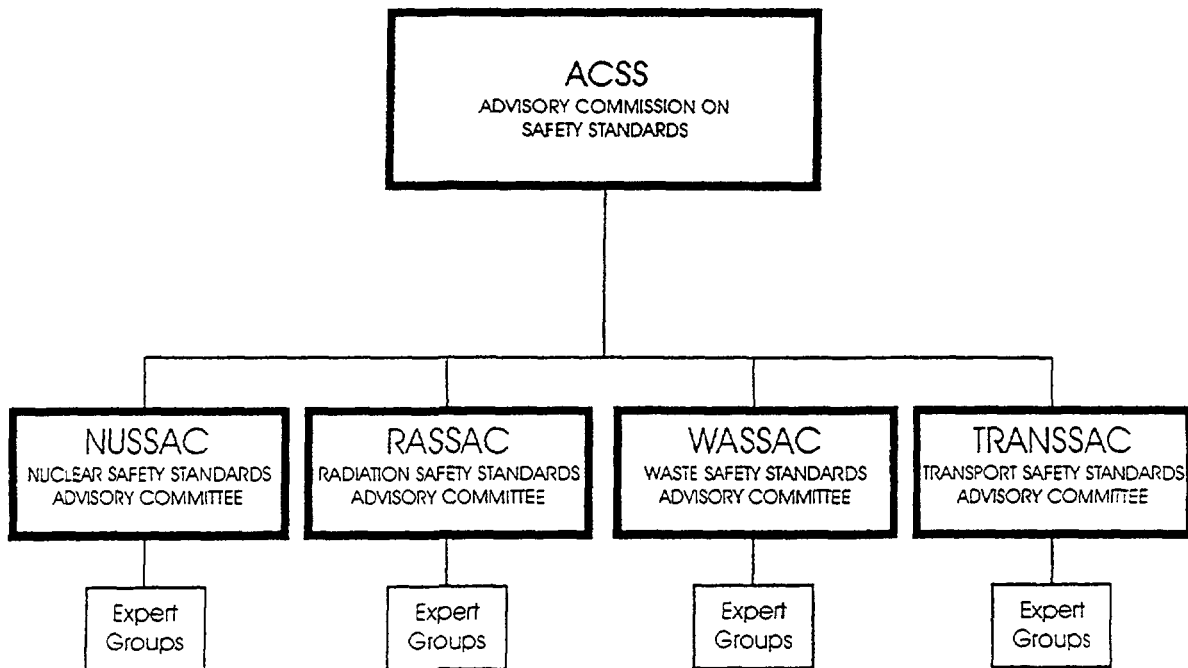
- to recommend the terms of reference of all radioactive waste safety documents in the Agency's Radioactive Waste Safety Standards (RADWASS) programme and of the groups involved in the development and revision of those documents in order to promote coherence and consistency among the documents and between them and the other Agency Safety Series documents;
- to agree on the texts both of Standards to be submitted to the Board of Governors for approval and of Guides and Practices to be issued under the responsibility of the Director General and to make recommendations to the ACSS, in accordance with the Agency's safety standards preparation and review process;
- to provide advice and guidance on a continuous programme for reviewing and revising the RADWASS documents;
- to provide advice and guidance on radioactive waste safety standards, relevant regulatory issues, and activities for supporting the worldwide application of the radioactive waste safety standards; and

- to identify and advise on any necessary activities in support of the radioactive waste safety programme.

5. MEMBERSHIP OF THE ADVISORY BODIES

In the interests of efficiency, the advisory bodies will each have a maximum membership of 15 persons. The terms of appointment of the members will be four years in the case of the ACSS and three years in the case of the advisory committees. In appointing the members of the advisory bodies, the Director General will ensure a balance of regional approaches and experience.

Attachment
SAFETY STANDARDS PREPARATION PROCESS



THE STATUS OF WORK ON THE CONVENTION ON SAFE MANAGEMENT OF RADIOACTIVE WASTE

G.A.M. Webb

International Atomic Energy Agency,
Vienna

My role here today is as one of the two Scientific Secretaries for the Convention, my own expertise is in radiation protection and waste management safety, the other Secretary is Ms. Odette Jankowitsch from the Agency's Legal Department. I am very aware though, as I give you this briefing on the current status of work, that the Chairman of the group of legal and technical experts responsible for agreeing a draft, Professor Alec Baer from Switzerland, is sitting in the audience. Still I will do my best and hope he will be understanding over any personal emphasis I introduce.

To provide some background I need to take you back to the development of another Convention, the Convention on Nuclear Safety, that was opened for signature at the General Conference last September after several years of preparatory work. You will hear more about this Convention in a presentation this afternoon by Mr. Domaratzki.

Originally, the intention was to cover waste management safety within the Nuclear Safety Convention but it became clear that it was necessary to limit the scope of the Nuclear Safety Convention to achieve anything concrete in a reasonable time. Hence waste management safety was excluded. However, one item in the Preamble declared "the need to begin promptly the development of an international Convention on the Safety of Radioactive Waste Management as soon as the ongoing process of develop waste management safety fundamentals has resulted in broad international agreement".

As a follow up to this declaration, the General Conference last year adopted a resolution, GC(XXXVIII)RES/6 on "Measures to Resolve International Radioactive Waste Management Issues". This resolution called on the Director General to begin preparations for a Convention on the Safety of Radioactive Waste. Note that this is the title in the resolution but not necessarily the eventual title of the Convention.

The Director General therefore convened a preparatory meeting in February of this year, attended by 100 delegates from 50 countries. At this meeting there was broad agreement that the aim should be towards an "incentive convention" similar to the Nuclear Safety Convention. From the discussion the Secretariat put together an extensive inventory of the Issues Raised.

Another important milestone (or kilometerstone) was reached in March this year when the Board of Governors approved a Safety Fundamentals Document covering Radioactive Waste Management. This had been deemed a necessary precursor to the substantive development of a Radioactive Waste Safety Convention. The main content of the Fundamentals will be presented to you this afternoon by Mr. Warnecke.

The major work started, however, last month when the first open-ended meeting of the group of legal and technical experts took place from 3-7 July. This meeting was attended by 128 delegates from 53 countries and observers from CEC, NEA, WHO and UNEP (Secretariat of the Basel Convention). This was the first meeting chaired by Professor Baer and also the first where I was one of the Scientific Secretaries. Remarkable progress was made during the week of discussions which were aimed at selecting the main substantive elements to be included in a Convention, as a basis for preparing a first draft text.

So far as the style and structure was concerned, there was no doubt of the usefulness of the Convention on Nuclear Safety. It was rapidly agreed to take this as a model, indeed to aim towards a "sister" convention on Radioactive Waste Safety. In particular, this should be an "incentive" convention, it should contain reporting requirements to a Meeting of Contracting Parties and rely for

implementation on a peer review process. It should take over, for Waste Management Safety issues, where the Convention on Nuclear Safety ceases to have application, so as to avoid any "gaps".

So far as the Scope was concerned, some aspects were resolved at least for a preliminary draft, but not without considerable discussion. For example, it was agreed that the Convention should cover all materials whether liquid, gaseous or solid form, and that it should apply to the safety of wastes deliberately released to the environment as discharges as well as those disposed of into repositories. The scope would also cover all activities in the definition of radioactive waste management, namely handling, pretreatment, treatment, conditioning, storage and disposal.

On other points of the scope there is not, as yet, agreement but as was explained by Mr. Semenov in his opening remarks, we hope that by discussions in a different context at this Seminar, the issues will be clarified. This may help toward their resolution in the Convention context. One example of such an issue is the application of the Convention to materials contaminated with naturally occurring radioactivity but which are not normally regarded as radioactive waste. These might result from previous practices that have left contaminated environments. The tailings from some mineral mines (not uranium mines) can have quite high activity concentrations of naturally radioactive materials. Should these be in or out? Another example of a different character is the question of the safe interim storage of spent fuel. There is agreement that when the national policy is to treat spent fuel as a waste destined for eventual disposal, then this spent fuel would come under the Convention after it is removed from the reactor site, where of course it comes under the Nuclear Safety Convention. If the spent fuel is intended for reprocessing, however, then it is not, by definition, a "waste" so there would be a "gap" in the safety coverage by convention while the spent fuel was in a store off the reactor site prior to reprocessing. This gap would occur unless some way can be found to include such storage in the scope. The scope is also defined by what is excluded, and what is exempted (or cleared in the waste management context).

Moving to the substantive content rather than the scope, there was agreement at the meeting that the Waste Management Safety Fundamentals document was a good starting point for discussions but there were reservations regarding the document's applicability in a binding Convention. There was not, however, any substantial dissent from the essence of the ideas in the "Principles". Similarly, there was general support for the ideas, if not the wording, of the requirements set out in Safety Series 111-S-1 "Establishing a National System for Radioactive Waste Management", approved by the Board of Governors at the same time as the Fundamentals.

A very helpful procedure was that the Group of Experts considered each of the Articles of the Chapter on Obligations of the Nuclear Safety Convention to see whether there were some that could be readily transferred to a Convention on Radioactive Waste Management Safety or where some analogy could be found, and where there were articles specific to Nuclear Safety that had no ready analogue in Radioactive Waste Management Safety.

The meeting also considered a number of specific issues, some of which I have already mentioned. Others were the concept of regional repositories and whether the convention could or should encourage them; and the need to cover timescales different to those in the Nuclear Safety Convention, especially the post-closure period.

At the end of the meeting it was agreed that the Chairman, assisted by the Secretariat and a small number of consultants to the Secretariat, would produce a first "Chairman's Draft". This would then be sent to a group of "Friends of the Chair". This was done and the Annotated First Draft of what is now provisionally entitled the Convention on the Safe Management of Radioactive Waste was sent out in the middle of August – about six weeks after the first meeting. We have asked for comments by the end of September so a second Chairman's Draft can be prepared, taking note of the comments from the Friends of the Chair. This will be distributed to all Member States well before the second meeting of the expert group which is scheduled for 4-8 December 1995.

I believe that brings us up to date and sets in context the technical discussions on some of these issues yet to be resolved but that we hope can be clarified in the course of this Seminar.

APPLICATION OF RADIATION PROTECTION REQUIREMENTS TO THE SAFE MANAGEMENT OF RADIOACTIVE WASTE

A.J. González

International Atomic Energy Agency,
Vienna

Let me commence this presentation on a personal note: I received a request from the Chairman, Mr. Lacoste, a few minutes ago to try not to use the word consensus in this Seminar. Unfortunately I have to start by violating this rule to say that we have achieved a wide consensus on difficult issues in the radiation protection area, some of them related to the safe management of radioactive waste. I will refer to some of these issues here.

The Agency's standards in the field of radiation protection - the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (BSS) - have been co-sponsored by a number of international organizations and a consensus was reached by the audience they represent. This is particularly important for obvious reasons. For example, the co-sponsorship of the ILO means that these Standards will apply to the convention on occupational health; the co-sponsorship of WHO means a *de facto* endorsement of many medical institutions; etc. The BSS co-sponsorship therefore has far-reaching implications.

The BSS are based on information issued by the relevant body of the UN system in this area - UNSCEAR - and also on the recommendations of the ICRP, INSAG and the ICRU. They were approved in 1994; they have been issued in an interim edition and the final edition is expected to appear early next year.

I will not refer to the whole body of the Standards but only to relevant issues for the safe management of waste. Before identifying the issues for discussion, however, let me say a few words about the structure of the Standards. The BSS include: a preface and a preamble presenting the basic philosophy; the principal requirements; appendices on particular types of exposure; schedules with numerical standards; and a glossary. Going into more detail, the principal requirements are of three types: administrative or general requirements; requirements for practices; and requirements for interventions.

Starting with the general requirements, probably the most controversial issues in the radioactive waste area have, to my surprise, been those of *exclusion* and *exemption* from the regulations - issues that, as is well known, relate to the legal expressions *de minimis non curat lex* and *de minimis non curat praetor*. It seems that in the radiation regulatory area, a lawyer, whose knowledge of Latin grammar was rather meagre, converted the ablative Latin expressions into an adjectival form, thereby creating "*de minimis* dose" and simultaneously creating a great deal of confusion which it has been difficult to allay. The real issues are twofold:

- The first issue is a *non curat lex* issue, or that which is *excluded* from the law; i.e. the issue is something that the law does not even consider - not because it is trivial but because there is nothing that the law can do to regulate it.
- The second issue is a *non curat praetor* issue; i.e. something that the regulator exempts because, although it is not excluded from the law, it is sufficiently trivial to be of no regulatory concern.

These are two completely different issues and the Standards divide them very clearly, resolving one issue reasonably well (the issue of exemption) and the other (the issue of exclusion) not so well - perhaps because it is very difficult to reach international consensus on this particular issue.

Regarding the *issue of exclusion*, let me recall that it has been accepted, since Roman times, that there are some legislative scenarios - however important they may be - that are excluded by the legislator from the law on the basis that there is very little that the law can do to regulate them; i.e. control is not feasible. As an extreme example: there is no legislation in the safety area for controlling meteorite impact - and this is not because meteorite impact is trivial (it can be very dramatic). In the radiation safety area, the Standards clearly say that *exposures essentially unamenable to control are excluded from the Standards*, and let me underline, "essentially unamenable to control". Also let me clarify that what is excluded is an exposure from a given type of radiation source rather than the source itself: some of the exposure from the source may be amenable to control and some not. The Standards give some obvious examples for exclusion: exposure to potassium-40 in the body, and some from cosmic rays and from unmodified natural concentrations of radionuclides; but there may also be other examples. The Standards, however, do not say much more in this area, probably because specific international consensus has been very difficult to achieve, since the rationale for excluding from the law depends very much on cultural factors. What is very important in one culture might not be so important in another, and what is considered essentially unamenable to control is very much related to these cultural factors. Is it possible to control the cosmic exposure in La Paz in Bolivia, for instance? One may certainly ask why the Spanish founded the city at an altitude of over 4,000 metres; in theory the city could be relocated! This, however, is for any reasonable person a situation "not amenable to control". This is an obvious example of - I believe - universal consensus but there are some others which are not so straightforward. For instance, some people believe that exposure from *monastic sand* should be controlled. The Brazilian authorities would probably laugh at the idea that this should be tried on the beaches of Brazil. Is this example on the borderline of what is essentially amenable to control and what is not?

In the Agency there is an internal programme trying to achieve formal international consensus in the area of exclusion, but it is becoming increasingly difficult to achieve a broad degree of consensus. It seems to be the role of the national authorities to define what is essentially amenable to control and what is not, and therefore what is to be included or excluded from the regulations.

The *second issue, i.e. that of exemption*, refers to scenarios which can be disregarded by the regulator, or *praetor*, on the basis that these scenarios are trivial. The immediate question is: trivial for what? This has been discussed ad nauseam by different groups. The answer seems to be that the scenarios should be trivial for the justification of a practice, for the selection of the optimum option of radiation protection, and also trivial as far as individual risks are concerned. After lengthy discussions, consensus criteria were reached, which, I would like to underline, are just an administrative agreement. It was considered that an absolutely trivial individual risk is that created by an exposure of the order of a few tens of millisieverts per year, and that a trivial detriment is a collective exposure in the order of 1 man-sievert per year of practice. Obviously it is presumed that the source is inherently safe, i.e. that once these conditions are given they will prevail under any circumstances. I do not defend the logic of these numbers: they are administrative numbers resulting from an international consensus and probably they are usable in this sense and have no other technical value.

Unfortunately the exemption levels derived from the foregoing criteria have been confused as numbers just intended to authorize a release to the environment. Therefore, by implication, it was considered that materials exhibiting values higher than these would be precluded from release to the environment. This, I believe, is the more severe confusion created by the exemption levels. They have nothing to do with the authorization of releases to the environment. Of course, if some source is exempted from regulations, it is permitted to do whatever is desired with the radioactive material, including releasing it to the environment. But this does not mean that values higher than the exempted levels cannot be released to the environment if the relevant requirements of the Standards are met.

Let me turn to a *different issue* of relevance in the waste area: *the regulatory distinction between practices and interventions*. As I indicated previously, the BSS include two types of technical

requirements: standards for practices and standards for interventions. The term *practice* is a jargon term, a very confusing jargon term, that has been used by the radiation protection community for historical reasons. It must be recognized that practice means any human activity involving radiation exposure, by which planning for safety and protection is possible on a prospective basis. Intervention, another jargon term, is used to mean what has to be done in an existing situation for which planning is no longer possible. It is necessary to deal with the situation retrospectively as it is; only remedial actions are possible.

Practices, in summary, are human activities from which an addition of exposure or an addition of risk due to exposure is expected. Interventions, by contrast, are activities intended to reduce an existing exposure.

Many examples of practices and interventions can be given in all engineering fields. The standards for these two types of situations, prospective or retrospective, in civil engineering, as a specific case, are completely different and - not surprisingly - in radiation protection they are also different.

On the one hand, for the practice, what is intended to be controlled is the increase in exposure caused by the introduction of the practice, above the background level of radiation. Public dose limits and other relevant numerical standards applicable to practices refer to incremental dose values, a delta - not an absolute value - above the background level. Intervention, on the other hand, deals with the reduction of a de facto existing level of radiation. Application of dose limits, constraints and other design restrictions have no meaning in the field of intervention.

I find that these two concepts, practices and interventions are very relevant for the application of the standards in the area of radioactive waste. On the one hand there are new activities for which advance planning is feasible and therefore dealing prospectively with the waste they will generate is also feasible. To these activities and their waste the standards for practices apply. On the other hand there are existing situations involving radioactive contamination, normally called in jargon *residues* from previous events. The standards for interventions are applicable to these residues and not the standards for practices. Advance planning is not possible with existing residues. I find that a clear distinction between these two concepts is very important for the future development of undertakings of countries in this field, such as in the case of the Nuclear Safety Convention, or simply for the production of standards in the field of wastes and residues.

Let me close this brief summary of the relevant issues by referring to the relative value of the numerical standards in the BSS. As we are all interested in standardized numbers, I should remind you that the numerical values in the Standards range over a very large scope of values, six orders of magnitude wide, which limits the magical quality we sometimes give to some of these numbers. The famous and magic 1 millisievert per year - the dose limit for the public - is in the middle of the range. The Standards indicate that intervention is absolutely mandatory only for dose rate values as high as 100 millisieverts per year (this does not mean that one would not intervene before, if it is possible and convenient to do so: there is a range of optimized values for intervention that go down from 100 to a few millisieverts per year). Action for radon contamination ranges in the area of 10 millisieverts per year. Radon contamination is an important reference because it represents a chronic exposure situation very similar to the residues from previous events. At the bottom of the range there is the administrative exemption level of around 10 microsieverts per year. This shows that there are no magic numbers for protection standards; their intrinsic value depends on how the numbers are applied.

This is a very short briefing on a very complicated and long document. I have tried to select a few issues which are, in my opinion, applicable to the safe management of radioactive waste.

KEYNOTE ADDRESS

T.P. GRUMBLY
United States of America

RADIOACTIVE WASTE MANAGEMENT FROM THE ENVIRONMENTAL PROTECTION PERSPECTIVE

T. P. GRUMBLY
United States Department of Energy,
Washington, D.C.,
United States of America

Abstract

Over the last 50 years, the United States Department of Energy has treated, stored, or disposed of over four million cubic meters of radioactive waste. Lessons learned from this experience are presented within the context of the broad international consensus embodied in the nine fundamental principles established by the Agency's Radioactive Waste Safety Standards Program. A brief overview of radioactive waste management in the United States, problems encountered, and the management strategy for the current program are described. Technical, legal, institutional, and ethical issues (e.g., inter and intragenerational equity) that must be addressed nationally and internationally to safely and successfully manage radioactive waste are identified.

1. INTRODUCTION

I am pleased to be able to participate in this seminar along with my counterparts from the other International Atomic Energy Agency (IAEA) Member States. I would like to thank Deputy Director General Semenov and his staff for organizing this meeting and inviting me to speak here today. I also want to commend the IAEA for all its efforts in establishing and promoting the basic safety philosophy for radioactive waste management under the Radioactive Waste Safety Standards (RADWASS) program.

Today we gather to address the safe management of materials which are recognized to remain lethal for hundreds of generations to come. We are here to share our experiences and concerns so that we can build trust and confidence in our ability to safely manage radioactive waste, now and in the future. Although we will be discussing specific technical and political waste management issues, I view the true theme of this international seminar to be **foresight**. It's about having the foresight to consider the impacts of our actions on people and the environment 30 years, 100 years, even thousands of years from now.

I recognize that a milestone on the path to international consensus was reached this past March with the approval of two key RADWASS documents by the IAEA Board of Governors, namely the *Safety Fundamentals* document and the *Safety Standard S-1*, which describe the necessary components of a national radioactive waste management system. The nine principles established in the Fundamentals document constitute a sound and complete checklist for safe radioactive waste management. I think it's fair to say, speaking for our program in the United States, that we must achieve everything that is embodied in those nine principles in order to be successful. It is my hope that the broad international consensus reached through the development of these principles and the experience shared during this week will assist Member States in implementing or improving sound waste management programs as well as support worldwide cooperation among nations in radioactive waste issues.

The nine fundamental principles, based on broad international experience, provide a common basis for the development of national radioactive waste management programs. History tells us that safe programs require a systematic integrated approach to management, foresight and flexibility in planning, clearly defined roles and responsibilities, and an autonomous legal framework. The recognition of the need for, and subsequent development of these principles, represents the kind of foresight needed to minimize the short and long-term impacts of radioactive waste management.

I hope that our discussions will contribute to the development of the international Radioactive Waste Management Convention -- a follow-up to last year's successful completion of the Nuclear Reactor Safety Convention. With due consideration of the complexity of the issues being discussed, I believe that the expeditious formulation and adoption of such a convention will demonstrate the solidarity and commitment of the international community to safely managing radioactive waste. Additionally, if the primary objective of such a convention is the protection of human health and the environment, which I believe it is, then it must apply to the broad spectrum of radioactive wastes that pose a threat - be they of civilian or defense-related origin.

The situation we face today, grappling with the issues associated with radioactive waste management, brings to mind what was happening 50 years ago in the United States. The best and the brightest were assembled there to harness the power of the atom. They had a very clear mission, one in which, with the world at war, failure was not an acceptable option. Shortly thereafter, however, one of the unforeseen consequences of developing the nuclear deterrent was identified.

I would like to read a quote from a 1948 Report of the Safety and Health Advisory Board of the U.S. Atomic Energy Commission:

"The disposal of contaminated waste in present quantities and by present methods (in tanks or burial grounds or at sea), if continued for decades, presents the gravest of problems."

Although this sentence was written almost 50 years ago, its wisdom has only been acknowledged in recent years. The result is that both the environmental and financial costs of coming to terms with the nuclear age are orders of magnitude greater than they could or should have been. For example, the current cost estimate for managing waste and restoring environments contaminated through development of nuclear weapons in the United States is approximately \$230 billion, and the program is expected to take 75 years¹ if we maintain a diligent level of effort now.

Today, I would like to begin with a brief description of radioactive waste management in the United States, and then I would like to focus on our responsibilities in the Department of Energy's Environmental Management program. It's a complex and complicated program, and radioactive waste management or more precisely, historical lack of proper management -- is a significant part of the problem we must address. BUT, radioactive waste management is also a significant part of the solution-- we can, and must, learn from our past mistakes and overcome technical, political and institutional barriers to establish a waste management program that assures safety, health, and environmental protection, now and for the future. I would like to share with you some examples of our radioactive waste problems, our management approach to solving those problems, and some of the lessons we've learned, in the context of the RADWASS fundamental principles.

2. BACKGROUND

In the United States, radioactive waste from power reactors and from research, medical and industrial uses (collectively referred to as "civilian" activities) are managed separately from waste generated during the production of nuclear weapons and other defense-related activities (e.g., nuclear naval propulsion). Spent fuel from the power reactors is planned to be placed in a deep geologic repository, which is scheduled to open in 2010. This repository program is managed by the Department of Energy, but in an organization separate from mine. They are currently testing to determine the suitability of the Yucca Mountain site in the State of Nevada. However, there is considerable debate in our Congress as to the future direction of the repository program. The schedule and funding needed for the development of interim storage capacity is being hotly debated in competition with the resources and schedule needed to develop geologic disposal capacity. The funding currently proposed by our Congress is not sufficient to do both.

¹U.S. DOE Baseline Environmental Management Report FY 1995.

Low-level wastes from these "civilian" sources are currently disposed in three shallow land burial sites. One is in the eastern United States, and two are in the West. Progress in developing new disposal capacity continues to be made as the Department looks with anticipation to the opening of a fourth site at Ward Valley site in the California desert. Treatment, storage and disposal of these low-level wastes are licensed by a Federal commission some of you may be familiar with, the Nuclear Regulatory Commission.

In contrast to wastes from civilian activities, the Environmental Management program, which was established in 1989 and for which I have responsibility at the Department of Energy, manages the waste generated by Federal Government funded and managed activities primarily nuclear weapons research, development, testing, and production. One small but highly controversial area of responsibility, which some of you are familiar with, is that of managing spent research reactor fuel proposed to be returned to the United States from about 40 countries around the world in support of United States non-proliferation objectives.

The production of nuclear weapons in the United States has required a vast array of facilities, including mines, laboratories, nuclear reactors, chemical plants, machine shops, and test sites. Our weapons production complex has manufactured tens of thousands of warheads over the past 50 years, resulting in radioactive contamination in thousands of buildings, soils, surface water and groundwater. The production complex, including sites in 33 of our states and Puerto Rico, totals 10.8 million square meters of buildings and 9,360 square kilometers of land (or 936,000 hectares)-- a total area about one-third the size of Belgium.

We currently have about one million cubic meters of radioactive high-level, intermediate-level and low-level waste and 26 metric tons of separated fissile plutonium² (e.g., nonweapons-grade plutonium scrap) that must be safely stored and managed. We must treat, store and dispose of the spent fuel and legacy waste generated during weapons processing and manufacturing and research activities as well as waste generated by site remediation activities. Remediation wastes will grow dramatically in the coming years, and appropriate plans and procedures for dealing with those wastes are vital.

Thus, while the source of the Environmental Management program's radioactive waste is different than the sources of most of the IAEA Member States, the basic philosophy for safe storage, treatment, and disposal of radioactive waste applies to both defense-related and civilian nuclear programs. I believe an understanding of our experiences in management, planning, and regulation will be useful to others currently developing radioactive waste management programs and will hopefully contribute to the development of the Radioactive Waste Management Convention as well.

3. U.S. RADIOACTIVE WASTE MANAGEMENT PROBLEMS

The United States has 50 years of experience in radioactive waste management and has learned many valuable lessons. These lessons have come at great cost and can almost all be traced back to inadequate knowledge, management ineffectiveness, or changed priorities. For example, the national security priorities of the Cold War often took precedence over sound waste management practices. Consequently, we must correct the mistakes of the past and have the foresight to avoid new mistakes in the future. Let me illustrate a few of the specific problems we have to address:

(1) In our collective ignorance, vast quantities of uranium mill tailings, thought to be benign, were routinely used for road and building construction and landscaping beginning in the 1940's. Since 1979, we have been correcting this mistake at a total cost of \$1.47 billion.

²Does not include highly enriched uranium or unseparated plutonium in spent fuel and targets.

TOTAL WASTE VOLUMES* (in cubic meters)

Waste Type	Current Inventory and Waste Generated Due to Ongoing Operations	Waste Generated Due to Remediation and Decontamination and Decommissioning	Total
High-Level Waste	403,000	400	403,400
Spent Nuclear Fuel	2,300	0	2,300
Transuranic Waste	106,000	113,000	219,000
Low-Level Waste	1,700,000	16,810,000	18,510,000
Low-Level Mixed Waste	510,000	999,000	1,509,000
Hazardous Waste	600,000	11,563,000	12,163,000
Total	3,321,300	29,485,400	32,806,800

* Does not include wastewater, sanitary waste, by-product waste, or mill tailings.

(2) For decades, we considered it acceptable to directly dispose of low-level liquid waste to the soil column where sand or clay was expected to capture contaminants. Long-term barriers were thought to be unnecessary. As a result, contaminated soil and groundwater must now be remediated at great expense, and involving the generation of vast quantities of additional wastes to be managed.

(3) Because ultimate disposal of high-level waste was not a management priority during the first few decades of the 'nuclear age,' "temporary" storage solutions have been used well past their intended life spans.

(4) For years, contaminated production facilities were simply locked up and abandoned when no longer needed. These facilities pose increasing threats to the public and the environment as they deteriorate. We must therefore go back and decontaminate them, followed by decommissioning and ultimate disposition. This poses a far greater safety and health hazard to workers, in addition to bringing significantly greater expense, than would have been the case had we addressed facility shutdown as part of facilities management from Day One.

(5) In the United States, radioactive waste management is further complicated by overlapping and often conflicting as well as frequently inadequate legal and regulatory requirements. Agreement on risk levels and cleanup standards is needed as well as the requirement to consider future land use when determining cleanup goals. How these issues are resolved will have a significant impact on the amount of waste generated by remediation activities.

(6) We must also confront the perennial problem of locating disposal sites. We must seek ways to demonstrate to those who live near existing or potential disposal facilities how we have used the best

available science and risk assessment tools to ensure safe permanent disposal. We have to be able to **demonstrate** safety with a reasonable degree of assurance, not only for the present generation, but for hundreds of future generations.

To solve these and other problems resulting from past practices and institutionalize proper waste management protocols for the future, is clearly an enormous scientific, technical and political challenge. I would like to share with you the management approach we are taking to meet that challenge.

4. MANAGEMENT APPROACH TO DEALING WITH RADIOACTIVE WASTE:

The Six Goals

One of the first things I did after assuming my responsibilities at the Department of Energy was to establish six strategic goals to guide the safe management of radioactive waste, against which we measure the progress of our efforts. They are, briefly stated:

- Addressing truly urgent risks;
- Assuring worker and public safety;
- Becoming more outcome-oriented in our cleanup activities;
- Assuming financial and managerial control;
- Focusing our technology development activities; and
- Becoming more customer/stakeholder oriented.

Except for the fact that these six goals are national rather than international in outlook, and thus do not address the issue of contamination across international boundaries, they are substantively very similar to the nine RADWASS principles. These six goals provide daily focus and guidance for **all** of our activities, and they provide the foundation for our waste management strategy, which I will describe for you now.

First, achieving protection of human health and the environment **and** maximizing the use of limited resources means identifying and addressing urgent risks. This is predicated on truly understanding risks at our sites. In other words, risk assessment must precede true risk-based management, which is our ultimate goal. The challenges of developing a consistent and accepted methodology for risk assessment should not be underestimated. Policy-makers, scientists, economists, and public administrators have long debated this subject. Risk assessment methodologies are susceptible to public attack when the public perceives methods were developed and used behind closed doors. Avoiding either a real or perceived bias requires heightened transparency of methodologies and opportunities for public input early in the developmental stages.

To begin this process, we recently released a report in draft form entitled *Risks and the Risk Debate: Searching for Common Ground*. As a first draft, it is not flawless, but it is a beginning, and I firmly believe that the only cogent way to sort out and deal with the many competing priorities in any complex radioactive waste program is to ensure that sound risk analysis and risk management are included in the decision-making infrastructure.

Because of competing national priorities and the overwhelming need to reduce the United States' budget deficit, we are having to meet our increasing responsibilities with decreasing resources. We must continuously improve efficiency to ensure that public funds are spent meaningfully. It is also critical that we maintain credibility with those who provide our funding. Efficiency gains have been realized by re-examining our core processes, eliminating activities not focussed on reducing risks, and initiating reforms in how we contract out work at our sites.

Technology development is a key aspect of the Environmental Management program and an area in which I believe international cooperation can produce enormous benefits. We must remember that we are in the initial stages of addressing many radioactive waste problems. In our case, we are in the sixth year of what could be a 75 year effort, and many long-term remediation solutions have

yet to be found. This is the time to invest in technology development. Our technology development program strategy is to identify and develop technologies that can clean up the nuclear weapons complex and manage radioactive waste more quickly, more safely, and at a lower cost. Recently, for example, at our Lawrence Livermore Laboratory in California use of innovative ground-water treatment technologies have resulted in cost savings of approximately \$20 million and site remediation in months rather than decades. Future improvements in technologies may enable sites to be remediated without removal of contaminants or may reduce the amount of contaminants generated during removals -- hence playing a key role in waste minimization efforts. We must seek new technologies that will increase the degree of remediation that is possible for a given level of funding while at the same time reducing risks to workers and the public. Finally, research in mission-oriented fundamental science is needed to address problems which currently have no feasible solution, such as the removal of tritium from groundwater.

Last but certainly not least is the need to encourage stakeholder input to our decision processes. By "stakeholders" I mean anyone with an interest in our program, including interest groups, individual citizens, government agencies and Indian tribes at the local, state and Federal level. Decision-making processes regarding radioactive waste management operations and development of standards and regulations should be open to input from all interested public groups.

The course of the Environmental Management program will be decided through broad public debate -- at all levels of domestic government and through international effort such as the development of the safety convention on radioactive waste management. How clean is clean? Should we exhume large volumes of contaminated soil in order to allow unlimited use of land in the future? Are plutonium and spent nuclear fuel wastes or resources?

Opinions on the answer to these questions must come early in the decision process so that the full range of perspectives is available to decision-makers prior to the start of policy research and formulation. Otherwise, stakeholder input will have little real impact on the decision process. Through the leadership of Secretary of Energy Hazel O'Leary, we have made great strides toward "opening" the activities of the Department to the public. The Environmental Management program has evolved to allow unprecedented levels of stakeholder participation in prioritization, planning, and budgeting activities.

5. RADWASS FUNDAMENTAL PRINCIPLES

Having briefly described for you the Department of Energy's Environmental Management program and some of the problems we must deal with, as well as our management approach to solving those problems, I would like to take a few minutes to reflect on the importance of the RADWASS fundamental principles. I believe that all nine principles are critical to planning and implementing a sound radioactive waste management program. In the interest of time, I will just elaborate on five of the nine today in relating the U.S. waste management experience to you.

First, I would like to touch on two basic principles which are certainly related, that of reducing burdens on and protecting future generations.

These principles are based on the ethical responsibility to protect future generations, at a minimum, in a manner similar to that required by today's standards and in doing so not impose undue burdens on those who follow. As I mentioned at the beginning of my remarks, I believe that our efforts center on having **foresight**, and assuring, more importantly, that waste management decisions adequately reflect such foresight. Assessing potential impacts on future generations is meaningless if it does not result in efforts to minimize them now. We at the U.S. Department of Energy have recently been reminded of the impacts of not heeding the advice of those who I quoted earlier in my remarks. Through our recently released Baseline Environmental Management Report (published this past March), the Department estimated the total life cycle costs of all projects and activities currently underway in the Environmental Management program. The price of not having addressed waste

management problems adequately and expeditiously has grown dramatically over time - and we have projected that further delays will continue to increase total life cycle costs. Of course, the longer the delay, the greater the burden on future generations.

Addressing these problems means balancing the needs of present and future generations in our decisions. For example, our current long-range plans show that a number of sites will have "restricted" land use once remediation is complete, due to the disposal of waste or the lack of sufficient technologies to completely remediate them. Obviously, we hope to minimize the number of areas that will no longer be available for alternate land uses, thereby reducing the long-term burden on those who must either monitor these locations or are simply denied access to natural resources. However, our analysis shows total program costs could effectively double from about \$230 to around \$500 billion as we work toward minimizing the number of restricted areas. Balancing present and future impacts also raises intra-generational concerns. For example, preliminary analysis indicates that using today's technologies, investments at many remediation sites yield increasingly "diminishing returns" with regard to risk reduction once contaminants have been safely contained. Significant resources are expended with minimal future benefit.

In trying to balance present and future impacts, we must consider not only the financial burdens but obviously the human health risks as well. We cannot limit our consideration to the risks posed after work is completed. Through several studies, we have become increasingly aware that the largest risks are worker-related, not those incurred by the off-site population. Decisions must therefore balance the requirement to minimize near-term exposures to workers and the requirement to reduce burdens on and protect future generations. In order to adequately assure protection of human health, I believe that remediation and disposal strategies should be selected based on the **cumulative** risk posed to workers and the public over time.

Complex decisions like these cannot be made in isolation-- As I mentioned, we have made significant progress in opening our decision-making processes to the public to allow affected groups to participate in our planning. This involvement, in conjunction with better analytical tools to better inform policymakers of the costs and risks of different strategies, is enabling us to address our radioactive waste management problems more efficiently, even with limited resources.

I would like to turn now to the principle of protection beyond national borders. Here again we have an ethical responsibility not to impose on others burdens which we would consider unacceptable at home.

I understand the sensitivity associated with the development of this principle; it was discussed at some length at the March Board of Governors meeting before approval of the fundamental principles. While one might think that this issue should be of relatively less concern for the Environmental Management program, because of the relatively greater distance from our sites to our international borders, we do have an analogous situation in dealing with our individual states as well as the ancestral lands of Native Americans. For example, concerns have been raised as to the potential for releases into the Columbia River, near the Hanford site in Washington State, to impact those living downstream in the State of Oregon. We are committed to addressing the concerns of such potentially affected parties and to involving them as much as possible in decisions that might affect their lands or their lives.

Furthermore, although I recognize that the main concern of this principle is to address routine emissions and release of contaminants from disposal facilities, it also brings up the issue of transboundary movement of wastes. In our experience in the United States, transportation of radioactive wastes across states' borders from one Department of Energy site to another is frequently a source of controversy. In fact, we have been prohibited by court order since 1992 from moving spent fuel from our nuclear navy vessels to the State of Idaho, where it has historically been examined and either reprocessed or stored. Unfortunately, these issues often involve litigation and/or lengthy

political negotiation, which takes time and frustrates those trying to make technical gains in the safe management of radioactive waste.

As I noted earlier, I also have responsibility for managing foreign research reactor spent fuel that is returned to the United States. The United States provided highly enriched uranium fuel to research reactors around the world from the 1950s to the early 1990s initially as part of the Atoms for Peace Program. The spent fuel was historically shipped to the United States, but this practice was discontinued in the late 1980s. In 1993, prompted by nuclear nonproliferation concerns, we proposed to establish a new spent fuel acceptance policy. In spite of our best efforts to clarify our nonproliferation concerns and pointing out that the enriched uranium in the spent fuel was of United States origin, it has proved very difficult to explain the virtue of accepting this fuel back to both the citizens along the proposed transportation routes and the people in the state where the spent fuel is proposed to be stored.

We are therefore faced with the complexity of balancing the domestic concerns over transboundary movement of spent fuel with international nuclear non-proliferation objectives. We expect to make a decision by the end of this year regarding establishment of a new policy.

But to summarize my thoughts on this point, it is in this area of protection beyond borders where I believe the development of the waste management safety convention will be of particular importance. By providing the framework and reporting mechanisms to cultivate trust and responsible waste management among the Member States, completion of the convention will ensure that this principle is internationally embraced.

Now, I would like to discuss the RADWASS principle dealing with management of radioactive waste within an appropriate national legal framework.

The United States' experience with regulating nuclear waste and operations is instructive. We are still on the road to developing a complete and appropriate regulatory regime, especially with respect to the Department of Energy's radioactive waste activities.

Historically, our radioactive waste was managed under the veil of secrecy that enveloped all production complex activities during the Cold War. Because of that secrecy, the Department of Energy and its predecessor, the Atomic Energy Commission, were self-regulating with regard to waste management, worker safety, and public health. Despite the development of rules and procedures, national security and production pressures dominated the Department's activities, and internal safety and environmental rules were often not enforced. This lack of attention to sound waste management practices contributed to the widespread contamination we face today.

Twenty years ago, there was a recognition in the United States that, at least for the commercial realm of nuclear power, an independent regulator needed to be established. The Atomic Energy Commission had acted in both an advocacy and regulatory role for atomic power. With the establishment of the Nuclear Regulatory Commission, the commercial nuclear power industry now had an independent regulatory organization. At the same time, the Energy Research and Development Administration inherited the nuclear weapons production responsibilities, and these in turn became Department of Energy responsibilities when the Department was established in October 1977. Independent, external regulation of 'things nuclear' was emerging, but nuclear weapons research, production, and testing were still self-regulated.

Today, all of the Department's activities, including those related to nuclear weapons, are subject to a much broader range of Federal and state regulations, implemented and overseen by outside agencies. For example, the Department is now subject to regulations regarding hazardous waste management activities and comprehensive response to past waste management practices which are enforced by both Federal and state agencies. However, simply applying existing environmental, health, and safety regulations to nuclear activities and waste does not provide an adequate and

effective regime. The existing waste laws, which were written to apply to commercial, non-radioactive operations, have been applied to a government program for which they were never designed. This has resulted in inappropriate requirements.

For example, one of our hazardous waste laws requires inspection of stored waste. However, as with the rest of the international community, we also have guidelines that require that human exposure to radiation be 'as low as reasonably achievable' (ALARA). In some cases, complying with inspection requirements (i.e., walking next to drummed waste with a significant direct radiation field) would violate the ALARA requirements. We have also learned from a recent study that incineration of certain intermediate-level waste containing Pu-238, in order to meet disposal requirements for hazardous waste, results in an unacceptable level of exposure to the offsite population. However, treating this waste stream might not provide a commensurate improvement in the performance of the disposal facility. Thus, in some cases, we have gone from a bad situation based on self-regulation, to a worse situation where laws not designed for radioactive materials and operations have been applied in a manner that actually increases health risks.

I believe that the solution lies in re-engineering the regulatory regime so that both government and private sector activities, generating radioactive and nonradioactive wastes, are regulated in a way that accounts for the relative risks they impose. To help solve the current regulatory problem, last January, Secretary O'Leary convened an Advisory Committee on External Regulation of Department of Energy Nuclear Safety. This Committee will make recommendations on whether additional external regulation of the Department is merited and how it ought to be implemented. Preliminary findings are that nobody is satisfied with the current system and that additional external regulation is merited. Internal controls must not be removed, but they should be modified to effectively work with new external regulations. The Committee will complete its final recommendations in December. This effort may well be the first step on the road to developing a comprehensive, holistic external regulatory regime for the Department's nuclear operations.

Next, I would like to discuss the RADWASS principle dealing with adequate consideration of the interdependencies among all steps in radioactive waste management.

This is another case where the experiences of the Environmental Management program substantiate the importance of the principle. Within the Department, we continuously confront the problem of insufficient interface between major functions. In order to address this problem, our waste management program is taking a systems approach to defining work activities. In major programs such as the high-level waste tanks at our Hanford site, we are examining each activity in the process and identifying how those activities interrelate and interact. For the first time, we are attempting to examine, in an integrated fashion the impacts of complex-wide waste management decisions for each waste type, and also the specific cumulative impacts for **all** the waste facilities at a given site.

Another key interdependency (also represented by one of the principles) is between waste generators and waste managers. It's an obvious point, but one that doesn't seem to receive nearly enough public attention, that the most effective way to reduce waste management costs-- whether radioactive, sanitary, **any** kind of waste-- is to reduce future waste generation. Unfortunately, I am finding that in a mature program such as ours, with decades of ingrained habits and limited incentive to change, the steps needed to reduce the generation of additional waste are very difficult to implement. With a dedicated staff and budget, I have made waste minimization a very visible part of my program. A recent Independent Technical Review of waste minimization and management programs at three of our defense laboratories concluded that "Mission programs have little incentive to predict, control, or reduce waste streams." The most important lesson we have learned-- and we learned it the hard way-- is that the impact of waste management must be factored up front into the life cycle costs and design of every facility and project. This is the norm in the commercial sector. However, in our government programs, the budget for waste management is separate from the budget which supports the programs generating the waste. There is no incentive to consider waste as a

liability and we must change that. We must work with our waste generators to develop processes and technologies that can reduce the amount of waste generated. We need to make a real effort to **not** produce waste-- pollution prevention can get us significant out-year cost savings, and we need to step up our efforts in that regard at all of our sites.

At Hanford, for example, an evaporator is used to reduce the volume of waste entering the high-level storage tanks. The standard practice for ten years of evaporator operation was to use filtered river water, which was then sent for wastewater treatment after one use. This year, we made process modifications that allow the reuse of condensate water instead of the filtered river water. The expected dollar savings per year of operation is \$3.1 million, and savings in filtered river water **not** used is 2.1 million gallons (over 8 million liters). We now require the consideration and incorporation of waste minimization features in the design process for all new facilities.

6. CONCLUSION

Today, I have summarized for you the radioactive waste management situation in the United States, focusing particularly on the Department of Energy's Environmental Management program. Much of the discussion has been of our problems, but I want to be sure and emphasize that we, like many of you, are making real progress. We've nearly completed regulatory applications for our first underground repository, the Waste Isolation Pilot Plant in Carlsbad, New Mexico, which will be used for disposal of intermediate-level alpha wastes. We've also made significant progress demonstrating and implementing high-level waste vitrification technology including the construction of the Defense Waste Processing Facility for high-level waste in South Carolina. We are also dismantling many surplus facilities.

What I have often said with regard to our program responsibilities at the Department of Energy also applies to our collective efforts through the IAEA, as exemplified by this seminar, to develop a Radioactive Waste Management Convention: we face extraordinary challenges, and it's incumbent upon us to turn these challenges into opportunities that can yield significant benefits for our children, and for the generations that will follow us.

Mankind persists, as it has since prerecorded history, in undertaking new efforts and processes without focusing on the consequences of the waste that will be generated. Archaeologists delight in finding our ancestors' trash, but the waste on which we are concentrating our efforts at this seminar can most assuredly **not** be left for archaeologists to stumble across hundreds of years from now. To successfully manage radioactive waste in a manner that will assure protection of the environment and of public safety and health for the future, we need the same sort of engineering and construction expertise that built the ancient pyramids in Egypt, coupled with the scientific genius that was brought to bear in the Manhattan Project 50 years ago. Most importantly, we must have the foresight to recognize and manage the uncertainties associated with safe management of these materials for the thousands of years required. We must acknowledge that we can never fully understand the implications of our actions in the future. This is one of the principle lessons we've learned and, recognizing this, we must constantly renew our efforts to anticipate and plan responsibly. Although we have made great progress in understanding radioactive waste management, we must not assume our knowledge is complete.

The principles developed and the recognition of the need for an international convention represent the kind of vision that is needed. I believe with the benefits of hindsight provided by some of the countries represented here, and the kind of foresight demonstrated by these IAEA activities, we can meet our responsibility to manage these wastes safely.

PLANNING FOR SAFETY

(Session I)

Chairmen

F.L. PARKER

United States of America

A.C. LACOSTE

France

DEVELOPMENT OF NUCLEAR SAFETY PHILOSOPHY

A. VUORINEN

Finnish Centre for Radiation and Nuclear Safety (STUK),
Helsinki, Finland

Abstract

Ionizing radiation has been used by man for 100 years. Some lessons have been learnt through unpleasant experiences but mostly through well-planned systematic studies. Understanding the harmful effects of ionizing radiation has improved rather slowly. This is mainly as a consequence of the complex nature of biological systems but it is also because of the difficulties in understanding and describing precisely the physical phenomena related to radiation and the interaction process of radiation with biological systems. That is why protection strategies and practices have progressed stepwise and sometimes even gone through confusing changes. However, we have good grounds for believing that our collective knowledge provides a sound basis for nuclear safety technology and for nuclear safety culture. Development of nuclear reactors over a period of 50 years has been one of the "flagships" of the industrial and technological progress since the Second World War. The progress has led from the beginning with wartime pilot-reactors to the present high-technology nuclear industry. This industry also provided a great deal of electrical energy in many countries. The safety record of the commercial nuclear power plants is generally rather good. However, safety is often brought up for discussion by nuclear opponents and groups of other critical citizens. Achieving a common acceptance is still a major challenge for the nuclear community. The process of finding final decisions on radwaste management is an essential component of the fuel cycle of the nuclear power plants. The basic elements are now available for a comprehensive safety strategy and safety practices including radwaste management. Safety of nuclear power plants is of both national and international interest. Safety of waste repositories is also of national and international interest, not only for our generation but for many future generations.

1. EARLY HISTORY OF RADIATION PROTECTION

1.1. Forming the Organizations

Hundred years ago, in 1895 Wilhelm Conrad Röntgen observed a new phenomenon while carrying out studies on a cathode-ray-tube. He discovered unknown radiation that the anode was emitting. He called these air-ionizing and penetrating rays the X-rays. These rays are now also known as röntgen rays. One year later, in 1896 Henri Becquerel noticed that uranium ore was emitting radiation similar to the X-rays. A few years later Marie Curie (Maria Sklodowska) succeeded together with her husband Pierre Curie in separating radium salt and polonium salt from uranium ore. Due to her many experiments Marie Curie cleared up the basic properties of this ionizing radiation as well as the radioactivity of some of the natural elements. It is evident that she had to pay for her intensive and long lasting work on radiation and radioactivity with her health, she died of leukaemia in 1934.

The increasing use of radiation for medical purposes resulted the establishment of professional associations both on national and international levels. The first International Congress on Radiology was held in London in 1925. The physicians and physicists working with ionizing radiation had a strong need to establish a system for metrology to be used with ionizing radiation. To fill this evident gap the International Commission on Radiological Units and Measurements (ICRU) was established during this first London congress.

ICRU's next meeting was organized in Stockholm in 1928 at the same time as the second International Congress of Radiology. The first metrological unit of "X-ray Intensity" known as the "Röntgen" was agreed upon there. An important step of establishing the International X-ray and Radium Protection Commission, later renamed as the International Commission on Radiological Protection (ICRP) was also taken in Stockholm. The International Radiation Protection Association (IRPA) was also established then as a professional cooperation forum for radiologists and physicists.

1.2. Development of Dose Limits

X-rays became more and more popular as a medical diagnostic tool and the need to adopt protection measures to avoid skin damage, anaemia, or incurring impaired fertility became obvious. As a result and remedy, the limitation of working hours and a longer vacation were recommended. However, the main emphasis of the first ICRP recommendations was dealing with shielding requirements. No dose limits were recommended in the Stockholm meeting. During the meeting in Zurich in 1934 the ICRP specified a concept of dose limit for the first time. It was considered that a healthy person tolerates occupational exposure to X-rays or gamma-rays up to 0.2 röntgen in a working day without adverse effects. The recommended dose level was understood as a "permissible level" of dose until as late as 1977. Its purpose was to prevent non-stochastic effects for which there are known dose thresholds.

Fifty years ago, in 1945 the first atom bomb was exploded in test conditions. The studies on the effects of the radiation herefrom also stimulated scientists for safety procedures although the main concern of the political decision making then was the great explosive power of the bomb. The bomb was immediately taken as a tool in warfare. After using the weapon on populated areas in Hiroshima and in Nagasaki and after the information on the effects of radiation on human beings started to leak out from Japan, concern about the safety became public in the contemporary media. All this happened, however, very slowly but it pressed the scientists for more intensive work on protective measures against radiation. ICRP published its first recommendations in 1951. That time the recommended permissible dose rate in a working week was for penetrating X-rays and gamma-rays 0.3 röntgen, for radiation affecting only superficial tissues it was 1.5 röntgen, and for neutrons 0.03 röntgen.

The first substantial report comprising nearly a hundred pages was published by the ICRP in 1955 as a supplement No.6 to the British Journal of Radiology. This report also included the maximum permissible concentration (MPC)-values for about 90 radionuclides.

The first UN Conference on Peaceful Uses of Atomic Energy was held in Geneva in 1955. The conference was a milestone in many respects. Openness around the new concepts was increasing and radiation risk to the members of public started to be a matter of general concern. ICRP established official relations with the UN through WHO. ICRP also made an agreement with Pergamon Press, whereafter the series of the ICRP Radiation Protection Recommendations have circulated widely all over the world and offered pieces of welcome advice to the radiation experts.

1.3. Deepening of Protection Concept

The expansion of peaceful use of nuclear energy as well as the global radioactive fallout from nuclear weapon test explosions were both recognized as a matter of great concern. This was a consequence of two reasons: first, because of the possible genetic impact of population exposures and second, because some evidence was being available indicating that the induction of leukaemia might be a significant late effect of radiation.

ICRP Publication 1 was adopted in 1958 and was available in the following year. This document gave background for a comprehensive protection system based on the knowledge that "Exposure to ionizing radiation can result in injuries that manifest themselves in an exposed individual and in his descendants: these are called somatic and genetic injuries respectively". Essentially the recommended system comprised a dose limitation concept based on "maximum permissible doses" applied to different exposure categories. Probably the best known of these recommendations is the formula $D = 5(N-18)$, where D is the maximum allowable accumulated dose in rem units and N the age in years.

Although the concepts of justification of practices, optimization of protection, dose commitment, and collective dose were all already treated and considered in the ICRP Publication 9 (1965), they were explicitly expressed not until in the ICRP Publication 26 (1977). The implementation of the new approach after 50 years of stepwise development meant adaptation of a modern protection concept which in a refined and addended form is continuously applicable.

ICRP was also concerned about the radioactive material present in man's environment. This material can be either of natural origin or as a result of man's own technological process. The Commission issued the Publication 29 (1979) where the topic was treated thoroughly for the first time.

The radiation protection recommendations developed by the ICRP have continuously served the need of the experts of radiation protection and the essential elements of these recommendations have been adopted as cornerstones for national radiation protection regulations. The key elements of the internationally accepted Basic Safety Standard (BSS) for radiation protection also are of the ICRP origin.

1.4. Central Elements of Modern Radiation Protection

Exposure situations are considered as practices (more or less like routine operations) or situations when protective interventions are needed (some natural situations or situations following the accidents). The central elements to achieve the adequate protection can be defined as follows:

Objective: To protect individuals and society against the undue effects of radiation (deterministic and stochastic health effects, environmental contamination).

Justification: The use of radiation or the exposure situations must be justified, i.e. the benefits must exceed the detrimental effects.

Optimization of Protection: Radiation facilities must be designed and constructed as safe as practicable to avoid accidental exposures and to keep doses (occupational and others) as low as practicable.

System of Dose Limits: For each exposure situation an appropriate system of dose constraints and limits should be developed.

Dose Registration: Radiation conditions and doses received should be monitored and registered.

2. DEVELOPMENT OF NUCLEAR SAFETY PRACTICES AND CONCEPTS

2.1. Early history

When getting the first graphite-uranium pile close to critical conditions in Chicago in December 1942, the scientists were prepared to take necessary countermeasures and return the pile to a safe condition. They even had redundant and independently diverse possibilities to do this (control rods and liquid neutron poison). Enrico Fermi, the scientist responsible also took the human factor seriously. He asked his crew to go for a lunch break just before the experiment was entering the most interesting phase.

The major concern of safety when working at critical facilities was the risk of criticality accidents. These facilities were meant to operate at zero or at very low power level. That is why the shielding and provisions for heat transport were often very limited. The safety was based on design calculations, reliable monitoring of power level, reactor period, and distance from critical condition.

There were some unpleasant experiences but only a few of them were serious. It was learnt from these experiences that the means to prevent unintended reactivity insertions must be very reliable. To achieve this reliability, for example mechanical limiters or constraints and electromechanical interlocking systems were used.

The step from zero power facilities to power reactors generated the need for massive shielding constructions and heat transport systems. Due to the high inventory of radioactive nuclides accumulating in the fuel the requirements to confine them with very high reliability stressed the necessity of air-tight containment buildings. In fact, even some low-power reactors were surrounded by massive containment

buildings. This was obviously necessary as a final barrier to prevent the escape of volatile radioactive materials into the environment.

With increasing power of reactors the smooth neutronic and thermo-hydraulic behaviour of the reactor system became more and more important. It was obvious that the power related intrinsic feedback coefficient should not in operational conditions be positive. The coefficient was on the contrary supposed to be negative. Otherwise, the requirements for electro-mechanical control systems would be unrealistically stringent and in practice impossible to fulfil in order to meet the high reliability requirements.

Practical experience as well as incidents and accidents acted as a guidance in selecting the main streamlines of the safety approaches. The key elements of safety principles and requirements were formulated as collection of General Safety Criteria. As an example it is worth mentioning that they were developed by US regulators 25 years ago.

2.2. Central Elements of Nuclear Safety Principles

- Defence in Depth:* Broadly speaking the defence in depth concept means the multiplicity of possibilities to protect the system from falling into a dangerous condition. If, however, the system fails the fact is that the consequences are limited by mitigating safety systems and multiple barriers. The defence in depth concept is an effective practical working frame which helps in systematizing when studying or designing complicated systems to meet very high reliability requirements.
- Protection System:* When operation parameters exceed normal operational limits the protection system actuates automatically and tries to return to normal operational conditions. If it fails it might give an alarm signal for possible corrective operator actions. However, if departure from a safe operational region occurs, protection system initiates the safety function. Examples of protection systems are the systems measuring temperature, pressure, neutron flux etc.
- Safety System:* When operating parameter is departing from the safe region the task of safety systems is to return the safe conditions by actuating the safety functions, such as reactor fast shut-down-system or emergency core-cooling-system.
- Mitigating System:* If an accident had already happened and the primary circuit had been broken resulting the leakage of radioactive gases and other volatile materials into the containment, then the radioactivity could as far as possible be removed from the containment air by using mitigating spray containing chemical additives which bind radioactive nuclides. If the release from the containment is unavoidable due to overpressure, the mitigation effect would be achieved by venting the contaminated air within the containment through a high efficiency filter.
- Multiple Barrier System:* The radioactive materials in fuel are inside the hermetic metal cylinders, fuel pins. The fuel pins bound in mechanically fairly rigid bundles are in reactor vessel which with connecting piping are mechanically very strong. The whole reactor system is inside the tight containment building, often with double walls.

2.3. High Reliability of Systems

There are some important practices and principles which are systematically followed to achieve a very high reliability in system functions. First, of course, the system has to be correctly designed meaning that the designer has to know which the expectations are and what the working conditions are like. Only the well-proven engineering solutions are to be used. Also the materials and components must be of high quality and properly tested for real working conditions. And finally, the design has to be reviewed by an independent high quality expert. The design documentation also includes the fabrication plan with quality control and testing programmes etc.

<i>Quality Assurance:</i>	The purpose of all systematic methods mentioned above (elements of quality assurance) and planned in advance is to make sure at the defined confidence level that the expected result will be achieved.
<i>Redundancy:</i>	A single component or system has always a limited reliability. That is why combinations of several systems are used when requirements higher than those achievable with a single system are set.
<i>Diversity:</i>	To avoid the so-called common mode failures it is better that the sub-systems in system combinations are not identical.
<i>Independence:</i>	To avoid the so-called common cause failures internal connection must, as far as possible, be avoided in system combinations.
<i>In-Service Testing and Maintenance:</i>	The combinations of safety systems should provide a flexible possibility for functional testing with adequate frequency.
<i>Predictive Maintenance:</i>	The systems should be replaced or maintained before disturbances appear.

All the collected information on the incidents at every plant should be carefully analyzed and the corrective actions should be taken when relevant experience is available.

2.4. Design Basis Accident Approaches

In the safety design of a nuclear power plant the ultimate purpose is to keep the radioactive materials, accumulated in the fuel during operation, confined. This is done at first stage by keeping the reactor in safe condition. It is achieved by preventing accidents. The vital functions which have to be maintained in all situations are the reactivity control, especially the capability to shut down the reactor, and the reactor core cooling system. If the reactivity control fails difficulties with heat transfer system capacity are possible. Deficiencies in heat removal from reactor core endanger the tightness of fuel encapsulation and might lead to the release of radioactive materials to the primary coolant.

The possibilities to exclude leakage from primary circuit are limited. That is why vital operational systems, protection, safety and mitigating systems have to fulfil their objectives even during and after the accident conditions. Nevertheless, there are limits in design and survivability.

Design Basis Accident (DBA): The limiting conditions for the design of the components and systems which have to survive accidents are defined as those loadings that follow the worst accident still considered realistic but with low likelihood. This design limiting accident is called a DBA. The sudden double-ended rupture of the main primary coolant line, which, however was not followed by major damage in reactor core, has most often been used as DBA in light water reactor design.

The evaluations of expected consequences of more severe accidents, hypothetical accidents, started to get more increasing attention. Since the time of the TMI accident in 1979, the experts prefer to use an expression beyond DBA's or simply severe accidents.

- Safety Margins:* Possibilities to forecast accurately post-accident conditions were limited to those aspects which were possible to be tested in realistic conditions. In many important areas the lack of accuracy had to be compensated with fairly large safety margins.
- Emergency Preparedness:* The objectives of safety design were defined in the sense that outside the plant area no serious health effects were expected as a consequence of a reactor accident within the design basis limit. Nevertheless, the requirements for emergency preparedness readiness were defined to cope more with severe consequences than that expected after a DBA.
- Emergency Management:* On-plant emergency preparedness included development of procedures and training of operators in order to provide them with means for correct diagnosis and after that to control the mitigating actions most effectively.
- Automatization:* The fast development of automatization in process industry and elsewhere provided improvements in reliability in initiating the protection and safety functions. The selected interlockings reduced disturbances initiated by mistake without challenging the fast initiation of protection and safety functions.
- Deterministic Approach:* A pragmatic choice of design target which is often based on rather conservative analyses of the selected accidents is characteristic to the DBA concept. However, the choice is based on collected experience and expert judgement.
- International Standardization:* Most of the existing nuclear power plants are like tailor-made but when looking at the details one finds great differences. From the standpoint of basic safety approaches these differences are not, however, fundamental. International co-operation, especially the one organized by the IAEA during the last 30 years has had a harmonizing effect on safety thinking. Concerning the practical results, differences in quality and hence in reliability are still great.

2.5. New Features in Nuclear Safety

A new era in safety thinking was initiated as early as seven years before the TMI accident by allocating large resources on probabilistic studies of nuclear power plant systems and practical experiments. Thus the understanding of the basic physical phenomena of core damaging accidents was improved. That resulted in a possibility to develop computer code packages with better modelling and to analyze probabilities of propagation of various failures in complicated systems as well as their consequences. The application of these advanced methods and knowledge formally in practical decision making was still rather weak at the time of the Chernobyl accident in April 1986.

One of the main lessons from the TMI accident was that a rather harmless initiating event might lead to very serious consequences through a sequence which had simply been overlooked in the DBA approach. It was for instance observed that even a fairly small leakage could lead to great difficulties, if it was not taken into consideration in operator training and plant instrumentation. To avoid failure sequences which might look rather harmless but which still might endanger the reactor core after an additional failure or operator error, all sequences should be studied. Possibilities are, however, too many.

That is why the probabilities of initiating failures and the propagation of failures had to be known to the extent probabilities are not very small. If the sequences with higher probabilities are selected for consideration from the design standpoint it would lead to the envelope of design parameters.

After the Chernobyl accident it was evident that the possibility of the beyond DBAs has to be considered more thoroughly than before. This difficult process became slow and long, and the results are not yet clearly crystallized. Except safety reasons there are also other ones in this lengthy process. Electricity consumption increased in the western countries much more slowly than the forecasts indicated 10 to 20 years ago. In addition new large oil and gas fields have been discovered.

However, there are more than 400 reactors in use for electricity production and more than 40 reactors are under construction, mainly in the Far East. It is important to have common understanding and also common sense on the acceptable level of the safety of nuclear reactors. Regarding the operating plants and those under construction, two aspects that were clarified after the Chernobyl accident, have to be considered. It has been continuously stated very strongly that radioactive clouds do not respect any borders between countries. And radioactive contamination, even rather low, might cause high economic losses. These are or they should be the reasons, why nuclear safety is a matter of common concern in all countries whether the country is producing nuclear energy or not.

Convention on Nuclear Safety: An international safety convention was developed in 1994 to enhance international cooperation and nuclear safety in general.

Safety Culture: The term Safety Culture was initially used to express the operators' awareness and willingness to act in a safety-minded manner. Safety culture has, however, a much larger scope, because nuclear safety is a matter of the whole society, from parliamentarians to laymen. Good safety culture is manifested in nuclear legislation, in lower level regulations, in company safety statements, in regulatory actions, in knowledge and commitments of individuals when carrying out their duties etc.

Auspicious safety culture includes some overwhelming characteristics such as transparency, quality assurance and priority of safety. Transparency means, among other things, that the obligation to protect individuals and society is written in legislation. It also means that the safety objectives are well formulated and that mass media and individuals have access to safety-related materials etc. The experts must have preparedness to explain to the public even the difficulties and problems of nuclear safety and radiation protection, such as the very low probability of severe accidents and low probability of cancer due to low doses. Good safety culture also means that all the relevant problems are properly solved and no major elements are pushed aside to the unknown future.

3. WASTE MANAGEMENT

3.1. Early Approach in Nuclear Waste Management

Nuclear power is concentrated power in the sense that a relatively large amount of energy is released from a small amount of fissile material. Thus, a nuclear power plant is producing a relatively small amount of waste when compared with that produced by a fossil power plant. It is the high concentration of energy and the small amount of waste which from the beginning has made nuclear power so attractive.

The peaceful use of nuclear power is a side product of military development. During and even long after the Second World War there was neither time nor need or resources to develop sustainable solution to radioactive waste disposal. The waste was simply stored and in some cases, unfortunately, released to the environment.

It is too simplistic to argue that lack of well defined responsibility would be the major reason for the delayed beginning of intensive radwaste studies. Physical decay and open options in fuel management

considering reprocessing as well as economy were in favour of delaying the practical steps as far as possible.

The delay of major decisions on final disposal area did not, however, mean passiveness in research and development. With a positive attitude one might say that carefulness has prevented unfortunate decisions which might require very expensive corrective actions. Examples like this exist.

3.2. Why Nuclear Waste Management is Difficult

Most people's attitude to nuclear power, radioactive materials and to ionizing radiation is emotional and linked to journalists' often sensational articles as well as TV programmes. Rather few members of our societies have got so much basic educational knowledge that they could objectively judge the message of news media on these matters. This is a fact which introduces difficult problems in the societies when decision-making is developing towards more and more participating democracy. However interesting, this issue will not be discussed more in this paper.

NPP Safety versus Radioactive Waste Management: The basic danger potential of nuclear power plants and radioactive waste repositories is similar; the threat of leakage of radioactive materials into the biosphere. Thus, there are some similarities in the safety approaches, too. For example, the safety objective in both areas is achieved as long as the radioactive materials are confined. When high reliability in confinement is required the multiple barrier principle is a natural solution. The differences between nuclear power plant safety and repository safety will be discussed in greater detail later in this paper.

As to the working methods there is an attempt to use management methods of nuclear power engineering on waste management, too. For example, quality assurance methodology and practices are directly applicable. Practical conditions in waste management differ, however, so much from conditions in nuclear safety that they earn a more profound discussion.

3.3. Safety Objective for Radioactive Waste Management

Safety objective in radioactive waste management is in general terms to isolate radioactive materials "safely" from biosphere. But as we know, it cannot be made with 100 % certainty. The question arises, how much there is certainty in the concept of "certain enough" and also what size of leakages could possibly be tolerable to the future generations. When we develop goals for nuclear power plants it is a question of judging the potential harm due to the radiation exposure against the benefits of energy production for the use of our generation. If we consider with the time, like we have done, that the dose limits need to be reduced, we can certainly do that by improving the facilities. In the extreme case, if we for some reason considered some of the power plants intolerable we might shut down these plants.

When developing safety goals for radioactive waste management we are obliged to take care and control that the radioactive waste repositories which the future generations will inherit from us will be in alignment of sustainable development.

3.4. Technical Safety Issues for Radioactive Waste Management

An active, fast and reliable reactivity control system is very essential for the safety of a nuclear reactor even though the reactor would have inherent safety characteristics. Nevertheless, sudden reactivity excursions cannot be totally excluded. Essential reactivity changes would not happen in a nuclear waste repository. The waste matrix is deeply subcritical by inherent properties of waste materials. No active reactivity control system is needed in nuclear waste repositories.

An active heat transfer system is another vital system in a nuclear reactor even though natural circulation has in some circumstances very important effect in safety. In a nuclear waste repository the heat production is fairly low and decreasing slowly with time. No active heat transfer systems are installed in waste repositories. Waste matrixes must be designed and located with respect to geological environment so that the temperature of waste and environment stays within specified limits.

The operating nuclear power plants are the results of systematic development of several reactor generations. Great amount of experience is hidden in the layout of main structures and components, in design, materials, fabrication, installation, commissioning, testing, operation, maintenance and even in dismantling of systems and components. The experience extends over the whole plant life designed. The advancement is on many areas at the stage of international standardization. Repositories for high level nuclear waste are at the stage of basic research. Practically no operational experience is available. As far as the design constraints are concerned, the conditions of a waste repository are very different compared with the constraints of nuclear reactor design.

The most evident difference is in the designed life-span. Reactors are designed to operate for a fairly short time, from 40 to 60 years, whereas the repositories should, according to the present knowledge fulfil their expected functions practically for ever.

Another very essential design constraint is that repositories must be tailored to the local environment. Geological formations cannot be standardized! This does not, however, mean that all the necessary research and development work must be done at each planned repository site. The site specific data is anyway only available from site-specific studies.

The adequacy of the design parameters of repositories cannot be tested in real operational conditions and as far as tests are carried out close to operational conditions they are timely limited. The verification analyses for checking the compliance are based on limited confirmation of the validity of calculation models as well as physical, chemical, geological, and other parameters.

4. SUMMARY REMARKS

Ionizing radiation has been a known phenomenon to mankind for 100 years. Lessons have been learnt through unpleasant experiences but mainly, however, through well-planned systematic studies. We live and Man has always been living under continuous exposure to radiation the intensity of which is varying by a factor of more than 10. We have learnt to utilize ionizing radiation in numerous ways for the benefit of our daily life.

The record of ionizing radiation and nuclear power is very good in despite of radiation pioneers' somewhat shortened life span due to the lack of knowledge, of the tragic effects of nuclear weapons and of a few unnecessary accidents. However, the general attitude is ambivalent. One of the issues which has given reason for such an attitude is the issue of radwaste. The majority of the public clearly considers the problem of radwaste to be an unsolved issue.

Most experts, however, agree that technical readiness for final steps of waste management is available or they are at least convinced of the availability of the solution. The issue is a difficult one. It is also the first time our societies have a responsible attitude towards long-living waste which has a potentiality to deteriorate seriously the living conditions of our future generations. Unfortunately, the earlier praxis with various poisonous wastes has too seldom been in alignment with ecologically responsible thinking.

Nuclear communities, including politicians, regulators, nuclear operators and laymen, are in the process of generating tolerable solutions for the radwaste issue. The problem is difficult but not unsolvable. Knowledge still includes uncertainties but on the other hand it is possible to provide safety margins to compensate for the uncertainties. Management of high active nuclear waste is an issue in which the quality of safety culture is tested. Perhaps the most important idea of a good safety culture is that a serious safety issue must never be challenged by compromising to the advantage of the economy.

"Mere power and mere knowledge exalt human nature but do not bless it."

Francis Bacon

SOCIO-POLITICAL CONSIDERATIONS

J. M. KINDELÁN

Consejo de Seguridad Nuclear,
Madrid, Spain

Abstract

There is presently a general increasing concern about the impact that the economical and industrial development may be causing to the environment and to human health. Although it is a fact that no industrial activity can be considered either one hundred percent safe or completely environment impact free, this concern is perceived by society in a particularly sensitive manner in the case of the electricity generated from nuclear origin and related radioactive waste management issues. This vague and not always rational concern felt by the general public in relation to nuclear energy is an objective reality which must be faced. It seems to be based on the origin of this type of energy, certainly accentuated by the position of some radical green organizations and by the attitude of the mass media, which are quick to spread and amplify the threatening component of any potential risk. This scenario clearly affects the attitude of our elected representatives as well as the role of our institutions, and consequently influences the decision-making process. This paper attempts to briefly analyze the role of the nuclear option in connection with the future energy needs, as well as the main factors influencing the public perception of this energy source and related waste management issues. It also aims at investigating the role of the institutions and the need for political action impacting sociological standpoints.

1. INTRODUCTION

At this end of the millennium we are once again witness to the traditional apocalyptic voices with their claim that there is a serious risk of Mankind coming to an end, the victim of unchecked growth, the depletion of natural resources and exponential degradation of the environment.

In the face of such catastrophic viewpoints, it is vital that the problem be addressed in a serious fashion, without heed to the clamour of the alarmists but with firm resolution in the adoption of whatever political measures are required to be taken on a technical and scientific basis.

The change in mentality we have seen is producing its first results. Energy and raw material savings are being promoted, as is the recycling of industrial products[1]. Since 1983 no low level radioactive wastes have been dumped in the ocean depths, as used to be the case, but are now being disposed of with the necessary safety measures in those countries in which they are generated. High level radioactive wastes must be disposed of deep underground in their countries of origin, with engineered and geological barriers guaranteeing their isolation for thousands of years.

The technology available to us at the end of the 20th century is certainly sufficient to allow us to achieve economic development for all Mankind, eliminating the misery currently affecting so many people. Nevertheless, the incapacity of our political organizations and the inertia of social habits and prejudices complicate and often prevent advantage being taken of technological progress with a view to palliating existing shortcomings.

Failure has not been the fault of science but rather of Man's incapacity to organize himself in such a way as to make the planet an inhabitable place for all. For this reason, resignation is an unacceptable attitude; being progressive at the end of this 20th century is refusing to accept that the best thing is to leave things as they are. The achievement of higher levels of equality and the adoption of solidarity as a practice still constitutes a driving force for the progress of Mankind and a reasonable utopia at which to aim. This is undoubtedly the fundamental political issue for the coming century.

This problem is clearly related to the development of nuclear energy throughout the world, an issue which has become one of those most concerning public opinion in various countries.

2. THE NUCLEAR OPTION AND THE PROBLEM OF WASTES

There can be no doubt that the nuclear option clearly depends on economic issues and on safety in relation to the long-term risk of radioactivity, as well as on the understanding of a public which is highly sensitive to such matters, albeit at times in a purely sentimental manner.

In any case, elementary economic rationale and - more important still - the respect we must show for future conservation of the environment of the planet, demand that increased energy consumption be controlled, and it is indeed the case that a priority issue for the governments of the world is to promote savings in consumption and efficient energy production and use, to the greatest extent possible.

Having said this, we must be realistic and assume that over the next 20 or 30 years energy consumption will tend to increase sharply at world level, due to an inevitable increase in the population and to the absolute necessity for the underdeveloped nations to emerge from their situation of extreme poverty.

Regardless of whatever perspective is chosen in relation to the consumption of primary energy, consideration should be given to the fact that electricity will be essential for economic and social development, and that however much effort is made and required in the development of electricity production using alternative methods, this will fundamentally be achieved through the use of solid fuels and nuclear energy.

It might be useful to bear in mind that while today the total consumption of primary energy world-wide amounts to some 9,000 million tons of petrol equivalent, even the most conservative calculations point to some 12,000 million in the year 2010, and to more than 20,000 million by the year 2050[4].

Given this context, it is impossible for electricity production by nuclear means not to increase in the forthcoming decades. Specifically, the last World Energy Council Congress assumed that this type of production would double its capacity in absolute terms by the year 2020, in relation to the 1990 level, even though its contribution to the total energy consumed decreased slightly. As regards concerns for the increasing CO₂ content of the atmosphere, the use of nuclear power constitutes the only demonstrated alternative[4].

However, regardless of one's position in relation to nuclear energy, the problem of wastes does not simply disappear. Whatever one's opinion of this type of energy from the economic, technical or political point of view, the risks posed by radioactive wastes must be eliminated, since the amounts of such wastes would increase even in the event of premature dismantling of nuclear power plants.

Many of the technical factors influencing the evaluation of risk are very difficult to understand and are, therefore, not widely accepted by the general public. The criterion of risk subconsciously used by the public varies considerably, such that at times things implying relatively high risk levels are accepted - for example the automobile - while the safety of any installation related to nuclear energy is questioned, despite the fact that the calculated risk associated with such facilities is much lower. For this reason it is particularly important to know what the perceived risk (not the calculated risk) is, in which respect there would appear to be a need for participation by psychologists and scientists with expert knowledge of social issues who might establish methods allowing the main elements of the public's perception of risk to be measured.

Absolute safety does not exist in any human activity, and much less so in industry. I believe, however, that nuclear power plants are every day safer and that radioactive waste disposal facilities will be safer still. Generally speaking it may be said that public concern for safety in this sector has forced those involved to enhance the measures taken. It should also be pointed out, however, that

a waste disposal facility is always a passive installation in which there is no nuclear reaction, as a result of which it implies much lower levels of risk than a production plant. I believe that with current knowledge it is perfectly possible to build a safe radioactive waste disposal facility[2].

Opposition to nuclear development should not be associated with management of its wastes. This is a false argument based on vested interest. Regardless of whatever one thinks about nuclear energy, it exists and its wastes must be managed in the best way possible, with support from all the social forces, with the necessary supervision but without demagogy. The confidence of the public must be won by telling the truth, recognizing the errors made and continuously contrasting opinions.

The vague and not always rational concern felt by the general public in relation to nuclear energy is an objective reality which must be faced, and is certainly based on the origin of this type of energy, related to the military environment and to development of the first atomic bombs.

This concern is at the basis of the difficulties involved in the environmentally efficient management of the wastes generated. It should not be forgotten, however, that we generate many other types of wastes, in larger amounts and with a risk of toxicity that might be described as being much greater; while radioactivity decays with time, the toxicity of other wastes never disappears. The efforts made in recent years to increase knowledge of the problems posed by radioactive waste management have led to a situation in which such management now enjoys much more favourable perspectives than other waste types, public acceptance of which is also problematical.

3. PUBLIC PERCEPTION

"Political matters are never what they really are but rather what they appear to be". This statement may be significant in underlining the difficulties posed by whatever policy is adopted in an attempt to make people understand the safety measures taken in relation to radioactive waste management. The objective difficulties are accentuated by three decisive factors which must be taken into account:

- The systematic actions of many environmentalist organizations enjoying a wide audience.
- Certain political parties have unfurled the environmentalist flag and use the issue of waste management - of whatever type - as their own, wielding it against those responsible for national, regional or local government.
- The media readily propagate concern regarding ecological risk, enlarging upon the issue even when they have an insufficient technical or scientific basis for such action. The important thing is to sell and to bring attention to whatever is frightening rather than to accept technological facts as being what they are, or at least treat them without a catastrophe-oriented approach.

As a result of the above, those responsible for government at different levels attempt to satisfy the demands for environmental protection they perceive in society. But often supplying the means required to achieve this is hindered or prevented by environmentalist groups which, despite their acting in good faith, request changes in society which are often unfeasible in the short term. The media act as an amplifier of the emerging contradictions; the objective truth may be considered to be no more than an item of statistical data, modifiable depending on the circumstances, this being applicable even to apparently unmovable physical and historical data.

There is another aspect which makes it difficult to find solutions to problems posed in the long term, and this is that governments at all levels - national, regional and local - last only a few years and are loathe to adopt unpopular measures not requiring an urgent solution. This happens both in democracies and in dictatorships and may be mitigated only by increasing general education and through a will to disassociate from political discussion - to the extent possible - subjects which, like

the efficient long-term management of toxic wastes, are of equal interest to all the members of the public. Unfortunately, politicians tend to postpone decisions and to wait for less negative situations to arise, situations which in fact might never come about.

One way or another, it should be pointed out that public reaction to perception of a fact will always depend on the version received or on whatever version appears to be most credible. Thus, for example, and in relation to the management of radioactive wastes, it is normal to come across statements such as "Nobody yet knows what to do with radioactive wastes". Given the current general perception of radioactivity, which is totally different from that existing 30 years ago, statements such as this serve simply to maintain or increase aversion. It should be remembered that the normal scarcity of news on problems relating to a lack of control of radioactive wastes probably points to the fact that these wastes are being managed without major problems.

There are several reasons for this type of public response. One of the most important is the information arriving through the media, which is often fragmented, incomplete, undocumented and tending towards the catastrophic. Under such conditions, public response tends to be emotional rather than rational. This type of reaction occurs in relation to a large number of public initiatives, but particularly those which the public perceives, or is told, produce a harmful environmental impact. Under these circumstances public opinion directly opposes the activity in question, due to its being highly sensitive to ecological and environmental issues.

It should be said, however, that under these circumstances and in view of the information available to the public, this response is logical, but that perceptions, and consequently responses, change when the public has access to real information, and even more so when its members perceive that their opinions are taken into account and that they participate in decision-making. If this is not the case they will adopt a contrary position even when such opposition is harmful to their interests.

4. THE ROLE OF THE INSTITUTIONS

The role of the politicians should be to provide the services required by society at the least possible cost. However, they cannot provide these services if the public opposes them in principle, and generally speaking unpopular decisions are not taken except in situations of great urgency, crisis, etc. Such a position, which is contrary to decision-making, is facilitated by the existence of different Administrations, such that between politicians belonging to one same party there may be different criteria as regards the performance of a given action, the point of view of the responsible person closest to the public - for example the local mayor - possibly being different from that of somebody else involved in political activity at a greater distance from this public.

A typical example of the above is the entire question of waste management in Spain. In view of the fact that the information received by the public has been totally catastrophe-oriented in nature, it has not yet been possible to implement a plan for industrial wastes nor for certain types of treatments such as incineration. On the other hand, coherent, serious and technically well-founded activity in relation to local public opinion, accompanied by economic incentives, has made it possible to implement a disposal facility for short-lived radioactive wastes.

Neither has there been an information campaign allowing public perception to be modified. Consequently, it will be difficult to access the environmental infrastructure required, since the environmentalist argument, which is the one that has managed to swing the public and the politicians against waste management facilities, is usually based on demagogy. As pointed out above, the problem is once again that the politician working at national or autonomous community level has it quite clear in his mind that there is a need for management, while the local politician will follow the tendency mapped out by the population under his charge and - since there is always somewhere else to put a waste facility - will oppose its being included in his municipal area or region. For its part, the political opposition will, unless there has been some prior pact, which is not always possible,

oppose the action proposed by the politically responsible individual whenever it has sufficient popular support, attempting to swing public opinion against him.

This puzzling situation, which would appear inevitably to be the destiny of all decisions relating to actions which might elicit public opposition, has a solution. For this solution to be achieved it is necessary to begin by informing the public objectively in order for them to understand what the proposed actions are and to promote a situation in which they will not reject them; under such circumstances the local politician will be able to undertake the necessary actions.

Unfortunately, the posture predominant among the environmentalist groups usually complicates the implementation of suitable measures:

- They oppose any implementation of infrastructure: their counter proposal is savings (water, energy, etc.). There can be no doubt that in part they are right, but deep down what they propose is a model of a society which might be called utopian and which is not accepted by the majority.
- As regards the management of wastes (toxic, radioactive, etc.) their approach consists of doing away with waste generation and implementing clean technologies. It is undoubtedly true that all industrial processes are open to improvement, but totally clean technology is utopian.
- They defend two emblematic positions which are apparently not open to negotiation: the shutdown of nuclear power plants and opposition to the construction of incinerators. Although the potential effects of ionizing radiations are beyond doubt, much of what has been said and written about radioactivity and dioxins is pure nonsense, and there has been a complete lack of rigour in comparing them to other agents of risk to which people are subjected.

The different institutions have not always adopted an intelligent and progressive standpoint in relation to such problems.

Until just a few years ago companies and institutions did not have any clearly defined communications policy but rather a press office whose aim was to ensure that the top executive appeared in the press a certain number of times a year and to annually present its results. In the 1980's it started to become clear that companies needed a well defined external image. This led to the development of Communications Plans specifically designed to project the image the company wanted or needed, among both the general public, the clients and the suppliers.

One way or another, the influence of the media would appear to be decisive. Television is probably the vehicle of greatest importance but is not always a suitable channel for messages of complicated technological content which are not easy to explain concisely. The press lends itself better to this task, but priority should be given to spreading reassuring messages in limited areas and to restricted audiences feeling themselves to be more directly concerned with the problem of radioactive wastes.

5. THE NEED FOR POLITICAL ACTION IMPACTING SOCIOLOGICAL STANDPOINTS

Science and technology are part of our daily life, and this has been the case for more than two centuries. There has always been public rejection of certain technological developments but previously this was kept at almost testimonial levels. In recent decades, however, this response has begun to take on greater dimension than was the case in the past, when such responses were case-specific; the outcome is that the public has now begun to level criticism at Science and its results.

The rejection of and lack of confidence in certain technologies and products, part and parcel of this criticism, might be based on an information problem. This problem has two sides to it:

- On the one hand, we now have more information, more free time and more education through which to widen our sphere of knowledge.
- On the other, the greater volume of information now available to us will inevitably be more general, possibly partial and even biased, owing to the transparency with which the media access all messages.

These two aspects of the problem mean that we will be more informed but will not have true knowledge of all the issues in question. If we attempt to go deeper into such issues, we shall first run up against the barriers involved in moving from general ideas to the semantics of the specialist. This problem makes it more difficult for the layman to understand science and technology and leads to a lack of real communication.

Furthermore, the message that is to be passed on to public opinion in relation to radioactive waste management relates fundamentally to the possibility of its being accomplished without risk for the environment, both at present and in the very long term, and without undue risk for future generations which will not have enjoyed the benefits of the energy produced by us.

These are clearly ethical considerations and ethics have little to do with positive science, being more closely linked to attitudes based on sentiment. There are, however, certain ethical principles which are accepted by the majority and which must be respected. These principles must govern all radioactive waste management policies and the way in which the possibility of such management being implemented is transmitted to the public. It should also be pointed out that ethics are not protected by the laws of the market and that the problem of radioactive wastes is not easily solved by the market alone.

This has led certain European Union countries to implement programmes aimed at bridging the gap between Science and Society.

The approach used to achieve communications seeking to bring about a balanced understanding of science consists of direct dialogue between scientists and technologists, on the one hand, and the general public on the other. The media used are the normal communications channels: radio, television, magazines, newspapers, books, brochures, panels, debates, conferences, open days, etc. For example, during 1993 the British Natural History Museum organized more than 1,200 events throughout the country, allowing half a million people to come into direct contact with experts in different fields. The Scandinavian countries also tend to hold public debates on controversial issues, allowing the members of the public to participate in decision making.

These cases, and others such as the existence of specialist centres created under the patronage of scientific and technological development institutions, for example the "Centre for Innovative Sociology" of the prestigious Paris University College of Mining, or the discussion on Public Perception of Science during the last Annual Conference of the European Association of Science Faculty Deans, underline the general concern that a solution be found to a situation which has emerged in recent years[3].

All the above has a fundamental influence on the questions we are dealing with here. There would appear to be a need for all organizations responsible for the different aspects of radioactive waste management to draw up communications plans with the following fundamental objectives:

- To inform local communities of the work required in the area, with consideration given to social, economic and cultural characteristics.

- To provide the authorities and opinion leaders with detailed data on the activities involved in radioactive waste management.
- To achieve the closest possible links with different social agents in areas surrounding locations in which radioactive waste management activities are to be carried out. In this respect it is important to have suitable information centres and to organize visits to the facilities; normal people must have the opportunity to see for themselves those industrial facilities which might elicit irrational fears.
- It is necessary to broadcast the fundamentally scientific and technical principles on which effective radioactive waste management is based, systematically and in an understandable manner.
- In addition to systematic attempts to explain the technical rationale and the lack of risk involved in the activities to be performed, local understanding must be promoted through contributions to the social and economic development of the neighbouring communities. This is an important aspect and has given positive results wherever it has been put into practice.
- In any case, the difficult task of transmitting to the general public the message that the risks are under control may be impossible to accomplish unless there is some previous political agreement regarding the need for the subject to be kept aside from political controversy. It is probably necessary for the leading parties to understand that there is a need for rational management of radioactive wastes and to collaborate in its development.
- The position adopted internationally with respect to issues of this scope also has an obvious impact on public opinion. The existence of consensus among those responsible for the most highly developed nations is certainly reassuring and helps to dispel vague concerns for a risk that might appear to be both large and ill defined. For this reason, any action taken to achieve such consensus is an important step on the path towards acceptance by the opposition of the means to be adopted. There is a clear need to complete and enhance all the technological and political agreements between different countries which have been mapped out in the past.

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NUCLEAR POWER PLANT SAFETY CONVENTION

Z. DOMARATZKI

Atomic Energy Control Board,
Ottawa, K1P 5S9 Canada

Abstract

Coming out of a 1991 IAEA conference on the safety of nuclear power was a recommendation for an international agreement on nuclear safety. Negotiation of a convention began in December, 1991 and culminated in a signing ceremony in conjunction with the IAEA General Conference in September 1994. The scope of the Convention on Nuclear Safety is limited to land-based civil nuclear power plants. Its stated objectives are to achieve and maintain a high level of safety worldwide, to protect people and the environment and to prevent and mitigate accidents. The Convention has three articles under General Provisions which embody the basic obligations to implement the Convention, to report regularly on compliance with the obligations and to ensure the safety of existing nuclear installations. The General Provisions are followed by thirteen articles that are statements of principle based on "The Safety of Nuclear Installations", a publication in the IAEA Safety Series. The Convention provides for regular review meetings at intervals of not more than three years. Each Party to the Convention is required to report on how it has implemented each article of the Convention. Parties to the Convention would meet to review the submitted national reports. The Convention does not stipulate the content of national reports nor how the review process should be conducted. Preparation of the Convention involved seven meetings of a Group of Experts. From the outset, there were many areas where experts disagreed on the substance of the Convention. However, there was always a common objective since all wished to have as soon as possible a convention that addressed, as a minimum, the safety of nuclear power plants. Negotiations in the Expert Group proceeded on a consensus basis. All the different national positions were heard and discussed thoroughly before searching for a compromise position. Furthermore, the discussions all took place in plenary. The process resulted in a draft text which was adopted by a Diplomatic Conference with relatively few changes. The Expert Group left undefined a number of major topics; form and content of national reports as well as the review process during meetings of Parties. Preparatory work is underway on these and other topics in anticipation of an early entry into force.

1. BACKGROUND

By July, 1995 fifty-nine countries had signed a convention on nuclear power plant safety and seven had ratified. This Convention will enter into force when the governments of twenty-two countries, seventeen of whom have nuclear power plants, deposit their instruments of ratification with the Director General of the IAEA.

Proposals for a convention on nuclear safety have been made for many years. In 1980, in the aftermath of the Three Mile Island accident, some saw the need for such an instrument. TMI had demonstrated that improvements should be made to the design and operation of what were until then thought to be very safe reactors. The objective would be to ensure that all countries applied the lessons learned from TMI and brought their safety practices up to an acceptable international standard. At that time, however, the proposal for a convention found little support.

In 1986, following the Chernobyl accident two conventions were prepared, signed and promptly ratified. These were:

- i) the Convention on Early Notification of a Nuclear Accident, and
- ii) the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency.

The objectives of these two Conventions are to ensure that in case of an accident measures will be taken to notify all States which might be affected, and to facilitate prompt assistance to countries that do not have the capability to take necessary counter measures. Neither convention addresses accident prevention.

The countries of western Europe were particularly concerned about the possibility of further accidents in eastern Europe. They saw a situation in neighbouring states where, in their opinion, reactor designs were inadequate to ensure safety, the regulatory framework was absent and there was an absence of a sound safety culture in the operation of nuclear power plants. A mechanism was necessary to ensure that a high level of nuclear safety was achieved and maintained worldwide. An accident in one country was clearly seen as an accident that affected the nuclear programs in all countries. The incentive for a convention on nuclear safety was evident and many countries began to promote the idea.

The year 1991 was a milestone year. An IAEA Conference on the Safety of Nuclear Power: Strategy for the Future was organized in Vienna in September of that year to examine actions which should be taken to ensure that nuclear power would continue to be a viable option for the future. During the discussion several countries, with Germany being the strongest voice, promoted the idea of a convention on nuclear safety. The recommendations formulated at that conference included:

"There is a need to consider an integrated international approach to all aspects of nuclear safety, including safety objectives for radioactive wastes ... which would be adopted by all Governments";

The Governing Bodies of the IAEA were requested to organize:

"the preparation of a proposal on the necessary elements of such a formalized international approach, examining the merits of various options and taking into account the activities and roles of relevant international and intergovernmental bodies and using the guidance and mechanisms already established in the IAEA".

The Conference in its final declaration, however, also recalled that:

"safety should be primarily enforced at national levels, by conscientious application of existing safety principles, standards and good practices at each plant, and within each regulatory body, making best use of national legal frameworks and working practices".

At the IAEA General Conference later that month a resolution was adopted entitled "Means to Strengthen International Co-operation in Matters relating to Nuclear Safety and Radiological Protection". The resolution

"noting in particular that the International Safety Conference recognized the potential value of a step-by-step approach to a framework convention for the promotion of an international nuclear safety regime", invited the Director General "to prepare, for the Board's consideration in February 1992, an outline of the possible elements of a nuclear safety convention, taking into account the activities and roles of relevant international and intergovernmental bodies and drawing on the advice of standing groups like INSAG, NUSSAG and INWAC, and also on expertise made available by Member States and competent international organizations".

The Director General of the IAEA, Dr. Hans Blix, moved quickly to respond to the resolution. In December 1991 he convened a meeting of legal and technical experts to advise on the possible elements of a convention. Thirteen countries and three international organizations were represented by 36 experts. This inaugural meeting was followed by seven meetings of an open-end Group of Experts during the next two years. In February 1994, the Group completed the preparation of a draft text. The text was submitted to a Diplomatic Conference in June, 1994 where after some changes it was adopted by consensus and the Final Act was signed by seventy-one States.

The Convention was opened for signature in conjunction with the IAEA General Conference in September, 1994. Canada was given the honour of being the first to sign and Dr. Agnes Bishop,

President of the Canadian regulatory agency signed on behalf of her country. A total of forty-five countries signed during that week. The signatories included most of the countries that have nuclear installations as defined in the Convention.

2. ELEMENTS OF THE CONVENTION

The title "Convention on Nuclear Safety" continues to reflect the wishes of some countries when drafting of this instrument was first undertaken. Many countries proposed a convention which would address the safety of all nuclear activities. The scope is more modest, however, being limited to the safety of land-based civil nuclear power plants. Nevertheless, the Convention addresses the activity of the greatest international concern; nuclear power plants.

As is customary in any international instrument the Preamble to the Convention gives some insight into how the obligations should be interpreted. The Preamble reaffirms that the responsibility for nuclear safety rests with the State that has jurisdiction over an installation. It recognizes that there are international mechanisms in place which can assist states in enhancing nuclear safety and this Convention is an additional opportunity for enhancement of nuclear safety. The Preamble mentions without elaboration the nature of this Convention. It is an "incentive" convention, that is, a convention without any sanctions. From the subsequent statements in the Preamble one can deduce an incentive for a signatory (a Contracting Party) of the Convention to achieve the objectives by national efforts and the use of existing international mechanisms. There is also an incentive to have peers from other countries recognize that a State is living up to its obligations. The Preamble also refers to the nature of the obligations in that they are commitments to the application of fundamental safety principles. To determine if the obligations are being met the Preamble does draw attention to the existence of internationally formulated documents that can provide guidance. While they are not mentioned by name, the Nuclear Safety Standards (NUSS) of the IAEA are clearly a major contribution to this guidance.

The objectives of the Convention are spelled out clearly in the first article of the Convention. The first objective is to achieve a high level of safety throughout the world and once having achieved it to maintain safety at a high level. The second objective is to protect individuals, society and the environment from harmful effects of ionizing radiation. The method of accomplishing this protection is given as the establishment and maintenance of effective defences in nuclear power plants. The third and final objective is to prevent accidents with radiological consequences but, recognizing that prevention cannot be perfect, to mitigate the radiological consequences of accidents which might occur. These are very broad objectives for the safety of nuclear power plants. They are equally applicable to most nuclear activities.

The first three obligations of the Convention, in Articles 4, 5 and 6, are the basic obligations on Contracting Parties and the remaining articles can be considered as an elaboration of these three articles. Article 4 requires that a Contracting Party, has or puts in place the laws, organizations and measures that are necessary to achieve and maintain a high level of safety. Article 6 requires that each Contracting Party reviews the safety of existing nuclear power plants in its country and takes any necessary corrective action. Article 5 is an obligation to submit, for review by other Contracting Parties, reports on the measures it has taken to comply with the obligations in the Convention. Expressed in another fashion these three articles require a State to have the capability to achieve a high level of safety, to utilize this capability and to report results.

Article 6 recognizes that when a Party ratifies the Convention the installations under its jurisdiction may not be in compliance with the obligations. Being an incentive Convention this is not an impediment to ratification. By ratifying, however, a Party becomes obligated to take actions which would bring it into compliance. Article 6 is explicit. When the Convention enters into force the Party is obligated to:

- a) review the safety of existing installations;

- b) make all reasonably practicable improvements as a matter of urgency if the safety of a nuclear power plant is not adequate;
- c) shut down the installation as soon as practically possible, if necessary safety upgrades cannot be achieved.

In planning a shutdown a Party may take into account the social, environmental and economic impact. These considerations may affect only the timing of the shutdown: not whether the installation will be shutdown.

Article 5 imposes the obligation for each Contracting Party to submit, for review by other Parties, a national report on the measures that it has taken to implement each obligation of the Convention. Subsequent articles in the next chapter elaborate on reporting and review of reports.

The three fundamental obligations are followed by thirteen articles, often referred to by the Expert Group as the "technical articles". These articles, 7 through 19, are based on a Safety Fundamentals document in the IAEA Safety Series; *The Safety of Nuclear Installations* [1]. The Safety Fundamentals document contains a series of principles, each preceded by one or more paragraphs that provide background material and a discussion of the issues which give rise to the principle. The articles of the Convention include only the principles from the Safety Fundamentals document.

In transposing the principles of the Safety Fundamentals document into the text of the Convention some modifications were made in the presentation of the principles. The spirit and the substance of the principles were nevertheless preserved. For example, Principle 4 of the Safety Fundamentals document calls for "policies that give safety matters the highest priority". This was altered and the comparable obligation in the Convention, Article 10, requires "policies that give due priority to nuclear safety". On the other hand a comparison will show that a substantial part of the principles were incorporated in the Convention almost verbatim.

The technical articles of the Convention on Nuclear Safety were drafted with nuclear power plants in mind. They are applicable to a great extent, however, to obligations which would be found in a convention on radioactive waste. There should be little if any difference in the required legislative framework, the role of the regulatory body, quality assurance programs, safety assessment practices as well as the siting, design and construction practices.

Most of the technical obligations in the Convention begin with the introductory phrase; "Each Contracting Party shall take the appropriate steps to ensure that" This phrase recognizes that a convention places obligations on a state but the successful discharge of the obligations may depend, in some cases, on non-governmental organizations. Thus, for example, the State cannot keep radiation doses to workers as low as reasonably achievable but it is obligated to "take the appropriate steps to ensure that" operating organizations and others keep radiations doses low.

Articles 16 and 17 of the Convention deal with siting and emergency preparedness and include reference to neighbouring states that are not found in the Safety Fundamentals document. Article 16.2 obliges a Contracting Party to provide its own people with information on emergency planning and response. It also requires a Contracting Party to make available to neighbouring States information necessary for planning before an accident and for responding if an accident occurs.

Article 16.3 requires a Contracting Party to prepare and test emergency plans even if it does not have a nuclear power plant in its country. Insofar as it is likely to be affected by a radiological emergency at a nuclear installation in the vicinity, a Contracting Party is obliged to prepare and test emergency plans.

Article 17(iv) on siting includes an obligation similar to Article 16.2 in that it obliges co-operation with neighbouring States. It requires a Contracting Party to consult with States in the

vicinity of a proposed installation. The obligatory consultation is limited, however, to States that are Parties to this Convention. The purpose of the consultation is to enable the country in the vicinity to evaluate the likely impact on its territory. This obligation goes beyond making available the results of safety and environmental assessments. If requested, it entails an obligation to make available enough information to permit another Party to do its own independent assessment.

The Convention does not elaborate on what information a Contracting Party is obligated to give to other States in the vicinity of its nuclear installation. Neither does the Convention attempt to define explicitly what is meant by "in the vicinity" other than what can be reasonably inferred from the phrase "insofar as they are likely to be affected by that installation". It is implicit that bilateral consultations would be required. If disputes arise, the mechanism for resolving them under this Convention is identified in the final chapter.

Chapter 3 of the Convention deals with meetings of Contracting Parties. This Chapter is skeletal in nature. Within six months after entry into force of the Convention a preparatory meeting shall be held to prepare and adopt rules of procedure and financial rules. Article 22 highlights some of the particularly important matters that must be resolved at the preparatory meeting. These include guidelines for the preparation of national reports and the process for reviewing of the reports by other Parties.

Article 24 deals with attendance at meetings of the Contracting Parties. Each Contracting Party is obligated to be represented at meetings. The composition of its delegation is naturally left to the Party to decide "as it deems necessary". The Article also permits Contracting Parties to invite, by consensus, any intergovernmental organization which is competent in matters of nuclear safety to attend as an observer. One is left to infer from the Article that no other participants or observers may attend.

Chapter 3 contains an Article on languages. The Article notes that the languages of meetings shall be the six languages of the United Nations unless otherwise agreed by consensus. The Article envisages a single designated language for national reports. While silent on which language would be so designated there can be no doubt as to the fact that English is the only feasible choice. The deliberations in the Expert Group would lead one to believe that the discussions in meetings will be conducted in most or all of the six UN languages. For budgetary reasons, however, English would need to be the single designated language for national reports.

An examination of Chapter 3 reveals that there will be no permanent organization associated with this Convention. Between meetings of the Contracting Parties there will be no organization that will function. The IAEA will provide the secretariat for the meetings but will not have a role between meetings (except as the Depository). An organization may be created under the Rules of Procedures but based on the fact that consensus would be required and on the discussions in the Expert Group this is unlikely.

The Convention does not give any guidance on financial rules. Article 28 of the Convention simply states that the costs of servicing of meetings shall be borne by the IAEA as part of its regular budget. Any additional services requested could be financed from the IAEA regular budget or by voluntary funding provided from an undefined source. A variety of potential issues can be foreseen. The impact on the IAEA regular budget cannot be established until the preparatory meeting of the Contracting Parties at which the Rules of Procedure and Financial Rules will be adopted.

3. PREPARATION OF THE CONVENTION TEXT

The first step towards preparation of a Convention was a meeting in December, 1991. Experts from thirteen countries met to advise the Director General of the IAEA on the possible elements of a Convention. The experts agreed on a number of points: that there was a need for a convention, that it should embody the principles found in two draft IAEA documents on safety fundamentals, that no

supranational regulatory body should be created and that "peer pressure" during meetings of Parties could be an effective means of ensuring compliance. The experts could not agree on the form or the scope of a convention.

Dr. Blix requested and the IAEA Board of Governors authorized work to begin on the task of carrying out the necessary substantive preparations for a nuclear safety convention. Preparatory work began in May, 1992 when an open-ended group of experts met in Vienna. A hundred experts from forty-five countries, the CEC, NEA/OECD and ILO began the deliberations which were to require six further meetings over a period of two years.

At this first meeting two issues, in particular, divided the experts; the scope of the convention and the need for technical specificity. On the question of scope many countries favoured a convention which would address the entire fuel cycle plus research reactors, transportation and the use of radioisotopes. A significant number of countries, however, argued for a narrow scope limited to the activity of greatest international concern, i.e. nuclear power plants. The most steadfast opposition to a convention limited to civil nuclear power plants came from States that wished to see waste management included. Indeed, the deliberations of December 1991 had led them to believe that it would be possible to achieve consensus on inclusion of waste management.

During the next two meetings various compromise positions were debated to deal with the disagreement on scope. (The Group of Experts also discussed all the other issues.) It was not until the fourth meeting of the Group of Experts that deliberations had proceeded to the point that the delegates were prepared to agree on compromise positions. There was recognition that all parties would need to compromise if a convention was to become a reality. The compromise on the question of scope led to the position reflected in the Convention; basically it would be limited to land-based civil nuclear power plants. Waste management would not be included because there were no internationally agreed safety principles which could be applied to waste management. The Convention would however include in the Preamble, a commitment to begin work on a convention on waste management as soon as there was broad international agreement on the safety fundamentals for waste management.

A second reference in the Preamble was necessary to obtain the agreement of countries who preferred a very broad scope. The Preamble therefore also recognizes that developments in the future may facilitate consideration of international instruments for other parts of the nuclear fuel cycle. Research reactors, the use of radioisotopes and transport of radioactive materials were understood to be covered by this reference. The clause in the Preamble is not a specific commitment to other conventions. Rather it simply leaves open the possibility of future instruments.

The second issue which divided the Group of Experts was the technical specificity to be included in the Convention. Many were adamant that the Convention should be limited to statements of safety principles. Others considered that the obligations of Contracting Parties would only be clear if the Convention was made more specific. They therefore proposed to include technical annexes which would be based on the five Codes of Practice [2][3][4][5][6] published in the IAEA Nuclear Safety Standards programme (NUSS). It was argued that this degree of detail would make it easier to judge whether or not a Party had complied with the obligations of the Convention. Consensus on the need for technical details could not be achieved and at the fourth meeting there was agreement to proceed with fundamental principles only. All experts recognized that the NUSS documents could and would be used as valuable input when Contracting Parties met to review national compliance with the Convention.

The debate on the need to include technical criteria also highlighted disagreements on the role which the IAEA should play in the implementation of the Convention. All parties agreed from the outset that the IAEA should not serve as a supranational regulatory body. It should not be given an institutional role such as it has in the safeguards field. Many wished the IAEA role to be limited to that of the secretariat, a purely administrative and organizational function. Others, predominantly

countries with no nuclear power programs and therefore less national expertise, wished to have the IAEA make a significant technical contribution. They proposed that the role of the IAEA should be broad enough to permit it to conduct reviews, summarize available information, organize ad hoc technical groups, give advice on technical matters and generally contribute to an effective review of the implementation of the Convention. There was no consensus to give the IAEA an expanded role. The role of the IAEA is limited to that of a secretariat to service the meetings of the Contracting Parties.

Article 28.3 does leave open the opportunity for Contracting Parties to request the IAEA to provide other services within its area of competence. The request would need to have the consent of all Parties. The cost of such services need to be financed from the regular budget of the IAEA or by voluntary funding. The sentence dealing with voluntary funding was debated at length. There was an insistence by a few delegations that the Convention not commit them to open-ended financial arrangements. They foresaw difficulties in becoming Parties to such a convention.

From the outset negotiations in the Group of Experts proceeded on a consensus basis. This approach required the Experts to focus at the outset on identifying the areas where there was agreement rather than on issues which divided them. They identified that there was consensus on nuclear power plants as an essential part of the scope, on the objectives of the Convention, that the principles from the Safety Fundamentals document should be included in the obligations, that review of compliance with the obligations would be by peer review at meetings of the Contracting Parties and that the IAEA should serve as the secretariat.

At each meeting delegates made proposals and sought consensus for including other elements in the Convention. All the different national positions were heard and were discussed thoroughly. However, individuals did not persist with a proposal when it became evident that it was not possible to achieve consensus. In many cases they did resurrect proposals at subsequent meetings if they had new arguments to present. The goal was to have a text which could be supported by all. It would need to incorporate as a minimum the basic elements that each State insisted be included and yet did not include any element that was objectionable to a State. The success of this process became evident in June 1994 when, at the Diplomatic Conference, the draft text after some modifications was adopted by consensus.

With only a few exceptions the Expert Group met in plenary sessions. This practice was dictated by a number of considerations. The first four meetings of the Group were devoted to exploring the issues and searching for compromise. Dividing into working groups along legal and technical lines would have been premature. The last three meetings were devoted to a review and modifications of the Chairman's draft text. Breaking into working groups might have been efficient but there was no clear distinction between legal and technical issues in many of the articles. Furthermore, it suited the countries with small delegations to operate in plenary only. A legal drafting group was set up during the final two meetings but this group met only when plenary sessions were not in session. Furthermore its mandate was largely restricted to revising text in accordance with clear direction from the plenary session.

The Expert Group benefitted greatly from the presence of the IAEA Safety Fundamentals document on the safety of nuclear installations. Although still a draft document it was accepted as authoritative by the Expert Group. When agreement was reached that the Convention text should be limited to statements of principle it was already a foregone conclusion that the principles in the Safety Fundamentals document would be accepted as the basis for the technical obligations.

The Expert Group operated for two years. Throughout this period there was a sense of urgency associated with the work. The time between meetings was always kept to a minimum; enough only to ensure adequate time for delegates to reassess their positions in their capitals. As a consequence of the relatively short period of time there was little change in the composition of the national delegations and little, if any, change in national positions.

At its first meeting the Expert Group elected a Chairman. The Group chose not to elect any alternates or vice-chairmen. This was a distinct advantage when, after four meetings, the chairman was asked to prepare a negotiation text. The preparation of a text became a one person responsibility with the freedom to contact and consult with any delegates. Disposition of many hundreds of comments on previous draft texts as well as a complete text submitted by one country was a challenge; a challenge which would have been much more time consuming if it had involved vice-chairmen.

The chairman used the first version of his text as the basis for consultation with a broad cross-section of Member States. He made every effort to benefit from a broad spectrum of viewpoints. He consulted with countries that had large nuclear power programs as well as with countries that as a matter of policy do not have nuclear power plants. He consulted with countries that are the industrial leaders as well as with those that are developing their industrial capability. On a geographic basis he consulted with countries from five of the six continents. A total of fifteen countries were consulted individually or in small groups.

The benefits of the consultation process were extremely positive. The draft text was significantly improved at the same time as the chairman was able to garner support for it. In retrospect, it was evident to the chairman that these private consultations were so valuable that they should have been expanded further.

The Expert Group left undefined a number of major topics. Principal among these are the form and content of national reports and the review process during meetings of Parties. These topics, and others, will be formally addressed when the Convention enters into force and a preparatory meeting is held in accordance with Article 21. Although formal preparations cannot start until the Convention enters into force a substantial amount of work has been done.

After the fifth meeting of the Group of Experts (October 1993), the chairman of the Group established a small informal group of experts chaired by C. Stoiber (USA) which developed a "conference room" paper containing Draft Rules of Procedure for the review meetings, guidance on the preparation of national reports, the basic elements of a review process and estimates of costs for meetings of Contracting Parties. A few months earlier, INSAG prepared, upon request of the Director General, a report on "Basic Concepts and Review Mechanisms" of the Convention which addressed the content of national reports and a process for peer review of national reports. A non-binding Annex to the Final Act of the Convention proposes some general principles for the review process.

Informative national reports will be required to permit effective review meetings of the Contracting Parties. The challenge will be to strike the proper balance between, on one hand, completeness to permit others to understand and comment on the national practices and experience and, on the other hand, conciseness to enable the review to be done in an efficient fashion. Effective review will require that reports go beyond a generic description of national practices. Specific information will be required on problems being experienced and attempted solutions which have or have not worked. Where an obligation has not been fully implemented the report would need to define additional actions planned and the anticipated timetable for corrective action. It is anticipated that national reports will also discuss results of evaluations done by international bodies, such as WANO and IAEA, to assess the safety of nuclear installations.

The preparation of national reports is solely a national responsibility. Parties can involve, however, outside organizations and experts. This could include requesting assistance from other countries or from the IAEA.

It should be noted that the question of languages in which national reports are to be submitted would have an impact on costs and the formula for sharing of costs. If all national reports are to be translated into the six United Nations languages the cost of a review meeting would be very high and

much more than could be provided from the current regular budget of the IAEA. Clearly the solution is to choose a single designated language (realistically, English) for all national reports. The cost of a review meeting would likely be less than one million dollars in such a case. Article 26 envisages that a designated language may be agreed upon for national reports. Such agreement would require consensus of the Contracting Parties.

With high quality national reports an effective peer review will be feasible. The review process should identify problems, concerns, uncertainties or omissions in national reports. However, the goal of the peer review process under this incentive Convention is not simply to determine whether the individual Parties have achieved the required level of safety. The peer review process should also be a candid discussion of problems encountered, solutions implemented and further actions required to achieve and maintain the required high level of safety. One goal should be to identify opportunities for technical co-operation in the interest of resolving identified safety problems.

While a formal preparatory meeting cannot be held until the Convention enters into force, informal preparation is already in progress. A group of 102 participants from 48 countries and two inter-governmental organizations met in Vienna in March, 1995 to begin the substantive work. They will meet again in November 1995. These meetings are being held in the expectation that the Convention will enter into force in 1996.

The entry into force of the Convention on Nuclear Safety is in sight. The experience gained in the preparation of that Convention as well as the preparatory work currently underway should be of value in developing a companion convention on radioactive waste.

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PRINCIPLES AND OBJECTIVE OF RADIOACTIVE WASTE MANAGEMENT

E. WARNECKE

International Atomic Energy Agency,
Vienna

Abstract

Radioactive waste is generated in various nuclear applications, for example, in the use of radionuclides in medicine, industry and research or in the nuclear fuel cycle. It must be managed in a safe way independent of its very different characteristics. Establishing the basic safety philosophy is an important contribution to promoting and developing international consensus in radioactive waste management. The principles of radioactive waste management were developed with supporting text to provide such a safety philosophy. They cover the protection of human health and the environment now and in the future within and beyond national borders, the legal framework, the generation and management of radioactive waste, and the safety of facilities. Details of the legal framework are provided by defining the roles and responsibilities of the Member State, the regulatory body and the waste generators and operators of radioactive waste management facilities. These principles and the responsibilities in radioactive waste management are contained in two recently published top level documents of the Radioactive Waste Safety Standards (RADWASS) programme which is the IAEA's contribution to foster international consensus in radioactive waste management. As the two documents have to cover all aspects of radioactive waste management they have to be formulated in a generic way. Details will be provided in other, more specific documents of the RADWASS programme as outlined in the RADWASS publication plan. The RADWASS documents are published in the Agency's Safety Series, which provides recommendations to Member States. Using material from the top level RADWASS documents a convention on the safety of radioactive waste management is under development to provide internationally binding requirements for radioactive waste management.

1. INTRODUCTION

Since the beginning of the twentieth century research and development in the field of nuclear science and technology have led to wide-scale applications in research, medicine, industry and in the generation of electricity by nuclear fission. In common with certain other human activities, these practices generate waste that requires management to ensure the protection of human health and the environment now and in the future, without imposing undue burdens on future generations. Radioactive waste may also result from the processing of raw materials that contain naturally occurring radionuclides.

Radioactive waste occurs in a variety of forms with very different physical and chemical characteristics, such as the concentrations and half-lives of the radionuclides. It may occur in gaseous, liquid or solid form. Such wastes may range from slightly radioactive, such as those generated in medical diagnostic procedures, to the highly radioactive, such as those in vitrified reprocessing waste or in spent radiation sources used in various applications. Radioactive waste may be very small in volume, such as a spent sealed radiation source, or very large and diffuse, such as tailings from the mining and milling of uranium ores and waste from environmental restoration. Basic principles for radioactive waste management have been developed [1] that should have broad application even though there are such differences in the origin and characteristics of radioactive waste. Their implementation will vary depending on the types of radioactive waste and their associated facilities.

To achieve the objective of safe radioactive waste management requires an effective and systematic approach within a national framework in which the roles and responsibilities of all relevant parties are defined. Based on the principles set out in the Safety Fundamentals document [1] such a national framework which includes the responsibilities of the parties involved and other important features (e.g. the licensing process and safety and environmental assessment) has been developed in the Safety Standard "Establishing a national system for radioactive waste management" [2].

These publications [1,2] are two of the highest ranking documents of the Radioactive Waste Safety Standards (RADWASS) programme [3]. They address the basic principles of radioactive waste management and the associated requirements in a generic way. Further details will be provided in other documents of the RADWASS programme (see Publication Plan in [3]) in particular in Safety Guides and Safety Practices. Some of the details are presented in the paper by A. Duncan et.al. [4].

The RADWASS programme provides for reviews from time to time. It was initiated in 1991 and originally included 24 documents. The programme was revised in 1993 and was extended to 55 documents including 20 Safety Practices. At this time a number of additional topic areas were brought into the programme such as environmental restoration, quality assurance, safety assessment, licensing of facilities, clearance levels, discharges and a glossary. The next planned review of the programme is scheduled for 1995 which coincides with a major reorganization of the IAEA's Department on Nuclear Energy and Safety. Changes to the RADWASS Publication Plan may be expected.

RADWASS is the IAEA's contribution to establishing and promoting, in a coherent and comprehensive manner, the basic safety philosophy for radioactive waste management and the steps necessary to assure its implementation. It is also intended to contribute to a further harmonization of safety requirements in various countries.

RADWASS documents will be published in the IAEA's Safety Series under number 111. These publications are organized in the four hierarchical levels of the IAEA Safety Series and are at present planned to comprise 1 Safety Fundamentals document, 6 Safety Standards, 28 Safety Guides and 20 Safety Practices. This may however change as a result of the review of RADWASS.

Safety Series publications contain recommendations of the IAEA. They will be applied to the Agency's own operations and operations using Agency support and may become mandatory if they are adopted into the national legal framework.

A binding document for signatory States will be the convention on the safety of radioactive waste management which is presently being developed. The publications [1,2] will form a basis for drafting this safety convention. As such a convention, in contrast to the RADWASS publications, is a stand-alone document the wording of the RADWASS Safety Fundamentals or other sources will have to be modified and adapted as necessary.

2. OBJECTIVE OF RADIOACTIVE WASTE MANAGEMENT

The objective of radioactive waste management is to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations.

3. FUNDAMENTAL PRINCIPLES OF RADIOACTIVE WASTE MANAGEMENT

Responsible radioactive waste management requires the implementation of measures that will afford protection of human health and the environment. Fundamental safety principles have been developed and their observance will contribute to achieving the objective of radioactive waste management.

Principle 1: Protection of human health

Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health.

The nature of radioactive waste implies in particular the hazard of exposure to ionizing radiation. Other hazards associated with radioactive waste are similar to those associated with toxic waste. In establishing acceptable levels of protection the recommendations of the International Commission on Radiological Protection (ICRP) [5-7] and the IAEA [8] and specifically the concepts of justification, optimization and dose limitation are taken into account. The relevance of these concepts depends on the type of radioactive waste management activities. The following examples may be given:

- In the case of a practice, radioactive waste management should be taken into account in the justification of the entire practice giving rise to the radioactive waste and therefore need not be justified separately: optimization and dose limitation remain applicable.
- In the case of an intervention, justification and optimization are required, but not the concept of dose limitation.

Special considerations which are necessary when long time periods and the associated uncertainties are involved, for example in geological disposal are being presented in [9-11].

Principle 2: Protection of the environment

Radioactive waste shall be managed in such a way as to secure an acceptable level of protection of the environment.

In protecting the environment particular emphasis has to be given to the limitation of radionuclide releases, non-radiological environmental impacts and the future availability of natural resources.

Derivation of discharge limits is important in order to keep releases of radionuclides into the environment at an acceptable level. The derivation of such limits for waste management facilities is a planned activity within the RADWASS programme [3]. Although the preferred approach to radioactive waste management is concentration and containment of radionuclides rather than dilution and dispersion in the environment radioactive substances may be released within authorized limits and also through the reuse of materials. When radionuclides are released into the environment, species other than humans should be taken into consideration. The presence of humans should generally be assumed in the assessment of impacts on the environment.

Non-radiological environmental protection requires that radioactive waste management is undertaken with a level of environmental protection at least as good as that required for similar industrial activities.

The future availability of natural resources is dependant on the limitation of radionuclide releases and the non-radiological environmental protection. Furthermore, migration of radionuclides after closure of a disposal facility has to be taken into account as a long-term risk for contamination of natural resources (see principle 4).

Principle 3: Protection beyond national borders

Radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will be taken into account.

Providing protection of human health and the environment beyond national borders is a matter of responsibility and ethical concern. Impacts on human health and the environment in other countries should not be greater than those which have been judged acceptable within the country of origin. In fulfilling this duty, recommendations of international bodies such as the ICRP and the IAEA should be taken into account.

Exchange of information or finding arrangements with neighbours or affected countries is of utmost importance, in particular in the case of diverging national requirements.

Import and export of radioactive waste is another important transboundary issue. A State should receive radioactive waste for management or disposal only if it has the administrative and technical capacity and regulatory structure to manage and dispose of such waste in a manner consistent with the international safety standards [12].

Principle 4: Protection of future generations

Radioactive waste shall be managed in such a way as to assure that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.

In the establishment of acceptable levels of protection of future generations, the latest recommendations of international organizations, for example the ICRP [5-7] and the IAEA [8], are typically taken into account. Protection is achieved by applying the multibarrier approach.

Implementation of radioactive waste management, particularly for disposal, faces the inherent difficulty that uncertainties in predicting impacts far into the future will increase with increasing time periods [9,10].

Principle 5: Burdens on future generations

Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.

This principle is based on the ethical consideration that the generations that receive the benefits of a practice should bear the responsibility to manage the resulting waste. The responsibility of the present generation includes developing the technology, constructing and operating facilities, and providing a funding system, sufficient controls and plans for the management of radioactive waste.

Limited actions, however, may be passed to succeeding generations, for example, the continuation of institutional control, if needed, over a disposal facility. The management of radioactive waste should, to the extent possible, not rely on long term institutional arrangements or actions as a necessary safety feature. Future generations may decide to utilize such arrangements.

The identity, location and inventory of a radioactive waste disposal facility should be appropriately recorded and the records maintained.

Principle 6: National legal framework

Radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions.

The national legal framework should provide laws, regulations and guidelines for radioactive waste management taking into account overall national radioactive waste management strategies. The responsibilities of each party or organization involved should be clearly allocated (see Section 4).

Separation of the regulatory functions, including enforcement, from the operating functions is required. Also, provisions for sufficiently long lasting continuity of responsibilities and funding requirements should be made.

Principle 7: Control of radioactive waste generation

Generation of radioactive waste shall be kept to the minimum practicable.

The generation of radioactive waste shall be kept to the minimum practicable, in terms of both its activity and volume. This includes the selection and control of materials, the recycle and reuse of materials and the implementation of appropriate operating procedures. Emphasis should be placed on the segregation of different types of waste and materials.

Principle 8: Radioactive waste generation and management interdependencies

Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account.

Because of interdependencies among and between steps in waste management decisions made at one step may foreclose alternatives for, or otherwise affect, a subsequent step. Furthermore, there are relationships between waste management steps and operations that generate either radioactive waste or materials that can be recycled or reused.

Those responsible for a particular waste management step or operation generating waste should adequately recognize interactions and relationships.

Where decisions must be made before all radioactive waste management activities are established the effects of future radioactive waste management activities, particularly disposal, should be taken into account when any radioactive waste management activity is being considered.

Principle 9: Safety of facilities

The safety of facilities for radioactive waste management shall be appropriately assured during their lifetime.

During all radioactive waste management activities priority needs to be given to safety matters including the prevention of accidents and limitation of consequences should accidents occur.

Site selection should take into account relevant features which might affect the safety of the facility or which might be affected by the facility.

Design, construction, operation and activities during decommissioning of a facility or closure of a repository should provide and maintain, where applicable, an adequate level of protection to limit possible radiological impacts.

An appropriate level of quality assurance and of adequate personnel training and qualification should be maintained throughout the life of radioactive waste management facilities.

Appropriate assessments should be performed to evaluate the safety and the environmental impacts of the facilities.

4. RESPONSIBILITIES ASSOCIATED WITH RADIOACTIVE WASTE MANAGEMENT

Safe radioactive waste management requires clear allocation of responsibilities to the parties involved (see Principle 6). The overall responsibilities cannot be delegated if work is performed by others, for example by contractors.

Responsibilities of the Member State

Responsibility 1: To establish and implement a legal framework

A legal framework for the management of radioactive waste shall be established and implemented which does not necessarily need to be designed solely for radioactive waste management. The components of this framework will vary from country to country depending, for example, on the political structure and the types and amounts of radioactive waste.

Responsibilities to all parties involved in radioactive waste management shall clearly be allocated. The national government or the government of a subnational unit may take direct responsibility for some or all of the radioactive waste management activities.

The national government should take responsibility for international matters.

Responsibility 2: To establish a regulatory body

A regulatory body that has the responsibility for carrying out the regulatory function with regard to safety and the protection of human health and the environment shall be established or designated. Where the regulatory function is divided among several bodies it shall be ensured that the regulatory system is comprehensive and coherent. The regulatory body may be assisted by advisory bodies and experts.

The regulatory body is to be provided with adequate authority, competence and financial and human resources. It shall be empowered to enforce legal requirements to issue, amend, renew, suspend or cancel licences or authorizations or to recommend such actions to the government.

The regulatory body needs to have an effective independence from operation organizations, designers, vendors and constructors.

Independence shall not be compromised, for example, if the government has taken over radioactive waste management responsibilities or if countries have limited use of radionuclides resulting in the generation of waste.

Responsibility 3: To define responsibilities of waste generators and operators of radioactive waste management facilities

The role and responsibilities of waste generators and operators who shall have responsibility for the safety of radioactive waste management activities are to be defined. If these activities are carried out by several operators in sequence, continuity of responsibilities shall be ensured.

Responsibility 4: To provide for adequate resources

Appropriate steps shall be taken to ensure that adequate financial, human and technical resources are available or will be provided.

Responsibilities of the Regulatory Body

Responsibility 5: To enforce compliance with legal requirements

Compliance with the established legislative and statutory framework for safety and environmental protection has to be enforced. No other responsibility assigned to the regulatory body should jeopardize or conflict with this mission. The regulatory body shall implement the licensing process and shall, where appropriate, develop and update the rules, criteria, guidelines, etc., and ensure that adequate records of radioactive waste management facilities or sites are maintained for an appropriate period of time.

Responsibility 6: To implement the licencing process

The regulatory body has the responsibility to review, approve or reject applications and to issue, amend, modify, suspend, cancel or otherwise act upon plans, licences or other authorizations for radioactive waste management activities or to recommend such actions to the government.

In implementing the licensing process the regulatory body shall review environmental impacts and safety, implement an inspection programme and require operators to take corrective measures where necessary.

Responsibility 7: To advise the government

The regulatory body shall, where appropriate, make recommendations to the relevant governmental authority regarding the development and implementation of national policy, strategies, laws and objectives to ensure the safe management of radioactive waste.

Responsibilities of waste generators and operators of radioactive waste management facilities

Responsibility 8: To manage radioactive waste safely

The responsibility for the safety of radioactive waste management activities rests with the operators.

They shall safely operate the waste management facilities. Generation of radioactive waste shall be kept to the minimum practicable. Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account.

Responsibility 9: To identify an acceptable destination for the radioactive waste

Waste generators or operators of a facility dealing with radioactive waste are responsible for identifying, on an appropriate time scale, an acceptable destination for their waste. The operator may dispose of the radioactive waste in a legally approved manner, or may transfer it in an authorized manner to another operator for processing, storage or disposal.

Responsibility 10: To comply with legal requirements

Waste generators and operators of radioactive waste management facilities shall comply with the legal requirements imposed on them and demonstrate such compliance to the satisfaction of the regulatory body.

5. CONVENTION ON THE SAFETY OF RADIOACTIVE WASTE MANAGEMENT

In September 1994 the IAEA's General Conference adopted a resolution which requested commencement of preparations for a convention on the safety of radioactive waste management. In June 1994 the convention on nuclear safety had already been adopted by a Diplomatic Conference. In the Preamble of this convention, the Contracting Parties affirm "the need to begin promptly the development of an international convention on the safety of radioactive waste management as soon as the ongoing process to develop waste management safety fundamentals has resulted in broad international agreement". The Safety Fundamentals [1] and the Safety Standard [2] have been approved by the Board of Governors in March 1995.

A meeting of experts from Member States was convened on 20 - 22 February 1995 with the objective of holding preliminary discussions on basic concepts and the possible scope of such a convention, and to examine working mechanisms and procedures for its preparation.

General support was expressed for the establishment of an incentive (i.e. rather a stimulating and encouraging than a prescriptive) convention with a broad scope to be prepared in a timely and comprehensive manner. A broad list of suggestions made and questions raised during the meeting was established by the Secretariat in the form of a paper entitled "Inventory of Issues Raised."

An open-ended group of technical and legal experts has been convened to carry out the necessary substantive preparations for a convention and had their first meeting 3 - 7 July 1995. This group has, in particular, addressed the objectives, definitions and scope of the convention, the obligations of the Contracting Parties and institutional arrangements. It is hoped that the convention on the safety of radioactive waste management will be prepared within about two years, which was the time frame for the convention on nuclear safety.

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RESEARCH AND DEVELOPMENT ON RADIOACTIVE WASTE MANAGEMENT

W. BALZ
European Commission,
Brussels

Abstract

R&D programmes on radioactive waste management have been implemented in most countries operating nuclear power plants for a few decades now. The resulting knowledge and achievements are considerable. They have been widely disseminated and lead to: the identification of the major problem areas, development and optimisation of waste treatment processes and waste forms in view of their later disposal, technologies for quality control of waste packages, selection of engineering concepts and demonstration of specific mining and handling techniques for disposal. Large amount of information and data have been collected on the behaviour of the various barriers under representative disposal conditions. Methodologies and models are available today to evaluate adequately the potential long-term radiological impacts of a carefully designed radioactive waste disposal system on humans and the environment. However, collection and evaluation of data from proposed disposal sites are the major tasks on which further progress is needed. International cooperation through organisations like IAEA, OECD/NEA and the European Commission has contributed to increase the information and experience among the Member States through a variety of mechanisms with the result to come closer to an international consensus on the fundamental principles and basic standards used in the disposal of radioactive waste.

1. INTRODUCTION

Since the Fifties, when the US Academy of Sciences recommended continental disposal by confinement of radioactive waste [1], large research efforts have been dedicated to investigate its feasibility and to assess its safety. In particular in the early Seventies when the number of nuclear power plants increased rapidly and radioactive wastes were produced in significant quantities, comprehensive R&D programmes were developed in many countries.

There are two main approaches to such land disposal by burial either in near surface facilities for low and non heat generating medium level wastes or in deep underground repositories in geological environments. Low and medium level wastes were disposed of in EU countries in near surface facilities in France, United Kingdom and recently in Spain and in deep disposal facilities in Germany.

Deep geological disposal concepts, in particular for alpha bearing (low or medium level) waste and heat generating high level waste, were developed mainly based on the multi-barrier concept. In this concept, the protection of humans and the environment should be guaranteed by an optimal combination of a number of barriers consisting of the waste matrix, container, buffer and backfill material, the repository structures and the geological environment.

Engineering techniques for excavation and construction were tested and demonstrated in abandoned mines and/or specifically established underground laboratories. A large amount of experimental data has been collected on the behaviour of the various barriers under representative disposal conditions. Methodologies and models were developed for the assessment of the long term safety of designed radioactive waste disposal systems. International cooperation through the IAEA, OECD/NEA and the European Commission has contributed to a better use of resources in manpower and money in the research efforts undertaken and allowed to come closer to a common understanding of the main issues.

In this paper, an overview is given of the achievements made, in the main research areas, of the critical issues devoted to HLW disposal which still need further investigations and current trends in R&D programmes are identified.

2. WASTE MINIMISATION AND PARTITIONING AND TRANSMUTATION

Much efforts have been undertaken to *reduce the volumes of radioactive waste produced by the nuclear industry* by incineration, melting and supercompaction. These techniques are now applied on industrial scale. Other approaches to reduce the volume of waste packages to be disposed of consist in:

- improvement of decontamination processes when applied to low level or alpha contaminated liquid waste. This will lead to a small volume of highly active or alpha contaminated residues and to a large volume of very low level waste which can be disposed of in a near surface site. In Europe, very selective extractants for Cs, Sr and actinides are being synthesised and tested. These extractants are new macrolytic compounds, which include calixarenes and crown-ethers;
- improvement in components design and in operating practices. Examples of such actions are the development of cleanable HEPA filters, the selection of dismantling processes minimising the production of secondary waste, and a permanent incentive to develop a waste minimisation culture at management and working levels;
- development of new fuel cycle concepts (e.g. thorium cycle).

Radioactive waste minimisation may also be obtained by means of a *reduction of the radioactivity* using a Partitioning and Transmutation (P&T) strategy [2].

After a considerable research effort in 1970-80, there has been a renewal of interest for P&T of long-lived radionuclides in several countries (China, France, Japan, Russia) and international organisations (IAEA, OECD/NEA and EC) since the beginning of the Nineties. It should however be pointed out that P&T cannot eliminate the need for geological disposal.

The actinides are the most important nuclides to be investigated in a P&T strategy from the point of view of potential hazards (source term without any barriers); however, some long lived mobile fission products (such as I, Tc) and actinides such as neptunium represent the main residual hazard (taking into account engineered and geological barriers) over a long term period of time.

P&T involves three steps: (i) partitioning of long-lived radionuclides (minor actinides (Np, Am, Cm) and fission products (I, Tc, Cs)) from high level waste; (ii) development of fuel and targets containing these long-lived elements in view of their (iii) transmutation in different burners (fission reactors and accelerator driven transmutation devices). The progress achieved in these three areas can be summarized as follows.

(i) **Partitioning**

Two classes of processes are being investigated:

- wet (aqueous) separation methods that are implemented in association with the PUREX process;
- dry pyrometallurgical processes that may follow the PUREX process or completely replace it.

Concerning the wet separation methods, the possibility to separate neptunium, the soluble part of technetium and perhaps zirconium directly during the PUREX process is being studied.

The major problem to be solved is the separation of the minor actinides (MA), mainly americium and curium, without producing large quantities of secondary waste. At present, most of the extractants are applied in a two-step process: MA are first coextracted with the rare earths from the high-level liquid waste and then MA are separated from the rare earths. One difficulty of this

partitioning process is curium, which is difficult to separate from americium and cannot be handled easily because of its very high radioactivity.

(ii) *Fuel and target development*

The technical feasibility of the use of MOX (uranium + plutonium oxide) and UOX (uranium oxide) fuels for the recycling of minor actinides in fast reactors has been proven to some extent. Studies are still in progress for recycling in Light Water Reactors (LWR).

Oxide, metal alloy and inert matrix fuels and targets containing MA and ^{99}Tc are fabricated, at a laboratory scale, and scheduled for irradiation. Concepts of nitride and molten salt fuels have been proposed for the advanced transmutation systems, e.g. actinide burners and accelerator driven systems.

(iii) *Transmutation*

Several transmutation devices are being considered, such as fission reactors and accelerator driven systems.

Light Water Reactors appear not very efficient for the transmutation of minor actinides, because the neutron capture cross section is much larger than the fission cross section for thermal neutrons.

Many countries are planning to recycle plutonium in LWRs as MOX fuel (~ 30% of the core or even as full MOX loading). This recycling scheme can stabilize the plutonium accumulation.

Fast reactors seem to have the best prospects for transmutation of MA and fission products; they could incinerate the production of 2-5 LWRs with a transmutation half-time of 10 years for MA and 25 years for ^{99}Tc respectively. The aim is the transmutation of MA and fission products produced by 10 or more LWRs.

Multiple recycling of actinides in a reactor is limited because it increases the radiotoxicity and radioactivity of the spent fuel.

Beside LWRs and fast reactors, accelerator driven systems are getting increasing interest. The increase of proton currents by two orders of magnitude from the present level is a very challenging task. Further research is needed to clarify which accelerators with good transmutation rates could be used in the future.

3. WASTE FORM PERFORMANCE

It is today well accepted that the components of the waste package (waste form, waste container) are designed to provide a complete confinement of the radionuclides for a period of a few hundreds to thousands years [3]. It is well recognised that more attention has to be paid e.g. to the long-term behaviour of the waste package. To predict the effectiveness of the waste package quantitatively as a function of time, information about their physical and chemical properties as well as the geological processes at the site that may change those properties are needed.

Ongoing characterisation programmes aim at obtaining results which can be incorporated in long-term predictive models for the waste form to be disposed of in underground repositories. As the conditions at potential repository sites are likely to vary considerably from each other, site-specific predictive models are to be developed. The ongoing characterization work for waste form involves testing in relevant repository conditions which are simulated in laboratory experiments or in in-situ environments which are considered to be similar to proposed disposal sites.

The wide chemical variation of radioactive wastes which are extremely complex in composition require different methods of immobilisation and containment. The waste forms range from Low Level Waste (LLW), Medium Level Waste (MLW) through to High Level Waste (HLW). MLW can be embedded in cement or bitumen whereas HLW is either reprocessing waste immobilised in borosilicate type glasses or is the spent fuel when declared as waste.

Research on glass aims at characterising its ability to retain radionuclides in the case of liquid intrusion into the container taking into account the influence of the different repository environments which also includes the container corrosion products and the glass composition. The radionuclide release through glass dissolution is very complex. It is governed by different mechanisms such as the kinetics of glass dissolution, solubility limits, sorption, co-precipitation, formation of secondary phases (crystal growth at the glass surface), etc. As a consequence of the uncertainties attached to the contribution of these various mechanisms the role of glass in the overall safety assessment of radioactive waste disposal has often been underestimated. Further efforts are required to obtain quantitative data on its long term durability rather than on relying on extrapolation of "orders of magnitude". This is especially true when applied to the behaviour of radionuclides during groundwater interaction with the glass and the long term glass corrosion kinetics under saturation conditions. The role of iron container corrosion products on radionuclide migration in the near-field is also investigated.

As well as the vitrification of the HLW from reprocessed spent fuel, many countries are examining the option of direct disposal of spent fuel in a geologic repository. Before this option can be properly evaluated it is necessary to have an understanding of the kinetics and mechanisms of spent fuel dissolution processes when it comes into contact with groundwater in the repository. Although considerable experimental data does exist on spent fuel dissolution processes there are nevertheless major uncertainties in their interpretation and quantification of the processes controlling radionuclide release during the long term spans to be taken into account for safety assessment purposes. In order to reduce these uncertainties efforts must be devoted to combine experimental investigations on real spent fuel with model development. This requires full investigation of the dissolution behaviour of UO_2 which is the major constituent of spent fuel, the fuel microstructure and its influence on the release or retention of actinides and fission products entrapped in the fuel. As well as looking at the behaviour in laboratory experiments and simulated in-situ scenarios, natural analogues are being investigated to provide information on what could happen over more realistic geologic time-scales.

Irrespective of whichever disposal route is chosen and as part of the multi-barrier concept, the HLW will be placed first in metal containers which in turn could be placed in overpacks before emplacement in a repository. Also the use of multi-purpose containers, that is containers which could be used for transport, storage and disposal are now being considered. A number of metals and their alloys have been considered suitable as candidate materials for nuclear waste containers. Two basic concepts have been considered which involve corrosion allowance materials (e.g. irons, stainless steels) and those which are corrosion resistant (e.g. nickel and nickel-based alloys, copper and copper-base alloys, and titanium). The selection of the most suitable material and concept will be influenced greatly by the geologic formation, the geochemical environments and the prevailing temperatures and pressures which will control the different corrosion mechanisms. Long-term tests must be carried out to investigate certain phenomena, e.g. localized corrosion, stress corrosion and hydrogen embrittlement, which are only initiated after long incubation times.

Cementitious materials where it is used as encapsulation material for LLW and MLW will be present in repositories and act as a chemical barrier. Therefore the physical and chemical properties of cement must be well understood to assess its long-term behaviour in a waste repository context. The interaction of groundwaters with the cement will influence its chemical properties as barrier which is dependant on its ability to maintain an alkaline environment with a high pH. The presence of a high pH encourages the precipitation of many of the elements likely to occur in radioactive wastes. Considerable efforts are being devoted to examine the phase changes which could occur in cement/groundwater interactions and to assess the changes which could be brought about in

the long term. To study the long term effects it is necessary to integrate the data from in-situ experimental set-ups with that obtained from accelerated testing and to develop computer based models to enable extrapolation of the test data to predict future performance.

It is becoming widely recognised and accepted that, before any waste packages can be put into interim storage or disposal, it will have to be demonstrated that they conform to the requirements set out by national safety authorities. To achieve this considerable efforts and resources are being devoted to develop quality control and assurance procedures and techniques. In some areas chemical, radiological and mechanical/physical tests are under development to continuously control the processes of low and medium radioactive waste conditioning from the time the waste is generated until it is placed in storage. Emphasis is placed on the development of routine easy-to-use non-destructive assay methods. Test equipments are being developed which include transmission tomography to check the homogeneity and the content of the waste packages, emission tomography to establish the distribution of radioactive materials and active neutron interrogation to determine the fissile material in waste packages. For example whereas active neutron counting is a well established method in safeguards control, the application of this technique to the determination of fissile material in typical waste containers is relatively rare. This is due mainly to the problems associated with waste packages where the matrices contribute to difficulties in neutron moderation and adsorption characteristics.

Therefore, decreasing the accuracy of the quantification of the fissile material present in the waste package. To improve this, resources are being devoted to assess the suitability of alternative neutron sources and detector systems.

4. THE GEOLOGICAL BARRIER

The geological barrier plays the main role in the multi-barrier concept, in particular where it concerns the long term. Various geological formations are under consideration such as clay, salt, crystalline rocks, tuff, etc. The emphasis put in the various national programmes on specific rock formations depends on the presence of one or another formation at the national territories [4]. Therefore, there is no best or second best rock formation but each of them has its own advantages and disadvantages.

Research on each formation is mainly concentrated on investigations on the *thermal, mechanical, hydrogeological and geochemical properties*. The European Commission has recently performed a review study on the status of understanding of these various properties with respect to deep geological disposal of radioactive waste [5].

In general, it was concluded that the large number of heating experiments which have been performed, both in laboratory and in the field, have provided sufficient knowledge about the nature of the purely thermal aspects and existing models seem to be adequate for predicting the resulting temperature field and its evolution with time.

It becomes more difficult when one has to consider the influence of temperature increase on the mechanical, hydrogeological and geochemical properties and in particular to understand and perform predictive modelling of coupled effects. Many tests and modelling approaches were and are still being developed. From the large field tests, one could mention the various heating tests and brine migration tests in the Asse salt mine (Germany) and at the WIPP site (USA), the research in the underground research facility HADES in the Boom clay (Belgium) and the large number of experiments carried out in research facilities in crystalline rock such as the Stripa mine (Sweden), the Grimsel Felslabor (Switzerland) and the URL in Canada. All these tests and the international modelling exercises such as COSA on salt [6], Interclay on clay [7] and DECOVALEX [8] on fractured media have certainly contributed to improving the knowledge but no decisive demonstration of understanding and predictability of these coupled processes was clearly established yet.

In this context, it has also been recognised that the couplings of chemistry with thermo-hydro-mechanical (THM) processes of the various host rocks is a crucial issue which has to be further investigated.

The *impact of radiation* on the near field has also been the subject of large research efforts and much emphasis has been put on investigations on radiation damage effects on salt. Irradiation experiments were a.o. carried out in irradiation facilities in Petten (Netherlands), Saclay (France) and Granollers (Spain), and in the Asse mine (Germany). It seems that an international consensus is being reached that radiation damage is not a safety problem and that explosive release of radiation induced stored energy is unlikely [9].

Another subject which has gained attention in recent years is the issue of *gas generation and transport* and possible impact on operational and long term safety. In any repository for radioactive wastes, gases will be formed due to corrosion of metals, microbial degradation of organic matter and to a lesser extent from radiolytic decomposition of water and organic compounds. As a consequence, gas pressure will build up in the near field until it is released through the system of engineered barriers into the geosphere at a rate equivalent to the production rate. Research efforts have been undertaken to assess the rate of production for various waste forms, disposed of in various host rocks. Moreover, models have been developed for describing gas transport and/or two phase flow through the geological formations. These models are being verified by experimental data, and compared between each other by benchmark exercises e.g. the European project PEGASUS [10]. The main conclusion of this work, so far, is that adequate models seem to be available for the evaluation of gas generation and gas transport for typical waste repositories. However, more research is needed for a better understanding of basic mechanisms of gas and/or two phase flow through the host rock or along preferential pathways, fractures and faults. Site specific data are necessary for the assessment of the possible impact of gas generation on repository safety. Technical measures are available or further being developed to cope with these issues by appropriate repository design e.g. venting systems or physical removal of hydrogen by using metal catalysts.

5. MIGRATION OF RADIONUCLIDES

Considerable research has been carried out to understand, describe and model the migration of radionuclides through various types of porous-aquifer and fractured rock flow system with the aim to predict their transport in space and time. Work is still concentrated on theoretical studies, methodological aspects, laboratory and field experiments on groundwater flow and geochemical transport phenomena as well as on specific natural system studies in order to develop and test conceptual and numerical models of flow and transport used in various computer codes. Enormous information and data obtained from generic sites, research sites, analogue sites but less real disposal sites (e.g. Mol, B, Gorleben, D) have been used to support in a more qualitative than quantitative way national repository performance/safety assessments in various countries in and outside of Europe or in international PA/SA exercises at Community level (see Chapter 7).

The principal mechanisms which are ruling the migration of radionuclides from the repository through its near field and far field back to the biosphere are related to two fundamental categories of processes in the geosphere which need to be understood and modelled:

- a) hydrogeological transport processes (hydrodynamics of fluids through the rock) and
- b) geochemical conditions and processes (geochemistry of fluids and rocks and their interaction between mobile and immobile phases).

The engineered barriers of a repository (waste form, container, clay buffer and backfill material and repository structure) which will degrade with time due to various physico-chemical processes, strongly affect the geochemistry of fluids and rocks of the near field environment (redox properties, sorption properties, solubility limits, equilibrium chemistry, etc.) and determine the speciation and the subsequent migration behaviour of the radionuclides into the far field. Extensive

studies in mainly all national research programmes have been done and are underway to clarify the complex interactions between host rock, groundwater chemistry, waste package degradation products, waste and their effect on RN transport (see also chapter 3).

The current technical basis for predicting the near field performance for HLW repositories has been reviewed and discussed in May 1993 in Cadarache, (F) at an international workshop [11]. As an outcome of this workshop, it seems that still various critical issues need further investigations such as the near field geochemical environment for various host rock formations, release of radionuclides from waste forms, transport and retardation mechanism of released radionuclides, source-term modelling and integration of the near field performance assessment with the far field.

Although it nowadays seems that in some recent repository concepts, the emphasis is more placed on the chemical containment of radionuclides in the near field and the barrier function of the engineered components of the repository, this should not be interpreted in such a way that the far field plays a minor role as a barrier to migration of radionuclides! It has to be borne in mind that the far field represents the last, important barrier between the repository and the biosphere. A considerable amount of research effort has been undertaken in the various national and international research programmes worldwide to assess and model the influence of various processes, mechanisms and parameters affecting their integrity as barrier to provide stable hydrogeological/geochemical conditions.

Structural and textural discontinuities in porous rocks and fractured, mainly crystalline rocks, can lead to high variation of the hydrogeological properties of such rocks and influence the groundwater flow system and with that the transport/retardation behaviour of radionuclides in the geological environment.

More recently, the treatment of geological heterogeneities especially in the evaluation of the radionuclide transport is again considered as a crucial topic to which more emphasis should be given at international level! In this context, it is worth mentioning past activities in that field, which are reviewed and discussed at a workshop on "heterogeneity of groundwater flow and site evaluation" organised by NEA/SEDE in 1990 in Paris [12], where the state-of-the-art on methodologies for investigation and interpretation of spatial variability and heterogeneity of groundwater flow systems were presented by considering results from various national site evaluation studies. Important issues were identified which are still of interest for further investigation: (i) spatial variability and heterogeneity of groundwater flow systems, (ii) quantification of hydrological uncertainty, (iii) characterisation of heterogeneity of large scale hydrogeological systems and features, (iv) conceptual model and (v) uncertainty in transport models.

In this context, it should also be recalled that considerable research has been carried out to understand, describe and model radionuclide migration through porous media (e.g. at the Mol site in Belgium, Gorleben site in Germany, Drigg site in UK) with the aim to predict their transport in space and time, and it seems that basic laws of water flow through porous aquifer systems and numerical models have been established. On the other hand, a lot of development work has been done in the past and is still underway in characterising and modelling transport through fractured rock, but which cannot be considered as fully understood yet. Still open questions of qualitative and quantitative nature are due to the characterisation of fracture flow (fracture orientation, density, channelling, degree of fracture connectivity and conductivity, etc.), the mass transport processes and the chemical, biological processes influencing the radionuclide transport. A recent overview about concepts of flow and solute transport in fractured rock discussed in the scientific community is given in the book of Bear et al., 1993 with a view of their application to radionuclide waste repositories by Neretniks, 1993 [13].

Research activities in this field, especially in those countries which consider crystalline rock as repository host rock and perform research activities in Underground Research Laboratories

(URL's), focus their present and future work on [14]:

- Canada: solute transport in highly fractured rock, groundwater tracer tests, scale dependence of the solute transport properties at increasing distances, study of the extent of the interconnected fracture network;
- Finland: flow characteristic of fractured rock, heterogeneity of rock fractures including channelling in modelling the RN migration, effects of matrix diffusion and colloids for RN transport, coupled T-H-M-C phenomena on groundwater flow;
- Sweden: characterisation and measuring of crystalline rock properties, modelling groundwater flow around a repository, developing and testing models of coupled T-H-M radionuclide transport processes;
- Switzerland: groundwater and multiflow around underground openings, migration experiments with measurement of migration distance by excavation.

For more than one decade now, a large number of EC coordinated projects have been performed under the umbrella of the international coordinated project MIRAGE (Migration of Radionuclides through the GEosphere), and a recently performed review study on the project MIRAGE aimed to come to a critical evaluation of the state-of-the-art in the different research areas of the project and to evaluate how the results obtained contribute to repository performance/safety assessment. The study focused on the three main research areas of that project such as:

- (i) geochemical behaviour of radionuclides in natural systems by addressing the critical issues identified by the Colloids and Complexation Working Group (CoCo)
- (ii) modelling radionuclide transport and geochemical processes
- (iii) natural migration systems (Natural Analogue studies)

The specific conclusions which can be drawn from the review study MIRAGE [15] and the recommendation given are multiple. Some remarks of more common interest where further studies are recommended are worth to be mentioned:

- Thermodynamic data for multi-component solid phases and for multi-ligand aquo-complexes are missing;
- Redox behaviour of RN of higher oxidation states needs to be better understood under deep geological conditions;
- Better understanding and meaningful quantification of complexation reaction processes under natural conditions (pH = 6-9) in the presence of competing ligands in various hydrogeological environments (porous, fractured media) is needed;
- Quantification of the reaction mechanism of RN pseudocolloids, their stability along the migration pathway and their modelling needs further studies considering natural hydrogeological systems;
- Understanding of RN migration mechanism at large scale either for porous-aquifer or fracture-rock flow system has to consider inhomogeneities for a better conceptualisation of the hydrogeological model;
- Incorporation of uncertainties on data, parameters, models into the assessment and to consider quality assurance as an integral part in model development and application is needed;
- Closer interaction between natural analogue studies, focused laboratory experiments and modelling work is required;
- Testing of the predictive capacity of geochemical models (solubility and speciation of trace elements) against natural analogue information has to be continued to know better what is the quantitative validity of any prediction.

Furthermore, it is well recognised within the radioactive waste community that information and experience exchange at international level at specific scientific conferences (e.g. MIGRATION:

Chemistry and Migration behaviour of actinides and fission products in the geosphere) and cooperation in joint working groups, workshops, research projects, is an important instrument to find consensus on critical issues, e.g.

- flow and transport model "validation"/confidence building (e.g. CHEMVAL, GEOVAL)
- thermodynamic database (EC-CHEMVAL database, NEA-Thermochemical Data Base)
- sorption properties of natural rocks/minerals (CHEMVAL, NEA-Sorption (Kd) Database)
- natural analogues as test beds for performance assessment models (EC-Natural Analogue Working Group)

and it is highly recommended that those activities are continued and even be more intensified. These activities have to be seen as a crucial process in providing confidence that the information and the data as well as the models and computer codes are adequate for the prediction of radionuclide migration through the geological environment.

6. REPOSITORY DESIGN, CONSTRUCTION AND OPERATION

Repository design depends, apart from factors such as volume and type of waste to be disposed of, to a large extent on technical features which are site and host rock specific. Technical factors to be considered are e.g. thermal load, hydrogeological characteristics, geotechnical conditions, etc. Several generic designs have been developed based on either mine-concept with waste emplacement in galleries or in-floor or in deep boreholes from the surface. These designs can be adapted to the site conditions encountered during site characterisation. A more recent factor which might influence design is a possible need for retrievability.

With respect to construction, a lot of experience has already been gained in the conventional mining industry, but the stringent specifications for the construction of deep repositories for radioactive waste require further development and testing of specific excavation and construction techniques. In particular, attention has to be paid to minimisation of host rock perturbations and creation of excavation damage zones.

Around the world, more than fifteen underground experimental facilities have been established either in abandoned mines or built for special purposes in salt, clay, granite, basalt, tuff (see Table I). Several techniques have been demonstrated for sinking of shafts, excavation of galleries and drilling of waste emplacement holes. Therefore, further development should only aim at optimising the available techniques in terms of excavation space and costs and minimising disturbance of the host rock.

Handling and emplacement of waste packages and spent fuel containers have been investigated at full scale, e.g. in salt (Asse, Germany). The necessary equipment has been designed, manufactured and tested. It should be recognised that the demonstration tests have mainly been performed in cold conditions, i.e. by using simulated waste packages, however, there is good confidence that all these engineering questions are solved or are being solved.

The backfilling and sealing of a repository has been studied in laboratories and in-situ scales. Various materials, mainly based on swelling clays or crushed salt, have been investigated on their effectiveness and full demonstration tests have been carried out or are being planned. Most emphasis was put on specific requirements, e.g. gas tightness, rock interface problems and long term performance.

Retrievability techniques, if required, have also been investigated and developed. The general feeling is that retrievability is technically feasible: costs will depend on repository design and host rock. Implications of retrievability requirements on safety aspects during operational phase and post operational phase needs to be further assessed.

TABLE I. UNDERGROUND RESEARCH FACILITIES FOR GEOLOGICAL DISPOSAL

Country	Site	Geologic medium	Status
Belgium	Mol	clay	operational
Canada	Lac du Bonnet	crystalline	operational
Finland	Olkiluoto	crystalline	operational
France	Tournemire	clay	operational
	Amélie	salt	operational
	???	clay and/or crystalline	planned
Germany	Asse	salt	operational
Japan	Kamaishi	crystalline	operational
	Tono	clay	operational
Sweden	Aspö	crystalline	under construction
Switzerland	Grimsel	crystalline	operational
	Mt Terri	clay	planned
United Kingdom	Sellafield	crystalline	planned
United States	WIPP	salt	operational
	Yucca Mountain	tuff	under construction

7. PERFORMANCE ASSESSMENT

Today it is generally accepted that 'Performance Assessment' (PA) of a disposal system, in the sense of the IAEA definition [16], will endeavour to predict the behaviour of a disposal system or subsystem (wastes, engineered barriers, repository, host rocks, surrounding geological environment and biosphere) over timescales of tens of thousands to millions of years. It is an iterative process that guides the design of the repository and the investigations at the site (e.g. geology, hydrogeology, rock mechanics, geochemistry) by defining the most sensitive components and issues and it will continue during the licensing procedures in order to ensure with increasing confidence that safety criteria are met in the long term. Furthermore, because the nature of radioactive waste disposal requires that performance assessment involves forecasting over extremely large temporal scales over which safety is sought and large spatial scales over which the disposal system extends (several to tens of kilometres), it is now widely recognised that uncertainty (i) in the future state of the disposal system, (ii) in models and (iii) in data and parameters must be dealt with. A review of different uncertainty and sensitivity techniques used in Performance Assessment have been recently reviewed by Helton [17] and Ekberg [18].

The status and development in Performance Assessment tools, techniques and procedures and their application in a number of national waste disposal programmes during the past 15 years has been presented in various overview papers at international symposia on safety assessment of radioactive waste repositories [19, 20].

A major review of the state-of-the-art of performance assessment methods, performed in 1989, has led to the 'International Collective Opinion' by OECD/NEA, IAEA, CEC addressing the question: "Can Long-Term Safety Be Evaluated" [21]. This 'Collective Opinion' confirmed that safety assessment methods are available today to evaluate adequately the potential long-term impacts of waste disposal systems but also noted that more information from proposed disposal sites (site specific) will be needed and that safety assessment methods can and will be further improved as a result of ongoing research work.

Several integrated safety/performance assessments (deterministic and stochastic analysis) of European concepts for deep geological repositories have been published or are currently under way in a number of European countries or have been launched by the European Commission as international methodological exercise (PAGIS, 1989; PACOMA, 1991) with the participation of various EU Member States (see Table II). A special place in this context should be given to the EVEREST exercise, also coordinated by the EC, and which is now in its final stage. It is a sensitivity analysis covering parameters variability and to the same extent, model and repository design characteristics with the objective of identifying the essential phenomena, and acquiring a better understanding of their interactions. It is worth to mention in this context the development of very elaborated approaches in the USA, in Japan (H-3) and in Canada (Environmental Impact Statement, AECL, 1994).

Significant benefits to improve the confidence in the results of these performance/safety assessments have certainly been obtained through international initiatives aimed at setting up or verifying models and mathematical tools such as INTRACOIN, HYDROCOIN, INTRAVAL, or through the EC coordinated project MIRAGE with activities such as CHEMVAL, CoCo (colloid and complexation) and the Natural Analogue Working Group. International conferences as GEOVAL (Validation of geosphere flow and transport models) have also contributed to improve the confidence in the results of performance and safety assessment, by starting the long process of "model validation".

Due to the differences in repository concepts, disposal host rocks and safety requirements addressed in the different performance assessments, which cover different time spans and address different aims and objectives with varying degree of completeness, it is very difficult to make comparisons between these studies and, in most cases the level of technical details at which a

TABLE II. SAFETY/PERFORMANCE ASSESSMENT EXERCISES OF EUROPEAN CONCEPTS FOR GEOLOGICAL DISPOSAL CARRIED OUT IN 1982 UNTIL 1994. THE 3 EC LAUNCHED INTERNATIONAL METHODOLOGICAL PA EXERCISES ARE: PAGIS, PACOMA AND EVEREST.

Belgium	Finland	France	Germany	Great Britain	Netherlands	Spain	Sweden	Switzerland
PAGIS	TVO-92	PAGIS	PSE	PAGIS	PAGIS	¹ PAGIS	KBS-3	Gewähr
PACOMA		PACOMA	PAGIS	DRY RUN 3	VEOS	¹ PACOMA	SKB-91	Kristallin-I
SAFIR		EVEREST	PACOMA		PACOMA	EVEREST	SKI-90	
EVEREST			PAE		PROSA		SITE-94	
			EVEREST		EVEREST			
			Licensing Procedure (KONRAD)					

¹ observer status

comparison still makes sense, is limited. This problem has been recently recognised and discussed within OECD/NEA's 'Performance Assessment Advisory Group' (PAAG) with the aim to explore the possibility to set up an ad hoc working group on 'Integrated Assessments' with the main task to be a forum for interchange of experiences and informal information exchange on quantitative inter-comparisons of recently issued assessments.

From the existing published review work in this field, critical performance assessment issues can be identified which have been investigated and significantly advanced over the last years, but which are still under debate in the scientific community and needs to undergo further research work; those are:

- conceptual model testing;
- uncertainty treatment;
- validation of models and codes;
- site specific repository system information;
- time frames for safety analysis.

From the above, it is clear that results of performance assessment studies also play an important role in focusing research activities and set priorities of investigation of fundamental PA issues of disposal systems (geological events, rock mechanics, groundwater flow, radionuclide transport, geochemistry).

In this context, the most difficult question might be how to provide 'confidence' that the information and the analyses are adequate for the prediction of very long term safety of radioactive waste disposal in deep geological formations. Here the careful use and application of Natural Analogue studies as an important component within the repository performance assessment process can be employed for 'demonstration purposes' and for arguing persuasively that a performance assessment accounts for all major effects that might occur in the vicinity of a repository and in the surrounding geosphere during geological time.

An important trend in the performance assessment studies, so far, appears to be the increasing willingness of the radioactive waste community to come to a general approach for performance assessment at international level, even if the details of implementation differ from one disposal site or concept to another and to communicate the capabilities and also the imperfections of performance assessments of disposal systems. This is an essential feature, because many questions still debated in the PA approaches will benefit of a world wide consensus.

8. CONCLUSIONS

Research activities over the last 30 years has brought considerable experience in various fields of Radioactive waste management and disposal. Waste treatment techniques have been developed up to the industrial scale with the primary aim of waste minimisation. In the last few years, partitioning and transmutation of long-lived radionuclides has regained interest in several countries and international organisations. Such an option of waste management is expected to reduce possibly the radiotoxicity of radioactive waste, but could never be an alternative for geological disposal. Investigation techniques of sites for disposal of radioactive wastes are well advanced and allow to obtain the information and data needed to characterise and evaluate the suitability of sites for repositories. A problem is however to get sites made available by authorities for investigations on their suitability for disposal. Hereby it is not important to find the "best" place, but to place the repository at a site where the geological, hydrogeological, geochemical conditions, together with the repository's engineered barriers, can give sufficient evidence for its long-term stability, to meet licensing requirements.

With respect to construction of repositories, various mining techniques have been tested on their potential for meeting stringent specifications in particular with a view to minimising excavation

damage of the host rock. Moreover, experience has been obtained with equipment for waste transport and waste emplacement underground so that one is rather confident that engineering questions are or can be solved.

To demonstrate and gain confidence in the long term behaviour of the disposal system, predictive models are developed and applied in performance assessments, covering not only the behaviour of individual components of the system but also the overall multi-barrier system. Many elements of performance assessments can be modelled today. Extensive international programmes and cooperation in this field are underway to improve performance assessment methods (e.g. scenario development, sensitivity/uncertainty analysis...) and with a view to "validate" performance assessment models. In this latter context, Natural Analogue studies and results from in-situ experiments have a great potential for model development and testing purposes.

The achievements made are very encouraging, but some fundamental questions are yet unanswered. There seems to be a latent conflict between those who produce "usable information" as a predictive understanding of the 'global disposal system' in space and time to be achieved through observations, process research, integrated modelling and assessment and those who use and apply this information. This lets the question open whether the certainly valuable scientific/technical results from R&D programmes necessarily contribute to the information needed by decision makers and licensing authorities for a repository in deep geological formations or by public to gain confidence in the concepts and techniques used for a safe long-term disposal of radioactive waste. A way to compensate this situation is certainly to focus further research activities on those significant and critical scientific/technical aspects discussed in this paper and those ethical aspects of radioactive waste management where international consensus does not yet exist.

ACKNOWLEDGEMENT

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**EXPERIENCE IN THE
SAFE MANAGEMENT OF RADIOACTIVE WASTE**

(Session II)

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A. LÓPEZ
Spain

REGULATORY AND OPERATING EXPERIENCE

F.L. PARKER

Vanderbilt University,
Nashville, Tennessee,
United States of America

Abstract

Regulatory and operating experience in the disposal of radioactive waste can be divided into three time periods, World War II and its aftermath, Post World War II till the end of the cold war, and crystal ball gazing into the future. In the first period, there was little regulatory guidance and operating practices, all conducted under wartime secrecy conditions, sometimes were not even up to the norms of the times. Environmental releases resulted in some seriously contaminated sites and high dosages to some offsite populations. Failure to consider even the storage of wastes in a systems context resulted in some stocks that were difficult to recover, treat and dispose of in a final manner. In the second period, increasing civilian uses of nuclear power and isotopes for medical, research, and industrial purposes and military pressure for increased production of Pu-239 resulted in large and more dispersed disposal of radioactive wastes. Regulatory regimes, following growing environmental consciousness, came into existence that minimized exposure to environmental contamination. Practices, in most instances, increasingly conformed to these regulatory demands. The future is unknowable. However, for high level wastes, except for thermodynamically stable forms, no technology can guarantee safety and present methodologies are calculated to produce doses orders of magnitude lower than regulatory limits. Therefore, it is possible that research will be limited to no higher technology than is reasonably achievable. Whereas for low level waste, where proof is practicably possible, as high technology as is reasonably achievable will be best in the long run.

1. INTRODUCTION

Since this paper deals with waste management experience, it is worthwhile to recognize that management or non-management of radioactive wastes dates back to 1898 when the Curies isolated approximately 0.1 gm of radium chloride from one ton (metric) of pitchblende residues from the St. Joachimstal mines in Bohemia [1]. I have not been able to find any record of where all that ore was disposed but we do know from later work that disposal was quite indiscriminate and the earlier workers suffered the consequences.

We also know that workers in these mines received extremely high doses, even up to recent times, with 81 excess lung cancers per 1000 miners [2]. The death rate from cancer to those miners was about 30 times the normal expectancy [3]. In those days, there were no international standards or recommendations. The International Commission on Radiological Protection (ICRP) was only formed in 1928 and in the same year the first quantitative unit of dose measurement, the roentgen, was specified. In the USA, the National Council on Radiation Protection and Measurements (NCRP) was formed in 1929 and in 1934 recommended a maximum permissible dose rate of 0.1 R (roentgen) per day. The first governmental regulations, with the force of law (individual sites operated by their own guidelines up to that time) were promulgated in the United States in 1960 [4].

Though there were tragic consequences from this earlier handling and other uses of naturally occurring radioactive materials, primarily from ignorance of the consequences, the number of people affected and the environmental degradation were limited. It was only after man-induced fission began that the number of people and the areal extent of the environment affected became so great that the consequences grew to more than a local phenomenon.

It should be noted that the title of seminar is *Safe Management* in recognition of the fact that practices and regulations while guided by scientific facts and understanding are still dominated by social, cultural and political factors that will vary for each nation and within each nation over time and result in different definitions of safety.

As is clear from history, regulations initially follow practice. Later, as we gain more experience, become wiser and more socially driven and bureaucratically bound, regulations dictate, in principle, practice. We could learn from the Bible about satisfactory practices where it says that wastes should be buried outside the town. They already knew in those days that it was the dose (exposure) not the amount of waste available that made the difference.

2. PRACTICE

As alluded to earlier, management practices and regulations are time dependent. For simplification, I intend to divide the discussion into three time periods, World War II and its aftermath, Post World War II till the end of the Cold War, and crystal ball gazing into the future.

2.1. World War II and Its Aftermath (<1954)

We can think of World War II period practices as plutonium production driven and embryonic efforts at civilian control. I have chosen 1954 as the cut-off date because that was the date of the transfer of control of nuclear energy in the United States from the military to the civilian control [5]. We could also use the date of the first International Conference on Peaceful Uses of Atomic Energy, Geneva, 1955 as a cut-off date. While the pressures for production were great in every country, how they manifested themselves differed from country to country depending upon its own social, political, and cultural patterns. At that time, there were only a few countries involved. Because I know the USA situation best, it inevitably will serve as the baseline of my comments-which is **not** to infer that it is the standard or the most desirable practice or regulatory regime.

2.1.1. Mill Tailings

Much of the early uranium ore used in the American weapons program was imported from the Belgian Congo and other countries, which, of course, did not result in mill tailings problems in the USA but did impact those countries. The search for domestic sources became so intense that the Chattanooga Shale that runs under Nashville, Tennessee with less than 0.10% uranium was seriously considered before adequate western USA sources were found. As the concentration of uranium has dropped in USA ores, the amount of mill tailings per mass of uranium recovered has increased which increases the amounts of other metals and inorganics exposed but decreases the unit concentration of the thorium and radium remaining in the tailings. For the relatively poor ores of the US, mill tailings have not been a major problem unless they were used for fill (foundations) in residential and commercial structures. The majority of the mill tailings have been covered as illustrated in Figure 1 [6]. The slime (fines) from mill tailings were slurried into ponds and allowed to dry while the bulk of the tailings were mounded near the mills in the typical slag piles found at all metal ore

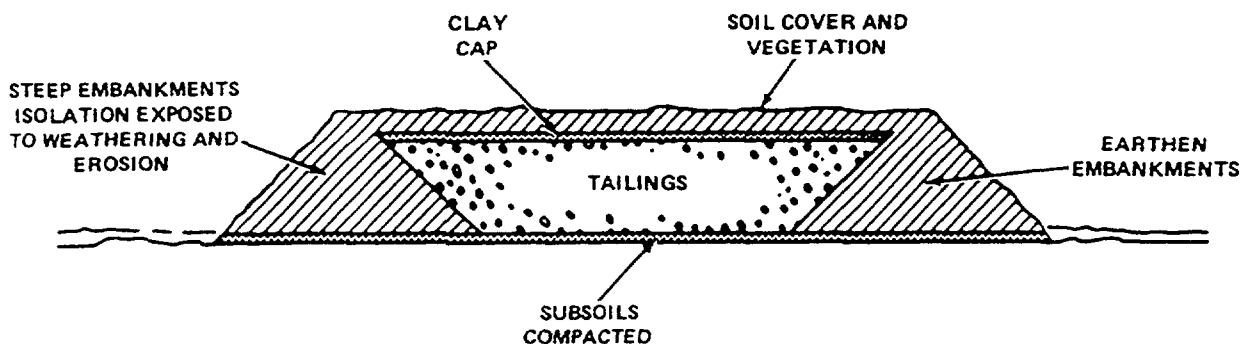


FIG. 1. Mill tailings cover.

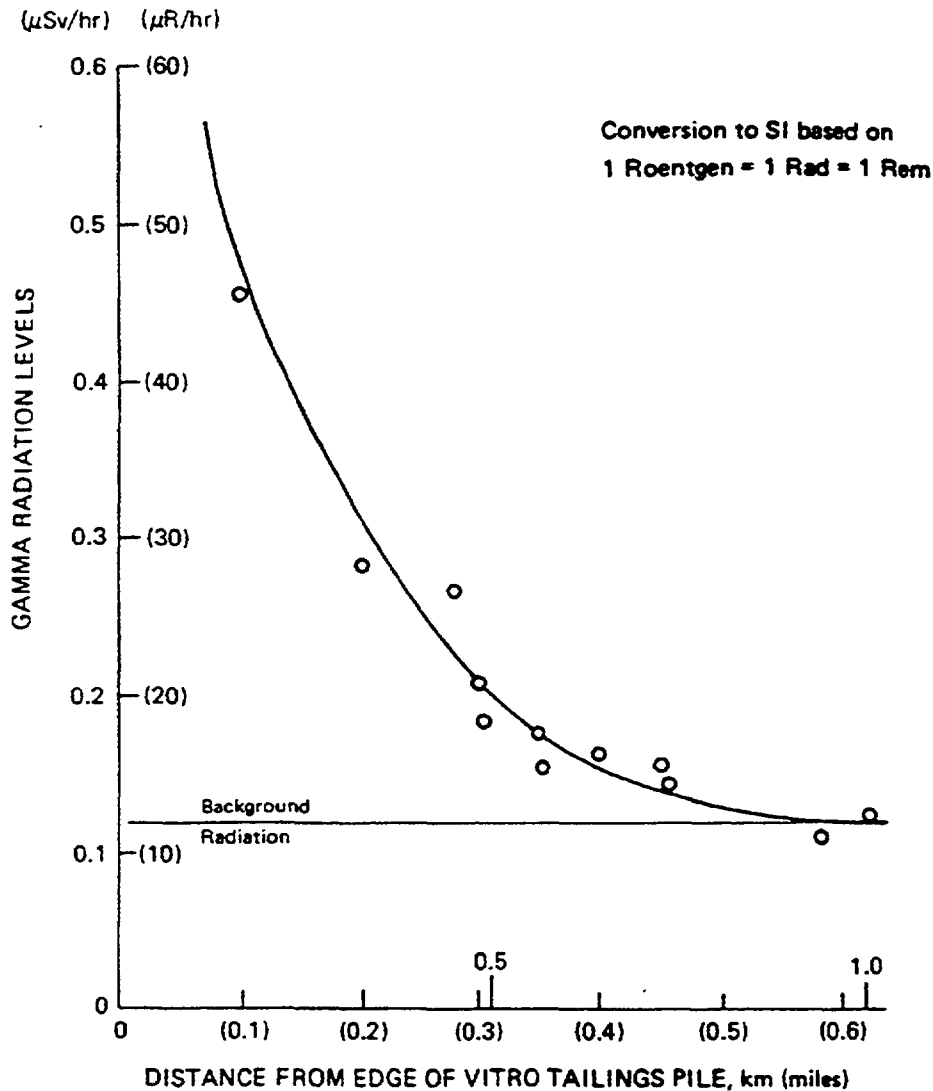


FIG. 2. External gamma radiation levels as a function of distance from vitro tailings pile.

treatment mills. Though problems were relatively minimal at US mills, earlier practices allowed radium to reach local streams in concentrations above permissible levels. After this was corrected, windborne particulates and radon became the major concerns. Wind fences and wetting were the extent of control efforts at that time. The dose rates at piles were sufficiently high, shown in Figure 2 [7], that Congress passed the Uranium Mill Tailing Radiation Control Act (PL 95-604) in November 1978. In addition, some of the depleted ores were used as backfill which also resulted in high doses. Congress passed the Grand Junction Uranium Remediation Act (PL 92-319) to clean up those buildings in Grand Junction (the center of the ore mining and milling facilities) that had used the tailings for backfill. This program has been substantially completed. At the other end of the spectrum are the Wismuth facilities in what was formerly the German Democratic Republic. There, the ore was much richer, and the human and environmental consequences substantially greater.

Mill tailings problems in other countries have run the gamut between these extremes. Perhaps the most ingenious method has sometimes been practiced by the French where they release the tailings into flood waters in the rivers on the basis that the tailings would be carried to the sea where they would cause a negligible increase in the radioactivity in the oceans.

2.1.2. Low and Intermediate Level Wastes

Initial solid and some liquid waste practices were near surface disposal as in municipal waste disposal. Wastes, packaged (cardboard boxes, plastic bags and 200-liter steel drums) or not, were dumped from the backs of trucks into shallow burial grounds. The liquid wastes were dumped into open reservoirs, covered pits, injection wells and directly into streams. Open pits were covered and disposal to covered trenches practiced when the radiation levels at the edges of the disposal facilities reached 5 to 10 R/hr when the water levels fell during the high evaporation season, such as occurred at Oak Ridge, Tennessee, USA. In other instances, direct discharge to rivers ceased when the dose to populations living along the river (Techa, Soviet Union) became so high that evacuation was necessary and when evidence of the discharges was found in the Arctic Ocean. Examples of measurements of the movement of liquid wastes from these disposal pits (landfills) and leachate from solid waste disposal facilities were presented at the first International Conference on Radioactive Wastes held in Monaco in 1959 [8]. The thrust of that first IAEA Conference on Radioactive Waste would not be totally unfamiliar to meeting goers today, Nature of Radioactive Wastes, Treatment and Processing of Radioactive Wastes, Present Methods of Waste Disposal, Administrative and General Considerations in Waste Disposal, Biological Aspects of Radioactive Waste Disposal into Sea, Physical and Chemical Aspects of Radioactive Waste Disposal into the Sea, General Considerations on Radioactive Waste Disposal to the Ground, Panel Discussion on Advantages and Disadvantages of Radioactive Waste Disposal into Geological Structures.

2.1.3. High Level Wastes

Till nuclear energy was turned to useful purposes, all fuel elements were irradiated to enhance their plutonium-239 production. Therefore, reprocessing of spent fuel followed shortly after removal from reactors and the wastes from reprocessing were stored in tanks. Because of war time shortage of stainless steel in the US, the decision was made to neutralize the acidic high level waste and store the wastes in carbon steel tanks. The neutralization increased the volume of the wastes, precipitated a fraction of the waste and stratified the wastes in the tanks due to density differences leading to great difficulties in retrieving the wastes and stabilizing them. As an aside, the reprocessed wastes at the Idaho site were not neutralized but converted to a solid calcined product. Some idea of the state of the art at that time can be gleaned from the reply I got from Les Silverman, the designer of the off-gas cleanup system. He said, "Frank, I took every single air cleaning device I was aware of and installed them serially after the fluidized bed calciner."

2.1.4. Other Wastes

It is obvious that decommissioning and environmental restoration wastes and the scientific use of isotopes and the industrial use of radiation sources were not an issue at that time.

2.2. Post World War (~ 1954) to Present

With the close of activities devoted to the plutonium production for World War II, two activities have dominated waste management till the end of the Cold War Period, competition in nuclear weapons production and the growth of civilian use of nuclear energy. Wastes from civilian uses on a radioactivity scale were dominated by civilian nuclear power production while waste production from nuclear weapons systems was dominated by the rivalry between the Soviet Union and the United States of America.

2.2.1. Mill Tailings

In the early part of this time frame, as the demand for nuclear weapons and nuclear power grew at exponential rates, so did the production of mill tailings that were handled in similar fashion to the World War II Period. Decisions were reached, after considerable technical and political

disagreements about the threat of the tailings problem, to reduce the near term release of radon from the tailings piles.

These disagreements were about the cost of dose reduction and the scientific justification for the US Environmental Protection Agency's approximation that 1 gm of radium-226 in the tailings would lead to 1 pCi/m².s of radon-222 in the flux from bare mill tailings [7].

One of the innovative approaches that came out of this activity was the decision to move the Vitro tailings pile located within Salt Lake City to a location some tens of miles from the city when the city agreed to pay the incremental costs for the move. Parenthetically, because of the precedent and infrastructure created at this remote site, the Envirocare low and intermediate level short lived waste site is located adjacent to the mill tailings disposal.

2.2.2. Low and Intermediate Level Wastes

Led by France's pioneering engineered tumulus disposal facility at Centre de la Manche, the trend was to deeper and more engineered facilities. Though there was not strong technical justification for such initially higher cost facilities, it quickly proved much more economical in the long run as it removed the technical aspects of disposal from consideration and did away with the public relations disaster of photos showing wastes scattered helter-skelter in puddles of water. This success prompted imitation in other countries, e.g., the Swedes built an engineered facility under the Baltic Sea, the Finns also have an underground repository, the Germans were refurbishing a deep iron ore mine to receive wastes, and Great Britain planned to build a deep disposal facility. In the USA, all of the proposed low level waste compacts have opted for some variant of the French design while Spain and Japan have near surface engineered facilities in operation. In addition, in the USA, transuranic waste will be buried in the Waste Isolation Pilot Plant, a deep disposal facility in bedded salt (NaCl).

2.2.3. High Level Wastes

High level waste siting and disposal have proven much more difficult. Despite geological surveys, deep geological test facilities, and performance assessments in the European Community, the USA and other countries, no site has yet been licensed for the disposal of high level waste or spent fuel classified as waste. In Germany, the Gorleben salt dome is being investigated as a potential site after successful experimentation in the Asse Salt Mine. The first deep geological disposal tests were carried out in Lyons, Kansas in bedded salt in the mid 1960s where the temperature and radiation dosages typical of a full scale repository were achieved. All the equipment for the emplacement and retrieval of spent fuel from a repository were successfully demonstrated. In Belgium, the Boom Clay has been extensively tested. Similar tests have been carried out in granite in Sweden, Finland, France, Switzerland and Canada, and in basalt and salt in the USA. This lack of progress in licensing a high level waste disposal facility has prompted out-of-pool storage facilities of spent fuel classified as waste on site (e.g. USA) or at a centralized site (e.g. Sweden) or storage of vitrified waste from reprocessing plants at the facility (Centre de la Manche and Marcoule, France). From a technical perspective, this is not all bad because of the substantial reduction in thermal energy in the waste packages during this time. However, it perpetuates the myth that there is no satisfactory solution to the high level waste disposal problem. Despite the pace setting European Community's Performance Assessment of Geological Isolation Systems for Radioactive Waste (PAGIS) study which calculated extremely low exposures from disposal in salt, granite, clay and subseabed, 10⁻⁵ to 10⁻⁶ Sieverts per year, there remained doubters, both political and technical [9]. This work followed the initial performance assessment study, the Swedish KBS-3 study on disposal in granite which emphasized the near thermodynamic stability of the material, copper, encapsulating the spent fuel [10]. These and many other studies have consistently shown extremely low calculated exposures, far below natural radiation background, even into the far distant future. However, there still remain philosophical and technical misgivings about the outcomes of these studies. Professor Castaing wrote that the only philosophically correct solution to the waste disposal problem is to send the material off into space out of man's environment or transmute the long lived actinides and fission

products into less hazardous materials [11]. Despite the success of the Mir-Atlantis hookup, the cost and risk of space launches still preclude space disposal. Transmutation concepts, after an earlier negative reception, have surfaced again led by Japan's Omega project, France's National Assembly's mandated study and the US National Academy of Sciences/National Research Council's review of US concepts. The impact of the studies has been heightened by the recent conjectures by Bowman and Venneri [12] that under certain circumstances, fissile materials from spent fuel in deep geological disposal can migrate to form critical masses. Though there has been strong criticism of these conclusions from within their own laboratory, the matter has not yet been laid to rest. Though final results of these transmutation studies are not yet available, recent reviews have indicated that the costs, production of secondary wastes, still unproven technology at a production level, the long term commitment to nuclear power necessary for transmutation to succeed and in those countries where reprocessing is not now taking place, the difficulty in siting extensive new reprocessing, fuel fabrication and reactor facilities make the value of the concept still questionable. Even if successful, geologic repositories will still be required.

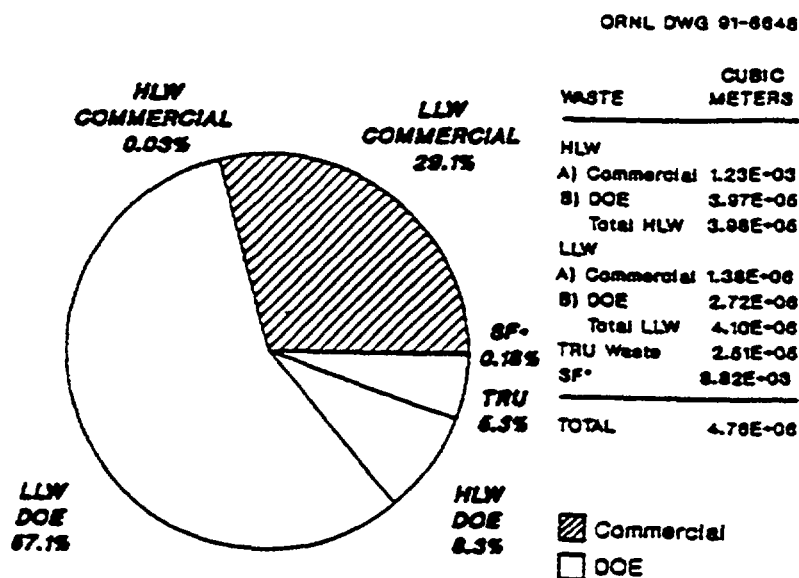
On the technical side, the questioning of the absolute results of the modeling [13] and the known deficiencies in performance assessment including the lack of proof in the absolute sense lead to unease in the minds of many. One cannot totally disregard Dostoevski's caution over 100 years ago "man has such a predilection for systems and abstract deductions that he is ready to distort the truth intentionally, he is ready to deny the evidence of his senses in order to justify his logic" [14].

2.2.4. Other Wastes

There has been a rapid growth in use of isotopes in medical research, medical therapy, smoke detectors, static eliminators, sealed sources for a variety of purposes including weld checks, geophysical examinations, etc. Most of these wastes will be buried in low level waste disposal facilities.

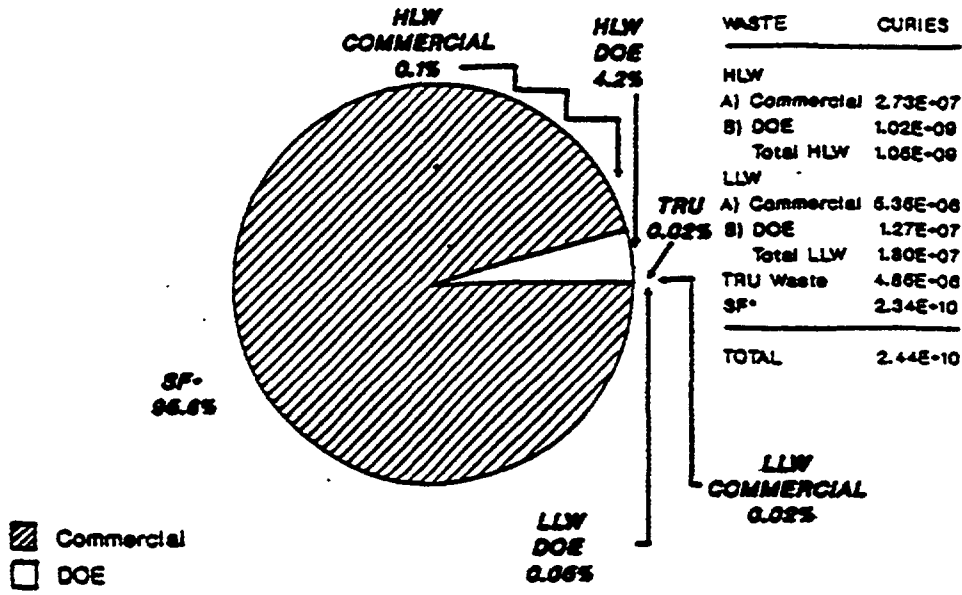
2.2.5. Summary

The total amount of radioactive wastes in the USA are shown in Figures 3 and 4 [15]. They show the activity and volume, respectively. The volume is dominated by low level wastes (weapons



*Includes spacing between fuel assembly rods.
Does not include DOE spent fuel to be reprocessed.

FIG. 3. Volumes of commercial and DOE wastes and spent fuel through 1990.



*Does not include DOE spent fuel to be reprocessed.

FIG. 4. Radioactivities of commercial and DOE wastes and spent fuel accumulated through 1990.

approximately 60%, commercial approximately 30%) and the radioactivity by the spent commercial fuel (greater than 97%).

2.3. Future

It would take a brave and foolish person to predict the future, especially in scientific matters; particularly, since the payoff is much better at the race track or the lottery. However, I shall do my best not to let the prejudice of experience cloud my thinking too much, but shall assume that civilization continues in somewhat similar fashion for the time period that those in attendance here will still be aware of it.

2.3.1. Mill Tailings

Since the yearly production of uranium has already fallen and it is very likely that some of the highly enriched uranium as well as some of the plutonium from deactivated weapons will be blended into mixed oxide fuels, it seems inevitable, in the short run, that demand for new uranium will decline even further. However, it should be noted that because the tailings contain the thorium parent of radium and radon, they will build back up to equilibrium values. At some point in the future, thousands to hundreds of thousands of years, the toxicity index (nuclide content divided by annual limit of intake) of the tailings will be the same as that of the high level wastes or spent fuel after the same time period. If we were consistent about far future threats, then we would vitrify the tailings and place them deep underground as we propose to do with high level waste. The same rationale holds for depleted uranium currently stored as UF₆ at diffusion plants in metal containers above ground. Alternatively, we would say explicitly, as we now do implicitly for mill tailings, that

worrying and spending large amounts to avert such minor radiological threats that may occur in the far distant future is total nonsense. If these threats become significant, then they will be dealt with at that time.

2.3.2. Low and Intermediate Level Wastes

The move to engineered structures, both above and below ground with greater stabilization of the waste will continue. This is evident in the investigation of vitrification of low and intermediate level waste. In addition, the difficulties of characterizing low and intermediate level waste, and in the United States, mixed hazardous chemical and radioactive waste, will hasten the movement toward a more stable and more uniform waste form. Though the cost per unit volume would be high, the volume per unit operation will continue to decrease due to waste minimization programs and waste treatment techniques. This has already occurred to a substantial extent. Commercial firms now advertise that they can reduce waste volumes after production by a factor of twenty.

The disastrous consequences, biological, ecological, and financial, of poor past disposal practices of intermediate level waste are still being unveiled. This lesson should discourage any return to those practices.

2.3.3. High Level Wastes

The search for thermodynamically stable forms and means of reducing the long lived radioactive residues will continue. However, since the calculated doses are already so low and this has not stilled anxiety among some parts of the public, it is highly unlikely that further calculated reductions will calm these fears. Potentially, as disposal becomes common place, the majority of the public might view disposal with a less jaundiced eye.

Decisions about what to do about surplus plutonium and highly enriched uranium from weapons have not been reached. If they were to be vitrified, then a whole new set of scenarios would have to be investigated, from a safeguards and criticality points of view. In any case more consideration would have to be given to the question of nuclear materials diversion to non-peaceful uses. Recently, the NAS/NRC has suggested that the minimum safeguards control should be at least equivalent to that accorded spent nuclear fuel [16].

3. REGULATORY EXPERIENCE

As is self evident, nuclear weapons work during World War II was developed under the strictest secrecy. As an example, when pictures of Oak Ridge school students were published in the public press, the last names of the students were omitted to prevent any linkage of famous surnames to the Project. As is also self evident but largely ignored today, the standard practice in the 1940s for hazardous wastes was "dilute and disperse." The maximum assimilative capacity of the environment was utilized. In those years the wastes dealt with were primarily simple biodegradable organics and discharges were planned to take advantage of the natural decomposition of the wastes in streams. The Streeter Phelps equation, first order kinetics of bacterial decomposition and oxygen demand and oxygen absorption from the atmosphere, developed in the 1920s, was the standard. This equation, dealing only with oxygen concentration in surface waters, dominated analytical approaches till the 1980s. Groundwater studies dealt only with extraction and development activities. The classic Russian text by Polubarinova-Kochina [17] and the major United States text by Muskat [18] contained not a hint of the movement of pollutants in the subsurface. Disposal into the ground was regarded as a magic, universal treatment system. Even the pathbreaking Freeze and Cherry text "Groundwater" contained not a single word on non-aqueous phase liquids, perhaps the single most intractable (most difficult to remediate) component in groundwater today [19].

Solid wastes, primarily municipal wastes, were dumped into open pits or mounded and most covered daily to reduce rodent and insect access. The goal of the 1976 Resource Conservation and

Recovery Act was to end the use of open dumps for U.S. municipal wastes. Leachates were not discussed in this legislation. While this is a review of U.S. practices, it was the norm in other countries as well at that time. The passage of specific legislation on low and high level radioactive wastes trailed the regulation of the waste. The first low level waste act was passed in 1980, and the first high level waste act was passed in 1982. The initial regulations on low level waste were promulgated in 1982, and of high level waste in 1981.

It is interesting that within the Atomic Energy Commission the separation of proponents of nuclear power and regulators of nuclear materials only occurred in 1974 with the establishment of the Energy Research and Development Administration and the Nuclear Regulatory Commission. The habits of wartime secrecy were difficult to shake. Only in 1984, when the Department of Energy lost a court case and chose not to appeal the decision, were the non-radioactive components of the waste brought under outside regulation. Even today, there is still sufficient self regulation, that the Secretary of Energy has established a committee to recommend to her whether or not the Department of Energy should abandon what self regulation still remains. A category of waste utilized in the USA but that is not generally used elsewhere is that of mixed waste, a combination of hazardous chemical and radioactive waste. Each component is regulated separately, the chemical portion by the U.S. Environmental Protection Agency or the individual states, and the radioactive portion by the U.S. Nuclear Regulatory Commission if it is non-DOE waste and DOE if it is low and intermediate level waste. Because of this absurdity and the fact that most other nations do not even recognize this category of waste, I shall treat it no further.

Returning to low level and high level waste regulation, it is clear that U.S. practice is more prescriptive than most European practice. Though the details are arcane and lengthy, the method of determining those limits do bear some discussion. For low level radioactive waste, four sites representative of the different climatological regimes in the U.S. were modeled with typical quantities of radioactive materials to determine the quantities that could be buried, with default values for leaching and transport, to produce a dose less than the permissible individual value of 25 mrem/yr whole body. There is minimal engineering design required of the facility (covers only) and minimum engineering design of the waste packages (no cardboard or fiberboard boxes), but most have structural stability [20]. High level waste regulations however, while still using representative deep geologic sites in basalt, rock salt, granite and shale, utilize geohydrological and climatic data typical of those sites, to calculate the population risk, 1000 deaths over 10,000 years, from releases from each of the repositories. The regulation was the first in the world that I am aware of that is probabilistically based, in that the values in the table of permissible releases hold for releases that have a likelihood of less than 1 chance in 10 of exceeding the quantities listed in the table, but the release limits are relaxed by a factor of ten if the likelihood of exceeding the quantities in the table is less than one chance in 1000.

The final deposition of the waste is primarily a function of the origin of the waste. Even though wastes from processing of irradiated fuel for production of plutonium for weapons can have much lower levels of activity than some low level wastes, they are still classified as high level waste. Identical material but with different origins can legally be classified differently. Attempts on the basis of risk, to reclassify these wastes have failed. This results in some so called low-level waste having higher risk potential than some so called high level waste.

These highly prescriptive USA regulations can be compared with those in Europe. Within the time constraints, it is not possible to compare all the regulations on a country by country basis though there are examples of such comparisons within each category of waste. A comparison with high-level waste regulations in other countries is shown in Table 1. A review of the proposal for the allocation of Switzerland's wastes is perhaps easiest since Switzerland has no uranium mining nor milling nor does it have reprocessing plants. It has a seamless demarcation between the waste categories as shown in Figure 5. As can be seen from the figure, the concentration profile of the radionuclides listed as 1 through 38 are shown on the left and compared with the maximum concentration of the same principal nuclides, which under the repository design, waste packaging requirements and release

TABLE 1. SUMMARY OF OBJECTIVES/CRITERIA FOR HIGH LEVEL WASTE DISPOSAL*

Organization/ Country	Main Objective/Criteria	Other Features/Comments
NEA (1984)	Max. Individual risk objective $10^{-5}/a$ (all sources)	No consensus on ALARA optimization.
ICRP Publication 46 (1985)	Individual dose limit 1 mSv/a and risk limit $10^{-5}/a$ (all sources)	ALARA taking into account both doses and probabilities.
IAEA Safety Series 99 (1989)	Idem ICRP Publication 46	Also technical criteria for disposal system features, safety analysis and QA.
CANADA AECB Regulatory Document R-0104 (1987)	Max. Individual risk objective $10^{-6}/a$	Period for demonstrating: 10^4 a, but no sudden increase thereafter. No optimization required.
FRANCE Basic Safety Rule (1991)	Max. long-term individual dose 0.25 mSv/a (normal evolution)	ALARA principle. Proof of long-term geological stability. Case-by-case eval. of disturbing events but no determ. effects.
GERMANY Rad. Prot. Ordinance (1989)	Individual dose <0.3 mSv/a for all reasonable scenarios	Calculation of individual doses limited to 10^4 a, but long-term isolation potential must be assessed.
SWITZERLAND Reg. Doc. R-21 (Revision underway) (since completed - added)	Individual dose <0.1 mSv/a at any time for reasonably probable scenarios (risk limit also set-added)	Sealing of the repository must be possible within a few years without the need for institutional control.
U. KINGDOM NRPB (1992)	Max. individual risk objective $10^{-5}/a$ (all disposal facilities)	Optimization should be relaxed if the max. Individual risk is less than $10^{-6}/a$.
USA, EPA 40 CFP Part 191 (Revision underway)	Release limits based on <10 serious health effects during 10^4 a from disposal of HLW from 1000 t of spent fuel	Individ. dose <0.25 mSv/a for the first 1000 a. Also requirements on drinking water contamination.
USA, NRC 10 C.F. Part 60	Waste package containment for 300-1000 a release via engineered barriers $<10^{-5}/a$ of the max. inventory groundwater travel time <1000 a	NRC subsystem requirements shall comply with the EPA standard.

*Disposal of High Level Radioactive Waste Consideration of Some Basic Criteria, The Radiation Protection and Nuclear Safety Authorities in Denmark, Finland, Iceland, Norway and Sweden, 1993.

scenarios for the three principal types of repository (high, medium and low dose radionuclide) (now only high level and low/medium level) would lead to doses less than 0.1 mSv/yr (10 mrem/yr). As can be seen in Table 2, the differences between the two approaches are great. There may, however, be some modification in the U.S. regulations. In the Energy Policy Act of 1992 (P.L. 102-486) the U.S. Congress asked the U.S. National Academy of Sciences (NAS) to advise the U.S. Environmental

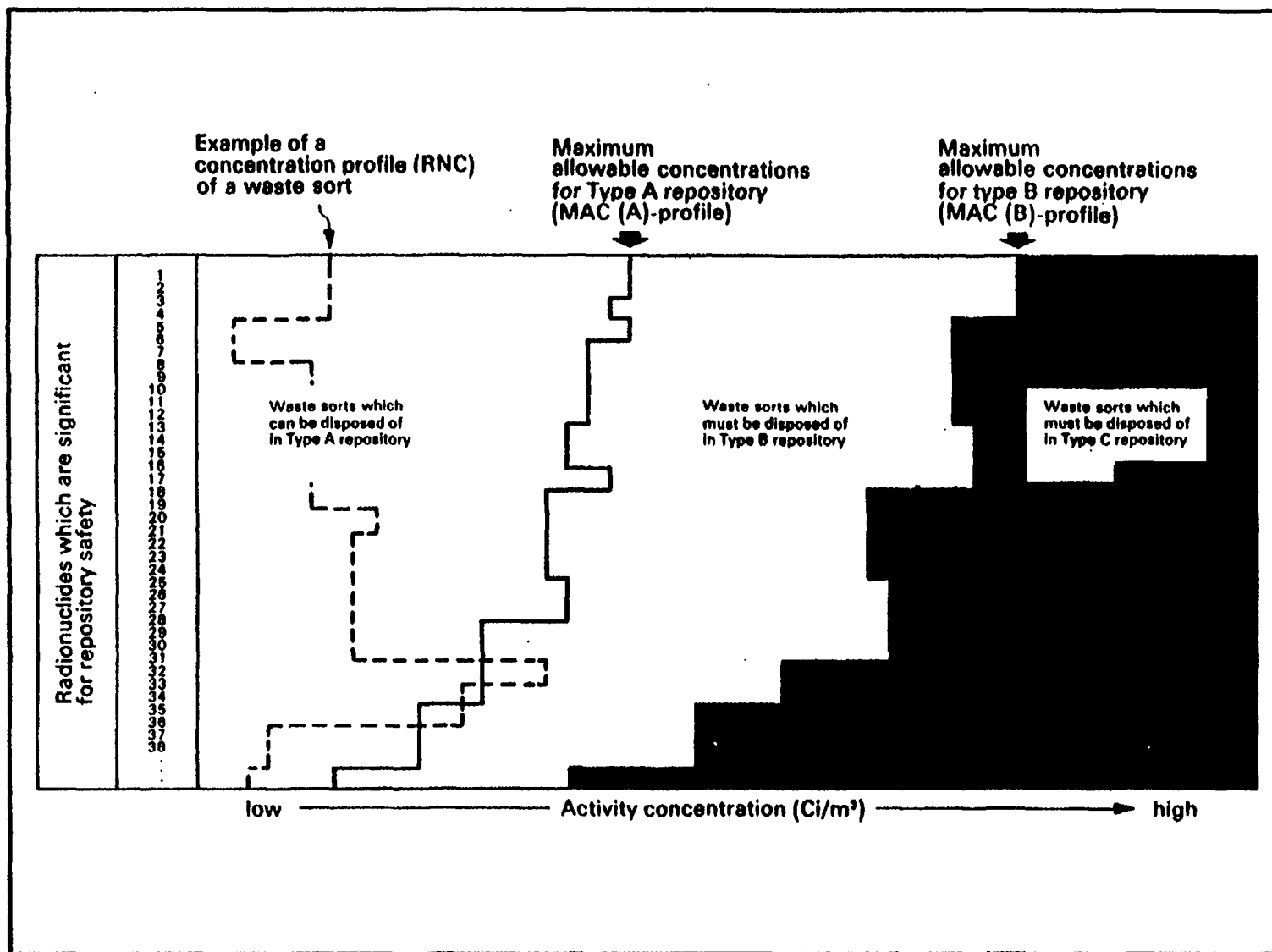


FIG. 5. Representation of the concept of maximum allowable concentration of radionuclides in a repository and of the RNC profile of a waste sort.

TABLE 2. COMPARISON OF REGULATORY REGIMES IN THE USA AND SWITZERLAND

	USA	Switzerland
Regulation	release rate (1,000 deaths/10,000 years)	dose (10 mrem/yr)
Site Specific	no	no
Impact	population	individual
Prescriptive	yes (default values used)	no (take advantage of modified waste form)

Protection Agency on the technical basis for the regulations for the disposal of high-level wastes. In the NAS report (August, 1, 1995) they have recommended that acceptability be based on the risk (not dose - in case the dose-effect relationship changes) to individuals in the critical groups (as defined by the International Commission on Radiological Protection) and not a population standard, that compliance "be measured at the time of peak risks, whenever it occurs" and that the human intrusion scenario be examined only to ensure that intrusion would not destroy the suitability of the repository to meet the critical group risk standard [22]. If adopted, the difference in regulating by objective rather than prescribing performance requirements of the components of the system would be eliminated.

For a more complete discussion of the regulatory conditions in the European Community one should refer to their recent report [23] where they list and elaborate on their general principles, shown in Table 3. The impact of the rise in environmental consciousness, as exemplified by the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, finds its expression in the radioactive waste disposal field in the recent Nuclear Energy Agency (NEA) publication [24]. There, they enunciate a set of principles to be used in making ethical choices about waste management strategies. They are:

- " • the liabilities of waste management should be considered when undertaking new projects;
- those who generate the wastes should take the responsibility, and provide the resources, for the management of these materials in a way which will not impose undue burdens on future generations;
- wastes should be managed in a way that secures an acceptable level of protection for human health and the environment, and affords to future generations at least the level of safety which is acceptable today; there seems to be no ethical basis for discounting future health and environmental damage risks;
- a waste management strategy should not be based on a presumption of a stable societal structure for the indefinite future, nor of technological advance; rather it should aim at bequeathing a passively safe situation which places no reliance on active institutional controls. "

This statement of principles, while admirable, neglects one of the most important components in resolving nuclear waste disposal questions, that is the fairness of the methodology and outcome. Recent studies have indicated that while the first response of the citizens and the State of Nevada to the decision to determine the acceptability of Yucca Mountain as the high level waste repository was to object on legal and technical grounds, for the last five years the overwhelming objection has been about the lack of fairness of the decision.

TABLE 3. GENERAL PRINCIPLES*

Field	Principle
<i>Radiation Protection</i>	
(a) System of dose limitation	- Justification - Optimization of Protection (Alara) - Individual Dose Limitation
(b) System of control	- Notification - Registration - Licensing
<i>Ethical and sociological questions</i>	
	- Care for others - Public involvement - Polluter should pay compensation for damage (civil liability)
<i>Environmental and natural resources protection</i>	
	- Prevention of damage - Rectification of damage - Protection of natural resources
<i>Nuclear Safeguards</i>	
	- Prevention of nuclear materials diversion

*S. Orlowski and K.H. Schaller, Editors, "Objectives, standards and criteria for radioactive waste disposal in the European Community", Commission of the European Communities, 1989.

4. CONCLUSIONS

Practices and regulations are interrelated. In the future we can anticipate that as high technology as reasonably achievable will be the guideline for low and intermediate level wastes. This will be so following the French lead, where the high technology solution can practically guarantee no technical problems and the cost avoidance from lack of technical challenge is sufficient to warrant the application of the best engineering technology.

For high level waste, except for thermodynamically stable forms, no technology can guarantee absolute safety. The long term models used in performance assessment can always be challenged as there is no scientific guarantee in the usual meaning of the word. Therefore, search for even higher technology solutions is futile if the objective is to reduce opposition to high level waste repositories. The ideologues, both for and against the repository, will be unimpressed. The major hope is to narrow the gap in the views of the technological optimists and those of the technological pessimists. Therefore, no higher technology, beyond that needed to meet the regulations should be the guideline.

We should expect spent fuel as a waste form to decrease in importance as the need for electric power increases. Despite the necessity for reprocessing, this will not lead to the introduction of transmutation as a waste management practice since the gain, if any, in the acceptance of deep

repositories and nuclear power will not be worth the cost nor the need for new facilities related to transmutation.

For mill tailings and depleted uranium, currently stored primarily as UF_6 , two different approaches will be taken. Mill tailings are too voluminous, too low a near term threat and too stable a chemical form to warrant more than cover and monitor operations to be sure that the mobility is limited. Depleted uranium, however, is different. These wastes must be put into a more stable chemical form and container to limit their mobility. These wastes, as is well known, will eventually, after 10^3 - 10^5 years, approach the toxicity of high level waste at that period of time, i.e., eating either would produce the same health effects.

Use of radioactive materials, in medicine, industry, research, etc., will continue to rise. However, the trend to the use of shorter life material will continue. The use of decay storage and the high cost of disposal will result in only slight increases in the volume of other wastes to be disposed of as low level waste.

Looking back over the past 40 years, each of us could come up with our own list of the defining moments. Mine are:

Practice

All wastes	First International Conference, IAEA
Low level waste	Tumulus Concept at Centre de la Hague, France;
High level waste	National Academy of Sciences Report on Geological Disposal, USA Demonstration of Geologic Disposal - Project Salt Vault, USA Vitrification at Marcoule, France Performance Assessment - KBS-3, Sweden
Environmental	Comprehensive Study of Discharges to the Clinch River, USA Decontamination and Decommissioning - Shipping port, USA

Regulations

Transfer to Civilian Control	MacMahon Bill, USA
Collective Opinion	NEA
Regional Criteria	CEC
Environmental	National Environmental Policy Act of 1970, USA

Past is prologue. We can learn that despite some mistakes in the past that, in general, the human impact of waste disposal practices have not been great. These impacts have also been local, i.e. they have not had global or transboundary effects. This is not to discount the seriousness of these impacts but emphasize their local character. In most other instances the impacts have been below small percentages of natural background minus radon effects.

The environmental effects in some instance were quite severe. In some cases, the land will have to be consecrated forever to waste disposal and the most that can be done will be to limit the spread of radioactive material offsite.

If the guidelines given by international organizations such as the International Atomic Energy Agency and the International Commission on Radiological Protection are observed, then the impacts in the future on man and the environment should be no greater than they have been, in general, in the past. The impacts, biological, physical, fiscal and social of cleaning up the residues of past disposal practices will be large but in most instances manageable. As we have shown increasing sophistication in our handling of both low and intermediate level radioactive wastes and high level wastes, the impacts of present and future disposal should decrease. The consequences of past disposal practices still must be dealt with. International consensus on how to deal with such aggravated cases has not yet been achieved. In particular, we have not succeeded in determining how to treat situations where some agencies of a government by force of circumstances deliberately dump wastes in a manner prohibited by international agreements which their governments have signed. Despite these continued uncertainties, I remain optimistic about our ability to safely dispose of radioactive wastes.

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EXPERIENCE IN MANAGING SHORT LIVED LOW AND INTERMEDIATE LEVEL WASTE

A.N. PRASAD, M.S. KUMRA, S.D. MISRA
Bhabha Atomic Research Centre,
Bombay, India

I. YABE
Nuclear Safety Research Association,
Tokyo, Japan

A. SUZUKI
University of Tokyo,
Tokyo, Japan

Abstract

Commercial utilization of radioactive materials in nuclear power production and other beneficial applications in medicine, research and industry generate residual radioactive wastes. Various activities associated with nuclear power production account for the major portion of waste arisings. The wastes differ widely in physical, chemical / radiochemical characteristics, quantities and associated hazard. The International Atomic Energy Agency has addressed this important aspect and latest guidelines have been issued in 1994. No single process or technology can be used for safe management of the wide variety of wastes. Therefore, classification of wastes is essential to adopt optimum management schemes for specific wastes. The approach for management of short lived, low and intermediate level wastes is to concentrate and contain the radiocontaminants. This involves various steps such as waste minimisation, segregation, collection, transport, treatment, conditioning, packaging, storage, disposal and surveillance. Options are available for carrying out these steps which are interrelated and selection of one option in a step can influence the option to be adopted in other steps. It is, therefore, essential to plan the waste management scheme in a complete and comprehensive manner for judicious selection of options. Adequate processes, technologies and equipment have been developed worldwide. The experience so far has indicated that these wastes can be managed safely in a manner guaranteed to protect human and the environment. Radioactive waste management is an ever evolving field and research & development is continuing in many countries. Innovations and improvements in the processes, technologies etc. will go on getting introduced to strengthen safety, improve economics and reduce radiation exposures. This paper deals with various aspects pertaining to the management of short lived, low and intermediate level wastes.

1. INTRODUCTION

All over the world radioactive materials are today utilised for electrical power production and other applications for the benefit of mankind on a large scale. Commercial scale application of materials inevitably leads to generation of waste and this is true also for radioactive materials. Nuclear wastes are potentially hazardous, if not properly managed, due to the radioactivity associated with them. It is due to this radioactivity that the nuclear waste decays by itself in a natural manner and as such the hazard comes to an end after a certain period of time, unlike some chemical toxic materials which will remain hazardous for ever. The radioactive wastes generated in nuclear fuel cycle facilities account for the major share and are of prime concern. However, the waste generated outside nuclear fuel cycle though comparatively small in quantity are also of great concern due to the large number of waste generators located over large area. The awareness of toxicity of radioactive waste made the nuclear industry highly pollution control conscious and safe management of various radioactive wastes was universally recognised from the very beginning for continued beneficial use of nuclear technologies. As a result processes, technologies, equipment and instruments have been developed and routinely used for safe management of the radioactive waste in a scientific and well planned manner. A wealth of experience has been accumulated in many countries. Constant efforts are being made to further increase the safety and economics in line with internationally accepted principles.

2. WASTE CLASSIFICATION

In view of the wide spectrum of wastes generated with respect to their physical, chemical, radiochemical and radiological characteristics, it is essential to have a classification system. The main objective of classification is to have a common terminology amongst all those who are associated with various aspects such as generation, management and regulation of radioactive waste.

The classification of waste can be adopted on the basis of health and safety requirements, practical experience of waste management facilities, or regulatory considerations. This important issue was addressed by the International Atomic Energy Agency in 1970 [1] and has been recently reviewed in 1994 [2]. This topic has been covered in detail in the paper entitled "Regulatory and Operating Experience" of this seminar.

The classification system as recommended by IAEA [2] is shown in Fig.1. The waste classes include:

- (1) Exempt waste (EW): contains so little radioactive material that it need not be considered 'radioactive' and can be exempted from nuclear regulatory control. This is to say, although still radioactive from a physical point of view, this waste may be safely disposed of, by applying conventional techniques and systems, without specifically considering its radio-active properties.

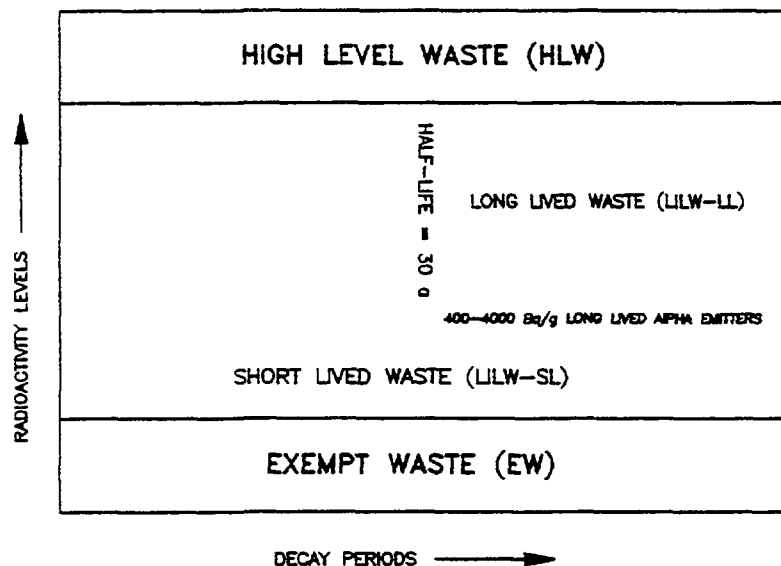


FIG. 1. Revised waste classification system [2].

- (2) Short lived low and intermediate level waste (LILW-SL): may also contain low concentrations of long lived radionuclides. The potential hazard represented by the waste can often be reduced by introducing a period of administrative control (as part of storage or after disposal) since high concentrations of short lived radionuclides, will fall due to radioactive decay. Concentrations of long lived radionuclides that will not decay significantly during the period of institutional control are limited to low levels consistent with the radio-toxicity of the radionuclides and with requirements set forth by national authorities.
- (3) Long lived low and intermediate level waste (LILW-LL): contains long lived radionuclides in quantities that need a long duration of isolation from the biosphere.

- (4) High level waste (HLW): contains large concentrations both of short and long lived radionuclides, so that a high degree of isolation from the biosphere, e.g., via geological disposal, is needed to ensure disposal safety. HLW generates significant quantities of heat from radioactive decay, and normally continues to generate heat for several centuries.

The waste classification system in most of the countries is in line with the IAEA recommendations. In India also, the present waste classification system is on the lines of IAEA Technical Reports Series No.101 [1] and is under review. The liquid wastes are divided into 5 categories depending upon radioactivity level. The solid wastes are divided into 4 categories depending upon contact dose level. The gaseous wastes are divided into 3 categories depending upon radioactivity level. In Japan the wastes are classified essentially into 2 categories namely high-level and low-level.

3. SOURCES AND CHARACTERISTICS OF RADIOACTIVE WASTE

The largest amounts of radioactive wastes are generated by the nuclear fuel cycle. The quantum and characteristics of wastes generated depend upon the type and performance of the facilities. Typical annual waste production data for 1000 MWe light water reactor is given in Table I. The typical generations in India are as given in Table II for 1000 MWe Pressurised Heavy Water Reactor. As can be seen from Table II the waste volume from mining and milling is orders of magnitude higher than high level waste. In fact, mining and milling waste is often considered a special category of its own. Bulk of the radioactivity in the entire fuel cycle is contained in the high level waste in small volume. Low and intermediate level waste account for substantial volumes and significant activity.

The wastes generated by users of radioactive materials in non-fuel-cycle facilities is not large. A Variety of radioisotopes are used for various applications in medicine, industry and research as shown in Table III. The management of such waste has been dealt with in IAEA Safety Series No. 70 [3]. The radionuclides commonly used have relatively short half-lives (few hours to one year) except in some cases such as Co-60 and Cs-137 which have half-lives of about 5 years and 30 years respectively.

With the ageing of nuclear facilities, their partial or complete decommissioning will become an important source of radioactive waste. Remedial action taken to mitigate the effects of unusual occurrences at the nuclear facilities will also generate radioactive waste. These waste are plant/incident specific.

4. MANAGEMENT OF SHORT LIVED LOW AND INTERMEDIATE LEVEL WASTE

The short lived wastes are essentially those which contain predominantly radionuclides having a half-life of not more than about 30 years (although limited quantities of longer-lived nuclides may be present). The approach for the management of these wastes essentially involves retention of radionuclides for sufficient period to allow decay to innocuous levels. Depending upon the volumes and the half-lives of the radionuclides, the retention may be in the as generated form or after volume reduction and conditioning.

The various steps involved in the management of radioactive waste are i) waste minimisation ii) segregation iii) Transport & Storage iv) treatment v) conditioning & packaging vi) storage & disposal vii) surveillance. The steps from (i) to (iii) above essentially constitute the pretreatment and help in improving safety and lowering the costs of waste management. Pretreatment has been addressed in IAEA Technical Report Series 272 [4]. The basic steps in radioactive waste management are shown in Figure 2.

The variety of processes and schemes which are in routine use worldwide prove that suitable technologies exist today. The detailed management steps are discussed in the following sections.

TABLE I: RADIOACTIVE WASTE PRODUCTION IN THE NUCLEAR FUEL CYCLE: SOLID OR SOLIDIFIED WASTE RELATED TO THE OPERATION OF A 1,000 MWe LIGHT WATER REACTOR DURING ONE YEAR [5]

Origin and Type	Volume in m ³ (after treatment, conditioning and encapsulation)	Activity or Weight
1. Uranium Mining and Milling - Ore tailings	60,000 (30000 to 40000 if Pu recycle)	3.7×10^8 Bq m ⁻³ (0.01 Ci m ⁻³)
2. Conversion, enrichment and fuel fabrication - UO ₂ fuels - UO ₂ - PuO ₂ fuels for an annual reload of 500 - 700 kg of Pu	-- 100	Negligible 5 to 10 kg Pu
3. Light water reactor - Various solid wastes and conditioned resins	200 - 600 ^a	3.7×10^9 to 3.7×10^{11} Bq m ⁻³ (0.1 - 10 Ci m ⁻³) beta-gamma
4. Reprocessing ^b - Solidified high-level waste - Compacted cladding hulls - Low and medium level beta-gamma solid waste - Solid and solidified alpha waste	10 3 80 10	5×10^{18} Bq (150 MCi) beta-gamma ^c + actinides (2 kg Pu for UO ₂ fuels 5 to 10 kg Pu for UO ₂ -PuO ₂ fuels 5×10^{16} Bq (1.5 MCi) beta-gamma ^c + actinides 4×10^{14} Bq (0.01 MCi) beta-gamma + alpha 1 to 5 kg Pu
5. Spent fuel ^b	50	30 Tons

a Depending on reactor type and conditioning process

b 4 and 5 are mutually exclusive

c 150 days after fuel discharge from the reactor

4.1. Waste Minimisation

This is an essential step to reduce the overall burden of waste management. It starts right at the generation point itself. Minimisation of volume and activity can be achieved by suitable design of the facility and by selection of proper materials, processes and equipment as well as by adopting operational procedures to facilitate recycling and reuse of the waste materials. A classic example for minimisation of waste volume is the decontamination of personnel protective clothing and equipment for routine reuse. Example of minimising activity is the use of special materials (of low Cobalt content) to reduce activation and corrosion products in reactors.

TABLE II: FUEL CYCLE WASTE DATA FOR 1000 MWe (Annual figures)
(Pressurised Heavy Water Reactors, INDIA)

Fuel Cycle Stages	Solid Wastes		Liquid Wastes	
		Vol. (M ³)	Vol.(M ³)	Acti.(Ci)
Mining & Milling	HL	-	-	-
	ML	-	-	-
	LL	-	6x10 ⁵	0.1
Fuel Fabrication	HL	-	-	-
	ML	-	-	-
	LL	90	1x10 ⁴	0.015
Reactor Operation	HL	-	-	-
	ML	-	2x10 ⁴	10
	LL	450	4x10 ⁴	600 ³ H
				0.01
			4.5x10 ³ ³ H	
Fuel Reprocessing	HL	-	150	6x10 ⁷
	ML	4	300	3x10 ⁴
	LL	100	5x10 ⁴	100

HL - HIGH LEVEL WASTE
ML - INTERMEDIATE LEVEL WASTE
LL - LOW LEVEL WASTE

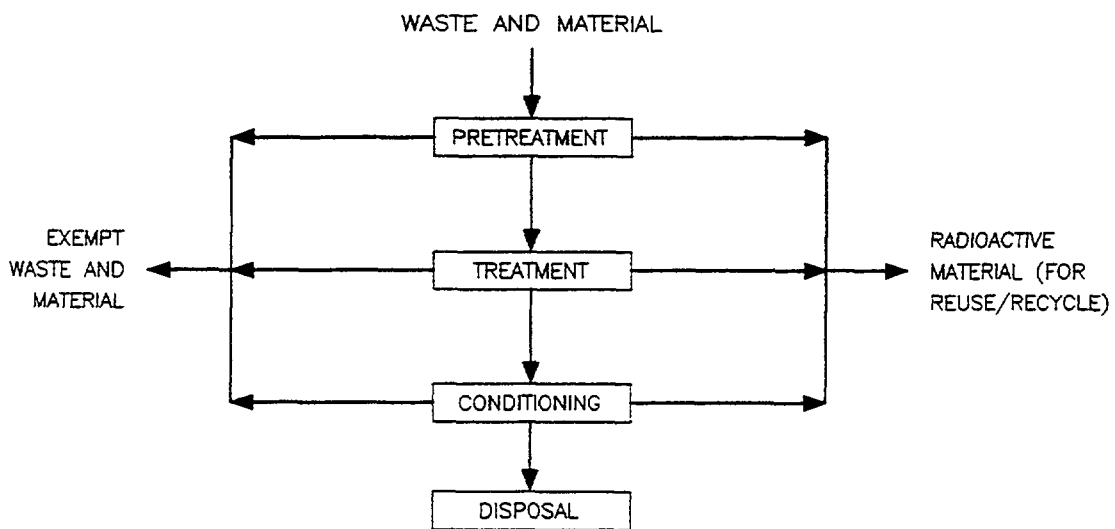


FIG. 2. Basic steps in radioactive waste management.

TABLE III: VARIOUS APPLICATIONS OF RADIONUCLIDES [3]

Nuclide	Form of application		
	Sealed Sources	Tracers	Others
^3H	Foil thickness measurements	Water movement	Luminous articles and electronic valves
^{32}P	Foil thickness measurements	Agriculture	-
^{41}A	-	Leak testing gas movement	-
^{46}Sc	-	Silt movement	-
^{57}Co	Check Sources	-	-
^{60}Co	Industrial, radiography, clinical therapy, sterilization	-	Occasionally in electronic valves
^{63}Ni	Foil thickness measurements	-	-
^{82}Br	-	Water movement, leak testing	-
^{85}Kr	Gauging	-	Occasionally in electronic valves
^{90}Sr	Thickness gauge Eye applicators	-	-
^{137}Cs	Industrial, Radiography, Calibration, Clinical therapy	-	-
^{140}Ba - ^{140}La ^{144}Ce - ^{144}Pr	-	Steel slag	-
^{192}Ir	Industrial Radiography Clinical therapy	-	-
^{124}Sb ^{226}Ra with ^{227}Ac Be ^{210}Po ^{239}Pu	Neutron sources	-	Activation and other studies
^{241}Am	Foil thickness measurements	Smoke detectors	

4.2. Segregation

Segregation of various waste streams is necessary for optimising the treatment scheme. Certain liquid streams are only potentially active and may not require any treatment such as those from personnel showers. Other streams may contain chemicals which render them unsuitable for treatment by some specific method, as in the case of decontamination waters containing surfactants and organics. The main criteria for planning the segregation of waste streams are:

- physical, chemical and radiological characteristics
- treatment scheme and disposal routes
- decay heat generation

In the case of solids, segregation is advisable from the point of view of selecting suitable process for volume reduction e.g. incineration, compaction, chemical oxidation or direct disposal.

4.3. Transport & Storage

Transport of waste is required for collection, storage, movement to the treatment facility and for discharge/disposal purposes. While planning this due considerations must be given to leaktightness, effect of radioactivity on the components of transport system, containment barriers, decontamination provisions and the radiation exposures.

The transport of liquids can be by mobile tankers or pipelines (above ground or underground). Mobile tankers are normally adopted for transport of small batches of liquids in specifically designed containers with appropriate shielding.

Pipeline transfer is more common for bulk transport of liquids at a nuclear installation site. The important features in the design of a piping system is the minimisation of liquid hold-up loops and provision of inspection chambers enroute to detect any leakage in the secondary containment if provided. A double walled pipe, with provision to monitor the annulus for leakage from the primary pipe, is advisable for substantially contaminated liquids. While underground piping systems have the advantage of natural shielding and safety against tampering, above ground piping has the advantage of ease of inspection and maintenance.

Various aspects of transport of solid waste have been dealt in IAEA Safety Series No.6 [5]. To facilitate formulation of transport requirements and regulations, specific categorisation schemes have been adopted for shipping purposes e.g.:

- low specific activity category
- surface contaminated object category
- type A category
- type B category
- special arrangement.

Storage of wastes is necessary for operational flexibility. Following are some of the important aspects need to be considered while planning the storage system:

- retrievability for operational control and radioactive decay
- provisions for shielding, sampling, monitoring and decontamination
- Safety provisions to take care of unusual occurrences like failure of storage system
- Chemical and radiochemical nature of waste.

The technologies for safe transport and storage of liquid and solid wastes are well established. A variety of designs have been adopted worldwide to meet specific requirements. In India, extensive experience exists in the safe transport of liquids using underground/above ground pipe lines and mobile

tankers. Solid waste transport casks/containers of various designs and capacities are being successfully used on routine basis meeting safety requirements.

4.4. Treatment

4.4.1. Treatment of Liquid Waste

The philosophy adopted for treatment of liquid wastes is to concentrate and remove the radionuclides and bring down their concentration in the liquid to the levels at which these can be safely discharged. The safe discharge limits are established by national regulatory authorities for any specific site according to the recommendations of the International Commission on Radiation Protection. The concentrated radioactive residue is suitably conditioned and packed prior to its disposal.

The concentration can be achieved by a variety of processes such as chemical treatment, ion-exchange, evaporation, reverse osmosis & ultrafiltration, and thermal or chemical dissociation.

Chemical treatment for low, and sometimes intermediate level, wastes has been applied in many forms since the early fifties, ranging from simple carbonate precipitation reactions to the use of flocculants, phosphates and more specific chemicals such as insoluble metal ferrocyanides. The decontamination factor is usually of the order of 10 to 100.

Ion exchange is currently being used, in particular for chemically pure aqueous effluents. Commercial synthetic products as well as naturally occurring materials notably vermiculite, bentonite, montmorillonite, zeolites etc. are in use.

Evaporation can be used to concentrate all types of radioactive aqueous effluents; it has high decontamination efficiencies. Several evaporator designs are available for treatment of liquid wastes; a common type used is the thermosyphon design. The decontamination factor is usually of the order of 10^3 to 10^5 [6][7].

Ultrafiltration, using synthetic membranes of controlled porosity may be very efficient for effluents in which the radioactive components are fixed on insoluble or colloidal particles; electro dialysis and reverse osmosis may be highly efficient for effluents with high salt concentration.

In India chemical treatment, ion exchange and evaporation have been adopted at many plants [8]. These plants are successfully operating for past few decades. The reverse osmosis system has been tested successfully for polishing of low level waste [9].

4.4.2. Treatment of Solid Waste

An important objective of treatment of solid waste is to reduce the volume. The volume reduction processes can be mechanical, thermal or chemical [10].

The mechanical treatment basically involves size reduction and compaction. The size reduction may be achieved through dismantling, sawing, cutting or shredding.

The thermal processes are essentially incineration and melting. The types of incinerators in use include excess air incinerators, controlled air incinerators, fluidised bed incinerators, etc. The available melting processes include conventional melters, electros lag melters, plasma melters, etc.

The potential chemical processes such as acid digestion, chemical oxidation, etc., are essentially alternatives to thermal oxidation and are mostly at the development or demonstration stage.

The design and experience aspects on incinerators and compactors are dealt with in the IAEA Technical Reports Series No. 360 [10]. In India and Japan excess air incinerators are being successfully used.

The schemes adopted for the treatment of waste by various countries may differ in respect of processes and engineering, however all have the same objective i.e. volume reduction and separation of radionuclides in a concentrated fraction leaving the bulk of waste depleted in radioactivity.

4.5. Conditioning

The waste concentrates are required to be appropriately solidified or conditioned to minimise the possibility of migration of radioactivity. The media in which the radionuclides are immobilised, are relatively stable, inert and impervious solid forms, commonly referred to as 'matrices'. The commonly used matrices are cement & cement composites, bitumen and polymers. Various conditioning aspects have been addressed in IAEA Technical Reports Series No. 222 [11].

Cement and cement composites in view of their low costs and amenability to simple processing techniques have to date met the acceptance criteria for immobilisation of relatively low active waste concentrates.

Bituminisation offers one step volume reduction and also better chemical durability. Processing requirements include simultaneous evaporation and blending of the waste salts with bitumen.

Polymers are used in only a few cases. Embedding of resins in polystyrene is one example. In general the monomers are combined with radioactive waste and polymerisation is initiated with the help of a suitable catalyst or radiation.

Cement as a matrix is being using in most of the countries. Bitumen and polymers are being employed by some countries. The matrices used in some of the countries are given in Table IV.

TABLE IV: MATRICES USED FOR CONDITIONING OF LOW AND INTERMEDIATE LEVEL WASTE IN SOME COUNTRIES[5]

Country	Cement	Bitumen	Polymer
Argentina			P
Belgium	C	B	
Canada			
Finland		B	
France	C	B	P
Germany	C	B	P
India	C		
Italy			
Japan		B	P
Netherland	C		P
Spain	C		
Sweden	C	B	
Switzerland	C	B	P
UK	C		P
Russia	C	B	
USA	C		P

4.6. Packaging

The objective of packaging is to facilitate handling, interim storage, transport and disposal of radioactive waste in a safe manner. The container for packaging is basically a vessel/drum/box made of metal, concrete, polymer or composite materials in different shapes, sizes. Standardisation of packaging is necessary to ensure compatibility of equipment as well as the handling and disposal techniques. The major functions of packaging containers are

- i) to act as a receptacle for the waste form or even to act as a mixing vessel itself and to give shielding against radiation.
- ii) to prevent spread of contamination and release of activity on disposal from solidified waste.

Standard 200 L steel drums are commonly employed in many countries. The drums may be modified for handling and additional shielding depending upon specific requirements. Rectangular/cubic concrete/steel containers of larger sizes are becoming popular. In India, standard 200 L drums, are in routine use. Rectangular carbon steel containers up to 2.5 cubic metres capacity are in use for in-situ conditioning. For specific waste, high integrity containers made of concrete and lined with steel are also used. Various aspects of packaging containers have been addressed in the IAEA Technical Reports Series No. 355 [12].

4.7. Disposal

4.7.1. Disposal of Liquid Wastes

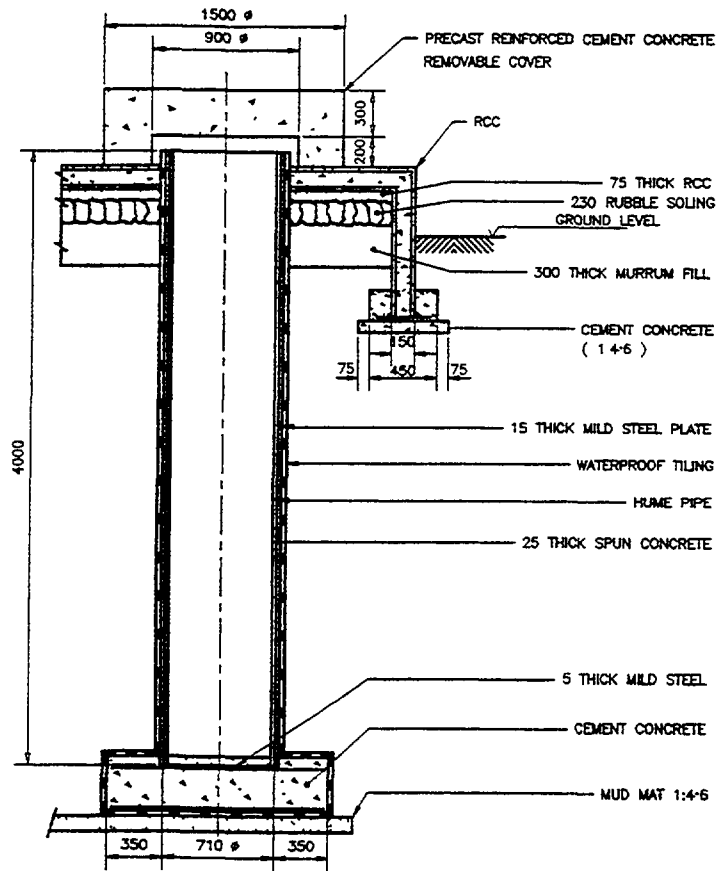
Liquid wastes which are below exempt level and the effluents generated during treatment of short lived, low & intermediate level liquid waste, containing radionuclides below safe levels are normally discharged into water bodies. The safe levels are site specific and are to be in conformity with international recommendations [13] [14]. The release of radioactivity is kept to the minimum in line with ALARA principle.

4.7.2. Disposal of Solid Waste

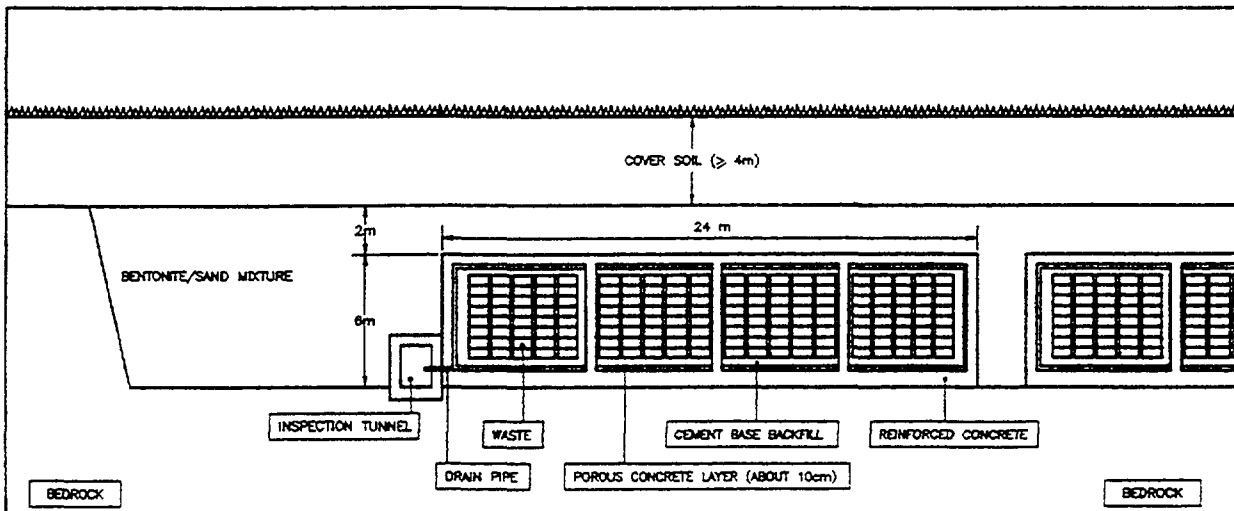
This is a very important step in the waste management programme from the point of view of environmental protection. Near surface disposal of short lived, low and intermediate level wastes is a realistic and practical method for their safe isolation. The option for disposal of these wastes are emplacement in near surface engineered facilities, emplacement in abandoned mines, cavities or in specially constructed underground facilities. The multibarrier concept is normally used in this type of disposal. Here the safety is based on the choice of waste form, package design, site location and the disposal structures. Surveillance of disposal site and measures to avoid uncontrolled access by man and living species are necessary for its safe operation. Guidelines on these aspects are available in IAEA Safety Series No.253 [15].

Some of the important factors to be considered for selection of a site for locating near surface disposal facility are :

- Low precipitation in the area.
- The area should be devoid of surface water bodies and generally stable w.r.t its geomorphology.
- The natural water table, at its highest level should be below repository.
- The area should be in clay rich zone, having very low effective porosity and permeability and the ground water flow should be very low with long pathway.
- The geological media in the area should have very good sorption capacity.
- The repository should be separated from fractured bedrock by a thick layer of geological materials.



TILEHOLE USED IN INDIA



TRENCHES USED IN JAPAN

FIG. 3. Underground waste disposal structures.

Depending upon the site conditions, different types of disposal structures are used in different countries for emplacement of waste. The types of structures include reinforced cement concrete (RCC) trenches, RCC vaults (above ground/ underground), steel lined concrete tile holes etc upto a depth of 10-100 meters.

The disposal facilities may be set up as a common central facility for various nuclear installations or as a dedicated facility co-located with each nuclear installation. The size of the disposal facility will accordingly differ with the extent of nuclear programme and the number of nuclear installations it caters to.

The near surface disposal facilities in various countries differ in respect of capacity, layouts, design of waste emplacement structures, provision of barriers against migration, sealing of structures, radiation shielding provisions etc. At the Drigg facility, UK about 0.75 million cubic metres of wastes has been safely disposed of till date and the facility has sufficient capacity to receive waste for the next four decades. The capacity of Swedish SFR centre is about 0.06 million cubic metres. The disposal facility at SRP USA has a capacity of about 0.4 million cubic metres. The La Manche facility in France has a capacity of 0.6 million cubic metres while the capacity of L'Aube facility is 1.0 million cubic metres. The El Cabril facility of Spain became operational on 1991 and has sufficient capacity for waste generated during next two decades. The Rakkasho Mura facility in Japan has a capacity of 0.04 million cubic metres extendable to 0.6 million cubic metres. The Olkilin disposal facility in Finland consists of two vertical silos, constructed at a depth of 60 to 100 metres, each of 24 metres diameter and 34 metres height. In India dedicated disposal facilities are located in the controlled area/exclusion zone of each nuclear establishment. Facilities of 0.1 million cubic metres capacity each, is operational at six sites. These utilise mainly RCC trenches, tile holes and above ground vaults as disposal structures. Typical schematics of disposal structures is shown in Figure 3.

The operating experience of near surface disposal facilities over the last four decades has provided valuable inputs and the concept of design and development of such repositories has undergone a steady evolution. From the initial unlined shallow trench disposal practices the present trend is towards facilities with sophisticated engineered systems. Some of the major factors which differentiate the current approach from initial stage relate to :

- Design based as multibarrier concept
- Considering the site specific conditions in repository design including application of engineered barriers.
- Establishment of adequate buffer zones between operational area and external boundary of repository.
- Provision of areas and equipment for purpose of segregation and repacking of waste and for decontamination.
- Means to take care of weather conditions on disposal operations like provision of movable buildings to prevent rain water entering disposal area .
- Provision of infiltration gallery / bore holes in close vicinity of disposal structure for collection and monitoring of ground water.
- Better capping designs to prevent intrusion and to limit water ingress.

World wide experience during the past 50 years has shown that short lived low and intermediate wastes can be successfully isolated from humans and the environment in near surface disposal facilities [16].

4.8. Sealing of disposal facilities

Water is the main transport medium for migration of radioactivity from the disposed waste. Therefore effective measures need to be taken to ensure that water will not come in contact with the disposed waste for periods till the activity in the waste decays to safe levels. Experience has shown that the portions of the disposal structure which are exposed to the atmosphere are the vulnerable

spots, specially the trench or tile-hole caps. The physical integrity of the disposal structures can also be impaired due to subsidence of the soil or the top cover. Therefore careful consideration should be given to these aspects and measures such as soil compaction, backfilling and reduction of voids (inside the package, around the package and around the disposal structure) as well as correct capping method of the disposal structures should be implemented [17].

In India extensive experience has been gained in capping methods for the trenches / tile holes and backfilling. These procedures have been standardised and found to be very effective in maintaining the water tightness and physical integrity of the disposal structures by resorting to water proofing treatment and adopting a monolithic concrete cap concept [18].

5. INTERDEPENDENCY OF WASTE MANAGEMENT STEPS

As can be seen from the above, various options are available for carrying out the different waste management steps. However, these steps are interrelated and the selection of one option in a step can influence the options to be adopted in other steps. The requirements for disposal will depend upon the type of conditioning chosen. The selection of a disposal system will depend upon the disposal site characteristics. The packaging requirements will depend upon the handling mode and the relative locations of the packaging facility and the disposal site. The conditioning method will be influenced by the treatment scheme adopted and vice-versa. In cases where the selection of disposal site is postponed or the disposal facility is not readily available, requirement for interim storage will be different from requirement when disposal facilities are existing. It is thus essential to plan the waste management scheme for any waste in a complete and comprehensive manner so that the options for carrying out various waste management steps can be judiciously selected.

6. SAFETY, REGULATION AND SURVEILLANCE

Siting, design, construction, operation and sealing of near surface disposal facilities need to be carried out in such a way as to ensure that all radiological exposures are kept well within regulatory limits. The regulatory authorities prescribe the conditions, limitations and restrictions on the types, quantities, levels of activity, etc. of the wastes that may be disposed of in these facilities. It is essential to ensure compliance with such conditions, limitations and restrictions. In addition to radiological safety requirements, industrial safety requirements are also very important.

Compliance with all safety and regulatory requirements is ensured through a systematic surveillance plan. The surveillance plan covers the operational as well as post operational phases and takes into account normal as well as abnormal/ conditions. Sampling and assaying of groundwater, surface run off, air, soil and vegetation on a routine basis, both on and off site, forms part of the surveillance plan during the operational phase. Intrusion by humans and invasion by deep-rooted vegetation and burrowing animals are additional factors to be considered in the post operational surveillance plan [17].

As migration of radioactivity from the disposed waste is most likely by transport through water. On site sampling of water and soil has been found to be very effective in detecting such migration. The sampling is normally done through bore holes/infiltration galleries suitably located depending upon the quantity and direction of ground water flow. The above aspects have been covered in greater detail in the two papers entitled "Operational Safety of a Disposal Facility" and "Requirements for the Closure of a Near Surface Repository" of this seminar.

7. RESEARCH & DEVELOPMENT

Experience over the decades has demonstrated that waste management practices presently followed are quite safe and adequate to meet current regulatory requirements. However, with the continued advancements in science and technologies, innovations and improvements in processes, equipments, materials and instruments are regularly introduced to further improve the waste management practices to reduce the exposures and bring down the release of radioactivity to the environment consistent with ALARA principle. Research & Development efforts are continuing in

many countries. The thrust is on minimising the generation of secondary waste while maximising the retention of radioactivity with an objective of realising the concept of zero release.

8. CONCLUSION

The short lived, low and intermediate level waste, generated comparatively in large volumes have been successfully managed world wide for last four decades and a wealth of experience has been accumulated. The technologies involved are being continuously improved through research and development efforts in many countries. There are some important issues which need international attention. These include harmonisation of approaches, optimisation of technologies, standardisation of practices, exchange of operational experience through common formats and finalisation of exempt levels. The International Atomic Energy Agency is already playing a vital role in addressing these issues.

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EXPERIENCE IN MANAGING HIGH LEVEL AND LONG LIVED LOW AND INTERMEDIATE LEVEL WASTE

W. THOMAS

Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH,
Garching/Munich, Federal Republic of Germany

Abstract

The management of high level and long lived radioactive waste comprises several different stages starting with interim storage of spent fuel elements for long lived wastes followed by various steps of waste conditioning or packaging up to disposal of the conditioned waste in a repository. There are two principal routes of managing high level waste: direct disposal of spent nuclear fuel, if spent fuel assemblies are considered as waste, and reprocessing of spent fuel with reuse of recovered fissile material, solidification of reprocessing wastes and disposal of these wastes. At present both routes of high level waste management are not completely implemented since final repositories for high level waste will not become operable before 2010. There is, however, no doubt from a scientific and technical standpoint that both routes of high level waste management including a repository in deep geological formations are feasible fulfilling near and long term safety requirements. There has been considerable progress in the last years for many steps of high level waste management, especially interim storage of spent fuel under wet and dry conditions, vitrification and development of concepts for direct disposal of spent fuel. Interim storage is at present and for the future the most important step. 80% or more of the arising spent fuel will be stored probably for several decades. Sound technical solutions for storage in wet pools and under dry conditions are available. For aged fuel dry storage in metal casks, concrete containers or vaults shows considerable advantages. In some countries and for some specific fuel assemblies storage capacities are not sufficient and timely action is needed. In any case public acceptance of interim storage of large quantities of spent fuel for several decades only is achievable, if in parallel sufficient progress is reached in developing and implementing repositories. Vitrification of high level liquid waste has reached industrial maturity. By vitrification the storage of large amounts of highly radioactive heat generating liquid waste can be avoided. This strategy of timely vitrification eliminates a significant on-site risk at reprocessing facilities. Storage of vitrified waste in concrete vaults or casks is technically established. Long lived low or intermediate level wastes from reprocessing or mixed oxide fuel production can be stored safely. Conditioning by cementation is an established practice. Some intermediate level wastes from reprocessing will be vitrified together with liquid high level waste. For some specific waste forms technical developments for volume reduction and improved conditioning are underway. Incineration of burnable solid and liquid wastes will become an important factor in the future also at an industrial scale.

1. INTRODUCTION

Managing high-level and long lived radioactive waste - that is indeed the heart of the problem of waste management of the nuclear fuel cycle. Without solving this problem - to store, condition and dispose of high-level radioactive waste in a safe, secure and economically feasible manner - I doubt that nuclear power reactors can continue to be operated and considered as an environmentally favourable source of electricity generation.

My main theme is experience with managing high-level waste (HLW) and I am pleased to show that considerable progress has been gained towards a sound and viable solution for HLW management. However, the steps of progress have been made slowly and different approaches have been followed in different countries for the same problem. And - most important for public opinion - up to now there is no final repository for HLW operating. In addition, the challenge to find a site for a repository seemed easier in some countries two decades than it does as at present. The main reason for this difficulty is clearly the opposition against nuclear power in general especially after the reactor accidents of Three Miles Island and Chernobyl.

The management of HLW and long lived waste comprises many different stages from storage of spent fuel elements in the storage pools at the reactor after unloading the fuel assemblies from the core till final disposal. There are two principal routes of HLW management: Direct disposal of spent

fuel, if spent fuel is not to be recycled and therefore is considered as waste, and disposal of vitrified HLW from reprocessing spent fuel elements.

A closed fuel cycle with reprocessing was the preferred route of HLW management in most countries for many years and remains the objective of those countries which consider nuclear energy generation as an important long-term energy option which allows increased independence from foreign energy supply. France, Japan and Russia follow this line. Other countries with limited nuclear programs or facing a situation where nuclear power encounters economic difficulties or strong public opposition, tend to long-term interim storage of spent fuel without reprocessing and to direct disposal. This is the attitude of for example Sweden and the United States. Some countries (eg. the United Kingdom and Germany) try to keep open both options in order to identify flexible and economically favourable solutions.

My presentation will cover both routes, but because primarily the accumulated experience has to be emphasized, the scope of my presentation will be limited to those following steps of waste management, where practical experience has been gained:

- Spent fuel storage at reactors and in storage facilities away from reactors,
- Spent fuel conditioning for storage or for final disposal
- Storage of high level liquid waste (HLLW)
- Vitrification and storage of solid HLW
- Treatment of long lived low and intermediate level wastes.

Planning of final repositories and all the work which has been performed to analyse and explore the suitability of geological media or sites for a final repository and to develop the system of retention barriers of the repository are a separate topic.

HLW contains most of the fission products and long-lived actinides generated during irradiation of the fuel in nuclear power reactors. HLW is characterized by a considerable level of thermal power and is considered in practice as long lived.

If spent fuel is declared as waste, spent fuel is solid HLW but including some volatile fission products in the fuel rods. The specific activity of spent fuel is very high: after five years cooling time UO_2 -fuel exhibits typically a specific total activity of $2.5 \cdot 10^4$ TBq/tHM. Mixed oxide fuel has nearly the same specific fission product activity as UO_2 -fuel ($1.8 \cdot 10^4$ TBq/tHM), but a considerably higher activity of actinides ($2.8 \cdot 10^4$ TBq/tHM). The specific activity is dependent on cooling time and burnup. In recent years there has been a steady increase of the burnup. Typical rates of heat generation are 2-4 kW/tHM after five years of cooling.

High level liquid waste (HLLW) arises from chemical separation of the bulk of fission products in the first extraction step of reprocessing. For each ton of heavy metal of reprocessed LWR fuel 0.5 to 0.8 m³ of HLLW are generated. The HLLW contains more than 99 per cent of nonvolatile fission products, higher actinides and small fractions of uranium and plutonium originally present in the spent fuel. Depending on the fuel and the reprocessing operations a variety of activation and corrosion products and other non-radioactive chemicals like boron, gadolinium, cadmium, iron and nickel is present in HLLW. Typically HLLW exhibits a specific activity in the order of 50 TBq/l and requires continuous cooling.

From the closed fuel cycle other long-lived wastes are generated which contain alpha-emitting actinides, especially plutonium. These wastes in some cases also include considerable amounts of fission or activation products. At least for some time, these wastes may be classified as highly active until radiation and heat generation levels have been reduced by decay. Sludges from feed clarification of the headend process of reprocessing belong to this category. Other alpha-bearing wastes are nearly or completely free of fission and activation products and generate only negligible heat. These liquid

or solid wastes have to be classified as low or intermediate level wastes. Examples are spent solvents from reprocessing or solid scrap and waste from mixed oxide fuel production. Due to the very high radiotoxicity of plutonium and other actinides, conditioning and storage of these wastes requires strict containment to prevent contamination of workplaces and operators. Long-term safety considerations for the disposal of these long-lived wastes are similar to long-term safety requirements for HLW.

Low level wastes from uranium processing, enrichment and fuel manufacturing are comparable to residues from uranium mining and milling. Disposal of this category and the ultimate fate of the huge amounts for UF_6 tails are an important issue of its own. These wastes, however, are not addressed in my presentation.

2. SPENT FUEL STORAGE

In the past, spent fuel storage was considered as standard industrial practice and just as an interim step before reprocessing. Wet storage in water pools for some years was the adopted procedure. Since the closed fuel cycle with reprocessing has not been implemented in as many countries as expected spent fuel storage has gained much more topical interest over the years. Even these countries with a closed fuel cycle have expanded their fuel storage capacities at reactor sites or at reprocessing facilities. This development is the result of several trends such as prolongation of cooling times before reprocessing, restrictions of recycling the recovered fissile material in power reactors, deferment or cancellation of Fast Breeder Reactor programs and the successful development of direct disposal concepts. On the other hand, the implementation of final repositories for HLW or spent fuel has also been delayed. At present, it is estimated that worldwide no final repository for HLW or spent fuel would be operable before 2010. Therefore spent fuel storage nowadays is recognized as an important separate stage which keeps open the options to go either to reprocessing or direct disposal. The provisions for spent fuel interim storage have to cope with the increasing amounts of spent fuel assemblies and with the prolongation of timespans for storage up to several decades. Even longer times up to a century are envisaged for storage in some countries.

Arisings of spent fuel from nuclear power reactors

In 1994, 441 nuclear power reactors were operating worldwide delivering nearly 10 000 t HM of spent fuel per year for interim storage. Projections indicate that this amount of spent fuel arising annually will remain more or less stable in coming years. Some estimations for coming years indicate a small reduction, despite a slight increase in the number of nuclear power reactors in operation. The reason for reduced annual spent fuel arisings are the reduced utilization of nuclear power reactors in Russia, Ukraine and some other countries, the increased burnup of fuel assemblies and the improved plant performance in the U.S.A., Japan and Western Europe. The accumulated amount of spent fuel up to 1993 is over 145 000 t HM [1]. Over the next 20 years, about the same amount is to be expected in addition. A new American forecast gives lower figures with additional 125 000 t HM up to the year 2015 [2].

The arisings of spent fuel assemblies are dependent on the reactor type and the mode of operation of the reactor. In this respect the trend to higher burnup may reduce the spent fuel arisings whereas the specific activity of the spent fuel increases correspondingly. Typical annual spent fuel arisings for various reactor types as normalized to 1 GWa are given in Table I.

There is, however, considerable variation of the annual spent fuel unloading for reactors due to the conditions of operation. For example partly burnt fuel assemblies may be reloaded to the reactor core.

Most of spent fuel produced to date is in interim storage, in total more than 90 000 t HM. Also in future, only a small fraction of spent fuel assemblies will be reprocessed despite enlarged reprocessing capacities in France and the United Kingdom. The highest estimations of the fraction of fuel going for reprocessing in the next two decades are around 20 %.

TABLE I. TYPICAL ANNUAL ARISING OF SPENT FUEL FOR POWER REACTORS PER GW_a

Type of reactor	Annual amount of spent fuel, (t HM)
PWR	25
BWR	27
AGR	28
VVER-440	30
VVER-1000	25
MAGNOX	190
RBMK	60
CANDU	130
PHWR	160

Interim storage modes and capacity

Spent fuel assemblies are stored at reactor sites (AR) or away from reactors (AFR) at reprocessing facilities or separate storage locations. Storage in water pools is the common practice at reactors after unloading the fuel from the core. Large pools exist also for storage of fuel assemblies at reprocessing facilities and as AFR storage facilities in some countries. Dry storage in metal casks, silos or concrete casks and vaults is also used in different forms in many countries. There is a general trend to increase existing storage capacities both at reactor sites and also away from reactors. At reactors the storage capacity of pools has been considerably increased by re-racking using fixed neutron absorbers. Generally in many countries there is on average sufficient free space up to the year 2000 to take the spent fuel from the core to the AR pool. However, there is a considerable number of reactors especially in the U. S. with very limited free space and without any possibility to transfer the fuel to other reactor pools. In Russia, Lithuania and the Ukraine there is an urgent need to increase the storage capacity for RBMK or VVER reactor fuel.

AFR storage capacity amounts presently to 50 000 t HM worldwide. More than 50 % of this capacity is installed at reprocessing plants in Sellafield, La Hague, Krasnojarsk and Tokai. Significant capacities have been created for storage of RBMK assemblies in separate storage buildings at the reactor sites of Kursk and St. Petersburg [3] with a capacity of 2 000 t HM. A further storage building is under construction at Smolensk. The CLAB wet storage facility in Sweden has been expanded recently to a capacity of 5 000 t HM. A similar storage facility in Finland at Olkiluoto has a capacity of 1 300 t HM. In Germany two AFR storage facilities at Ahaus and Gorleben for storage of spent fuel in metal casks are in operation with capacities of 1 500, resp. 3 800 t HM each. The first loaded CASTOR cask with spent fuel from Philippsburg power station was shipped this spring to Gorleben giving rise to strong protests from nuclear opponents. In Switzerland, Japan and the Czech Republic the implementation of significant AFR storage capacity is planned.

A comparison of existing storage capacity with the present and future spent fuel deliveries reveals a strong need for additional capacity AR or AFR. For some reactors and some countries this problem is very urgent. Lack of resources may aggravate this situation in some cases.

Wet storage, status of technology and experience

Storage of spent fuel assemblies in water pools is a long-standing proven technology with a very high safety standard. There are well-developed criteria and guides of good practice available for design, operation and safety assessment of these facilities [4-6]. Provisions are made in the design and in the operational procedures to ensure containment and subcriticality of stored fuel assemblies, heat

removal and radiation protection. Storage pool integrity is ensured by a double-walled pool construction and by an underlying heavy concrete structure designed to withstand the worst foreseeable seismic loads relevant for the site characteristics. Shielding is provided by at least 3 or 4 m depth of water. Redundant heat removal systems are installed making a significant loss of cooling water very unlikely. But even in this case the temperature rise would be relatively slow giving ample time for corrective action [7]. Subcriticality is achieved by positioning of fuel bundles in storage racks or containers with adequate spacing often in combination with fixed neutron absorbers. Criticality safety normally is based on enrichment limitation for fresh fuel, burnup credit has been taken into account only in few cases. Precautions have to be taken to prevent a criticality hazard whilst loading and unloading fuel assemblies with the risk of dropping of transport containers or fuel assemblies. Special attention has to be given to fuel element consolidation processes which take place in storage pools. Defective fuel has to be properly canned to prevent undue contamination of the pool water. In any case, an adequate control of water purity has to be made to prevent corrosion and increased radiation levels. For zircaloy clad LWR fuel, experience shows only very small corrosion rates even for storage over several decades. Also stress corrosion does not appear to be a problem during cooling of the fuel. Increased corrosion has been encountered only with metallic MAGNOX fuel in the case of incorrect water chemistry.

In general, for pool storage a highly developed and reliable technology is available. AR and AFR pool storage reached industrial maturity many years ago. The safety record is very good. No major incident resulting in an overexposure of workers or a release of significant amounts of radioactivity to the environment has been recorded. Annual discharges of radioactivity from pools by off-gas or water are negligible.

Dry storage, status of technology and experience

Storage of spent nuclear fuel under dry conditions is not a new idea, but dates back to the end of the fifties. MAGNOX fuel has been stored in dry vaults since 1957. Under dry conditions, there have been no major problems with MAGNOX fuel storage. In-leakage of rain water into the dry vault at Wylfa power station, however, has led to severe corrosion of a few fuel elements. Also spent fuel elements from research reactors and fast reactors have been stored in the U. S., in Japan and France for many years without problems.

A major shift to dry storage came in the mid-eighties when it became evident that in future large amounts of aged spent fuel with relatively small heat generation would have to be stored for a long time. Dry storage for aged spent fuel looks favourable in comparison to wet storage in pools for the following reasons:

- inherent safety due to cooling by natural air convection
- no moderation of fuel, therefore reduced risk of criticality
- no permanent water treatment necessary, no liquid discharges and secondary wastes
- flexible modular design possible in combination with transportation in case of casks, small initial investment
- high degree of shielding and protection against external impact.

Today there are many different techniques for dry storage developed and commercially available. They can be divided in three categories: metal casks, concrete casks or silos and concrete vaults.

The design of metal casks for storage has been derived from existing casks for transportation of fuel assemblies. The cask design in most cases takes into account the conditions for storage as well as for transportation. There is a large variety of casks available commercially for many different types of spent fuel assemblies (PWR, BWR, HTR, VVER, RBMK, FBR). Steel or nodular cast iron casks

holding up to 26 PWR or 60 BWR fuel assemblies have been developed. Full scale demonstration tests have been undertaken in Germany and the U. S. to investigate the behaviour of casks and stored spent fuel. In general the results from these investigations were very satisfactory. No fuel failure occurred during the demonstration phase, radiation and temperatures remained well within the predicted levels. Fuel elements are kept under an inert gas atmosphere, leaktightness of the double barrier lid is monitored permanently. At present HTR and LWR fuel assemblies are stored in metal casks in Germany and the U. S. Expansion of cask storage is planned for RBMK or VVER-fuel in Ukraine, Lithuania, Czech Republic and Slovakia.

For storage of spent CANDU fuel there is remarkably good experience with dry storage in concrete canisters and dry storage containers. In total more than 800 t HM presently are stored under dry conditions without any abnormal occurrences [8]. In parallel a research program on the long-term behaviour of spent fuel under dry storage conditions is being carried out. The results to date show no apparent change of non-defective fuel elements from their condition before storage. Similar good experience was gained in the U. S. with PWR fuel assemblies.

The experience with spent fuel stored in dry vaults is also very encouraging. Besides the storage of MAGNOX fuel there is good experience with storage of fuel assemblies from research reactors in the CASCAD facility at Cadarache and from breeder reactors [10]. In the U. S. spent fuel from the Fort St. Vrain HTGR has been stored in a dry vault store for many years. Modular concrete storage systems have been developed and licensed for LWR fuel assemblies.

In summary it can be stated that dry storage of spent fuel in metal or concrete containers and vaults has reached technical and industrial maturity. Table II shows dry storage concepts in various countries.

Long term aspects of spent fuel storage

Long term storage of aged nuclear fuel is attracting more and more interest. In fact, taking into account the opposition against a further expansion of reprocessing and the difficulties and delays in implementing final repositories long term storage will be the most probable interim solution of the back end of the fuel cycle. Countries with expanding nuclear power generation following the concept of a closed fuel cycle tend to wet storage in connection with their reprocessing plants (France, UK, Japan, China, Russia). Other countries prefer dry storage for long term storage of spent fuel. Dry storage will be the preferred solution for long-term and large-scale storage of aged fuel.

Facilities for long term storage represent large inventories of long-lived fission products, fissile material and actinides. Therefore adequate protection against external impacts and physical protection is necessary. Given the long storage times of up to a century and the possible social or political uncertainties over this long timespan, these aspects require serious consideration. Siting the facility underground as for example of the CLAB facility in Sweden seems to be a favourable solution.

In future additional AR storage facilities are to be expected at most of the reactor sites, unless centralized AFR storage facilities can be implemented. Optimization of these developments should result in a consistent strategy taking into account economics, safety issues, security and public attitudes. To overcome public suspicion that long-term storage might in reality mean disposal, adequate progress towards implementation of final repositories is necessary.

Present experience with wet and dry storage indicates no safety problems for long-term storage up to a century. Research and demonstration programs, however, are to be performed to extrapolate the existing experience and to monitor any deterioration of fuel and containment integrity.

TABLE II. STATUS OF DRY STORAGE [8-10]

Country	Dry storage concept	Progress to date
Argentina	concrete canisters	Dry storage containers in operation at Embalse, planned for Atucha
Canada	concrete canisters, vault, concrete container	Concrete canisters used at 5 sites, First CANSTOR module operable 1995 Dry storage container facility at Pickering has construction licence
Czech Republic	metal cask vault	cask storage in operation Concrete vault planned
France	concrete vault	CASCAD facility at Cadarache in operation. Design for CASCAD concept for LWR fuel completed
Germany	metal cask vault	AFR storage at Ahaus (HTR fuel) and Gorleben (LWR fuel) operable, CASTOR cast iron casks licensed and in use. Construction of AFR Greifswald storage facility FUELSTOR concept developed
Japan	metal cask	Development of metal cask
Lithuania	metal cask	CASTOR-RMBK cask
UK	vault	Storage of MAGNOX fuel AGR fuel storage proposal (Torness)
U. S. A.	modular vaults concrete modules metal casks	Dry storage in use for HTR and LWR fuel, Dry storage foreseen for MRS, various types of concrete and metal casks used for at reactor storage

Issues for further development

Increasing needs for an expansion of storage capacities at reactors have led to reracking of pools and to disassembling the fuel bundles to single rods and to rod consolidation. In addition, movements of partly burned fuel and canning of defective fuel and fuel assemblies before going to transport or dry storage have to be undertaken. In storage pools, therefore, a lot of handling activities have to take place with the possibility of failures which might jeopardize the safety of the stored fuel. Special care has to be taken to prevent any risk of criticality (especially in case of burnup credit) and any damage to fuel bundles or to vital containment or cooling functions. There have been some technical difficulties in following prescribed procedures for loading of heavy transport and storage casks at reactors. Improvements of equipment design and procedures - especially to prevent any contamination of external storage facilities - should be considered.

Special provisions have to be made to cope with defective fuel. In PWR and BWR, fuel failures have been reduced to a large extent. More serious seems to be the situation with some fuel assemblies from VVER- an RBMK-reactors.

Modified storage casks for MOX fuel assemblies and LWR fuel with very high burnup have to be designed. Peak burnups of 60 GWd/tHM for LWR fuel assemblies are to be expected.

To develop a consistent concept of spent fuel transportation, interim storage and disposal, a reexamination of the existing various cask and container concepts and design seems to be valuable.

Especially the aspect of minimizing fuel handling and inspection should be recognized. In this context the Multi-Purpose Canister (MPC)-concept in the U. S. may represent a real progress [11]. This concept is based on a sealed multi-purpose canister as a common element for different overpack casks for transportation, storage and disposal.

3. CONDITIONING OF SPENT FUEL

Conditioning of spent fuel assemblies may be necessary for economic interim storage and has to be done in case of direct disposal.

RBMK fuel assemblies have to be separated from their long upper support rods and separated into two fuel bundles before storage in dry casks. To achieve closer packing of fuel rods, fuel assemblies can be disassembled and consolidated for better economics of storage. Before going to dry storage, fuel casks have to be dried and filled with inert gas.

For final disposal various container concepts have been developed in accordance with the concept of final repositories. The most advanced concept exists in Sweden [12]. After storage in the CLAB facility for about 40 years, the spent fuel will be loaded in an encapsulation facility into a copper canister. There are various design concepts for this canister for final disposal. As a basic design in the KBS-3-report [13] a 80 cm diameter and 4.5 m long copper canister for 9 BWR - or 2 PWR- and 4 BWR-assemblies has been proposed. To withstand outside hydrostatic pressure and pressure from backfill material the interior space of the container was intended to be filled with copper powder or molten lead. In the meantime various alternative container concepts have been proposed. A composite copper-steel canister was selected as the prime canister alternative [14]. The design of the corresponding encapsulation facility at the CLAB site has not yet been completed.

In Germany, for conditioning of spent fuel the PKA facility is under construction as a versatile multi-purpose facility [15]. For LWR fuel assemblies, a final disposal cast iron cask POLLUX with a Hastelloy C 4 corrosion resistant surface has been developed. This cask consists of a shielding cask and an inner cask holding 10 standard PWR fuel assemblies. As an alternative, also a final disposal canister holding the rods of 4 PWR or 12 BWR assemblies has been designed. The granting of a type B(U) licence for the POLLUX cask is expected at the end of this year. With respect to the final repository the design of POLLUX cask is based on a temperature of 200 °C in the repository and a maximum rocksalt pressure of 300 bar [27]. In the PKA facility it is intended to load first several POLLUX containers for research and demonstration before a decision for a final repository is taken. The PKA facility is equipped with a hot cell area and auxiliary facilities. Development work and demonstration of encapsulation techniques for various types of spent fuel and waste can be performed.

Also in other countries there are similar developments for conditioning of spent fuel in containers for final repositories. Depending on the conditions of the repository, different approaches to container design, with or without filling material in the interior of the container, are pursued [17].

In general, most techniques to be applied for spent fuel conditioning are based on processes already used in the nuclear fuel cycle industry or conventional industry. Up to now, however, spent fuel conditioning technology has not yet been demonstrated at an industrial stage and remains in the design phase.

Issues for further development

Most important is active demonstration of the developed techniques at full scale. There remains a considerable area for further optimization of container design for final disposal. A consistent approach including all steps after unloading the fuel assemblies from the core until final disposal should be applied. Optimized concepts for only one stage may prove not to be optimal for the complete system of waste management. Conditioning of spent fuel for direct disposal is closely related

to the conditions of final repositories. Final decisions on spent fuel conditioning therefore require sufficient progress and knowledge from site exploration and design of the corresponding repository.

4. STORAGE OF HIGH LEVEL LIQUID WASTE

HLLW resulting from the first extraction cycle of reprocessing is concentrated and then stored in storage tanks with typical volumes of 100 - 150 m³. The radioactive inventory of these tanks is very high in the order of 10⁷ to 10⁸ TBq. The HLLW-concentrate is a solution / suspension of nitrate salts in nitric acid. As a result of reprocessing operations, decontamination processes or neutralization some tanks may contain considerable amounts of sludges. Because HLLW-concentrate generates considerable heat, continuous and reliable cooling is of high safety relevance. During storage adequate ventilation has to be provided to prevent accumulation of radiolytic hydrogen and decomposition products from organic residues. The concentrate is agitated to prevent settlement and accumulation of sludges with high heat generation. Reliable and redundant systems are installed for cooling, temperature control and monitoring liquor levels. The storage tanks are protected by heavy concrete cells which provide shielding and protection against external impact.

Status and experience with HLLW storage from military reprocessing

There is considerable difference in the design and corresponding experience for old tanks which were installed in the context of weapons programs and new tanks for commercial reprocessing facilities. As an example, the situation at Hanford may be illustrated [18]. At the Hanford site approximately 217 000 m³ of HLLW are stored in the form of caustic liquids, slurries, sludges and salt cakes. From 149 single-shell tanks made of reinforced concrete with a carbon steel liner with a capacity of 208 m³, 67 have leaked or are suspected to have leaked. The total amount of leaked waste is estimated to 3 800 m³. No leaks have occurred from the 28 double shell tanks. Serious safety problems exist in several tanks due to hydrogen generation and development of potentially explosive mixtures. A consistent and long-ranging tank waste remediation system has been established to improve the situation. Similar problems are encountered at Savannah River where approximately 130 000 m³ of HLLW are stored.

At the MAJAK reprocessing site in Russia high active wastes from military reprocessing were discharged in earlier times to a river and later collected in the small Karachaj lake. Tank storage was installed with relatively simple cooling systems in a water basin common to 14 tanks. A loss of cooling of the tank farm after a contamination incident of cooling water resulted in 1957 in a chemical explosion, leading to widespread and still existing contamination [19]. At present, about 25 000 m³ of HLLW are stored in 99 tanks on site. At the reprocessing facilities of Tomsk and Krasnojarsk liquid wastes from reprocessing are injected into deep impermeable strata in the geological underground.

Status and experience with modern technology

Experience with stainless steel tanks of improved design at commercial reprocessing plants is far better. By conservative design and careful operation, combined with strict monitoring, the relevant safety functions for HLLW tank storage have been reliably maintained. Main safety functions are:

- Containment and shielding of radioactivity
- Heat removal
- Subcriticality
- Prevention of accumulation of flammable gas mixtures
- Prevention of corrosion and sludge accumulation to avoid hot spots
- Low aerial discharges and low radiation exposure during maintenance and control
- Provisions for leak detection and removal or transfer of HLLW to spare tanks or to vitrification

Under normal conditions modern stainless steel tanks provide a safe storage of acid HLLW solutions for long periods of time without significant corrosion rates. There is only little maintenance required and exposure during maintenance is low. No leaks occurred with these modern tanks nor other remarkable incidents. There remains, however, a very low probability risk of a tank failure from external impact, such as a strong earthquake, airplane crash or sabotage. This could result in widespread consequences and a major emergency.

Modern reprocessing strategy therefore includes timely solidification of HLLW by vitrification as an integral element of the reprocessing operation. This strategy is facilitated by longer cooling times before reprocessing, with a corresponding reduction of specific radioactivity and heat load of the HLLW. No new storage tanks for HLLW are to be built at La Hague and Sellafield. Considerable progress has been achieved in vitrifying HLLW concentrate at Marcoule and La Hague; in total more than 4 000 m³ of HLLW have been vitrified [24]. At Sellafield the rate at which the backlog of HLLW has been vitrified was behind schedule in recent years. Presently 1 400 m³ HLLW are stored. By increasing the vitrification capacity it is expected to speed up the rate of emptying the tanks.

Issues for HLLW tank storage

In general, for stainless steel double shell tanks no significant improvements seem to be necessary. With old designs, there are considerable problems due to leaks, prevention of flammable gas mixtures and emptying. The removal of sludges and saltcakes remains a very difficult task and there is doubt if complete emptying of some tanks ever will be achieved. HLLW tank storage involves- even with modern design - on principal some risk of a large release of radioactivity in case of an extreme external impact. As a consequence, storage of large volumes of HLLW has to be and will be avoided by adequate availability and performance of vitrification facilities.

At some locations smaller volumes of HLLW are present, for instance at the pilot reprocessing plant at Karlsruhe, Germany. For these cases it might be not economic to have a vitrification facility on site. Alternative solidification processes may be envisaged or transportation of HLLW to other sites may be arranged.

5. VITRIFICATION

The preferred and most developed method of HLLW solidification is vitrification. There are two main technical processes which have reached industrial maturity:

- A two-step process based on calcination followed by vitrification of the calcined oxide in a metallic melter
- A one-step process using a large ceramic melter with direct introduction of liquid waste to a molten-glass volume.

France played a leading role in developing the two-step process, starting with the PIVER pilot plant 1960. Successful industrial experience followed with the AVM facility at Marcoule [21]. Today two vitrification facilities are in operation at La Hague (the R7- and T7-facilities) (Table III). The French vitrification process was also adopted for the WVP at Sellafield, which is in operation since 1991 with two lines. A third line will be added.

The direct vitrification route using a large ceramic melter was developed in Germany, the U.S. and Russia. Based on German technology the pilot plant PAMELA at Mol, Belgium was constructed and operated for several years to vitrify the liquid wastes from the former Eurochemic reprocessing plant. In the U.S. there have been different technological developments for vitrification. Extensive testing with inactive material has been performed to take into account the specific chemical compositions of the wastes from reprocessing at Hanford, Savannah River and West Valley. No radioactive waste has been vitrified in the US up to now. At the MAJAK site in Russia considerable amounts of HLLW solutions have been vitrified. Supernatant solution was treated successfully whereas

sludges have been not yet removed from the tanks. This year a new ceramic melter vitrification facility went into operation at Tokai, Japan.

Experience with vitrification

Technical experience with the French continuous calcination-vitrification process is excellent; the results from operation are really impressive. By end of 1994, the French vitrification facilities had solidified in total over 4 000 m³ of waste solutions with more than $5.5 \cdot 10^7$ TBq filling over 5 000 canisters [24]. There have been no major incidents or malfunctions of equipment. The lifetime of metallic melting pots has been continuously increased. For 2100 glass canisters in R7 and T7 in total 47 melting pots have been consumed [20]. Off-gas treatment was very effective; decontamination factors of 10^6 before filtering by three stages of HEPA filters have been achieved. Fine particles from fuel dissolution and alkaline effluents from solvent regeneration have also been incorporated into the glass. At the WVP at Sellafield some difficulties with remotely controlled cranes and manipulators were the reason for poorer plant performance than expected.

At the Belgian PAMELA plant the overall experience also was very encouraging [22]. After an operation time of almost three years, the first ceramic melter had to be replaced due to corrosion attack at electrodes, bottom outlet and the overflow drain system. This melter exchange was performed remotely without major problems. The second melter worked as expected. To prevent problems with the draining system, ceramic melters should have a 60 ° bottom slope to avoid formation of glass layers with high amounts of noble metals [23]. During operation there were no safety problems, the cleaning of the off-gas proved to be very effective.

Most vitrification processes use a borosilicate glass as matrix material with a content of fission products and actinides of 12 - 15 percent. These compositions have been found satisfactory. In Russia a phosphate glass matrix has been used.

TABLE III. STATUS OF VITRIFICATION FACILITIES UNDER HOT OPERATION

Facility (country)	Status of operation	Melter design	Achieved cumulated throughput
PIVER, Marcoule (F)	1969 - 1972 decommissioned	calcination, metallic melter	12 t glass
AVM, Marcoule (F)	since 1978	calcination, metallic melter	1 500 m ³ HLLW to 2 000 canisters (660 m ³ glass)
R7, T7 La Hague (F)	R7 since 1989 T7 since 1992	calcination, metallic melter	R7: 1 700 canisters (640 t glass) T7: 400 canisters (160 t glass) up to Sept. 1993
PAMELA, Mol (B)	1985 - 1991	ceramic melter	900 m ³ HLLW to 2 200 canisters (500 t glass)
WVP, Sellafield (UK)	since 1991	calcination, metallic melter	1 000 canisters up to July 1995
EP-500, Chelyabinsk (RF)	since 1987 in modification	ceramic melter, new melter under construction	6 000 m ³ HLLW to 1 060 t glass (phosphate)
WIP, Tarapur (India)	since 1985	metallic melter	no data available
TVF, Tokai (Japan)	since 1995	ceramic melter	

In conclusion, vitrification of HLLW has been demonstrated as an effective and industrial-scale enterprise. It can be expected that this technology is able to improve also the situation at the sites of weapons reprocessing.

Other solidification techniques for HLLW

Calcination of HLLW has been applied as a first step to solidify the wastes from the Idaho reprocessing plant. Since the mid-sixties the waste has been converted to a solid powder which is presently stored in underground vaults [28].

Issues for further development

Vitrification in general has been proven as an industrial established technology. No major modifications of processes and technical equipment are to be expected. The feedback of experience will be primarily used for improvement of plant performance, melter lifetime and equipment for remote operation. Hot vitrification of the variety of HLLW from weapons program reprocessing has to be demonstrated. Specific challenges exist for vitrifying these military wastes due to the presence of sodium, aluminum or organic material. In the framework of disarmament, vitrification of weapons grade plutonium together with stored HLLW solutions has been proposed. Research and development may be needed to adapt existing vitrification processes for this purpose to prevent criticality risks.

From the standpoint of long-term disposal, glass seems to be an adequate and satisfying matrix for the disposal of high active wastes. There are, however, ongoing programs to develop alternative waste matrix materials like glass ceramics and synthetic minerals. For specific purposes these alternative waste products may have advantages. Radiation induced degradation, microstructural characterization and long term durability of these products are under investigation. At present these developments have not yet reached industrial maturity and remain to be topics for research and development.

6. STORAGE OF SOLID HIGH LEVEL WASTE

Glass blocks from vitrification are stored in concrete vaults cooled by natural or forced air convection. Storage times up to 50 years are the basis of the design. The most relevant safety issues are adequate cooling, prevention of contamination and physical protection. As experience shows with the waste storage vaults at Marcoule, La Hague and Sellafield, these safety functions can be achieved reliably without undue maintenance and radiation exposure. The maximum glass temperature is generally below 600 °C, the temperature of the outlet air is 100 - 150 °C. With these parameters there is no concern on glass block stability, corrosion and concrete structure stability during the lifetime of the storage vault.

Cladding waste and structural material of spent fuel may also be classified as highly active for one or two decades until the cobalt activity and the activity of remaining fission products has declined. These wastes are stored in wet silos to prevent fire risks and to provide shielding. Cementated cladding waste is stored in concrete stores equipped with ventilation with filters to prevent accumulation of hydrogen and spread of contamination. Cooling by air ventilation is sufficient. As an alternative to cementation, compacting of cladding hulls by a supercompactor has been developed. Tests performed in France have shown very substantial volume reduction [25].

Feed sludges from the dissolution step of reprocessing sometimes contain so large activities - for example ruthenium - that they can be classified for some time as highly active. Presently, most of these residues are temporarily stored pending ultimate treatment. Progress has been achieved in France to incorporate these wastes together with HLLW into vitrification. An alternative is cementation after some time of decay.

7. LONG LIVED LOW AND INTERMEDIATE LEVEL WASTES

There are two main sources of low and intermediate level wastes in liquid or solid form, which contain long lived actinides and especially plutonium: reprocessing with plutonium extraction and purification and mixed oxide (MOX) fuel production. From reprocessing washing solutions, aqueous concentrates, spent organic solvents or tributyle phosphate are generated. These wastes contain fission products and plutonium in various concentrations. A great variety of combustible and non combustible solid material arises from reprocessing and MOX fuel element fabrication.

For conditioning these wastes, there are different processes available and in use depending on the specific fission product activity and chemical composition of the waste. Wastes with relatively high fission product concentrations like sludges and concentrates are routed to vitrification together with HLLW. There is a general tendency to reduce intermediate level waste volumes to limit the great variety of waste forms and the waste volumes [26]. Other liquid alpha-bearing wastes are incorporated into bitumen or cement. Bituminization has been performed effectively at the EUROCHEMIC plant in Belgium and in France. The process has reached industrial scale, the safety record in general is good. One fire occurred at the EUROCHEMIC facility in 1981 with only minor consequences. However, on principle the risk of fire remains with bituminization. Generation of hydrogen by radiolysis is also a concern.

Cementation of alpha-bearing liquid or solid wastes, has also been shown practical and without problems. Disadvantages, however, are the large volumes of cementated waste and the risk of gas generation by radiolysis and corrosion. This effect can result in pressure build-up in the sealed containers, which have to be tight to prevent alpha contamination. All handling, pretreatment and conditioning of low-level alpha-bearing waste with transuranics has to be exclusively under tight containment in glove boxes or containment cells.

Incineration of burnable liquid and solid wastes contaminated by transuranics has the advantages of major volume reduction and practical elimination of long-term gas production by burning all combustible material. Several types of incinerators have been developed and tested. Minor malfunctions due to corrosion or clogging of filters by airborne particulates have been reported. The design and operation of large-scale incinerators for transuranics wastes remain a challenge for design and operation. Not only the problems with containment, ash treatment, subcriticality and effective and reliable off-gas filtering have to be mastered. There are also requirements for off-gas cleaning to prevent emissions of dioxine or other toxic chemicals. For the new French MOX fuel fabrication plant MELOX, a large incineration facility for combustion of plutonium contaminated waste is being constructed.

Other treatment processes like acid digestion and washing processes, developed primarily for the recovery of plutonium at a time when plutonium was considered as a rare and valuable material, are presently of reduced interest. Now volume reduction and production of a stable waste form for disposal are the main objectives for conditioning.

Interim storage of unconditioned transuranics waste may pose fire risks in the case of storage of large amounts of burnable liquids or solids. Conditioning to an inert and stable waste form is highly desirable. Storage of conditioned cemented alpha-bearing waste is common practice with no problematic safety aspects. Provisions have to be made to prevent alpha contamination in case of handling incidents or damage due to external impact.

Issues for future development

There remains for some specific low and intermediate level wastes containing trans-uranics a considerable area for further development of waste treatment. Vitrification together with HLW of some of these wastes especially from reprocessing might be the best option. In particular alpha-contaminated organic liquids and TBP need specific treatment; in some cases incineration may

be a satisfying solution. Incineration of combustible waste and cementation seem to be the best options for the treatment of other alpha contaminated wastes from MOX fuel manufacturing.

Abandoned radiation sources

In some countries there is an increasing number of radiation sources which are no longer used and have to be disposed of. Some of these sources contain plutonium or americium. There have been serious accidents with high active isotopes from radiation sources like cesium or cobalt. A strict safety regime has to be followed to prevent hazards by unauthorized use or negligence.

8. CONCLUSIONS

In summary, management of HLW and long lived low and intermediate level waste has made considerable progress. Spent fuel and stored HLLW, at least from the commercial nuclear fuel cycle, remain under control and containment. There have been, however, serious problems with HLW from military reprocessing. Solving these problems remains a major challenge.

Interim storage for several decades is today and will be in future the preferred interim solution for HLW management. For aged fuel, dry storage shows considerable advantages and has reached technical maturity in the form of storage of metal casks, concrete containers or vaults. Adequate progress, however, is also needed for the implementation of final repositories. Otherwise the public will consider long term storage as de facto disposal. In this case, interim storage will encounter strong opposition.

There is a great variety of cask and container design for transportation, interim storage and final disposal. It seems advantageous to reconsider these developments and to try to find an optimized consistent approach to minimize handling of spent fuel and vitrified waste. The design of a sealed multipurpose canister with various overpack containers seems to be progressive.

The storage of HLLW in tanks should be eliminated as far as possible by timely vitrification of liquid wastes. For some sites this task may last many years; in the meantime, safety of HLLW tank storage can be and has to be maintained by strict control and monitoring.

The progress made in vitrification is very impressive. Vitrification eliminates a significant on-site risk at reprocessing facilities and is an important step towards a stable waste product for final disposal. Storage of glass blocks in vaults or casks is technically established.

Other low or intermediate level wastes from reprocessing or MOX fuel production can be stored safely. There remains an area for technical development for some specific waste forms. Incineration of combustible liquid and solid waste looks promising but has yet to be demonstrated at an industrial scale.

In general, managing HLW under safe and secure conditions is achievable for both routes - the direct disposal route and the closed fuel cycle. In addition to safe interim storage facilities final geological repositories must be sited and developed. That is the only way to convince the public and ourselves that nuclear power can be an important element of a sustainable development philosophy.

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EXPERIENCE IN DECOMMISSIONING URANIUM MINING AND MILLING SITES

P.A. BROWN
Natural Resources Canada,
Ottawa, Ontario

R.W. POLLOCK
Atomic Energy of Canada Limited,
Gloucester, Ontario

Canada

ABSTRACT

Uranium mining and milling wastes take many forms such as tailings, waste rock, contaminated equipment and structures, processing residues, as well as in situ wastes from leach mining operations. They are unique in the spectrum of radioactive wastes by virtue of their large volume, long half-lives of the natural radionuclides and, in some cases, potential to cause non-radioactive environmental impacts such as acid drainage. In the past, some mines, mills and tailings have either been abandoned or shut down in a way that might pose continuing adverse impacts to health and safety, or to the environment. Remedial programs have been successfully completed, or are in progress, in a number of countries and a range of examples are described in the paper. New and operating mine/mill facilities are designed to meet regulations based on a good understanding of tailings confinement technology and the measures required for long-term protection of human health and the environment. Adoption of effective measures by the industry has demonstrated that uranium mining and milling, and the management of uranium tailings, can be carried out safely, both for the present and future generations.

1. INTRODUCTION

Some 420 nuclear power stations with a total capacity of more than 330,000 MW(e) are currently in operation and more are being constructed or planned. A large number of uranium mine and mill facilities have been developed to produce the uranium required to fuel these power stations. These mines and mills, including the large volumes of residues produced during their operation, will have to be decommissioned when the facilities have reached the end of their useful life.

Uranium mine and milling waste may take many forms such as tailings (milling residues), waste rock (low grade uneconomic mine waste), contaminated equipment and structures, process residues such as ion-exchange resins and treatment sludges, as well as in situ wastes from leaching mining operations. The nature of the uranium mine itself may vary from an underground mine to an open pit to an "in situ" leaching operation. The type of mine affects the relative amount of waste produced. For example, open pit mining usually yields large amounts of waste rock while in situ leaching generates very limited amounts of tailings.

Milling facilities vary from alkaline to acid leaching processes. This can lead to non-radioactive environmental impacts that are as significant as those due to radioactive contaminants.

Mining and milling wastes are unique in that they are typically large in volume and contain long lived natural radionuclides. This limits the range of management options which can be used. Moving the waste to more favourable sites or burying it in deep geological repositories are not generally considered to be viable alternatives to managing the wastes on the surface where they were deposited.

Past activities resulted in some mines, mills and tailings areas being abandoned or decommissioned in a way that is no longer acceptable. However, present, mine/mill facilities typically have a number of licence conditions and regulations related to health, safety and protection of the environment. Inspections and monitoring operations by the regulatory authorities, to ensure compliance

with the licence conditions, are conducted routinely. Adoption of effective measures by the industry, to limit adverse environmental and health effects, has demonstrated that uranium mining and milling and the management of uranium tailings can be carried out without undue risks.

This paper discusses the technology used for decommissioning both operating and abandoned facilities.

2. OBJECTIVES AND PRINCIPLES

The objective of radioactive waste management is to deal with the wastes in a manner that protects human health and the environment now and in the future without imposing undue burdens on present and future generations.

There is international agreement on the principles needed to meet this overall objective. These principles, and the rationale behind them, are outlined in the International Atomic Energy Agency (IAEA) publication entitled "Safety Fundamentals - The Principles of Radioactive Waste Management" [1]. Requirements for the safe management of radioactive wastes and the requirements for establishing a national system for radioactive waste management are further described in a series of RADWASS Safety Standards [2-7] as well as in other IAEA documents [8-11].

Mining and milling waste management requirements fall into three broad categories: new facilities, existing mines/mills and waste sites, and abandoned sites. For uranium mining and milling facilities only the first two of these cases will normally have been licensed by regulatory authorities.

In principle the need to protect people and the environment is independent of the history of the facility. However, the management options possible for existing and abandoned sites depend in part on the previous management practices and the location of the waste on the sites. Thus, it may not be practicable to use the most modern solutions for older operations and hence the degree of radiation protection may vary for older operations.

The fundamental objective is to isolate the radioactive waste from the accessible environment for as long as is needed to prevent unacceptable radiation exposure. In practice, some releases may occur and it is therefore necessary to limit the associated risk to individuals. This leads to a hierarchy of possible protection levels from exemption from control (unrestricted release) through to active institutional controls.

The goal with regard to decommissioning uranium mine sites is to achieve unrestricted use of a site without the need for institutional controls. However, this is frequently not a practical option, since tailings are often emplaced on or near the surface which makes them accessible. This may result in accidental, and unacceptable, exposures. Thus additional measures such as institutional controls or enhanced containment barriers are needed to either reduce the likelihood of exposure or to reduce the magnitude of the dose. National authorities should ensure that operators use practices which go as far towards this goal as can practically be achieved. It must however be recognized that it may not be possible to achieve the same level of assurance as is possible in other parts of the nuclear fuel cycle.

In view of the long half-lives of the natural radionuclides involved, institutional controls and barriers have to be in place over correspondingly long time periods, beyond tens of thousands of years. It is recognized that estimates of future performance of waste facilities are increasingly uncertain in the future and that beyond 10^4 years may have little quantitative value. Furthermore, institutional measures may not be reliable beyond a few hundred years and some engineered barriers such as dams and covers are unproven over these long time scales. The regulatory authorities must use judgement to decide what can be practically achieved.

3. EXPERIENCE IN DECOMMISSIONING PROGRAMS

3.1. General

Decommissioning at a uranium mine/mill complex includes the decontamination and dismantling of sites, buildings, structures and equipment so that the items can be reused or recycled, if appropriate, or disposed of, as required.

The decommissioning of impoundments for tailings or other large volumes of radioactive residues includes ensuring that retaining structures meet the regulatory/design requirements; isolating wastes for a reasonably long period to time; and restricting the release rate of pollutants from the containment to the environment to acceptable levels, while minimizing reliance on institutional controls for the protection of public health and safety and the environment.

A recent IAEA report [12] presents an overview of factors involved in planning and implementing the decommissioning of uranium mine/mill facilities. The information applies to mines, mills, tailings piles, mining debris piles and leach residues that are present as operational, *mothballed or abandoned projects, as well as to future mining and milling projects. The report* identifies the major factors that need to be considered in the decommissioning/close out activities, including regulatory considerations; decommissioning of mine/mill buildings, structures and facilities; decommissioning of open pit and underground mines; decommissioning of tailings impoundments; decommissioning of mining debris piles, unprocessed ore and other contaminated material such as heap leach piles, in situ leach facilities and contaminated soils; restoration of the site, vicinity properties and groundwater; radiation protection and health and safety considerations; and an assessment of costs and post-decommissioning or post-close out maintenance and monitoring needs.

The following sections report on activities in Canada, the US, Germany, and France, all possessing large volumes of uranium tailings. Section 3.6 provides a brief overview of the situation in other selected countries.

3.2. Canada

Canada is now the world's largest uranium producer. Mining of radioactive ores began in 1932 at the Port Radium Mine in the Northwest Territories, initially for radium and subsequently for uranium. Development in the 1950s led to the beginning of uranium production in the Beaverlodge area of northern Saskatchewan in 1953, and development of fifteen mines from 1955 to 1958 in the Elliot Lake and Bancroft area of Ontario. After the downturn in demand of the 1960s, the early 1970s saw an increased demand for uranium, resulting in expansion of existing mines at Elliot Lake and major new developments of higher grade deposits in Saskatchewan. By 1986, 60% of Canadian uranium production was from Saskatchewan. More recently, the low grade of ore in combination with the declining price of uranium has led to a progressive shutdown of the mines in the Elliot Lake area. In parallel, proposals for new mines in Saskatchewan have undergone environmental assessment.

Decommissioning activities and plans are described briefly in the following paragraphs, with research activities and tailings management at recent and planned uranium mines discussed in Section 4.

In Canada, the decommissioning of four sites has been completed by the owners [13]. Three were old sites from the 1950's, with conventional mills, and with a total of about 10 million tonnes of tailings. The fourth was an underground in situ leaching operation. In general, all tailings were decommissioned in situ, some with soil cover, some with rock cover, and underwater at one site. Waste rock was consolidated into tailings, or used as cover material where appropriate. Mills and other buildings were decommissioned, and the wastes disposed of in tailings, in mine shafts, or covered in situ.

Two companies are currently in the process of decommissioning mines and tailings impoundments, containing over 125 million tonnes, in the Elliot Lake area. The plans are now the subject of a public review through the federal Environmental Assessment and Review Process (EARP). In developing the plans, various options for the tailings facilities were assessed, including wet cover (i.e. flooding the tailings), dry covers of various materials, relocation and disposal in a lake, and underground disposal in the mines (limited to part of the volume) [14-15].

The long-term objectives include minimizing acid generation and the resulting leaching of radionuclides and heavy metals, minimizing radiation exposure from future casual access, and ensuring stability of structures. Acid generation is a major consideration due to the pyrite content of the ores and resulting residual sulphides in the tailings. Because of favourable geology, and the long-term concerns about acid generation, water covers are favoured by the owners. The risk assessments indicate future risks are low with ongoing monitoring and site control.

3.3. United States

The exploration and mining of radioactive ores in the United States began around the turn of the century, with the initial interest in high-grade radium ores. Uranium became important during the war, and uranium production from the mid-1940s to the mid-1960s served mainly military purposes. The commercial use of uranium for nuclear power plants increased as the military requirements declined. Historically the United States has had the largest uranium production of any country.

Initially, the mining and milling of radioactive ores was treated no differently than other mining activities. There were no special regulations for radioactive ores nor were there government guidelines or directives for siting plants or discharging tailings. Discharges of contaminated seepage from tailings to rivers, the vulnerability of storage sites to wind erosion and the possibility of contaminated materials used at construction sites led to implementation of controls and remedial actions, beginning in the early 1970s. In particular, the Uranium Mill Tailings Reduction Control Act (UMTRCA) of 1978 provides for the cleanup and stabilization of uranium mill tailings at currently inactive uranium processing sites.

UMTRCA is the basis for present day control of uranium mill sites. It vests the Environmental Protection Agency (EPA) with the overall responsibility for establishing environmental standards and guidelines, but regulatory responsibilities for US nuclear facilities, including uranium mills, remain with the Nuclear Regulatory Commission (NRC). Uranium production facilities may be categorized as Title I or Title II facilities based on this legislation. The Department of Energy (DOE) is responsible for conducting the cleanup and tailings stabilization at mills designated as Title I, which were operated to supply the uranium requirements of the federal government.

The Uranium Mill Tailings Remedial Action (UMTRA) project was established by DOE in 1980, and includes 24 (of 50) US mill sites and 5195 vicinity property cleanups [16]. Tailings volumes per site range from about 0.1 million m³ to 3.5 million m³ with an estimated total of about 24 million m³. EPA standards require that remedial actions be effective for 1,000 years to the extent reasonably achievable and in any case for at least 200 years and that they meet specific numerical criteria for radon release from completed sites, and for cleanup of lands and buildings, including vicinity properties. The site performance criteria are met by consolidation and stabilization of tailings, and installation of a multi-layer cover of natural material. An individual site project follows sequential steps from initial assessment to final licensing by NRC, including an environmental assessment step which results in a decision on whether to stabilize the tailings on site, or relocate them. As of the end of 1993, surface work is complete at ten sites, with work in progress at eight others, and cleanup of vicinity properties is about 95% complete.

The operator is responsible for decommissioning Title II production facilities, which primarily served a commercial market. Licenses issued by the NRC, or the "agreement" states set forth the conditions of operating including site decommissioning to regulatory standards. Licensees are required

to provide surety (in the form of cash, tangible assets, or both) until restoration and reclamation are completed. At present, the uranium industry has committed over \$300 M of surety, which is reassessed annually to accommodate inflation and to take into account decommissioning work completed.

A comprehensive study of the decommissioning process and associated costs, for both conventional and non-conventional (in situ leaching) facilities has recently been published [17]. For conventional facilities, decommissioning includes decontamination and dismantling of the mill, site restoration (including groundwater cleanup), reclamation (close out) of mill tailings, and long-term monitoring of the site. The ultimate purpose of tailings pile reclamation is to return the site to the DOE, or the appropriate state, for perpetual custodial care.

There are 26 such mill sites in the US which, collectively, had a total capacity of 56,850 tonnes of ore per day, and which have generated more than 200 million tonnes of tailings. Decommissioning is at various stages at 20 sites. Decommissioning of non-conventional in situ leaching facilities includes decontamination, dismantling and removing plant facilities and wellfield equipment, site restoration, groundwater restoration and long-term monitoring of the site. There are 17 such facilities in the US, four operating, four on standby and nine either decommissioned or being decommissioned.

3.4. Germany

Uranium mining started in 1946 in the former German Democratic Republic (GDR) in the Erzgebirge Mountains region of Saxony. These particular deposits, which straddle the border with the Czech Republic, have been mined since the 12th century, first for silver, and later for cobalt, nickel, and other base metals. Uranium production from other mining districts in the GDR began soon after, and continued until 1990, when it was terminated for economic reasons. A total of about 220,000 tU was produced in the former GDR from 1946 to 1990 - 87% by underground mines, 9% by open pit mining and 2% by in situ leaching. Two major processing operations, with annual capacity of 2.5 million tonnes of ore and 4.6 million tonnes of ore utilized acid, and alkaline extraction methods. Only minor rehabilitation was carried out by the former joint Soviet-German company Wismut.

With the unification of the former East and West Germany the Federal Government of Germany took over responsibility for Wismut in 1990. The first decision made was to terminate all commercial mining activities for economic reasons. Second, a program was initiated to evaluate the extent to which cleanup activities will be necessary. On behalf of the Federal Ministry for Environment, Nature Conservation and Nuclear Safety, the Federal Office for Radiation Protection (BfS) was commissioned to conduct a radiological evaluation of abandoned uranium mining and milling facilities [18]. On the basis of recommendations by the German Commission of Radiological Protection, the evaluation was conducted with special emphasis on 1 mSv/a dose rate as the threshold value for individual exposure of the population (additional to the pre-mining exposure). The study areas were defined and field inspections with measurements of radioactivity were carried out. About 5,000 abandoned mining-related sites, originating from medieval silver mining and later base metal and uranium mining, were identified in an area of 1,500 km². Results of the evaluation indicate that a reduced area of about 250 km² will require further investigation and cleanup measures. The comprehensive evaluation will be finished in 1996/97.

Other than the orphan mining sites, all mining and milling facilities that were active until 1990 were transferred to the new Wismut rehabilitation company. Administered and financed by the Federal Ministry of Economics (BMW_i), this government-owned but privately organized and privately managed company is responsible for the decommissioning and remediation of its facilities and sites.

After evaluating the complexity and magnitude of the necessary restoration measures, it was decided to take a site-specific, risk-based approach. Because this agricultural and industrial area is

densely populated, all remediation activities had to be carefully planned. The ongoing restoration activities are illustrated by the following examples [19]:

- ▶ Open pit mining has produced about 600 million m³ of ore and waste rock, of which about 160 million m³ was taken from a single open pit (Lichtenberg) nearly 200 m deep with a surface area of about 1.6 km². After mining activities ceased, the open pit was used for disposal of waste rock from adjacent mines. About 80 million m³ had been backfilled before 1990. About 100 million m³ of waste material remains nearby, most of which will be backfilled in the open pit.
- ▶ Underground mining has yielded about 300 million m³ of material, half of which was ore. In one district about 40 piles with a total volume of over 45 million m³ cover an area of about 3 km². A major program of stabilization, reshaping, covering and revegetation of these piles is being carried out.
- ▶ Mill tailings: The operation of two major conventional mills has resulted in about 150 million m³ of tailings.

Status of Work

Detailed engineering studies in 1990 and 1992 yielded conceptual models for remediation measures. The most important measures include the following:

- ▶ Underground remediation:
 - cleaning and flooding of the mines,
 - backfilling of mine workings,
 - hydrological control,
 - groundwater protection and monitoring.
- ▶ Surface restoration:
 - demolition of buildings,
 - site rehabilitation for other uses
 - repair of surface damage caused by mine subsidence,
 - cleaning of contaminated soil,
 - groundwater protection and monitoring.
- ▶ Mill tailings remediation:
 - in situ stabilization and covering of tailings,
 - cover design,
 - improvement of dam stability,
 - groundwater protection and monitoring

At present, many of these activities are ongoing. DM 700 to 800 million are spent annually and it is estimated that about DM 13 billion will be required over a period of 10 to 15 years.

3.5. France

Uranium mining started in the mid-1950s and, both historically and currently, France has been amongst the leading ten producing countries. The activities of the major operating company and its subsidiaries have resulted in some 200 mining sites, both open pit and underground, 11 sites for milling or heap leaching operations, and 22 storage sites for tailings or heap leaching residues. Processing and impoundment sites contain a total of about 50 million tonnes of tailings and heap

leaching residues. A substantial program [20] is underway by the company, based on the principles of cost-effectiveness, compliance with all regulatory requirements, responsibility for liabilities, preventative action preferred to corrective action, and public information and consultation. Within this framework, the objectives are described as:

- long-term public security and health,
- long-term stability to ensure the confinement of the radioactive materials,
- prevention against human intrusion,
- reduction of residual impacts in accord with the ALARA principle,
- choice of natural barriers,
- reduction of the total land required and the need for ongoing institutional control,
- integration of the site into the surrounding landscape,
- technically and economically workable.

At present, production is completed at seven sites, with decommissioning completed at three sites and in progress at four others. Decommissioning is also planned, or in progress by stages, at two other sites still in production.

3.6. Other Countries

The four countries where programs have been described generated about half of the cumulative worldwide inventory of uranium tailings. Brief summaries for representative projects from several other countries are given in the following paragraphs:

Australia

Environmental restoration at an earlier abandoned mine has been carried out at the Rum Jungle site, while the Mary Kathleen mine site was decommissioned at the end of production. Operations at the Rum Jungle uranium/copper mine ceased in 1971, leaving three waste rock piles, three open pits, a tailings disposal area and a heap leach pile with, in total, about 11 million tonnes of waste materials located over about 80 hectares. The major environmental impact was heavy metal contamination due to acid mine drainage from the waste rock piles and heap leach pile. A major environmental restoration project was carried out between 1983 and 1986 [12]. Waste rock piles were contoured, covered and vegetated. Compacted clay covers, comprised of a low permeability sealing zone, a moisture retention zone, and an erosion protection zone, were used. Tailings and the heap leach pile were relocated to an open pit where other tailings had been placed during operation, and covered. An environmental monitoring program has demonstrated the effectiveness of the project, and a reduced program of long-term monitoring, land use control and maintenance has been implemented.

China

Both the general program in China [21], and details of a recent decommissioning project are described in recent publications. The uranium mine and mill located in the Jiangxi province of southwest China, operated from 1962 to 1990. The decommissioning project involved five open pit mines, the mill tailings (2.7 million tonnes) impoundment, and waste rock piles (2.9 million tonnes). Four of the open pits were covered with topsoil and revegetated, while the fifth was allowed to flood. After decontamination to regulatory requirements, some mill equipment will be reused with contaminated equipment dealt with in situ or placed in the tailings impoundment. The tailings impoundment and waste rock piles will be covered in situ, with layers of soil, rocks, cobbles and other materials to control radon emanation and water infiltration. Surface and groundwater controls, and an environmental monitoring program, are incorporated into the design.

Czech Republic

Uranium ores have been mined since 1840, first for making paints, and then for radium and polonium during the early decades of this century. With the advent of nuclear power, uranium exploration and production grew rapidly between 1945 and 1960, with total production through 1989 of 96,000 tonnes (85,000 tonnes from underground mining, 11,000 tonnes from in situ leaching). Uranium production has declined substantially since 1989 and the government of the Czech Republic has decided to close all but one mine.

The uranium mines in Straz pod Ralstam and Hamr were chosen as the first area for the remediation program because in situ leaching and underground mining are operating together in one hydrogeologic unit. Both mining activities are influencing the groundwater regime, with extensive contamination from the in situ leach site covering an area of 28 km². The first steps in the remediation program are in operation and involve use of an underground hydraulic barrier and treatment of a large (50 m³/min.) groundwater flow [22]. An extensive survey program to locate old mine sites and waste deposits in other parts of the country is also underway.

Spain

An inactive uranium mill tailings site (about one million cubic metres in volume) has been decommissioned in place between 1991 and 1994 [23]. Mill equipment, buildings and process facilities have been dismantled, and the resulting wastes placed in the tailing pile. The tailings mass has been reshaped by flattening the side slopes to improve stability and a thick multilayer cover placed over the pile and the sideslopes. Individual layers are incorporated to promote revegetation and drainage, to act as barriers against radon emanation and water infiltration, and to prevent bio-intrusion and erosion.

Sweden

An inactive uranium mine/mill tailings site (about one million cubic metres in volume) has been decommissioned [24]. All mine tunnels and ventilation shafts are permanently closed and the mill facility decommissioned. A multilayer barrier cover system was implemented for reducing the weathering of the pyrite in the tailings and minimizing the leaching of uranium, radium and heavy metals. Performance control of the cover system and especially the leak-tight barrier was carried out by groundwater monitoring. The open pit mine was transformed into a lake for recreation and wildlife. A second stage will be carried out in 5 to 10 years when all of the restoration measures have taken full effect, so that purification of leachates can be stopped, and the surface water left to follow natural courses.

IAEA Technical Cooperation Projects

IAEA technical cooperation projects on environmental restoration in Central and Eastern Europe (CEE) are contributing to decommissioning plans for uranium mining and milling sites [25]. The first project, carried out through three separate workshops was directed at a range of environmental restoration projects. During its implementation, it became apparent that a number of countries in the region shared the problems arising from previous uranium mining and milling practices. A follow-up project concentrating on developing plans for restoration at uranium mining and milling sites has been initiated.

4. CURRENT TECHNOLOGY USED FOR DECOMMISSIONING

It has been predicted that about 500 GW(e) of nuclear generating capacity will be in service in the world some time after the year 2000 and that the total quantity of uranium needed by then would be about 2 million tonnes. If this uranium were produced by conventional mills from 0.1% uranium ore, some 2,000 million tonnes of uranium mill tailings would be left behind for disposal,

plus large quantities of material that is below ore grade and other mining wastes. The tailings inventory would be accumulating at the rate of some 75 million tonnes per year at mine/mill sites throughout the world [12].

During the 1980s, great efforts were made worldwide to develop the understanding and technology needed to ensure the long-term safety of decommissioned uranium mine sites.

Canadian experience is used as one example of the changes in understanding for management of uranium tailings and mine waste rock [26]. The National Uranium Tailings Program (NUTP) operated from 1983 to 1988. It focussed on developing geochemical models to predict long-term water quality from various decommissioned tailings management areas. Acidic drainage is not only a problem for the uranium industry, but is also a major environmental concern for the metal mining industry generally. Simple soil and enhanced vegetative covers were investigated under the NUTP, and shown to have minimal impact on the geochemical activity of stacked tailings.

In 1988, the Canadian mining industry, provincial governments and the federal government organized the Mine Environment Neutral Drainage (MEND) program. Some examples of the technology being developed in over 100 MEND projects that are applicable to uranium mine wastes are:

- ▶ refined chemical prediction procedures to determine if waste rock or tailings will acidify.
- ▶ improved geochemical models including field evolution of models to predict the performance of dry soil covers on stacked tailings and rock piles.
- ▶ the use of underwater disposal to prevent acid generation from unoxidized sulphide containing wastes, and to control it in already oxidized tailings and rock. Results to date on uranium tailings in the Elliot Lake area show that oxidation is effectively stopped.
- ▶ multi-zone earth covers are being investigated, since many uranium and base metal mine waste sites are not physically suitable for water covers.
- ▶ other cover materials and waste disposal technologies are being assessed, since multi-zone earth covers are costly in many areas of Canada.

Improvements in technology are reflected both at the newer uranium mines in the Athabasca Basin region of Saskatchewan, where higher grade deposits are being mined, and at the older mines in the Elliot Lake area of Ontario.

There are many other examples. In the United States, the UMTRA program [16] has led to the development of thick multi-layer covers designed to control radon emanation and water infiltration, and to provide long-term stability and resistance to erosion. These types of cover are used both in the semi-arid climate area of the United States, and at sites in other countries. Other programs, for example in Australia [12] and Germany [19], have focussed on developing the understanding, and resulting technical approaches, for their sites.

Site selection, design and engineering of the tailings impoundment must be considered in connection with the overall mining and milling operation and the characteristics of the tailings residues [27]. Tailings impoundments generally consist of a combination of both natural and man-made features. A range of impoundment methods are now used. These include valley dam impoundments, ring dyke impoundments, mine pit impoundments, specially dug pit impoundments, and underground mine emplacement of tailings. Dams, embankments and dykes are now constructed of low permeability materials or incorporate a low permeability core or liner. Grouting is also used at some sites to control seepage.

Worked-out mine pits are another form of impoundment for tailings and waste rock. The procedures for backfilling the pit with tailings varies considerably, depending on the climate, the depth to and variability of groundwater, the proximity to streams, the susceptibility of the pit to flooding, the permeability of the wall rocks, the mining program adopted, and the characteristics of the tailings, including whether wet or dry tailings management is considered.

In arid regions, such as in the western parts of the United States, where evaporation considerably exceeds precipitation and the depth to groundwater is great, backfilling takes place above the water table. This is not the case in many other areas, for example, in the high rainfall area of Northern Australia, in France and in Canada, where impoundments are designed for tailings emplacement below the water table.

A range of natural or man-made liners are used for seepage control. The preferred method in Canada is to use a hydraulic liner, where a "pervious surround" granular filter is placed against the pit wall. The naturally occurring, high groundwater table provides a hydraulic barrier to seepage by preventing a hydraulic gradient across the deposited tailings. An alternative commonly used with underground mining operations is to separate the coarser sand fraction for backfill within the mine. Use of deep lakes for the disposal of uranium tailings has been considered for mining operations in Canada, although there are no uranium mining operations currently using this method.

A range of tailings management methods are also in use [27]. Saturated management refers to placement methods where the tailings are transported, distributed and maintained during operation in a saturated state. The tailings slurry, commonly thickened to about 40% solids by weight is discharged beneath the water surface in horizontal layers, resulting in an even distribution of the coarse and fine fractions. Wet management methods use tailings of similar solids content, with discharge at the periphery of the impoundment area. A beach forms, with coarse solids settling close to the discharge point, and the fines and water forming a pond. The fines then settle and the partially clarified surface water evaporates or is decanted and recycled to the mill. Semi-dry management uses a controlled ring discharge to allow beaches to be developed from the periphery inwards. In dry management systems, dry tailings are produced either by evaporative drying in layers and retransport to the eventual tailings impoundment, or by mechanical drying in the mill plant.

Cover materials are generally natural materials such as clay, native soils or rip-rap, since synthetic materials do not provide the necessary long-term durability. Wet covers are also now used where the site and climate characteristics are suitable.

5. CONCLUSIONS

With the accumulated international experience, it is clear that adequate technology and experience exist around the world for appropriate selection of processes, sites, impoundment designs, and stabilization methods under a wide variety of climate and other conditions. There is usually a need to assess several different options for long- and short-term tailings management and various methodologies, including mathematical modelling, are available for this purpose. Methods of monitoring the performance of the disposal systems and assessing their long-term reliability are available. Uranium tailings are being managed safely both for the present and for future generations.

Several broad conclusions can be reached about the decommissioning of uranium mining and milling sites.

There is a recognition that remedial action plans are required to mitigate past practices.

Not until the 1970s did many industrialized societies understand the importance of protecting the environment. Most industries did not put a lot of emphasis on properly managing their waste. This included the mining industry. Tailings were usually deposited in natural basins without much thought

to, or understanding of, the short- and long-term impacts on the environment. Some of these basin sites, by happenstance, were revegetated naturally and provided some containment, although not necessarily sufficient for compliance with present day environmental standards. Other historic sites require more effort to ensure that no undue risks will be imposed on the public or the environment over the long-term. In the case of uranium mine tailings sites, the degree of intervention will be highly dependent on the marginal reduction of radiation dose for a selected number of decommissioning options.

In addition, due largely to a lack of understanding, and consequently a lack of regulatory controls, tailings or contaminated material from mining and milling infrastructures were used for construction purposes, from paving roads to building houses. Present day radiological surveys continue to discover materials taken from the historic uranium mine sites that have ended up in construction material. In most cases, where no private party can be held responsible for the necessary cleanup funds, governments have assumed the financial responsibility. In order to prevent this situation from ever occurring again, strict regulatory control for releasing radioactive materials off-site have been, or are being, developed by national authorities.

Modern management of uranium tailings is based on health, safety, and environmental protection.

Since the beginning of uranium mining, a greater understanding of the associated environmental impacts has been developed and a greater importance has been attached by society to the protection of the environment. Today, much has been accomplished in this regard and the uranium mining industry in most countries is now a leader in environmental protection. Industries and governments recognize the importance of environmental protection within the context of sustainable development. Recently this concept was endorsed by the many countries supporting the Rio Declaration and Agenda 21 at the United National Conference of Environment and Development (UNCED) in 1992 in Brazil. Mining associations also participated in the development of country positions and endorsed the concept of sustainable development.

Research activities continue to advance the adequacy of mitigation measures.

With respect to advancing the understanding of the impact of uranium mining and environmental impact mitigation measures, uranium producing countries have conducted significant research to establish the technical basis for ensuring the protection of human health and the environment.

Uranium tailings must be properly regulated by governments.

National authorities control radiological and other potential impacts by setting limits on new and existing operations to ensure that workers, members of the public, and the environment are not subjected to undue risks. With regard to the historic or so-called "abandoned sites", intervention measures based on cost benefits analyses should be required rather than necessarily setting the same limits as for existing and operating mines.

Although the goal remains a permanent solution, where the site is released for unrestricted use, there is recognition that most uranium tailings sites will require long-term care after decommissioning. For many sites, engineered dams or other structures will need long-term monitoring, acid seepage may have to be treated on a continuous basis for many years, or soil covers will have to be checked for erosion. Some sites will need to be properly fenced and their locations clearly registered, to prevent intrusion into the tailings or containment systems. Monitoring programs will need to be put in place and institutional controls established. The uranium producer will be allowed to leave the site only when decommissioning activities are completed and after they have ensured the necessary funding of activities required over the long-term. Governments will be responsible for managing these long-term programs.

Uranium producers must fund decommissioning activities.

Due to the large volumes of uranium tailings at a site, decommissioning activities can be costly. In most countries, the principle that the producer is responsible is well established. Nevertheless, the concept of providing financial assurances for decommissioning activities has only recently been developed.

The concept of providing financial assurances, to ensure that the waste producer has sufficient funds for the decommissioning of its site, is a relatively new concept not only for the uranium mining industry or the mining industry in general, but is also an emerging concept for many types of industries. Today, regulators see the need for requiring financial assurances after witnessing cases where sites required major remedial programs funded by governments, after the waste producers either went bankrupt, abandoned the site or refused to finance cleanup activities. The uranium industry is in the forefront of developing appropriate mechanisms related to financial assurances. These financial assurances are required at the beginning of new operations to provide funds for the eventual decommissioning and long-term activities.

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SAFETY REQUIREMENTS AND RECOMMENDATIONS FOR RADIOACTIVE WASTE MANAGEMENT

A.G. DUNCAN
HM Inspectorate of Pollution,
London, United Kingdom

Y. KAWAKAMI
Japan Atomic Energy Research Institute,
Tokyo, Japan

Y. ANDO
Power Reactor and Nuclear Fuel Development Corporation,
Tokyo, Japan

Abstract

The requirements and recommendations for safe management of radioactive waste according to the IAEA RADWASS Safety Fundamentals are described in outline. The description presumes compliance with the basic requirement that generation of waste will have been kept to the minimum practicable and emphasises the requirement for conducting waste management in the context of a comprehensive system. The requirements for human health and safety address all forms of hazard, and not only those associated with ionising radiation. They are addressed in a general context since they apply to all aspects of waste management. Other requirements are addressed in the specific contexts of pre-disposal management, near-surface and geological disposal and decommissioning of nuclear facilities. The requirements and recommendations described are not new. They reflect many years of experience and it is emphasised that they should be applied in a flexible way, being adapted in the light of changing knowledge and circumstances.

1. INTRODUCTION

This paper describes the requirements and recommendations for safe management of radioactive waste according to the principles set out in the IAEA RADWASS Safety Fundamentals [1]. These requirements and recommendations are being developed in further documentation in the RADWASS series and the aim here is not to present them in detail but rather, at a broad level, to show how they are linked to the Safety Fundamentals.

For this purpose radioactive waste is defined as "material that contains or is contaminated with radionuclides at concentrations or activities greater than clearance levels as established by the regulatory body and for which no use is foreseen". In principle, radioactive waste is like any other hazardous waste in requiring safe management according to the nature of its associated hazards. The fact of its containing or being contaminated with radionuclides, however, makes it unique in regard to the widespread societal concerns about radioactivity and its associations. Beyond providing unbiased information about radioactivity and its hazards as well as its uses, it is no part of our purpose to be judgemental about these concerns. Rather, we must recognise them as part of the background against which safe radioactive waste management has to be conducted and we must develop our systems accordingly.

Safety requirements and recommendations are discussed here first in a general context in regard to protection of human health and safety. They are then discussed in the specific contexts of low and intermediate level solid waste and high level solid waste in regard to the requirements for predisposal management, for disposal and for waste management associated with decommissioning of nuclear facilities. This discussion presumes that, before any consideration of the management of radioactive waste, its generation will have been kept to the minimum practicable. This is an essential element of the Safety Fundamentals and underlies all that follows.

2. THE NEED FOR A WASTE MANAGEMENT SYSTEM

The objective of radioactive waste management is to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations.

In order to achieve this, radioactive waste management ought to be carried out in the context of a comprehensive system. This has been said repeatedly but is sometimes ignored in practice with the consequence that some waste management actions are incompletely developed or are not optimised, in the general sense. It does not necessarily imply the need for a single, centralised system. Rather, the system requires a structured aggregate of elements such as a body of laws and standards, operators with procedures, plans, facilities, funding and R&D support, regulatory organisations, etc. Such systems may differ markedly from country to country but they must be coherent and recognise the interdependencies between their essential elements regardless of whether they are designed to deal with wastes arising from a large nuclear power programme or, in the case of countries without such a programme, with radioactive waste arising only from medical, research or non-nuclear industrial activities. At its simplest this means carrying out sufficient system analysis to ensure, so far as possible, that actions taken to deal with waste in one step of waste management do not prejudice unnecessarily the ability to take appropriate actions at a later step. It also means that the planning of activities involving radioactive substances should have regard to the requirements for safe waste management. This applies as much to research with a test reactor or to medical treatment as it does to the generation of electricity for example.

Also, and particularly because of the widespread perception of the hazards associated with radioactivity, it is essential to view the waste management system in both space and time. As with many industrial activities, the wastes arising from activities which involve radioactivity may have an impact beyond the borders of the country of origin. This has to be managed in a responsible and fair way and in a way that is accepted as being so by the international community. Equally, the wastes may have impacts, direct or indirect, over lengthy periods of time and it is a matter of basic ethics to ensure that the consequences of present day activities, from which the benefits have been essentially contemporary, do not fall unnecessarily on future generations nor in any way that would be unacceptable to contemporary society.

Careful consideration of the objective of radioactive waste management in this systematic way gives rise to the principles set out in the RADWASS Safety Fundamentals [1] and to the requirement for establishing a National System for Radioactive Waste Management [2] both of which are discussed in detail elsewhere [3].

3. PROTECTION OF HUMAN HEALTH AND SAFETY

Two of the RADWASS principles refer to Protection of Human Health and to Safety of Facilities. Both recognise that management of radioactive waste must have regard to all relevant hazards. As well as those associated with ionising radiation, hazards may arise from the presence of toxic, corrosive, inflammable or biologically active materials. They may also be associated with operation of process plant and the excavation or mining of disposal facilities.

A basic requirement is therefore the establishment of a safety culture in which organisations and individuals engaged in radioactive waste management are dedicated to safety and accountability in respect of all aspects of the task. Notwithstanding the responsibility of each individual involved, the primary responsibility lies with senior management for developing policies, plans, facilities and procedures, for ensuring adequate training of personnel and for reviewing performance across all safety-related activities. This leads to the requirement for formal quality assurance arrangements as a common feature of the RADWASS safety requirements for all steps in waste management and for these arrangements to include effective provision for emergency preparedness.

In regard to the specific hazards associated with exposure to ionizing radiation, national radiation protection arrangements are required. These must cover protection of the workforce involved in waste management activities and protection of members of the public exposed to the consequences of these activities, such as release of radionuclides into the environment or direct radiation from transport of waste for example. They must also consider the timescales over which the consequences may be experienced. In practice, many countries take account directly or indirectly of the recommendations of IAEA [4] and ICRP [5] and specifically of those recommendations relating to the concepts of,

- Justification
- Optimisation
- Dose limitation.

In this specific context, the principles refer to the need for a National Legal Framework which ensures that radioactive waste is managed according to appropriate standards and with clear allocation of responsibilities and provision of independent regulatory functions. This is an essential element of a National System and it is described fully in the related RADWASS Safety Standard [2].

Another RADWASS principle requires Protection of Future Generations. Attention is currently being focused on the measure by which this should be judged and on the way in which it might be applied. There is general agreement, reflected in the recent publications of IAEA [4] and ICRP [5], that "risk", or "potential exposure", is an appropriate measure for those consequences of contemporary activities which would only be experienced in the future and only then with a probability of occurrence significantly less than one. (Where the probability of occurrence is close to unity, dose would continue to be an appropriate measure.) There is less general agreement, however, on how it might be applied for the purposes of regulation for example. For the time being it is widely accepted that a risk of less than 1 in 10^6 per year to individual members of the public, predicted by probabilistic assessment methods, is an appropriate target for the design of disposal facilities. It is also widely accepted that the nature of the predictive method may vary with timescale and that predictions for the far future may be based on more qualitative considerations.

The important point in this context is to recognise the nature of the risk associated with long-term evolution of a waste disposal facility and to distinguish it from the kind of risk associated with a nuclear reactor accident for example. Although of the same single numerical value, the two risks may be comprised of different combinations of the probability of occurrence of a radioactive release and the consequences of that release. In normal, expected evolution, the probability of eventual release from a waste repository may be relatively high, with the consequences being very small, whereas the reactor accident may have a very low probability but be associated with high consequences. It is not obvious that society views these two types of risks similarly even if they are identical numerically; hence the importance of clear distinction and explanation.

In the context of protecting members of the public, both now and in the future, it is also a basic principle that Protection Beyond National Borders be provided. In fulfilling this duty, a country should take account of the recommendations of international bodies such as IAEA and ICRP directly, or indirectly as in the situation where regional arrangements apply. A country responsible for releases to the environment could also choose to develop more detailed arrangements for implementing this principle directly with neighbours or affected countries.

These requirements for human health and safety are common to all forms of radioactive waste and to each step of the waste management system. What follows, therefore, are those other safety requirements specific to each step.

4. PREDISPOSAL MANAGEMENT OF RADIOACTIVE WASTE

In the RADWASS programme "predisposal" waste management is defined as being those steps carried out prior to radioactive waste disposal, such as pretreatment, treatment, conditioning, storage and transportation; and "pre-treatment" may include collection, segregation, chemical adjustment and decontamination. Some of these steps apply as much to liquid and gaseous effluent, prior to their authorised direct discharge to the environment, as they do to other wastes. This section, however, focuses on those low, intermediate and high level wastes which are intended for disposal in solid form in near-surface or geological disposal facilities. Against this background, the purpose of predisposal management is to convert waste into a form suitable for safe transport and disposal in those cases where there is an established disposal route and, where there is not, to convert the waste, if necessary and without unreasonably foreclosing options for its disposal, into a form which may be safely stored until such time as a disposal route and its requirements are established.

Predisposal management of radioactive waste must address two main safety-related considerations. One is the set of requirements for safe transport and disposal and the other is the set of requirements for occupational safety of those involved in its management. Where a disposal route exists, as may be the case for low-level waste, the requirements are usually clear and the issues relatively straight-forward. Where no disposal route exists, as is currently the norm for intermediate level and high level wastes, these two considerations must be carefully balanced as between the need to limit the risks of dispersion of waste and hazard to workers on one hand and the need to avoid taking steps that will prejudice eventual safe disposal of waste on the other.

The requirements for predisposal management are described in a RADWASS Safety Standard [6] in which the importance of planning is emphasised. The first requirement is to identify the destination of the waste, taking full account of possibilities such as recycling and re-use, storage for radioactive decay or even release from regulatory control, if appropriate, for some of it. It is then necessary to develop a plan which identifies the action necessary for dealing with the waste in a way which satisfies the requirements for its safe treatment and handling, for the safe operation of associated plant and equipment and for its eventual transport and disposal. If no disposal route exists, the plan will focus on requirements for safe retrievable storage until such time as the requirements of a disposal route have been established. In both cases it is essential to recognise another RADWASS principle, namely the need to consider interdependency of different steps of the waste management system and, where there are uncertainties about eventual requirements, to maintain viable alternatives until the uncertainties are removed.

This plan will be the basis of any submission to the relevant regulatory bodies and in this context will have to justify selection of the proposed course of action. It will address all relevant technical issues, ranging from a description of the waste and a forecast of the rate of generation, through options for disposal or interim storage with details of related requirements for pretreatment, treatment, conditioning etc, to details of availability of appropriately qualified and trained staff, arrangements for protection of workers, document traceability and quality assurance. The degree of detail of such plans may vary depending on the complexity of the issues involved; small radioisotope users, for example, will need only a simple plan, but all plans will need to identify relevant organisational structures, the institutions involved and the contractual arrangements needed to ensure continuity of responsibility and delivery of the objective of the plan.

The requirement for detailed planning of pre-disposal waste management is generic to all forms of radioactive waste and relevant experience of its implementation has been described elsewhere in respect of low and intermediate level wastes [7] and of high level wastes [8]. In general, experience seems to indicate that, where disposal routes exist and waste acceptance criteria are available, predisposal management planning and implementation are relatively straight-forward. Where disposal routes do not exist but where the requirements for safe storage are paramount, as in the case of highly active liquor from reprocessing of spent nuclear fuel which must be solidified to prevent its dispersion, the situation is also straight-forward. It is more difficult, however, in those cases where

there is no disposal route and the shorter-term requirements of interim storage and longer term requirements for avoiding prejudice of the options for eventual disposal are more finely balanced.

It is essential that this important aspect of waste management is carefully considered by all relevant parties and is not overlooked.

5. NEAR SURFACE AND GEOLOGICAL DISPOSAL OF RADIOACTIVE WASTE

Disposal is defined as the emplacement of waste in an approved, specified facility without the intention of retrieval, (although some countries may prefer to keep open the option of retrieval for a period of time). Near-surface disposal refers to a facility on or below the ground surface, where the final covering is of the order of a few metres thick, or in a cavern a few tens of metres below the ground surface. Typically, short-lived low and intermediate level wastes may be disposed of in this way. Geological disposal refers to isolation of radioactive waste, using a system of engineered and natural barriers at depths of up to several hundred metres in a geologically stable formation. This is currently the favoured route in plans for disposal of long-lived and high level wastes.

Although the RADWASS requirements for near-surface and geological disposal are described in two separate Safety Standards [9,10] the logic giving rise to the basic requirements is essentially the same in both cases. The lifetime of a disposal facility is seen as comprising three phases; pre-operational, operational and post-closure. The pre-operational phase includes siting, design and construction. The operational phase includes waste handling and emplacement operations, perhaps an element of construction such as mining of galleries, and closure. The post-closure phase may include institutional and post-institutional control periods. These three phases may overlap in part, as mentioned in regard to construction.

The basic requirements for protection of human health and safety have been discussed above and they apply to all three phases of a disposal facility. The requirements for a safety culture and quality assurance apply throughout. The requirements relating to protection from ionising radiation are clearly relevant to the operational and post-closure phases and the references to other, conventional hazards are most relevant to the pre-operational and operational phases. All of these requirements, together with those concerned with protection of the environment, need to be addressed in a comprehensive assessment of the safety and environmental impact of a proposed disposal facility, having regard to the nature of the hazards, their timescales in the evolution of the disposal facility and to the probability of events which may cause them to be realised. The safety assessment, if judged by the regulatory authorities to be satisfactory, will be the basis of conditions and limitations to be included in the necessary licences, authorisations or permits for development, operation and closure of the facility. It will thus become the means by which the disposal site is approved, the design of the facility and arrangements for operation, waste retrieval (if appropriate) and closure accepted and waste acceptance criteria defined.

Defence in depth is considered to be best provided by facilities which have multiple barriers against release and transport of radionuclides. There can be no unique set of requirements or recommendations for such facilities as the overall safety depends on the combined characteristics of all the elements of the disposal system. Nevertheless it is clearly important that, in regard to the site, a safety assessment must address its geology, hydrogeology, geochemistry, tectonics and seismicity, surface processes, meteorology, the impact of human activities and protection of the environment. In regard to the disposal facility it will be necessary to consider structural and engineered features, linings, grouts, backfills and closure arrangements as well as details of its construction and operation. With regard to the waste itself, attention will need to be given to the radionuclide content and surface contamination, chemical and biological properties, physical and mechanical properties, thermal resistance (where appropriate) and arrangements for identification and checking of waste packages.

In addition to the factors associated with human health and safety, and having regard to the RADWASS principles, it is also necessary to pay attention to basic requirements for protection of the

environment in all of its aspects and to avoid imposing burdens on future generations by way of sterilising natural resources, for example, or leaving unreasonable requirements for long-term institutional control. Although the post-closure safety of a disposal facility should not depend on them, institutional controls may enhance safety, particularly in the case of a near-surface facility. Such controls may be active (for example, monitoring or inspection) or passive (for example, use of permanent markers) or some combination of the two. The basic requirement in regard to such controls is for a clear understanding of their roles, if any, in the safety case for disposal, for regulatory agreement to the duration of such controls and for clear specification of the measures required and of the institutions responsible for them. It would clearly be incompatible with the RADWASS principle above if these controls were to be a burden on future generations but there is a reasonable requirement for contemporary society to leave relevant information which will allow future generations to decide for themselves how or whether to exercise such controls.

6. MANAGEMENT OF RADIOACTIVE WASTE FROM DECOMMISSIONING OF NUCLEAR FACILITIES

The RADWASS programme addresses the issue of decommissioning waste management in a Safety Standard entitled "Decommissioning of Nuclear Facilities [11]. In the programme, decommissioning is defined as actions taken at the end of the useful life of a nuclear facility in retiring it from service with adequate regard for the health and safety of workers and members of the public and for protection of the environment. The ultimate goal is described as being unrestricted release or use of the site. This means in effect that, apart from material or equipment which can be reused or recycled, the whole facility eventually becomes waste of one kind or another and requires disposal. Only some of the waste is radioactive and, in the context of radioactive waste management associated specifically with decommissioning, the key issue is that of keeping generation of radioactive waste to the minimum practicable. The timescales and phasing of decommissioning operations may have an effect, by way of radioactive decay, on the levels of activity in waste for disposal but these are matters more relevant to issues of occupational health and safety, costs and land use and are not discussed further here.

In principle, the radioactive waste arising from decommissioning operations may be managed in the same way as that arising from other operations involving radioactivity and is subject to the same general requirements for protection of human health and safety and the more specific requirements for predisposal management and disposal as described earlier. In practice, however, decommissioning of nuclear facilities often involves activities such as large-scale decontamination, cutting and handling of large items and the progressive removal or dismantling of safety systems. This has the potential for creating special hazards at all stages of waste management and their health and safety aspects must be fully recognised and properly managed.

As regards the key issue of minimising the creation of radioactive waste from decommissioning of nuclear plant, the essential requirement is for planning. This should start at the design stage and should draw on already available experience of decommissioning various types of nuclear facilities. This experience points to design features, procedures, methods and technologies that may facilitate decommissioning and reduce waste. These include selection of materials that minimise the creation of activation products, materials that are easily decontaminated and construction techniques that ease dismantling, segregation, etc.

Also at an early stage, it is necessary to prepare an initial decommissioning plan and, in the context of this discussion, consideration must be given to the waste arising from decommissioning, its destination and all elements of the system required for its safe management through to eventual disposal. This plan must be reviewed at appropriate intervals during operation of the facility and maintained together with technical documentation about the structures, systems, components and material of the facility, including details of modifications, contamination incidents or procedures that may have an impact on decommissioning and associated waste management. At final shut-down of the facility a detailed decommissioning plan will be necessary for approval by the regulatory bodies.

This should address all of the requirements described earlier in regard to human health and safety and predisposal management and disposal and in this specific context it might be expected to focus on arrangements for minimising generation of secondary wastes and for careful segregation of waste with a view to possible release from regulatory control of large volumes containing extremely low levels of activity in accordance with established clearance criteria.

The final requirement will be for the operating organisation to provide regulatory bodies with such information as may be required to release it from further responsibility for the facility or the site. As regards radioactive waste management matters this information will include

- a description of the completed decommissioning activities.
- a description of any remaining systems or structures, including foundations.
- a final radiological survey including details of any residual activity, supported by an independent verification and certification.
- project objectives, including the radiological release criteria for equipment, materials and the site.
- occupational and public doses received during decommissioning.
- the characterization, including quantities, and destination of radioactive waste generated and what and how radioactive materials were reused or recycled.
- a characterization, including quantities, of other materials released for reuse, recycling or for disposal as non-radioactive waste.

7. CONCLUSION

Little of what is described here is new. Rather, it is a condensation of the experience of Member States over many years and the RADWASS documentation is designed to capture and reflect this. The essential point is that safe waste management is an integral part of planning and execution of nuclear applications. This includes decommissioning of facilities and requires detailed attention to minimise the creation of radioactive waste at all stages.

Other important points to note are:

- Attention must be given to **all** aspects of safety.
- An overall system approach should be used for waste management planning, and the interdependencies between different stages recognised.
- The requirements for site selection, waste acceptance, etc are tied directly to the safety case for disposal.

Application of the RADWASS requirements and recommendations will help provide a framework of certainty within which to build waste management systems but it is still essential to maintain a flexible approach and, using the mining analogy, to probe ahead and be prepared to adapt in light of changing knowledge and circumstances.

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THE WASTE ISOLATION PILOT PLANT: A DOMESTIC SUCCESS WITH GLOBAL IMPLICATIONS

G.E. DIALS
United States Department of Energy

L.G. ERIKSSON
Advanced Sciences, Inc.

Carlsbad, New Mexico, United States of America

Abstract

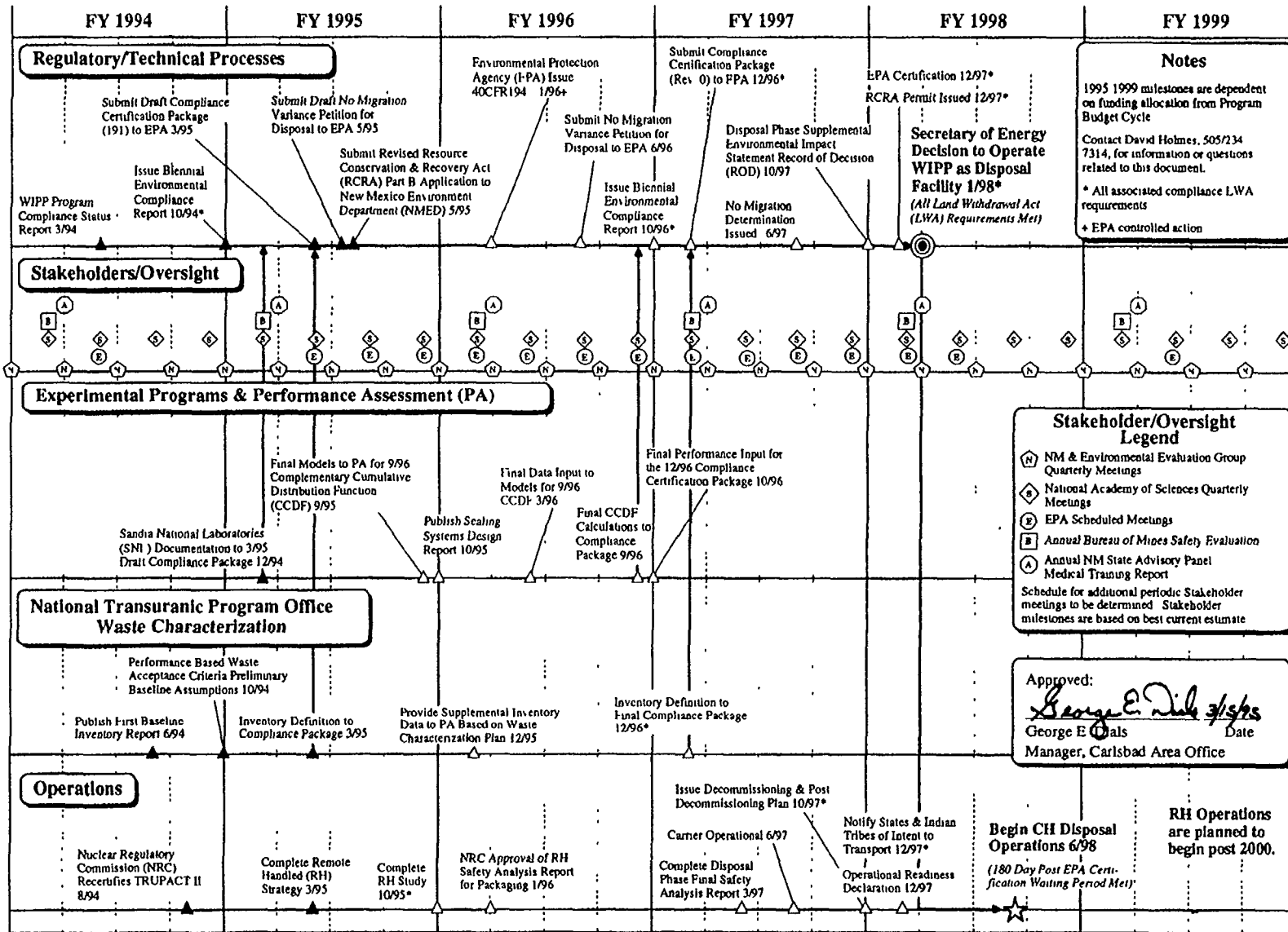
The missing global link in the nuclear fuel cycle and safe radioactive waste management is the opening of the world's first facility/system for safe disposal of long-lived and high-energy emitting radioactive wastes such as transuranic radioactive waste (TRUW) and spent nuclear fuel and other high-level radioactive wastes (HLW). Pursuant to currently applicable laws in the United States of America (USA), both TRUW and HLW will be disposed of in deep geologic repositories but at different locations. This paper provides a brief historical overview, and a status report on the development and opening of a TRUW repository at the Waste Isolation Pilot Plant (WIPP) site located in the southeastern portion of the State of New Mexico. The WIPP project began in 1974 and it has a long-standing record of excellent science and safety. In October 1993, the United States Department of Energy established the Carlsbad Area Office (CAO) with a mission to review and integrate the safe management of all TRUW in the USA. By April 1994, the CAO had conducted the review and implemented a new mission which included an accelerated schedule for the opening of the WIPP in 1998 rather than in 2001. Subsequently, the CAO has set precedents at the WIPP with early regulator and stakeholder involvements in the regulatory process, and with the development of a detailed, well-structured, and defensible decision-making basis for the most cost-effective path to the timely opening of the WIPP in 1998. At the end of August 1995, the WIPP is well into the certification/permitting process and on schedule to open in 1998. The timely opening of the WIPP repository would reduce risks and increase the protection of human health and the environment by removing existing TRUW from surface-based and near-surface-based temporary storage facilities and, possibly, contaminated soil to a repository located at a depth of approximately 650 meters below the land surface. Moreover, the opening of the WIPP repository would be a global first-of-a-kind operational facility, and its continued safe operation in compliance with one of the strictest environmental radiation protection standards in the world should enhance public confidence in the safety of deep geological disposal of TRUW and HLW both in the USA and abroad.

1. INTRODUCTION

The missing global link in the nuclear fuel cycle and safe radioactive waste management is the opening of the world's first facility/system for safe disposal of long-lived and high-energy emitting radioactive waste such as transuranic radioactive waste (TRUW), and spent nuclear fuel and other high-level radioactive wastes (HLW). Pursuant to current laws in the United States of America [1-4] (USA), both TRUW and HLW will be disposed of in deep geologic repositories, but at different locations. This presentation provides a brief historical overview, and a current status report on the development and pending opening of a TRUW repository at the Waste Isolation Pilot Plant (WIPP) site in the state of New Mexico. The United States Department of Energy Carlsbad Area Office is setting precedents at the WIPP in terms of early regulator and stakeholder (citizen/interested parties) interactions and the development of a detailed well-structured, and defensible decision-making basis for the most cost-effective path to the timely opening of the WIPP in June 1998.

2. DESCRIPTION OF THE ACTUAL WORK

The WIPP site was identified in 1974 as a potentially suitable site for a TRUW repository, and an extensive site characterization program was initiated. Based on the result from the site characterization program (including laboratory testing, model developments, and analyses), the construction of an underground test facility at an approximate depth of 650 meters below the surface in the center of the candidate host rock, the Salado Formation, commenced in 1982. The Salado



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FIG. 1. WIPP disposal decision plan.

Formation is a 250-million-year-old, regionally extensive, 600-meter-thick, stable, sedimentary evaporitic sequence of rocks dominated by rock salt (mainly halite). The construction and testing of the underground facility as well as all facilities and equipment required to commence the receipt, handling, transporting, and emplacement of TRUW were essentially completed in 1988. However, despite an excellent safety record and a long-standing strong support from the local community to open the WIPP, the opening is still pending.

One main reason for the repeated delays in the opening of the WIPP is continually evolving and changing legislation and regulations. For example, pursuant to the WIPP Land Withdrawal Act of 1992 [2], the WIPP must comply with the environmental protection standards promulgated by the United States Environmental Protection Agency. Moreover, because TRUW contains both radioactive and non-radioactive ("hazardous") constituents, the WIPP repository must comply with both radioactive and hazardous waste laws, e.g. [1-5] and regulations, e.g. [6-8]. Albeit the United States Department of Energy has worked closely with affected and involved state of New Mexico agencies from the outset, in terms of radiological protection, it was essentially self-regulating at the WIPP site until 1992. Consequently, one major challenge to the timely opening of the WIPP in 1998 is to demonstrate that data, codes, and models developed prior to 1992 meet the 1993 United States Environmental Protection Agency radiation protection regulation [6].

The WIPP Land Withdrawal Act of 1992 also states that the WIPP repository cannot exceed a total TRUW capacity volume of 175,584 cubic meters. The current baseline/reference WIPP repository design consists of eight panels. Each panel is subdivided into seven TRUW emplacement rooms, approximately 10 meters wide, 4 meters high, and 91 meters long each. The final TRUW repository will include both natural and engineered barriers. The natural barrier is the volume of soil and rock surrounding the underground facility within the vertical boundaries of the 41.42 square kilometers land parcel set aside for the WIPP by the WIPP Land Withdrawal Act of 1992. The main candidate engineered barriers are: the waste form; the waste package; backfill of underground openings; and the design of the underground facility.

3. RESULTS

After a thorough evaluation of the WIPP experimental programs, the TRUW inventory (both existing and projected), and the engineered barriers, the Carlsbad Area Office announced a new TRUW management strategy on April 5, 1994. This strategy accelerates the opening of the WIPP repository by three years, i.e., from 2001 to 1998, and the key milestones are shown on Figure 1, the WIPP Disposal Decision Plan. The main objectives of this strategy are to:

- (a) resolve regulatory compliance and technical issues;
- (b) characterize the waste;
- (c) address transportation and safety issues; and
- (d) involve stakeholders in the regulatory compliance process.

At the end of August 1995, the Carlsbad Area Office has met the first three regulatory-interface milestones, i.e.:

- (1) The submittal of the Draft Compliance Certification Application (radioactive waste) to the United States Environmental Protection Agency on March 31, 1995;
- (2) The submittal of the No-Migration Variance Petition (hazardous waste) to the United States Environmental Protection Agency on May 31, 1995; and
- (3) The submittal of the Resource Conservation and Recovery Act of 1976 (RCRA) Part B Permit application (hazardous waste) to the New Mexico Environment Department on May 31, 1995, one month ahead of the Disposal Decision Plan schedule.

Another recent major Carlsbad Area Office achievement is the Systems Prioritization Method (SPM) initiative, which commenced in March 1994. After completing an initial prototype

demonstration in September 1994 (SPM-1), a very complex, computer-based analysis was undertaken and completed by March 31, 1995 (SPM-2) that focused the WIPP experimental programs from 116 activities to eight programs/activity sets. The SPM-2 results provided the Manager of the Carlsbad Area Office a logical and defensible basis for selecting the most timely and cost-effective path to opening the WIPP in 1998. The SPM process was designed to solicit and address regulator and stakeholder concerns early and throughout the process. The Carlsbad Area Office is committed to continuing the open regulator- and stakeholder-dialogue through the entire regulatory compliance process.

4. CONCLUSIONS

The opening of the WIPP repository would reduce human-health risks and increase the protection of humans and the environment by facilitating the removal of existing TRUW from surface-based and near-surface-based storage facilities and contaminated sites, several in proximity of population centers, to a TRUW repository located in a virtually uninhabited desert area at a depth of approximately 650 meters below the surface in the center of a stable and virtually impermeable rock salt formation.

Moreover, the WIPP repository would be a global first-of-a-kind facility for safe disposal of long-lived and high-energy emitting radioactive waste such as TRUW and HLW. Conceivably, its continued safe operation in compliance with several hazardous waste regulations and one of the strictest environmental radiation protection standards in the world should enhance public confidence in the safety of deep geological disposal of TRUW and HLW both in the USA and abroad.

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RADIOACTIVE WASTE MANAGEMENT ISSUES

(Session III)

Chairman

A.G. DUNCAN
United Kingdom

WASTE MANAGEMENT PERSPECTIVES

R. ROMETSCH

Grindelwald, Switzerland

Abstract

Perspectives of realizing repositories for high level radioactive waste depend on three groups of aspects: - optimized timing of disposal given by the decay heat production of the waste as well as by economic considerations, - the solving of important controversial matters as discussed in Seminar Session III, - acceptability and acceptance resulting from a public dialogue which includes anti-nuclear movements. Present experience indicates that emplacement operation of high level waste in repositories need not start before the middle of next century and closure and sealing not before the its end. Economics speak for late, politics for early beginning of disposal. The time frame appears ample for completing the detailed scientific knowledge for site selection, design and construction of deep underground repositories. It is, however, difficult to estimate the time needed to solve the related philosophical and psychological issues. Recognition of long-term hazards of radioactive waste has caused awareness about intergenerational responsibilities. Now, we want to see clear whether it is more ethical that present generations do what they think best to lessen the burden on future generations or leave a degree of freedom of action to those who might become wiser. Such questions complicate the solution of issues like retrievability of wastes, confidence in safety assessments, monitoring versus completeness of isolation, understanding of uncertainties, etc. In addition, thinking and opinion building is swayed by feelings. Fear of nuclear and of radioactivity has accompanied the technical development long before the discovery of fission. Images creating fear, for instance produced in science fiction literature since the beginning of this century, remain deeply engraved in the minds of people. The general trend of human spiritual development points in the direction of overcoming fears by facing them. However, these are slow processes which require persistent dialogue. With regard to radioactive waste disposal this dialogue must include antinuclear movements. Acceptability and public acceptance are dependent on the outcome of that dialogue. In some countries the chances seem quite good for a democratic decision to build high level waste repositories sometime in the course of next century. Acceptance in one country will facilitate acceptance in other countries. Human societies will further develop confidence in their ability to master complex and psychologically difficult technologies. I hope that the domino effect between countries will even lead to sufficient understanding that multinational high level waste repositories become a practical possibility.

1. STATE OF THE ART

During some 50 years of experience most stages of the management of radioactive wastes have become a practical routine, covered by well established safety regulations. The one important exception is the last stage, disposal, more particularly disposal of high level and long lived wastes. Thorough discussions have led to a broad international consensus on the technical merits of incorporating such wastes in deep and stable geological formations and a great number of valid repository proposals have been worked out.

However, the perspectives for realization of these repository projects are not clear. They depend, in fact, on three groups of aspects which I would like to discuss today:

- (1) the point in time when the first high level wastes will be ready for disposal, the quantities then arising, and the technical and economic optimization of disposal thereafter,
- (2) public opinion, acceptability and acceptance, anti-nuclear movements, trends and fashions,
- (3) the solving of issues or important and controversial matters - my dictionary says these are synonyms - in connection with disposal. Such matters are the subject of this Session III on 'Radioactive Waste Management Issues' and are as follows:

Remediation activities, land cleanup and mining and milling waste;
Alternatives for waste disposal, "The Natural Cycles of Matter";
Supra-national issues, activities by international and regional organizations;

- Operational safety of a disposal facility - waste acceptance requirements;
- Requirements for the closure of a near surface repository;
- Repository system integration and overall safety;
- Safety assessment methodology and confidence building measures;
- Reviewing post-closure issues;
- Formulation of regulatory and licensing requirements;
- Exemption, clearance and remediation; and
- Compliance with regulatory requirements.

2. TIMING

The timing of construction of repositories for long lived waste in deep geological formations is to some extent controversial.

On the one hand, in many countries political pressure calls for early decisions and rapid realization, probably to get the question of acceptance of repositories out of the way and more importantly, to assure that responsibilities towards future generations are discharged in a proper way by those generations benefiting directly from the advantages of nuclear technology [1].

On the other hand, the time pressure given by technical reasons is often greatly overestimated. Scrutinizing the schedule of production of high level and long lived waste (Fig. 1 indicates it for Switzerland) shows that no really significant quantities of these heat producing wastes would be ready for underground disposal before the year 2020. The bulk of such waste would in most countries be ready around 2060. This is due to the fact that the technical optimization favours awaiting sufficient decay so that the heat production is reduced to a level allowing a repository temperature below 100° centigrade. Some quantities of long lived wastes with little heat production could already now be made ready for disposal. However, the excellent safety record of intermediate storage suggests also for them that there is no urgency to change as soon as possible to a more definitive solution.

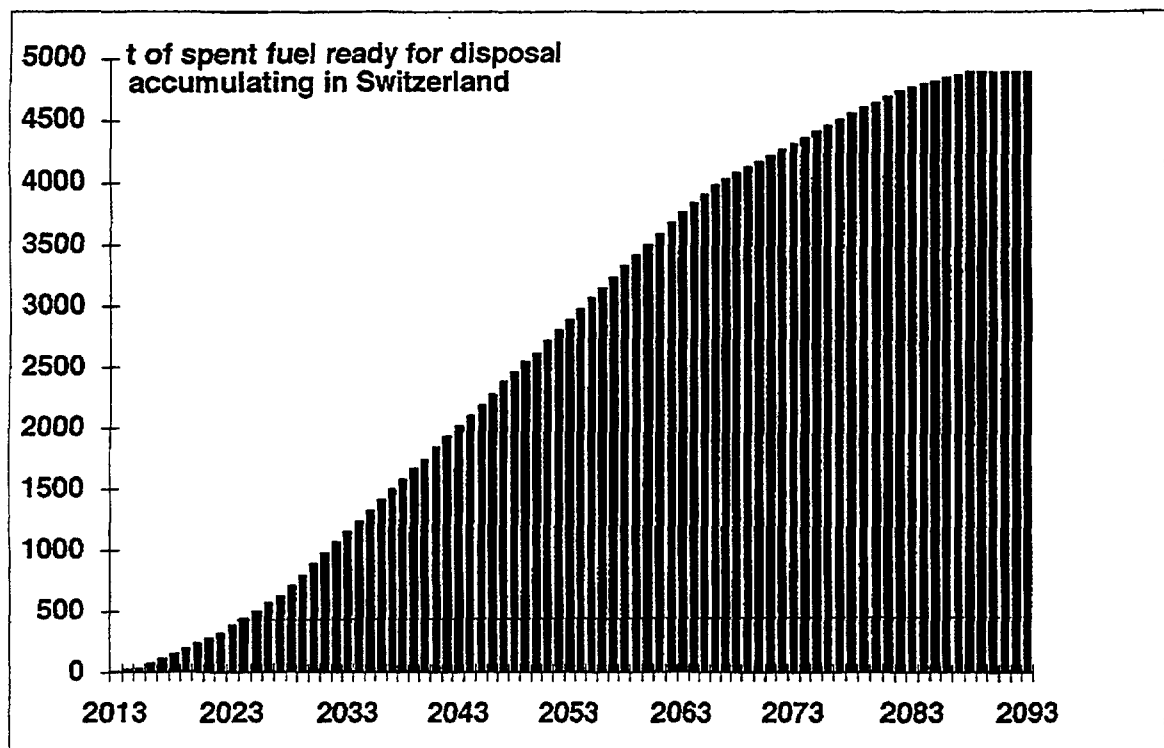


FIG. 1. Schedule of production of high level and long lived waste in Switzerland.

Considering that the last high level wastes from nuclear power plants beginning operation now, will only be ready for disposal in about 100 years (40 to 60 years operating period and 40 to 50 years decay period), economically optimized emplacement in deep repositories should certainly not commence before 2050. Even then, the period during which the repository must be kept open for continuous emplacement of waste would be at least 50 years. That means repository closure and sealing in more than 100 years from now.

New nuclear power plants starting operation after the year 2000 would, of course, postpone repository closure accordingly. However, for the present considerations, only wastes from existing and planned facilities are taken into account. These have to be disposed of anyway, regardless of the future chosen for nuclear power utilization.

The time schedule for waste production and pre-disposal handling gives also an indication of the long time available for solving the issues mentioned in the programme of this Session.

3. CONTROVERSIAL MATTERS

There are some such matters, not explicitly mentioned in this Session's programme, which mar the public discussions. It is indispensable to assess their influence on the perspectives of high level waste disposal.

Firstly, the **Perception of Risks**: Risks related to the handling of radioactive wastes are perceived very differently by different groups of people.

Those who have learned to work with radioactive material can treat it on the same objective basis as for other toxic material. They adopt self-protective measures and precautions which avoid their suffering any detrimental effects.

For the general public, however, the fact that the toxic effects are based on radiation, stamps the radioactive wastes as something extraordinary. In spite of comparable toxicity levels, their far larger quantities and the fact that they do not decay with time, inorganic non-radioactive toxic waste products trigger much less fear than radioactive wastes.

The rough comparison shown on Table I illustrates the risk or hazard perception. Household waste seldom causes fear in spite of its content; yet it contains, for instance highly toxic cadmium or mercury in quantities much higher than e. g. the quantity of plutonium in nuclear waste.

TABLE I. PRODUCTION OF SOLID WASTE IN SWITZERLAND 1988

Origin	Quantity in kg/y. inhabitant	Examples of poisons contained	Time to decay to 1/1000 (years)
Households	440 kg	Cadmium 4 kg Mercury 0.9 kg	infinite infinite
Chemical industry	20 kg	Organics and heavy metals	variable to infinite
Nuclear energy: short lived waste	1.6 kg	Cesium-137 Strontium-90	300 a 300 a
Alpha bearing	0.17 kg	Neptunium-237 Plutonium-239	23 000 000 a 240 000 a
Vitrified high level waste	0.005 kg	Np-237 (0.04 %) Pu-239 (0.01 %)	23 000 000 a 240 000 a

By comparison with many chemicals, the toxicity of radioactive substances is much better understood. But the subjective fear of radioactivity has to be recognized and responded to. It has, in fact, led to a particular safety philosophy which more and more bears fruit also for the concepts of chemical waste management and disposal.

Secondly, what are the practicable **Options for Disposal** ?

The objective of disposal is to isolate the wastes from the human environment. As nothing in the physical world happens to 100 %, the question of what degree and duration of isolation would be sufficient, is an essential theme of safety analysis, as discussed in the second part of this Session.

There are essentially three options for achieving isolation of wastes:

Historically, the first was to *dilute and disperse*. This option came into use a long time ago when smaller quantities of shorter lived radioisotopes served for analytical purposes. After the discovery of the fission chain reaction, nuclear energy generation resulted in much larger quantities of radionuclide mixtures, containing long lived components which had to be taken care of as waste. Then the second option came in use, namely to *store and keep under control*, with a view to go eventually over to the third option to *concentrate and contain*.. For this last option, the most promising approach, identified at an early date, involved passive control following incorporation in selected geological formations.

It is being argued that the destruction of the toxic atoms by nuclear transmutation is another option and research on this possibility has been lately intensified. However, it appears that the complex process - involving in addition to the nuclear transmutation repeated chemical separations - would not have the overall efficiency to eliminate **all** long lived radioactive wastes. Some long lived fission products and unprocessed spent fuel will, in any case, remain to be confined. An isolation strategy appears, therefore, unavoidable, even if separation and transmutation techniques might eventually reduce substantially the radionuclide quantities to be disposed of in geological repositories

A variety of motivations influence the choice between the three basic disposal options:

Dilution and dispersion of radioactive wastes in the air and water of the biosphere is today subject to strict regulatory control. In order to minimize potential risks, in the nuclear industry, and increasingly in the chemical industries, aqueous and gaseous streams are decontaminated to a high degree before dispersal. This means that more solid waste material has to be taken care of by the other disposal options.

In the comparison between storing under active control and the option of concentrate and confine under passive control, the arguments have circled around the question of **retrievability**:

20 years ago, the nuclear industry opted, then for the time being, to store the high level wastes under control because it considered that improving reactor technology and solving the related safety problems had higher priority. It was then claimed by nuclear opponents that it is irresponsible to produce wastes when no *final* solution is available to take care of them. In reaction to these reproaches, in many countries organizations were set up, some governmental, some private, which had to assume the responsibility for research and development work for geological repositories; that is their mission was to prepare waste disposal by the third option 'concentrate and confine' under passive control.

Some ten detailed repository proposals and reference projects resulted. All of these are based on the recognition that predictions on long-term stability of geological formations are much more reliable than prediction of stability of human society, the latter being the pre-condition for continued human control of surface waste stores.

But exactly this point - namely, the remoteness from the human environment of wastes in a deep repository - has caused reversal of the arguments. It was realized that the idea of avoiding the burden to future generations by moving to dependence on passive safety which would be assured in the long-term by geological conditions, means in fact loosing, at least to a large extent, possibility of further actions or even controls by humans. In particular members of anti-nuclear movements plead today for storing wastes under human control, even for indefinite duration. They assert that confinement must remain completely reversible to allow action against any emergency and to grant future generations freedom to decide how to handle the wastes.

There may be an unexpected alliance of interests supporting the option of long-term or indefinite storage under full human control: There are the neutral concerned citizens who have doubts in the geological disposal strategy because of the uncertainties associated with predictions and recognized by scientists; there are nuclear opponents who want to keep the possibility to use the accusation that "the waste problem is still unsolved"; and there are commercial nuclear industry interests based on the recognition that delaying construction of expensive facilities appears economically attractive to the short-sighted. The prime counter-argument to all these differently motivated groups is that we have a responsibility to offer subsequent generations solutions which are acceptable with regard to safety, engineering feasibility and costs.

The store and control approach would clearly pass responsibility for real action to future generations, and might lead them to pass it further on, and so on. For this reason this option has been judged unethical by technical and policy experts in many countries [2].

The question which option meets best the ethical principles has not been conclusively answered. Retrievability is an important ethical consideration. It will be discussed into some detail in the last paper of this Session. At this point, I draw attention to the realistic timing mentioned before which implies that a repository will be open for up to 100 years; easy retrievability is assured during this operational period which would start only in the middle of the next century. After closing and sealing, it is very unlikely that retrieval would be necessary; the design of repositories is aimed that way. Retrieval is, indeed, on purpose made technically difficult for the sake of safety; but it will certainly not become impossible - mining engineers who can extract the extremely rich uranium ores worked today could certainly also re-extract a repository, given sufficient time and resources.

Another problem which affects public acceptance and hence the perspectives for realizing geological repositories is the **uncertainty of predictions** of their radiological safety. The analysis of safety must necessarily be based on extrapolations and predictions over at least ten thousand years. Any predictions are, of course, associated with uncertainties. Acceptance of the results includes judging the importance of the uncertainties and is therefore dependent on our confidence in human scientific understanding, technical planning and imagination. The undisputed uncertainties do create scepticism. This philosophical handicap is unavoidable. Safety assessment will be discussed in detail in the second part of this Session.

At this point, it seems to me important to note that the greatest uncertainties are not derived from the scientific performance assessment of the confinement barrier systems but clearly from the possibilities of disruption by human intrusion. Even deliberate human intrusion for the sake of recovering resources, such as plutonium left in spent fuel, cannot be excluded as technically impossible. If at the time when repositories for spent fuel will have to be closed and sealed, i. e. in 100 to 150 years from now, if then the non-proliferation regime will still have the same political importance as today, then technical means will have to be implemented to allow Nations to receive international confirmation of the continued presence of any fissile material which is left over in the repository, or - as the case may be - that such material is retrieved for peaceful purposes only.

4. PUBLIC ACCEPTANCE

In democratic societies, public acceptance is a prerequisite for realizing high level waste disposal repositories. Perspectives are accordingly dependent on the outcome of the related public discussions in which anti-nuclear movements play an important role. Sometimes in combination with political parties, such movements have become today a political force which can not be neglected. What they have to say has to be seriously analyzed and it is important to establish a proper dialogue. Even with the understandable intention to avoid unnecessary confrontation, one must not avoid controversial and emotional debates involved.

Today safe management and disposal of radioactive waste has become a valid objective in itself, independent of further exploitation of nuclear energy. However, in the public acceptance debates the two areas remain intimately connected. Anti-nuclear organizations commonly support political opposition to repository projects and some make their position even clearer by proposing to support disposal projects under the stringent condition that further peaceful use of atomic energy is abandoned.

To enable a continuous dialogue, it is essential to understand the origins and motives of the antinuclear movements. No doubt, one finds at the bottom always fear. But nuclear fear alone would not have inspired such furious opposition had there not been also increasing misgivings about all modern civilization, in particular its structure of authority (the fight against the 'establishment') and including its commitment to technology and rationality. Recent revelations concerning radionuclide releases or contaminations at nuclear sites have, of course, stimulated mistrust.

This kind of philosophical analysis of the evil of modern society was certainly furthered by the fear of bombs. When atomic bombs brought world war II to an end 50 years ago they boosted a simmering fear of world doom. In fact, annihilation of the world by some kind of atomic chain reaction has been a literary theme since the beginning of this century when Ernest Rutherford's first explanations of radioactivity were misunderstood [3]. A most disturbing atomic weapons tale came from H. G. Wells already in 1913 [4]. It was dedicated to Frederik Soddy, co-worker of Rutherford, and was directly inspired by Soddy's writings on radium. Literary connections can also be shown to medieval alchemy and related fears and hopes.

It appears that a basic fear of world doom has always existed. Today it is focussed on nuclear matters including high level waste repositories. It has recently shown up in an article in the New York Times [5] suggesting the possibility of an explosion in a spent fuel repository. A few basic facts and laws of nature had to be misinterpreted to make such an explosion appear possible. The ensuing debate has shown the influence of the media upon the scientific process developed to ensure the quality of published technical work [6]. The theory of repository explosion has been refuted by a large team of scientists from Lawrence Livermore National Laboratory [7] But the fear remains.

5. ACCEPTANCE OF NATIONAL AND INTERNATIONAL RADIOACTIVE WASTE REPOSITORIES

It is obvious from the political debates that feelings of fear and the connected reactions of mistrust towards licensing authorities and the responsible designers of repositories do heavily influence public acceptance. This in spite of the fact that acceptability can be made plausible to a rational person by means of technical arguments and a very extensive experience of modelling and comparison with nature. The uncertainties in safety predictions, recognized by all sides, leave room for distorting the rational argument by appealing to deeply ensconced, subjective feelings. I believe that only persistent discussion and analysis provides a chance to overcome them and finally achieve consensus.

These complex philosophical, psychological and socio-political issues make difficult any prediction of how disposal projects will develop. The uncertainties in this kind of prediction for the coming few decades seem even greater than the uncertainties of predictive modelling of geological repository performance over ten thousand years.

There are as many ways to proceed with solving the human problems as there are democratic forms of societal living. Where a solid scientific background for repository planning and construction is available, the debate becomes easier. Observing intermediate results, I am hopeful that, here and there, the development towards acceptability for high level radioactive waste repositories is progressing well enough to indicate that acceptance might be reached within the coming two or three decades as required. Then a domino effect will occur; democratic acceptance and formal licensing in one country will facilitate reaching the same status in other countries.

The most important domino effect will occur when several national high level waste repositories will have found acceptance. Then it will be possible again to discuss and even negotiate on what appears today to be a political taboo: international repositories.

It has for a long time, been recognized that the combining of several repositories related to limited nuclear programmes in smaller countries into one common facility, promises to provide an advantageous solution, at least for technical and economic reasons, and probably also for safety. The simple fact that such a repository must be situated in one host country led too easily to the suspicion that the others may wish to be rid of their waste. As long as one can point out that high level waste repositories have nowhere found acceptance, this argument will prevail. Therefore in the eighties a tacit consensus developed that each nation should look for repository sites on its own territory. Some countries have even legislated that radioactive waste may not be imported for disposal. Hopefully, the spreading of acceptance from one country to others will make common solutions possible.

6. THE IMPORTANCE OF AN INTERNATIONAL CONVENTION CONCLUSION

The International Convention on safe management and disposal of radioactive waste, being now negotiated within IAEA, will certainly help in the development towards acceptability and acceptance of national and/or multinational repositories. I think it is important that such a convention recognizes not only results of rational research and logical analysis but also takes into account concerns of any origin. There is no point in ignoring the existence of deeply rooted feelings or discarding them out of hand; they must be brought to light and debated. This is the only chance to modify them, to overcome fear. I am hopeful that international consensus on how safe management and disposal can be achieved will reach at least the same level as the consensus reached on the non-proliferation regime.

The development and modification of public attitudes is a slow process. Faster ups and downs make it sometimes difficult to detect progress. It is, however, comparable with historically notorious processes like the replacement of the belief in demons by ethical rules derived from social experience or from facts which may acquire a certain objectivity by scientific analysis.

The slow process may be influenced if not accelerated by leadership of smaller groups such as the scientific community. However, this can only happen if this leading community is open to considerations of everything that moves human beings. It is then possible that a well developed society finds a sufficient degree of confidence in its ability to handle complex technologies for the benefit of all its members - in spite of psychological difficulties.

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REMEDATION ISSUES AND ACTIVITIES

R. LIGHTNER, J. AHLQUIST, T. GERUSKY
US Department of Energy,
Washington, D.C., United States of America

Abstract

The United States, like many other countries, faces new challenges as the result of the ending of the cold war and increased emphasis on cleaning up the legacy of the first 50 years of the nuclear age. This paper deals with some key management issues and discusses topics where special management emphasis needs to be placed if wastes are to be safely, economically, and expeditiously dealt with. These topics include the need for comprehensive planning of activities and potential costs; the need for a consistent approach to evaluating risks in prioritizing environmental management activities; the necessity of establishing the future uses of land to be reclaimed; and the implications of residual radionuclide contamination standards. Examples of how the Environmental Management program of the United States Department of Energy is dealing with these issues are discussed.

1. INTRODUCTION

Since the inception of the nuclear age over fifty years ago, an increasing number of nations have had to deal with the problems of storage, treatment, and ultimate disposition of wastes from nuclear activities. The sources of these wastes range from the mining and milling processes used to acquire uranium and other resources through purification and isotope enrichment activities, manufacturing and reprocessing, and finally high level fuel element and residue disposal. These wastes are most universally associated with the nuclear power industry but the nuclear weapons establishments are also major sources of this waste. Most recently, cleanup of earlier "solutions" to the disposal of waste and earlier accidents has resulted in large volumes of environmental restoration materials needing ultimate, safe disposition.

Within the United States, we encounter the whole gamut of these wastes since we have had active power and weapons programs from the beginning. We have an enormous legacy of waste repositories and sites which do not meet existing standards of safety and environmental protection.

This paper summarizes some key management issues faced in dealing with these wastes and the sites contaminated by them, with emphasis on environmental restoration, which is the remediation of contaminated locations that exist either because of mishaps or ineffective waste management practices of the past. This paper discusses topics where special management emphasis needs to be placed if these wastes are to be safely, economically, and expeditiously dealt with. These topics include the need for comprehensive planning of activities and potential costs; the need for a consistent approach to evaluating risks in prioritizing environmental management activities; the necessity of establishing the future uses of land to be reclaimed; and the implications of establishing residual radionuclide contamination standards.

2. THE ELEMENTS OF ENVIRONMENTAL MANAGEMENT

Although the United States continues to maintain a reduced arsenal of nuclear weapons, as well as some production capacity, the nation has embarked on an ambitious and far ranging cleanup of the environmental legacy of the Cold War. In 1989, the Department of Energy's Office of Environmental Management was established to carry out this new program.

The Environmental Management mission involves a variety of interrelated activities, often referred to as "cleanup." In reality, the mission includes four major activities involving a great deal more than "cleanup." These activities constitute one of the largest environmental programs in the world - with more that 130 sites located in over 30 states and territories (Figure 1). The Department

of Energy manages more than 1.1 million square meters of buildings and over 900,000 hectares of land - an area larger than Delaware, Rhode Island, and the District of Columbia combined.

Regardless of size, an environmental management program will need to address similar elements in accomplishing its mission. The Department of Energy's Environmental Management Program is described in "Closing the Circle on the Splitting of the Atom" [1].

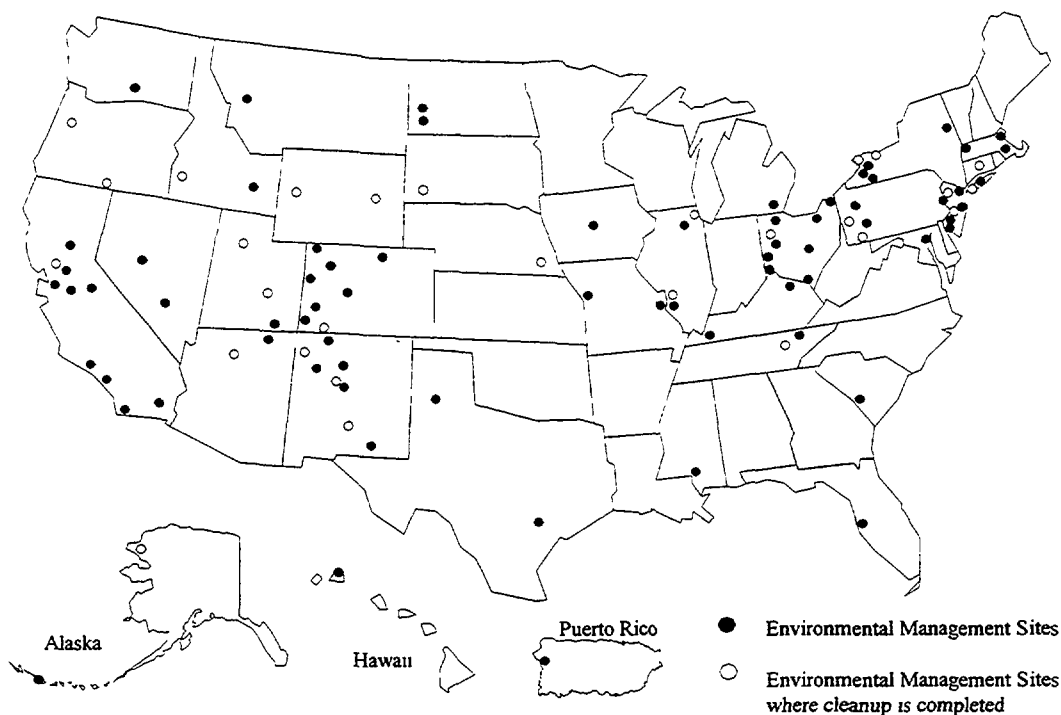


FIG. 1. Environmental management sites.

2.1. Stabilization

The most urgent activity is to stabilize and safely maintain nuclear materials and facilities. For example, reprocessing plants are no longer needed for the extraction of weapons grade plutonium, and the nuclear material residues are no longer intended for use in nuclear weapons. The task of stabilizing these facilities and sensitive materials to prevent leaks, explosions, theft, terrorist attack, or avoidable radiation exposure is an essential part of an environmental management program.

Maintaining these facilities becomes more difficult because many of them are more than 40 years old. Many have reached or exceeded the lifetime for which they were designed and have begun to deteriorate. They must be stabilized merely to maintain safety and to protect workers and the public before the resources can be made available to accomplish the actual decontamination and decommissioning.

2.2. Waste Management

The second major activity is the management of large volumes and varieties of waste. The primary source of these wastes in the United States was the nuclear weapons program. In addition, some waste from nuclear reactor research and basic science projects, as well as waste generated by the commercial nuclear power industry under certain circumstances, such as the debris from the

accident at the Three Mile Island nuclear power plant, needs to be managed. Most of this waste is radioactive and much of it has non-radioactive hazardous constituents. A large volume of waste has already been disposed of at Department of Energy facilities. However, the wastes that remain in storage pending permanent disposal contain most of the radioactivity. These wastes are intended for deep geologic disposal. Excluding uranium mill tailings, a recent report indicates that the current inventory of radioactive waste and operational waste from the next 35 years will amount to 2.7 million cubic meters. Future projections to the year 2070 estimate that the total radioactive waste to be disposed will total 20 million cubic meters (Table I).

2.3. Technology Development

Technology development is vital to the long-term success of an environmental management mission. Both the private sector and government are conducting a variety of applied research to develop more effective and less expensive remedies to the environmental and safety problems of the nuclear cleanup. Recently, this effort at the Department of Energy was redirected to focus resources in the areas posing special problems or requiring immediate attention: facility decontamination and decommissioning; underground plumes and landfills; mixed waste; tank waste; crosscut programs; and program integration and technology transfer. The new emphasis on groundwater cleanup as part of the plume technology efforts reflects the realization that very little new technology has been used to date to solve this difficult problem. Remedies have been mainly pumping to control the direction or extent of underground plumes. Actual cleanup using pump and treat of groundwater has not proven to be an adequate solution, producing uncertain results after long and expensive operations. By re-focusing efforts, it is expected that the research and development most needed by the field programs will be carried out more rapidly and that new or improved processes will be more readily usable.

TABLE I. TOTAL WASTE VOLUMES FROM 1995 - 2070 (IN CUBIC METERS)

Waste Type	Current Inventory	Environmental Restoration	Facility Stabilization	Total
High-Level	403,000	400	100	403,500
Spent Nuclear Fuel	2,300	0	0	2,300
Transuranics	106,000	113,000	18,000	237,000
Low-Level	1,700,000	16,810,000	28,000	18,538,000
Low-Level Mixed Waste	510,000	999,000	27,000	1,536,000
Total	2,721,300	17,922,400	73,100	20,716,800

2.4. Environmental Restoration

The last major part of an environmental management mission is environmental restoration. It encompasses the stabilizing or removing of contaminated soil; pumping, treating, and containing ground water; decontaminating, decommissioning, and demolishing process buildings, nuclear reactors, and chemical separations plants; and exhuming sludge and buried waste where storage techniques of the past pose safety or environmental hazards. The succeeding sections of this paper will focus on some key management considerations in accomplishing environmental restoration activities.

3. BASELINING ENVIRONMENTAL MANAGEMENT

As with any large project that stresses a nation's resources, there is a need to fully understand the ultimate extent of a project, estimate its costs, and scope the pace of progress to meet resource availability. We refer to this process as baselining and have over the past five years taken a number of approaches to satisfying this need. In 1995, the United States Department of Energy submitted a "Baseline Environmental Management Report" to update the Congress on the activities and potential costs required to address the waste, contamination, and surplus nuclear facilities that are the responsibility of the Department's Environmental Management program. This report was issued in May, 1995 under the title, "Estimating the Cold War Mortgage" [2].

3.1. Base Case

The "Base Case" total cost for Environmental Management over the next 75 years was estimated to be \$230 billion. This estimate was tied to the following assumptions: significant productivity increases would be attained over the course of the time involved; current compliance requirements as established by regulatory bodies would be met; and existing technologies would be used. Excluded from this estimate were: cleanup where no feasible technology exists (e.g., nuclear explosion sites; most contaminated ground water; cleanup of currently active facilities (e.g., Pantex, National Labs); Naval Nuclear Propulsion cleanups handled by the U.S. Navy; and activities (\$23 billion) already completed during the first 5 years of the program.

The need for a baseline is strengthened in times of shrinking resources. At such times, difficult decisions must be made about which work will go forward and which will be delayed or not performed at all. The baseline is a quantitative statement of the scope of the job. From it, options can be identified and selected to match priorities and resources.

3.2. Top Five Sites

Within the US environmental management program five large sites were found to represent about 70% of the projected cost. These include the former production reactor and fuel reprocessing sites at Hanford (21%) and Savannah River (21%), the former uranium and plutonium processing and manufacturing plants at Rocky Flats (10%) and Oak Ridge (10%) and the reactor and process testing site at Idaho (8%).

3.3. Program Costs

Long term costs were projected to be divided among the principal activities as follows:

- Nuclear Material and Facility Stabilization - 10%
- Waste Management - 49%
- Technology Development - 5%
- Environmental Restoration - 28%, and
- Other - 8%

3.4. What Was Learned?

Analysis of this baseline has led to a number of conclusions which will help build a more effective and less expensive program in the future. The more interesting of these conclusions are summarized here:

- Total projected environmental cleanup costs are comparable to total U.S. nuclear weapons productions costs.
- Projected future land use will dramatically affect total program costs.
- Significant reductions in ongoing programs could be achieved through greater pollution prevention in the future.

- Development of new technologies will reduce certain cleanup costs and make possible other cleanups that are currently not feasible.
- The minimum action to stabilize the sites would cost a large fraction (75%) of the base case estimate, indicating the desirability of doing the job permanently and not trying to merely prevent further degradation of the situation.

4. ENVIRONMENTAL RESTORATION MANAGEMENT

Environmental restoration must address sites and facilities contaminated with radioactive, hazardous, and mixed waste from a spectrum of nuclear programs. The restoration process is constrained and guided by laws, regulations, and environmental compliance agreements among the performer (in our case DOE), the regulating agency, the local governments, and other affected parties. Program responsibilities include interim/remedial actions, decontamination and decommissioning, waste management, surveillance and maintenance, and landlord responsibilities. The Environmental Restoration Strategic Plan was published in August, 1995 [3].

4.1. The Environmental Restoration Mission

The overall direction for a large environmental restoration program should be set by a concise statement of purpose used to guide all of the planning and execution. Called the mission statement, it serves as a constant indicator of the direction of progress. A simple test of the worth of an activity is whether or not it furthers the mission. Within the USDOE environmental restoration program, the mission statement reads:

Protect human health and the environment from risks posed by inactive and surplus DOE facilities and contaminated areas, and remediate sites and facilities in the most cost efficient and responsible manner possible to provide for future beneficial use.

4.2. Environmental Restoration Vision and Core Values

Restoration will be completed by optimizing an appropriate mix of uses for the restored land: residential, recreational, industrial, and retained by the government. This mix defines the vision of where the program expects to be at conclusion. Within the US program we intend to achieve this vision by adhering to the following core values:

- Ensure protection of worker and public health and safety and the environment;
- Serve as a model steward of natural and cultural resources;
- Comply with Federal, State and local statutes;
- Prudently use taxpayers' money in achieving tangible results;
- Focus on customer satisfaction and collaborative decision making;
- Demonstrate a commitment to excellence.

4.3. Program Priorities

Because the inventory of work to be done will most likely exceed the available resources, priorities must be applied to get the most effective results from the resources expended. The US program has applied the following eight priorities to budgetary and other resource decisions to determine the tasks that will contribute most effectively to the mission and the order in which to pursue them:

1. Reduce Offsite Contamination

Eliminate, reduce, or contain contamination that has migrated outside of controlled site boundaries and that may pose an adverse risk to the public and the environment.

2. Prevent Contamination Migration

Contain contamination and prevent further migration of contaminants from their source through timely identification, assessment, application of best technologies and safe storage.

3. Restore Non-controlled Sites and Facilities

Identify, decontaminate and/or control all sites and facilities formerly used for government nuclear activities.

4. Reduce Onsite Contamination

Eliminate, reduce, or contain onsite contamination that in future site use, as determined with the public and the regulators, may pose an adverse risk to the public and the environment.

5. Cost-Effectively Maintain the Essential Infrastructure

Responsibly invest in activities such as: safety, security, utilities and support services that are required to maintain the infrastructure to support the restoration mission. A concerted effort must be made to reduce or eliminate the conditions that create the need for these expenditures, through activities like decommissioning, to make more resources available for directly productive restoration activities.

6. Release Facilities and Land for Public Beneficial Use

Increase efforts to expeditiously cleanup and/or restore and release sites, facilities, buildings and equipment no longer needed and that have little or no contamination for other uses. The public should be involved in land and facility reuse decisions.

7. Make Prudent Business Decisions

Fund activities that are not directly tied to eliminating or reducing contamination if they support and enhance the effective and efficient achievement of the mission, such as: capital projects that upgrade the efficiency of operations, completing projects which are near their end to reduce continuing overhead expenses, and training of employees.

8. Reduce Uncertainty Through Characterization

Increase efforts to identify sources, nature and extent of contamination to allow more accurate determination of relative risk, scope, cost and schedule of restoration projects.

4.4. Performance Measures

Performance measures should be used to track overall achievement of the program mission and vision within the context of program priorities. The measures discussed here are "strategic measures" for examining macro-level, long term trends. The US program is in the process of establishing such a system of measures to aid in the management of the environmental cleanup. Strategic measures which might be considered include, for example:

A. Relative Risk Reduction -

The program would classify and track all release sites and facilities by categories of relative risk. Relative risk groupings would be based on a simple (e.g., high, medium and low) classification scheme. As program priorities are implemented and program goals are attained, there is an expectation that higher relative risk release sites and facilities will either move to

a lower relative risk classification or into a "no further action" category. Similarly, the general trending of medium and low relative risk sites should be toward the no further action category. Tracking these movements will enable management to get a high level sense of progress toward completion of the mission.

B. Lands and Facilities Status -

The program priorities and program objectives dictate that lands should be remediated and facilities should be decommissioned with all possible speed. The program would track trending patterns in both lands and facilities status. The ultimate objective will be to remediate lands and decommission facilities so that they are ready to be transferred to others for future beneficial use.

C. Resource Distribution -

The program should be dedicated to increasing the proportion of resources allocated to actual remediation progress while reducing the resources for other, less productive activities. Most program priorities and program goals require measurable remediation progress. The program would track overall trending in the distribution of funds committed to core activities, assessment activities, and remediation progress.

D. Program Efficiency -

Important components of the mission, vision, and priorities are the concepts of cost-effectiveness and efficiency. Cost-effectiveness and efficiency can be achieved through reductions in infrastructure costs, elimination of unnecessary management and oversight costs, and utilization of best technologies. Indices such as infrastructure costs, program management costs, and cost per outcome might be used for measuring effectiveness and efficiency trends.

5. BASING PRIORITIES ON RISK

Theoretically, the setting of priorities using risk estimates is most reasonable. It is, however, not a routine matter to measure the relative risk removal potential of many diverse activities. In the US many previous attempts to establish risk-based priorities have not succeeded.

In June, 1995, the Department submitted a draft risk report to Congress, entitled Risks and The Risk Debate: Searching For Common Ground, "The First Step" [4]. Congress had required the Department to prepare the report as a link between budget, compliance agreements and risk activities. It represents a first step toward achieving a consistent approach to evaluating the risks to human health, worker safety, and the environment posed by conditions at the Department's sites and facilities.

The report defines high risk as "high risks to the public, workers, and the environment which represent either major impacts (death; permanent total disability; or widespread irreversible damage to the environment) that are expected to occur within one to ten years, or intermediate impacts (significant exposures, injuries, or environmental damage) that are expect to occur at least yearly."

Medium risk is defined as "either major impacts that are expected to occur one a century or less, intermediate impacts that are expected to occur within 10 to 100 years, or moderate impacts (no hospitalization required, or localized short-term environmental damage) that are expected to occur within one to ten years."

Low risk is defined as "either intermediate impacts that are expected to occur one in a century or less, or moderate impacts that are expected to occur within 10 to 100 years."

Applying this technique, while stressing that there are significant limitations in the evaluation, the first look at the issues concluded that the Environmental Management budget for 1996 does address public, worker or environmental risks. Specifically, 49 percent of the budget evaluated was found to address high risks to the public, workers, or the environment and to represent 23 percent of the activities. Eighty-eight percent of the budget addresses medium and high risk, and represents 74 percent of the activities.

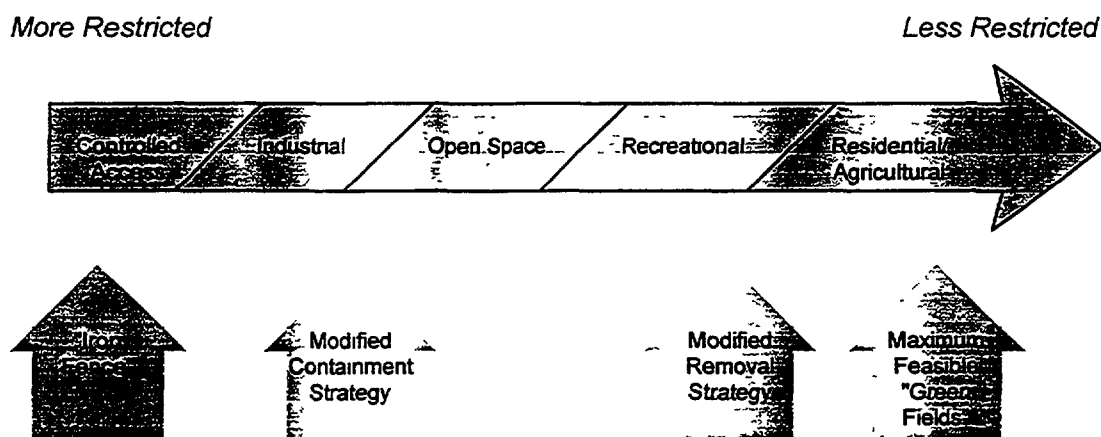
An important finding was that without limited public access and other institutional controls, the environmental management sites would pose much greater risks.

This was a new attempt at comprehensive risk analysis. The document is now out for public comment. There is a need to continue efforts to provide a common understanding and consistent framework for comparing multiple risks and hazards throughout the Department of Energy program.

6. FUTURE LAND USE ISSUES

Any environmental restoration program which plans to turn land and facilities free for new uses must consult with stakeholders and regulators regarding the ultimate disposition of lands. Land-use decisions, which determine both the type and extent of site remedial approaches, will be a significant variable in the ultimate cost of an environmental restoration program. For example, merely containing contamination at a site may be sufficient for land that will remain restricted (i.e., off limits to human activity), while removal may be required for unrestricted land use. The range of costs associated with differing land-use scenarios is substantial. To illustrate the significance of future land-use decisions, the Department recently examined how total program cost would vary assuming a range of alternative future land uses.

Figure 2 depicts a continuum of future land uses ranging from completely restricted or controlled access to completely unrestricted or residential use. Four cases were developed for comparison with the Base Case cost estimate. Two cases illustrate the extreme opposite ends of the land-use spectrum. The "Iron Fence" case, based exclusively on containment strategies, represents the most restrictive case, while the "Maximum Feasible Green Fields" case, provides for essentially unrestricted land use. Two other cases, referred to as "Modified Containment" and "Modified Removal," illustrate what were judged to be more reasonable alternatives, taking into account existing legal obligations and departmental commitments that were reflected in the Base Case.

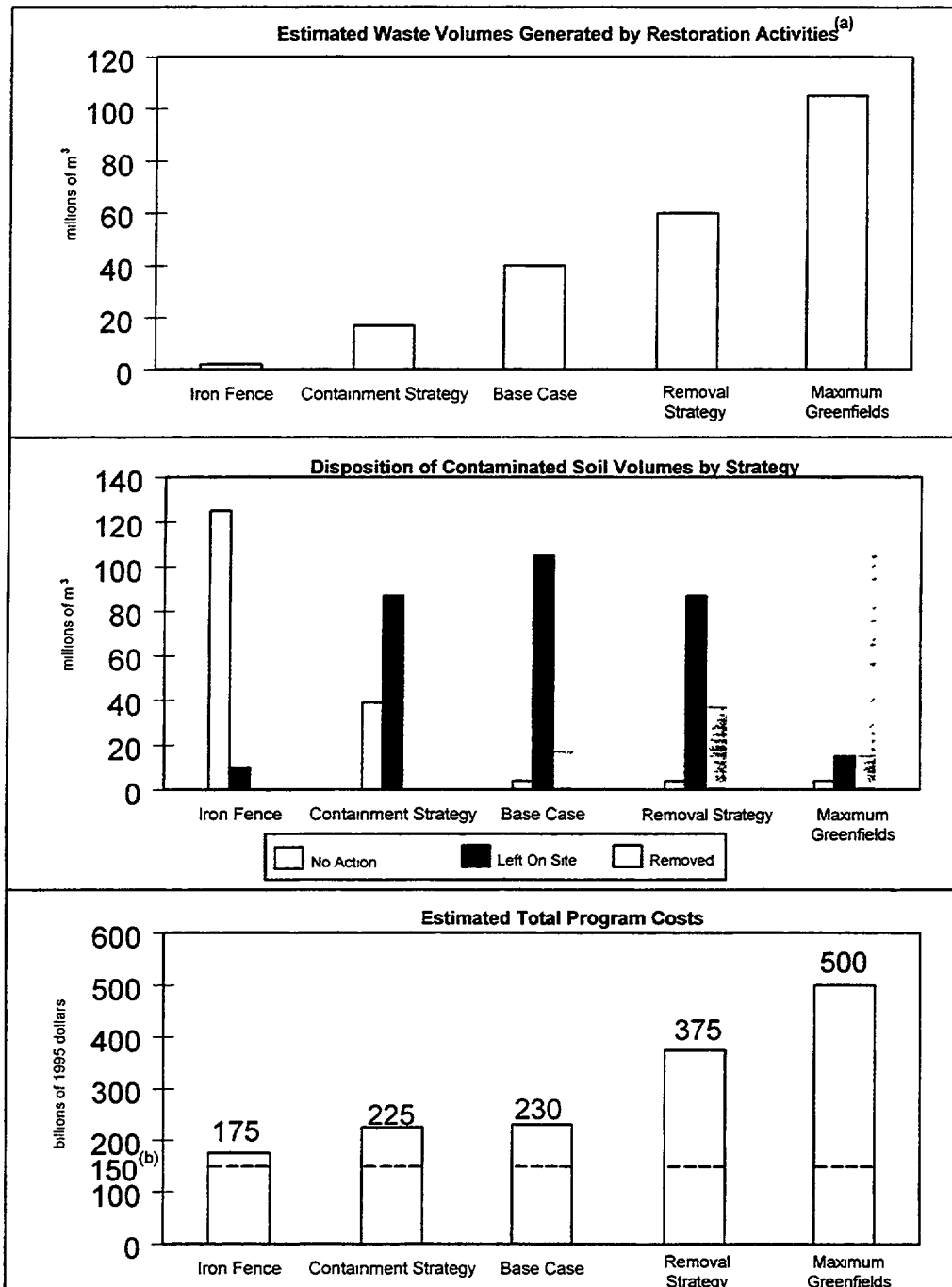


(a) This scenario represents a modified "pure" Green Fields case, which is not achievable at all sites with today's technology.

FIG. 2. Conceptual illustration of the land-use continuum.

The costs for all four scenarios were estimated using a relatively simple computer model, using unit activity costs derived from experience at several of the Department's larger sites as well as nongovernmental cleanup projects.

As can be seen in Figure 3, the costs vary from the \$175 billion for the "Iron Fence" case to \$500 billion for the "Maximum Greenfields" case. In all cases, approximately \$150 billion in costs are from managing existing waste and surplus contaminated facilities.



(a) Includes mill tailings, sanitary waste, low-level waste, low-level mixed waste, transuranic waste, and hazardous waste

(b) Approximately \$150 Billion in costs are from managing existing wastes and surplus contaminated facilities.

FIG. 3. Results of land-use analysis.

7. RESIDUAL CONTAMINATION STANDARDS

One of the most fundamental problems facing an environmental restoration program is the question, "How clean is clean?" During the past year the USDOE environmental restoration staff has looked at this issue in reference to residual radioactivity standards now being drafted by the U.S. Environmental Protection Agency (EPA) and the U.S. Nuclear Regulatory Commission (NRC). Both of these agencies are utilizing a residual risk approach rather than applying a specific cleanup level. Both agencies are proposing to use 0.15 mSv per year as the annual committed effective dose equivalent to the maximally exposed individual. At this dose level, EPA estimates that the residual lifetime risk allowed following cleanup for a relatively conservative scenario is $3E-4$. It is noted that the committed effective dose levels being considered by the US regulatory bodies fall within the range of lifetime dose after cleanup as presented in the draft IAEA "Criteria for Cleanup of Contaminated Areas" [5].

7.1. Department of Energy Residual Risk Guidance

At present, the Department of Energy internal standards require that sites be remediated to an annual committed effective dose equivalent not to exceed 1 mSv per year to a maximally exposed individual, plus a requirement that the potential exposure be As Low As Reasonably Achievable (ALARA). An analysis of previous remedial actions reveals that, in many cases, the actual committed effective dose equivalent is less than 0.01 mSv per year following remediation.

7.2. Superfund Reauthorization

During the last session of the U.S. Congress, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) was being reviewed by various Committees for amendment and reauthorization. CERCLA establishes a national mechanism for the clean-up of radiologically, chemically, or biologically contaminated sites throughout the United States. The Act requires that the Administrator of the EPA establish standards and regulations related to these clean-ups. This legislation, known as "Superfund", caused much concern and debate over the years over many of its provisions, especially related to the private sector.

One of the proposed new sections would require that the Administrator of EPA establish a single national lifetime risk goal for clean-up of all sites for all agents. Utilizing that residual risk goal, EPA would be required to establish specific standards. In the past, EPA has accepted lifetime residual risks for radionuclides in the range of $1E-2$ to $1E-4$. A more likely scenario under this proposed amendment is that the Administrator of EPA would establish a lifetime residual risk goal of $1E-6$ (one in a million) for all contaminants. This goal has been used in the past for non-radiological contaminants. The Department of Energy must comply with all EPA standards under the Atomic Energy Act and with CERCLA regulations. In the case of conflicts, the most conservative regulations would apply.

7.3. Department of Energy Study

The technical staff of the Department became concerned that the proposed CERCLA language would not only impose a greater burden on the Department's environmental restoration efforts, substantially raising the costs without commensurate benefit, but also that there may be no way to accurately verify that the cleanup standard had been reached. Two key factors, background radiation (including fallout) and laboratory or instrument capability were of particular concern. A study, entitled "Preliminary Analysis of the Technical Feasibility of Achieving Various Residual Risk Standards for Cleanup of Radionuclides in Soil" [6], was carried out to determine the scope of the problem. It had two principle objectives:

- A. To examine the technical feasibility of a radionuclide cleanup standard for soil equivalent to residual levels of $1E-4$, $1E-5$, and $1E-6$ excess lifetime cancer risks to the maximally exposed individual; and

B. To present site specific information (including background concentrations) on radionuclides.

7.4. Radionuclides Selected

Fourteen radionuclides were identified at these sites to represent the spectrum of the technical challenge in detecting radionuclides (Table II). For example, the list has alpha emitters with low amounts of X or gamma activity (such as Plutonium-239), alpha emitters with higher amounts of X or gamma activity (such as Uranium-235), fission products with a strong gamma emitter (such as Cesium-137), a weak beta emitter (such as Technetium-99), and a strong beta emitter (such as Strontium-90).

TABLE II. SELECTED RADIONUCLIDES

Uranium (U)-234, 235, 238	Strontium (Sr)-90
Plutonium (Pu)-238, 239	Cesium (Cs)-137
Americium (Am)-241	Hydrogen (H)-3
Radium (Ra)-226	Technetium (Tc)-99
Thorium (Th)-230, 232	Iodine (I)-129

7.5. Cleanup Standards for Soil Equivalent to 1E-4, 1E-5, or 1E-6 Risk Levels

Risk assessments were required to determine the cleanup standards for concentrations of radionuclides in soil equivalent to 1E-4, 1E-5, and 1E-6 residual risk levels. DOE has developed a computer code (RESRAD) to calculate these standards using site specific data to calculate cleanup levels, radiation dose and excess lifetime cancer risk estimates to an on-site resident (a maximally exposed individual or member of a critical population group). The RESRAD code has undergone a thorough peer review process and is used extensively by the Department, the NRC, EPA, and state agencies for performing risk analysis. Actual site data will vary depending on individual site parameters and radionuclide concentrations may vary depending upon the risk model used. For the purpose of this study, the radionuclide concentrations needed to achieve the 1E-4 through 1E-6 residual risk levels were obtained from EPA, which used RESRAD to generate these concentrations as part of their analysis of radioactive cleanup standards to support the proposed rulemaking discussed previously.

For the rural residential scenario, EPA assumed that individuals live on-site and are exposed chronically--both indoors and outdoors--to residual concentrations of radionuclides in soil through the following exposure pathways: external radiation exposure, inhalation of resuspended soil and dust, incidental ingestion of soil, ingestion of drinking water, ingestion of home grown produce, ingestion of beef, ingestion of milk, and ingestion of locally caught fish. A 30 year exposure period was used.

For the commercial/industrial scenario, EPA used an 8-hour on-site workday, both indoors and outdoors. In general, exposures to on-site workers were less than those for residents of rural areas, because worker exposures are limited to working hours and do not include contributions from ingestion of home-grown produce or locally caught fish.

EPA also constructed an analytic model of a representative (generic) site to calculate the radionuclide concentrations needed to achieve the residual risk levels for residential and commercial/industrial land uses. Table III contains the radionuclide concentrations needed to achieve the 1E-4, 1E-5, or 1E-6 residual risk levels (as well as typical U.S. background for comparison).

TABLE III. CONCENTRATIONS IN mBq/g TO ACHIEVE RESIDUAL RISK LEVELS

Radionuclide	1E-4 Risk Residential	1E-4 Risk Commercial/ Industrial	1E-5 Risk Residential	1E-5 Risk Commercial/ Industrial	1E-6 Risk Residential	1E-6 Risk Commercial/ Industrial	Typical U.S. Background Concentration (mBq/g)
Am-241	300	700	30	70	3.0	7.0	<0.37 - 0.56
Cs-137 + D	62	410	6.2	41	0.62	4.1	3.7 - 130
H-3	4800	12000	480	1200	48	120	30 - 740
I-129	1.1	3.7	0.11	0.37	0.011	0.037	*
Pu-238	5200	26000	520	2600	52	260	<1.1
Pu-239	5200	26000	520	2600	52	260	<1.1 - 1.5
Ra-226 + Radon	3.7	15.0	0.37	1.5	0.037	0.15	8.5 - 160
Sr-90 + D	150	410	15	41	1.5	4.1	7.4 - 150
Tc-99	190	520	19	52	1.9	5.2	*
Th-230	190	590	19	59	1.9	5.9	4.4 - 140
Th-232 + D	33	110	3.3	11	0.33	1.1	3.7 - 130
U-234	370	930	37	93	3.7	9.3	4.4 - 140
U-235 + D	330	810	33	81	3.3	8.1	<1.1
U-238 + D	220	520	22	52	2.2	5.2	4.4 - 140

* Background concentrations for these radionuclides are not typically surveyed.

SOURCES: 1E-4 risk level contaminant concentrations were obtained from U.S. EPA generic site data using RESRAD (draft). Actual site data will vary depending on individual site parameters. Radionuclide concentrations may vary depending on the risk model used. 1E-5 and 1E-6 risk level data were derived from the draft EPA 1E-4 risk level concentrations. Typical U.S. background data were principally from the National Council on Radiation Protection and Measurement Report Number 94.

TABLE IV. COMPARISON OF THE CONCENTRATIONS NEEDED TO ACHIEVE THE RESIDUAL RISK LEVELS FOR THE 14 RADIONUCLIDES WITH TYPICAL U.S. BACKGROUND RANGES AND MINIMUM DETECTABLE CONCENTRATIONS (ALL VALUES ARE IN mBq/g).

Radionuclide	Typical U.S. Background Range	Laboratory MDC	1E-4 Risk Goal		1E-5 Risk Goal		1E-6 Risk Goal	
			[Conc]	Status	[Conc]	Status	[Conc]	Status
Am-241	< 0.37 - 0.55	0.37	300	○	30	○	3.0	○
Cs-137 + D	3.7 - 130	0.37	62	□	6.2	□	0.62	□
H-3	30 - 740	0.74	4800	○	480	□	48	□
I-129	*	740	1.1	■	0.11	■	0.011	■
Pu-238	< 1.1	1.1	5200	○	520	○	52	○
Pu-239	< 1.1 - 1.5	1.1	5200	○	520	○	52	○
Ra-226 + D	8.5 - 160	3.7	3.7	□	0.37	●	0.037	●
Sr-90	7.4 - 150	0.74	150	□	15	□	1.50	□
Tc-99	*	37	190	○	19	■	1.9	■
Th-230	4.4 - 140	1.9	190	○	19	□	1.9	□
Th-232 + D	3.7 - 130	1.1	33	□	3.3	□	0.33	●
U-234	4.4 - 140	1.1	370	○	37	□	3.7	□
U-235 + D	< 1.1	1.1	330	○	33	○	3.3	○
U-238 + D	4.4 - 140	1.1	220	○	22	□	2.2	□

○ = Neither MDC nor background are of concern in achieving the stated risk goal. □ = Background may limit the ability to achieve the stated risk goal. ■ = Minimum detectable concentration (MDC) may limit the ability to achieve the stated risk goal. ● = Both the MDC and the background may limit the ability to achieve the stated risk goal. * = Background concentrations for these radionuclides are not typically surveyed. Concentrations associated with the various risk goals assume residential land use. Data sources for site-specific background levels vary and are currently under DOE review. Note: Minimum detectable concentrations and backgrounds are only two pertinent issues. Other issues related to achieving the various risk levels are the availability of treatment technologies and disposal capacity; the threats to ecosystems and workers; potential transportation risks; and higher costs.

7.6. Minimum Detectable Concentrations

In general, field screening instruments are unable to detect radionuclides at the concentrations required to achieve the 1E-4 to 1E-6 risk levels. This implies that the majority of detection tasks would need to be performed in a laboratory setting rather than in the field. Table IV lists the minimum detectable concentrations in millibecquerels per gram and represent the standard practice at commercial laboratories and in the field. These commercial capabilities may not represent the current state of the art analytical capabilities. State of the art capabilities in many cases requires much more sophisticated techniques, chemistry, equipment and additional time and cost.

7.7 Background Concentrations

Background data were obtained from a variety of sources, including annual reports, Records of Decision, and other documents. Data are provided as a range of the minimum to maximum detected concentrations. Where DOE site background data were unavailable, state data were used (for the state in which the DOE site is located).

7.8. Findings

A. Five of the 14 radionuclides can routinely be detected at 1E-6 risk level at levels that are not affected by the background concentration (Am-241, I-129, Pu-238, Pu-239, and Tc-99). The other 9 radionuclides occur regularly in the environment at concentrations that make it difficult to distinguish between background and man-emplaced radionuclides at the 1E-4 to E-6 residual risk levels (Cs-137, H-3, Ra-226, Sr-90, Th-230, Th-232, U-234, U-235, and U-238).

B. Commercial laboratory methods can be used to detect 10 of the 14 radionuclides at concentrations equivalent to risk levels in the 1E-4 to 1E-6 residual risk range for residential land use scenarios. Four of the 14 radionuclides evaluated cannot be detected using standard practices at commercial laboratories because their minimum detectable concentration is greater than the concentration required to achieve the 1E-6 risk level for residential land use scenario (I-129, Ra-226, Tc-99, and Th-232).

C. Since the existing background levels of Ra-226, U-234, U-238, Cs-137, and Sr-90 in the environment throughout the United States are in the same range as levels needed to meet possible residual risk levels of 1E-4 to 1E-6 for the residential scenario, determination of whether the radionuclide was background or man-emplaced is not feasible.

7.9. Study Conclusions

Although the study was limited and data are still being gathered and analyzed, the findings (see Figure 4) indicated that it may not be technically feasible to verify soil cleanup standards required to meet residual risk levels of 1E-4 to 1E-6 for residential land use for certain radioisotopes at DOE sites for the following reasons:

- Naturally-occurring or fallout produced background levels are in the same range or higher than residual risk level of 1E-4 to 1E-6 for some radionuclides at some DOE sites.
- Commercial laboratory detection capability is currently not available to measure some radionuclides present in soil at DOE sites at the concentrations needed to meet the 1E-4 to 1E-6 residual risk levels for residential land use scenario.

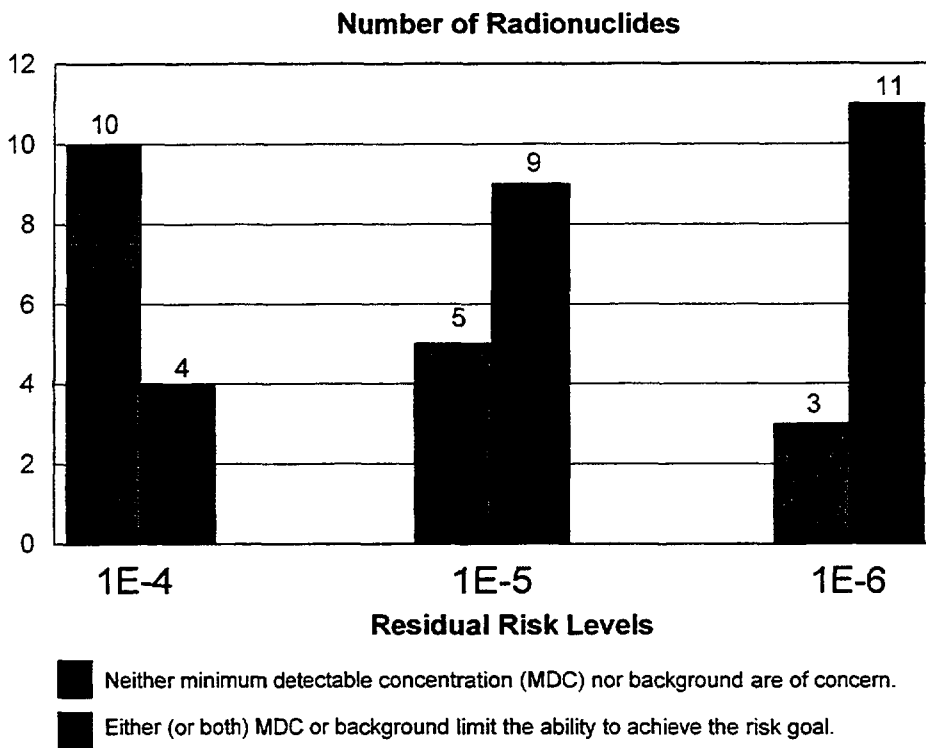


FIG. 4. Summary of results of 14 radionuclides examined at 14 DOE sites.

8. CONCLUSIONS

Because of their size and complexity, environmental management programs require extraordinary attention be paid to management issues. Their successful completion requires accurate scoping and informed priority setting.

Environmental restoration is only one segment of a comprehensive clean up effort but it should be guided by a clearly defined mission statement, accomplished under a carefully constituted set of priorities, and judged against measures which are formulated to track their overall success.

Standards for remediation should be based on planned future use for the remediated land or structures. Evaluation of priorities based on risk and cleanup standards related to risk will aid in the effectiveness of the work performed but represent a challenge to formulate and defend.

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MANAGEMENT STRATEGIES

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DISPOSAL CONCEPTS AND DISPOSAL ALTERNATIVES

C.J. ALLAN, J. McMURRY
Atomic Energy of Canada Limited,
Pinawa, Manitoba, Canada

Abstract

Land-based disposal concepts—including geological repositories, near-surface repositories, and shallow burial in trenches or reinforced vaults—are the main types of disposal that have been implemented or that are currently being developed for radioactive wastes. A key issue in disposal is whether the waste is suitable for surface or near-surface disposal (short-lived) or requires geological disposal (long-lived). The disposal of short-lived wastes can be effected in shallow or near-surface facilities with a combination of engineered systems in concert with institutional controls, but the objective for long-lived wastes is to develop a passively safe system so that safety does not depend on institutional controls in the long term. For long-lived wastes, there is a broad international consensus among waste management experts that the preferred method of waste management is based on deep geological disposal, which utilizes a system of engineered and natural barriers to ensure long-term safety. Other disposal concepts—including disposal at sea, in ice sheets, and in space—also have been considered over the years. Currently none of these other concepts are being pursued because they have been found to be poorly controllable, confront international sensitivities, or pose unacceptably high risks. Alternate waste management practices and options, such as dilution/dispersion, decontamination, incineration, prolonged storage, reprocessing, and transmutation, can supplement disposal; however, none of these ultimately eliminate the need for disposal. Methods of waste reduction for short-lived LILW can have a significant impact in reducing overall volume for disposal. Prolonged storage, though likely to be safe for many decades, is not a permanent solution, and it transfers the burden of responsibility to future generations. Treatment of used fuel by reprocessing, possibly augmented by transmutation, does not obviate the need for geological disposal.

1. INTRODUCTION

Throughout this century, the application of nuclear science has produced many benefits—in medicine, in industry, and in the generation of electricity. As with all human endeavors, these applications lead to the accumulation of waste. The waste generated by nuclear technology can have different physical and chemical forms and a range of concentrations with widely varying half-lives. The radioactivity in nuclear waste can range from very low levels of intensity, such as in waste resulting from the use of radioisotopes in medical diagnostic procedures, to very high levels, such as in waste resulting from the reprocessing of used fuel. Radioactive waste may be very small in volume but intense in activity, such as spent, sealed cobalt-60 sources, or very large and diffuse, such as the tailings from the mining and milling of uranium ores.

Just as there are different types of radioactive wastes, a number of different strategies over the years have been considered, implemented, or are being developed to manage these wastes. The purpose of this paper is to summarize the main disposal concepts and alternative waste management practices, and to discuss their viability.

Radioactive waste classification procedures group wastes according to the physical, chemical, and radiological properties that are of importance for a particular set of operational requirements. For example, the intensity of radiation is an important classification characteristic for present-day handlers of waste because it affects the amount and type of operational shielding that is required to isolate and handle the waste safely. In contrast, a key issue for disposal is whether the waste is suitable for shallow or near-surface disposal (short-lived wastes) or requires geological disposal. A third characteristic, which is important for both long-term and present-day safety, is the heat-generating capacity of the waste. Besides radiological hazards, waste can also

have chemically toxic properties that may represent an environmental concern and which need to be taken into account in handling and disposal.

The classification of radioactive waste proposed by the IAEA [1] combines concerns about long-term safety with those about present-day (operational) safety. In the proposed classification, wastes are characterized by hazardous lifetime (short-lived, long-lived) and by increasing intensity of radiation (LLW, ILW, HLW).

As is true for other hazardous substances that cannot be recycled or displaced by alternative technologies, there are essentially two options for management of radioactive waste. The first option is to contain and isolate the waste from the environment for as long as is necessary. The second option is to disperse material at levels that do not produce an unacceptable radiological risk. Most radioactive waste management strategies are based on a combination of these two options, but the emphasis is on containment and isolation for the large majority of the wastes. Dilution and dispersal are implemented less in terms of direct discharge to the environment than as part of a natural cycle of matter. Our world is a product of complex interactions among the atmosphere, the hydrosphere, the pedosphere, the lithosphere, and the biosphere [2]. The cycled residence times of elements and compounds in these various reservoirs differ greatly. Toxic elements released to the atmosphere could circulate globally within a year or two, and the same elements may be cycled through the ocean or the shallow subsurface in tens or hundreds of years. In contrast, it is possible to isolate toxic elements in deep geological formations for up to millions of years [3].

2. DISPOSAL CONCEPTS

The main types of disposal concepts that have been implemented or that are currently being developed for radioactive wastes are land-based--including geological repositories, shallow burial in trenches or below-ground vaults, and near-surface repositories. Other disposal concepts--including disposal at sea, in ice sheets, and in space--have also been considered over the years. Currently none of these latter disposal concepts are being pursued as feasible waste management strategies.

2.1. Land-based disposal concepts

In developing disposal strategies for wastes that contain predominantly short-lived radionuclides, advantage can be taken of the fact that the hazard from such waste will decay to a level at which there is no residual risk to human health or the environment after a suitable period of time (up to a few hundred years). Disposal concepts for short-lived wastes can rely on institutional controls and/or engineered systems that have a limited lifetime, on the order of several hundred years, to contain and isolate the waste. During this time, the majority of the radionuclides will decay, mitigating or eliminating the risk posed by any eventual failure of containment. Some wastes, particularly used nuclear fuel and the solidified waste that is produced by reprocessing used nuclear fuel, contain a number of radionuclides with very long half-lives and so present a hazard for many thousands of years. Neither institutional controls nor engineered systems can be expected to contain and isolate such long-lived wastes indefinitely.

2.1.1 *Deep geological repositories*

Geological disposal has emerged as the method that is currently regarded as the most viable concept for the management of long-lived radioactive waste. The approach is defined by the IAEA as "the emplacement of waste in a facility constructed in a deep geological formation

with reasonable assurance for safety, without the intention of retrieval and without reliance on long term surveillance and maintenance" [4]. Long-term safety is based on a multibarrier concept that includes as components a stable waste form, long-lived waste packages, other engineered structures, and the natural barriers associated with the site. Together, these features provide for containment and isolation on the scale of many thousands of years. Where the effectiveness of engineered barriers in a deep disposal facility may eventually decrease, the loss of containment of radionuclides is gradual, and this, coupled with radioactive decay as well as with dilution and dispersal at depth, reduces adverse impacts in the biosphere. Safety is assessed usually on the performance of the system as a whole, but the multibarrier approach also means that any deficiency in a given barrier is compensated, at least to some extent, by the properties of the other barriers.

In several countries formal environmental and safety assessments for deep geological disposal have been carried out (e.g., Sweden, Finland, and Switzerland) or are in progress (e.g., Canada). For the most part, national programs have concentrated on research and development activities to evaluate the safety and feasibility of various design options, the selection of suitable disposal sites, and optimization studies covering safety, environmental, industrial, and economical issues. It is generally estimated that disposal facilities for long-lived waste will not be operational before about 2010-2020.

Geological disposal need not be and indeed probably cannot be limited to HLW from nuclear fuel. The safety cases for shallow disposal facilities and near-surface geological repositories are based on institutional controls and/or engineered barriers that have a limited lifetime, on the order of several hundred years, during which the containment is "guaranteed" and during which the majority of the radionuclides in short-lived waste will decay. Beyond this period of "guaranteed" containment, the material remaining is effectively no longer controlled. Hence the amounts of long-lived radionuclides in LILW--e.g., alpha emitters, ^{14}C , and ^{129}I --that can be disposed of safely in near-surface facilities are not essentially different from the amounts of long-lived radionuclides that can be released without restriction. In economic terms, the cost to enlarge a facility that is being constructed for nuclear fuel waste to accommodate other types of long-lived waste is relatively small. Thus a number of countries, including Belgium, France, Sweden, and Switzerland are planning to dispose of nuclear fuel waste as well as other long-lived wastes in a deep geological repository, and to deploy near-surface disposal facilities for short-lived wastes [5,6]. Germany has decided to dispose of all kinds of radioactive waste, including short-lived LILW, in deep geological formations. The Morsleben repository in a disused potash and salt mine has been operated since 1981 for the emplacement of short-lived LILW and spent radiation sources. After German unification, waste emplacement was suspended in 1991 to examine questions about safety and licensing procedures in the facility [7] but now has resumed. Germany is also awaiting licensing approval to place non-heat-generating short-lived wastes in the Konrad repository, a disused iron ore mine.

The depth of a repository for geological disposal depends on the specific geological characteristics of a site, the engineered characteristics of the system, the nature of the waste, and the regulatory requirements for long-term safety. Generally speaking, however, it is projected that geological repositories will be constructed at depths of 250 to 1500 metres [8,9]. Desirable geological features include a mechanically stable formation in which to construct the repository, groundwater geochemistry that enhances the stability of the wastefrom and the engineered barriers, a low groundwater flux, and long groundwater transport time from disposal depth to the surface. In addition to retarding the migration of radionuclides by sorption, matrix diffusion, and dilution, the geosphere enhances long-term safety by protecting the system from damage

from surficial processes, such as glaciation or flooding, and by decreasing the risk of inadvertent human intrusion [10].

2.1.2 Shallow disposal

Shallow disposal refers to the emplacement of wastes at or very near the surface [11]. Used mostly for LLW, shallow land-based disposal has been practiced internationally for over 30 years. Probably the simplest shallow disposal method has been the use of unlined earth trenches [12]. The greatest success for this approach has been for sites located in arid areas. In wetter climates this method has been less successful. Under certain circumstances such as trench flooding due to improper siting or inadequate drainage, radionuclides can spread laterally beyond the zone of the trench, downwards into the soil profile, and in some cases into local streams and groundwater [13]. Under arid conditions, however, there is little or no percolation of groundwater through the buried waste, and radionuclide leaching and transfer to the groundwater is very low. A successful example of this disposal method was the U.S. operation at Beatty, Nevada, which has now closed. A comparable operation is being planned for a disposal facility at Ward Valley in the Mojave Desert, where the water table is more than 200 m below ground level.

In regions where groundwater leaching of radionuclides is a safety consideration, additional engineered components increase protection. Many countries use lined or concrete-reinforced trenches or tile holes for the disposal of short-lived wastes. For example, at the waste management facility at Rokkasho that is operated by JNFL in northern Japan, short-lived wastes in metal drums are placed in reinforced concrete trenches, which are filled with mortar, closed with concrete, and covered with a bentonite-sand mixture and soil [14]. Below-ground vaults with concrete lining and underdrains are used at the Drigg site in the United Kingdom. In the mounded-type design that was used at the Centre de la Manche in France, low-level waste was placed in concrete modules on concrete pads both below and above the original land surface [12].

In recent years, more complexly engineered shallow vaults have been designed for short-lived wastes. France and Spain have begun disposing of LILW in recently opened shallow structures at Centre de l'Aube and at El Cabril, respectively, that are designed to allow unrestricted use of the site after about 300 years. At both facilities, the floors of the disposal structures collect any infiltrating water and channel it away from the structure for monitoring. The facility at Centre de l'Aube isolates wastes in structures built above the highest level of the water table. It features movable buildings that prevent rainwater from contacting the waste disposal area during operations [14,15]. At El Cabril, waste packages are placed inside modular concrete containers that in turn are stacked within engineered disposal structures [16]. If retrieval of waste should ever become necessary, the modular design would simplify the process [17]. In Canada, a prototype near-surface facility known as an Intrusion Resistant Underground Structure (IRUS) has been designed. An IRUS unit would consist of a below-ground vault with reinforced concrete roof and walls and a permeable floor, located on a free-draining sand ridge above the water table. The multiple-barrier structure is designed to last for 500 years.

In all types of shallow disposal, the trenches or the structures are covered with layers of natural and/or artificial materials designed to prevent or reduce the effects of infiltration or erosion by wind and water. These layers are also designed to minimise intrusion by plants and animals. The risk of human intrusion, particularly after institutional control has ended, nevertheless generally remains a key factor in safety assessments for shallow disposal facilities.

2.1.3. Near-surface repositories

The engineered barriers in these repositories are similar in many ways to those for shallow disposal vaults, but near-surface repositories also resemble geological repositories in that their design includes a zone of undisturbed rock or sediment that physically separates the emplaced waste from the surface environment. Besides taking advantage of the possibly beneficial hydrogeological and geochemical properties of this natural barrier, such a design greatly reduces the risk of inadvertent human intrusion.

Near-surface repositories, at depths of more than 50 m, have been successfully licensed and are in operation in several countries. In Sweden, the Final Repository for Radioactive Operational Waste (SFR) was constructed for disposal of LILW in gneiss, a crystalline metamorphic rock, at a depth of 60 m under the Baltic Sea near Forsmark; this facility has been operating since 1989. In Finland, the utility TVO has been operating the VLJ repository for LILW since 1992 at Olkiluoto [18]. LLW and ILW are separated and placed in concrete-lined silos excavated in crystalline bedrock at a depth of 70 to 100 m below ground surface. The utility IVO is constructing a comparable facility at a depth of about 110 m in Rapakivi granite near the Loviisa plant site. Plans for all of these facilities call for an eventual expansion of the repository in order to accept decommissioning wastes.

A number of other countries, including Belgium, Canada, Germany, Finland, and the United Kingdom are also examining the disposal of short-lived combined LLW and ILW in near-surface repositories at depths of more than 50 m. Similarly, South Korea is studying the feasibility of constructing a near-surface repository on a largely uninhabited island, Kurrup-do [12,19].

2.1.4. Hydrofracturing and In-Situ Bulk Grouting

Two alternative land-based disposal methods are being investigated by China for disposing of liquid radioactive wastes [14]. In the hydrofracturing process, liquid wastes are to be mixed into a cement and pumped into fractures of a deep geological formation such as shale. In the in-situ bulk grouting process, the cement-mixed wastes are to be pumped directly into underground reinforced concrete vaults. The controllability and viability of these techniques are being assessed.

2.2. Deep sea disposal

2.2.1. Disposal into the ocean

Disposal into the ocean is a disposal concept that has been used historically by a number of countries for limited amounts of radioactive waste, but it is no longer supported internationally. Prior to 1983, the controlled dumping of containers of radioactive waste in the North Atlantic Ocean was practiced by member states under the surveillance of the Nuclear Energy Agency of the OECD. Concerns about possible environmental and health effects associated with this practice led to the London Dumping Convention in 1983, which established a voluntary moratorium on the sea dumping of HLW and some types of ILW. This agreement gradually has been replaced by a complete international prohibition on the sea dumping of radioactive waste [3,20]. Investigations into the possible health risks from such practices to human health and the environment are continuing [14,21].

2.2.2. Seabed disposal

In contrast to disposing of wastes directly into the ocean, disposal under the seabed is a form of geological disposal. The concept involves putting containers of waste tens to hundreds of metres deep in sediments or rock beneath several thousand metres of ocean water. Most proposals considered for this type of disposal are for areas far from continental margins and from the edges of tectonic plates. These areas would be preferred because they are locations where geological conditions are expected to be stable and predictable and where important biological and mineral resources are expected to be absent [22].

Two main waste emplacement options for seabed disposal have been investigated-- emplacement by free-falling penetrators and emplacement in boreholes. In the penetrator option [23], a missile-shaped penetrator containing titanium or steel containers of waste would be dropped from a disposal ship with the intention that it would embed itself up to 70 m deep in the seabed sediments. Field trials of about 100 penetrators have demonstrated that this method of emplacement is feasible. In the trials, the holes closed behind the penetrators to the extent that no significant differences between the properties of the disturbed and undisturbed sediments on the seabed could be detected. In the borehole option [24], strings of containers would be lowered from a ship into predrilled boreholes several hundred metres deep. For this option the drilling technology is considered to have been demonstrated by the Deep Sea and Ocean Drilling Projects of the United States National Science Foundation, although sealing of seabed boreholes has not been demonstrated.

For a decade beginning in 1977, countries conducting research on seabed disposal of nuclear fuel waste exchanged information as members of the Seabed Working Group (SWG), established by the OECD/NEA. Belgium, Canada, France, the Federal Republic of Germany, Italy, Japan, the Netherlands, Switzerland, the United Kingdom, the United States, and the Commission of European Communities were members of the SWG. The objective of the SWG was to provide scientific and technical information to enable national and international authorities to assess the feasibility and safety of seabed disposal.

The SWG conducted geotechnical studies to varying levels of detail in 15 study areas in the North Atlantic and North Pacific Oceans. On the basis of engineering studies, the group concluded that emplacement by penetrators or in boreholes was feasible, but that further tests were required both to confirm the results obtained so far and to demonstrate that the seabed sediments would be an effective barrier to transport of contaminants from boreholes. For several hypothetical sites in the detailed study areas, the SWG also estimated potential radiological consequences of penetrator emplacement of reprocessing wastes. For the particular sets of assumptions used, the calculations showed that only transportation accidents were likely to cause adverse effects, and then only if containers of waste could not be recovered.

Although the work of the SWG suggested that seabed disposal was potentially both feasible and safe, its implementation would depend on international acceptance and on the development of an appropriate international regulatory framework. Neither of these prerequisites exist, nor are they likely to exist in the foreseeable future. Therefore, even though it may be technically feasible, seabed disposal is not currently a viable waste management option.

2.2.3. Subduction zones

Disposal in deep oceanic trenches associated with subduction zones has also been proposed [25]. Subduction zones include areas of the earth along some continental margins

where the continental crust (one tectonic plate) is moving over the adjacent ocean floor (another tectonic plate). The intent of this disposal concept is that the emplaced waste would be carried deeper into the earth with time as the ocean plate was overridden by the continental plate.

The same adverse international considerations apply to disposal in a subduction zone as apply to deep seabed disposal [22]. Moreover, subduction zones are associated with the most unstable regions of the planet's surface, where earthquakes and volcanoes are common, and they are generally associated with coastal areas where biological resources are concentrated. Furthermore, not all sediments on a descending plate are carried to depth; in some cases they are scraped off and deformed near the contact of the plates.

If land-based access to a subduction zone were to be used rather than the technology proposed for seabed disposal, a major research and development effort would be required to establish the feasibility of identifying and penetrating the plate boundary at suitable depths and to determine what depths would be suitable in the plate boundary environment. The engineering requirements for disposal in a subduction zone have not been investigated.

2.3. Disposal in ice sheets

Three main concepts have been considered for disposal of nuclear fuel waste in the very thick ice sheets of Antarctica and Greenland--meltdown, anchored emplacement, and surface storage [26]. In the meltdown concept, the heat-generating containers of waste would be placed in shallow boreholes in the ice and allowed to melt their way down to the base of the ice sheet over a period of about a decade. In anchored emplacement, the containers would be attached by cables to a surface anchor that would limit their penetration into the ice to a depth of 200 to 500 m. This concept was designed to provide waste retrievability for a period of a few hundred years before additional accumulation of ice covered up the anchors. In surface storage, containers would be placed in a storage facility constructed above the ice surface on piers. As the piers sank, the facility could be jacked up to remain above the ice for perhaps a few hundred years. Then the entire facility would be allowed to slowly sink into the ice sheet.

There has been little research on ice sheet disposal, largely because waste disposal in the Antarctic is expressly forbidden by international law, as set forth in the Antarctic Treaty and the Madrid Protocol. Alternative sites on the Greenland ice sheet are under Danish jurisdiction and so are excluded from consideration in the national programs of other countries. Other problems with ice sheet disposal include high transportation and handling costs, and uncertainties in the climate of these regions over the geological time span for which containment must be considered [9]. Therefore, even though ice sheet disposal may be feasible technologically, it is not currently a viable alternative. Permafrost, however, continues to be evaluated in Russia as a possible medium for a geological repository for long-lived reprocessing waste and spent nuclear fuel from RBMK graphite-moderated reactors [14].

2.4. Disposal in space

Disposal of nuclear fuel waste by sending it into space has the attraction of removing waste from the surface environment for all time. The various concepts that have been considered include using space shuttle technology to place the waste into a permanent orbit between Earth and Venus and using rockets to fire the waste directly into the sun. The main problems involved with disposal of radioactive waste in space are the extremely high cost of this option and the comparatively high probability of launch failure with catastrophic vehicle loss, which makes the radiological risk for disposal in space much greater than for geological disposal [9].

Even if disposal in space were restricted to waste from reprocessing used fuel, the economics of launch payloads would mean that this option could be considered only for the most problematic radionuclides [27], thereby requiring additional processing of the waste stream to extract these elements. The need for disposal of the other wastes would not be eliminated. Even more compellingly, this option has been all but eliminated from consideration by the risk of launch failures such as the Challenger disaster in 1986 and by the adverse repercussions of the \$8 million search and clean-up exercise in northern Canada in 1978 after the breakup on re-entry of a satellite nuclear power-pack.

There are also legal and ethical concerns associated with disposal in space. International acquiescence, if not approval, would be required for the use of space for disposal. Countries without a space program would also need the approval of a nation with launch facilities and permission to transport their waste through that nation.

3. ALTERNATE WASTE MANAGEMENT PRACTICES AND OPTIONS

Over the years, a number of practices and possible options have been developed or are being considered for radioactive waste management. Some of these alternate methods may supplement--though ultimately they do not replace--the need for disposal.

3.1. Dilution/dispersion

The direct discharge of liquid and gaseous effluents from a nuclear facility and their subsequent dilution and dispersion is permitted by regulatory agencies provided that releases are controlled to ensure that human health and the environment are protected. But as alternatives to containment and isolation of most types of radioactive waste, dilution and dispersion generally are not viable disposal options. It should be noted, however, that dilution and dispersion have an important role in geological disposal concepts. They are a safety factor in any system that cannot guarantee "zero release", which is to say that they are a factor in any system that must function over many thousands of years.

3.2. Decontamination and incineration

By enabling the reuse or recycling of tools, equipment, and other materials, decontamination significantly reduces the volume of radioactive material that otherwise would require disposal. In addition to the practical need for decontamination in the day-to-day operations of a nuclear facility, it is recognized that decontamination is an important component of decommissioning such a facility [28].

Decontamination procedures generally result in contaminated liquid or gaseous cleaning streams, which themselves must be decontaminated by various waste conditioning activities to reduce the residual concentration or total amount of radionuclides below limits set by the regulatory body for the discharge of liquid or gaseous effluent from a nuclear facility. Waste concentrates then are stabilized in solid form, packaged, stored, and eventually sent to a disposal site.

Experience has shown that between 50 and 80% of solid radioactive waste produced at nuclear power plants can be classified as burnable waste [12]. Incineration of this waste provides a substantial reduction in volume and mass over other waste reduction methods such as compaction. Although incineration is only suitable for combustible waste, it can destroy organic

liquids which otherwise are difficult to treat. The final product is a homogeneous ash that can be packaged into containers without further treatment.

Current incineration equipment used in nuclear facilities is fitted with high-performance filters and sometimes scrubbers for gaseous effluents to protect both workers and the general public from potential exposure to radionuclides or toxic chemicals. Centralized waste facilities in Sweden, Belgium, France, and a few other countries have more complex incineration units that can treat waste with relatively high specific activity [12].

Both decontamination and incineration of wastes change the characteristics and the volume of waste, but ultimately a solid wasteform remains. The wasteform requires storage and disposal. Therefore, decontamination, incineration, and other methods of waste reduction can supplement but do not eliminate the need for disposal.

3.3. Prolonged storage/containment

Prolonged storage of waste is a form of containment and isolation; it differs from disposal in that further handling or retrieval of the waste is intended at some time. Most issues and concerns involving prolonged storage pertain to long-lived wastes. Even countries without nuclear power programs can have small but hazardous inventories of long-lived wastes derived from medical, industrial, and research-related nuclear applications. Continued storage of these wastes is necessary until one or more of the long-term waste management options are put in place. Nuclear fuel waste worldwide is presently stored either in water-filled pools or in dry concrete or metal structures. Although heat and radiation intensity decay exponentially while the fuel is in storage, some of the radioactive waste material in used fuel represents a potential health hazard for millenia. Surface storage systems have design lifetimes on the order of decades, not centuries, and they require continued surveillance, maintenance and periodic replacement of systems.

There is a general recognition that storage must be considered an interim measure for waste. Even so, in many countries public debate continues to address the possibility that it is short-sighted to pursue a strategy of immediate geological disposal rather than of prolonged storage, which would ensure that future generations of technologists have all options available. In the Collective Opinion of the Radioactive Waste Management Committee of the OECD Nuclear Energy Agency pertaining to the environmental and ethical basis of geological disposal, the Committee noted:

The indefinite storage and monitoring strategy has indeed a number of technical and ethical arguments in its favour, particularly if it were to be accompanied by suitable efforts to ensure continued development or improvement of options for final solutions and to ensure that financial resources would be available when needed at all times in the future. One interpretation of the concept of sustainability would support such an approach, wherein one generation would pass on to the next generation a world with "equal opportunity", and so on for the generations coming after, thus preserving options and avoiding the difficulty of predicting the far future. According to this idea of a "rolling present" the current generation would have a responsibility to provide to the next succeeding generation the skills, resources, and opportunities to deal with any problem the current generation passes on. However, if the present generation delays the construction of a disposal facility to await advances in technology, or because storage is cheaper, it should not expect future generations to make a different

decision. Such an approach in effect would always pass responsibility for real action to future generations and for this reason could be judged unethical.

A most significant deficiency of the indefinite storage strategy is related to the presumption of stability of future societies and their continuing ability to carry out the required safety and institutional measures. There is also a natural tendency of society to become accustomed to the existence and proximity of storage facilities and progressively to ignore the associated risks. Such risks would actually increase with time in the absence of proper surveillance and maintenance, leading at some indefinite future time to possible serious health and environmental damage. There are many well-known examples of bad environmental situations inherited from the past which show that this deficiency of a waiting strategy should not be underestimated [29].

From an ethical standpoint, taking into account long-term safety considerations, present-day responsibilities to future generations with regard to the management of long-lived radioactive waste are better discharged by a strategy of final disposal than by reliance on strategies which require institutional surveillance, bequeath long-term responsibilities of care, and may in due course be neglected by future societies whose structural stability should not be presumed. Also, it is worth noting that geological disposal does not necessarily rule out retrieval of the emplaced wastes if this is desired by society in the future, although the cost of retrieving waste could be significant after the operational phase of the disposal facility had ended.

3.4. Reprocessing

Reprocessing refers to the practice of recycling used fuel by extracting plutonium, uranium, and undesirable fission products and actinides. The plutonium is available for re-use as fuel. The uranium may be recycled as fuel or may be used for other applications, but in many cases it is considered to be a waste product because it is depleted in fissionable ^{235}U . The fission products and remaining actinides, which comprise only a small fraction of used fuel, are incorporated into a suitable matrix, such as glass, for disposal. The vitrified waste form is highly active, heat-generating, and contains long-lived radionuclides. Reprocessing also is an option for some types of research reactor fuel--to produce a more stable wasteform, for example--though it may or may not involve the recovery of the fissile material.

Although it changes the characteristics of the wasteform, reprocessing used fuel does not alleviate the need for geological disposal. Moreover, the size and cost of the required repository would not be affected significantly. This result comes about because the quantity of heat-generating waste per unit volume of a repository is limited by the maximum acceptable heat load from the waste on the waste container, on the repository sealing systems such as clay-based buffer materials, and on the surrounding host geological formation. The amount of heat that used fuel generates depends on the fuel burnup, which normally corresponds to the amount of electricity that was generated by the fuel, and the time elapsed since the fuel was removed from the reactor. Reprocessing does not reduce the heat-generating capacity of the waste. Consequently, the size of the repository required to allow dissipation of the heat is similar for a given amount of electricity production regardless of whether the waste form is used fuel or a smaller volume of heat-generating vitrified waste from reprocessing. As well, the overall cost of geological disposal includes many more-or-less fixed costs, such as those associated with site characterization, the construction of shielded waste handling facilities, supporting research and development, safety assessments, etc. These costs do not depend so much on waste volumes as on factors such as geological setting and the design of the waste container, including in the case

of vitrified reprocessing waste, the design and cost of any overpack that might be adopted. For example, the Swiss and Japanese systems include overpacks, the volume of which can be close to a factor of 10 greater than the volume of the vitrified waste form [30,31]. Thus, the costs of disposal, not including the cost of reprocessing, per unit of electricity produced, are comparable for the direct disposal of used fuel and for the disposal of the long-lived wastes that arise from reprocessing [5].

Reprocessing operations also produce streams of LILW that contain long-lived radionuclides. These relatively more voluminous wastes do not generate significant amounts of heat, but many countries are basing their plans on deep geological disposal to isolate these wastes from the biosphere. In some ways this waste can present more of a disposal challenge to the waste manager. Efforts are under way to reduce the volumes of these wastes [32], but nonetheless they represent a waste stream that will be disposed of in a deep repository.

Recycling fuel does have the advantage that less newly-mined uranium is required to produce a given amount of electricity. As a result, fewer tailings from uranium mining and milling operations will require long-term management. If minimization of mine and mill tailings were the only issues in deciding whether or not to reprocess fuel, then reprocessing would be favoured. However, decisions on whether to reprocess fuel are determined by the need to balance such considerations as the cost of different fuel cycle management options, the availability of indigenous fuel resources, the desire to maximize energy extracted from uranium resources, the capacity of interim storage for used fuel, and the energy value of recovered uranium and plutonium as feedstock for the manufacture of new fuel. The question of whether or not to reprocess used fuel from power reactors is thus not fundamentally a waste management issue.

3.5. Partitioning and transmutation

It is possible to destroy some radionuclides with long half-lives by transforming them into either stable nuclides or into nuclides with shorter half-lives. Transmutation, a nuclear process, transforms one nuclide into another by bombardment with subatomic particles in nuclear reactors or in particle accelerators designed for this purpose. Treatment of nuclear fuel waste by transmutation would first require reprocessing the used fuel and partitioning the waste stream to separate the resulting species according to the various nuclear methods to be used to transmute the different radionuclides.

The potential for partitioning and transmutation has been reviewed by many agencies. Early studies in the U.S. concluded that it was theoretically possible, following reprocessing, to separate and transmute some but not all of the hazardous fission products and activation products with long half-lives [33], but the studies also concluded that there were no safety or cost incentives for pursuing transmutation as a waste management strategy. The IAEA reached similar conclusions on the basis of European studies, but it placed more emphasis on the immense magnitude of the technical effort and the cost that would be associated with transmutation in comparison with the small and uncertain potential benefit in terms of reducing the long-term radiological hazard [34]. In addition, as noted by Chapman and McKinley, "the large amount of processing involves handling vast quantities of very short-lived and hence extremely active radionuclides. This work results in considerable radiation exposure to the work force involved, which must be balanced against potential exposures to future populations, which are predicted to be very low (or negligible) in direct disposal techniques. This is an important factor which also has to be taken into account in waste conditioning. Present exposures to an

existing work force are real, whereas predicted small-scale benefits gained in the long term by having a more durable waste form, for example, are speculative and hypothetical" [9].

During the last ten years, however, commercial reprocessing has become a reality in both the UK and France, and plutonium is being recycled for use in commercial reactors. These developments, along with advances in reactor design and robotics as well as changes in the regulatory and public environment, have recently led to renewed interest in transmutation, particularly in France, Japan, and Russia [35,36]. Canada is studying the possibility of burning plutonium in combination with other actinides in an inert matrix in CANDU reactors [37]. In CANDU, the combination of good neutron economy, on-power refuelling and the possibility of high thermal neutron fluxes suggests that high consumption rates are feasible. Other aspects of partitioning and transmutation continue to be investigated by research programs in many other countries, including Belgium, China, Germany, Italy, India, Korea, Norway, the Netherlands, Sweden, Switzerland, and the United States [35].

Recent evaluations by the IAEA and by the Radioactive Waste Management Committee of the NEA/OECD nevertheless have emphasized that the current and proposed partitioning and transmutation programs are long-term projects that do not impact on the present fuel cycle strategy, and that the concept cannot avoid the need for long-term deep geological disposal [38,39]. American researchers similarly have concluded that there are no cost or safety incentives to introduce transmutation into the United States disposal strategy for highly radioactive waste [40]. This conclusion was based in part on their judgment that the risk from radioactivity from a geological disposal vault is very low, and the activation products that would be removed or reduced by transmutation do not contribute significantly to that risk. They further estimated that it would require 100 years of operation of a transmutation fuel cycle to reduce the inventory of the activation products in used fuel from existing American light-water reactors by 90 percent.

If nuclear fuel is to be reprocessed for the purpose of recycling, and if transmutation of some long-lived radioactive species can be effectively incorporated in the fuel cycle, then partitioning and transmutation may eventually be worthwhile. At present, however, the required efficiency of separation is beyond existing technology, and the advanced nuclear reactors or the neutronically inert fuel matrix that would be required have not yet been developed. Moreover, the need for geological disposal would still remain for other long-lived nuclides. Thus, the current perspective is that disposal of nuclear fuel waste and other material contaminated with long-lived radionuclides will be required whether or not used fuel is reprocessed, and whether or not practical techniques can be developed for separating and transmuting the long-lived waste components.

4. SUMMARY

A number of waste management strategies and concepts have been implemented or are being developed to deal with short-lived and long-lived radioactive wastes in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations. Of the various disposal concepts that have been evaluated, only land-based options are now considered viable. The other concepts are either poorly controllable, confront international sensitivities, or pose unacceptably high risks. Ultimately, no alternate waste management practices and options eliminate the need for disposal. Research and development should continue, however, into methods for reducing the volume and hazard of wastes.

The disposal of short-lived wastes can be effected in shallow or near-surface facilities by employing a combination of engineered systems in concert with institutional controls. Near-surface repositories for LILW are being planned, or have been licensed and are operating successfully, in a number of countries.

For long-lived wastes, there is a broad international consensus among waste management experts that the preferred method of waste management is based on deep geological disposal, which utilizes a system of engineered and natural barriers to ensure long-term safety. Although many technical issues involving geological disposal remain to be addressed, there is general agreement that these issues are tractable.

Prolonged storage, though likely to be safe for many decades, is not a permanent solution for the hazards posed by long-lived radionuclides, and it transfers the burden of responsibility for the waste to future generations. The objective for managing long-lived wastes is to develop a system that is passively safe so that safety does not depend on institutional controls in the long run. This does not mean that society will choose not to exercise institutional control, but it does mean that if such control is lost, for whatever reason, that the generation that has produced the waste will have done its best to meet its ethical obligation to prevent future generations from being exposed to unacceptable health risks and environmental degradation.

A key issue in waste management is whether a given waste is suitable for near-surface disposal or requires geological disposal. Only waste with limited quantities of long-lived radionuclides can be emplaced in shallow or near-surface facilities without exceeding regulatory safety criteria or guidelines for passively safe disposal.

All countries that utilize nuclear technology have accumulated radioactive waste. The cost of geological disposal remains an important issue for countries that have small quantities of long-lived waste from medical, industrial, and research applications, but that do not have to dispose of any nuclear fuel waste.

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SUPRA-NATIONAL ISSUES

K. KÜHN

GSF - Forschungsbergwerk Asse,
Remlingen, Germany

Abstract

Nearly all topics or issues being discussed during this Seminar - especially those with regard to repositories in geological formations - are "international or supra-national issues". This paper deals with some selected ones. Geology does not know or respect national boundaries. This is illustrated through the areas which were covered with ice in Europe during the last Pleistocene glaciation period which only ended some 10,300 years before now. Also, possible radionuclide releases from future geological repositories may easily cross presently existing national borders. Looking backward into our history, 300 years - the relevant time span which is considered for institutional control for near-surface repositories - are relatively long. In 1695, however, the United States did not even exist and Germany was a patchwork of different entities. Recent examples of national instabilities are the disintegration of the former Soviet Union and the split of the former Czechoslovakia. Reprocessing of spent fuel was politically declared "Europeanized" in the political discussion in 1989. The next logic steps to do the same for radioactive waste management and disposal were, however, not performed. Every country is still following its national strategy. Even discussion of international repositories is a political taboo. This Seminar should initiate or at least catalyze such discussions and possibilities. A very important supra-national issue is the harmonization of the regulatory framework for geological repositories. This is the more necessary because the problems - especially with regard to public acceptance - are nearly the same in all countries. A possible step forward could be done by either installing an independent "International Commission on Nuclear Waste Disposal (ICND)" in parallel to the well known and respected ICRP and/or by establishing a "Convention on the Safety of Radioactive Waste Management" within the IAEA.

1. INTRODUCTION

The Agency asked me to prepare a presentation on "Supra-national Issues" related to the requirements for the safe management of radioactive waste. If you have listened to the lectures of this Seminar on Monday and yesterday, you certainly will ask yourself: "Why do we need this specific presentation? Are not all the problems and questions which were presented and discussed up to now international or supra-national issues?"

Right you are! Radioactive waste management and especially radioactive waste disposal into geological formations are indeed supra-national tasks in general which only have a few national facets, like selection of a suitable site for a repository. But some of the issues are more supra-national than others. And on these, I want to focus my presentation.

2. GEOLOGY

The most recent geological period of our planet Earth is called "Quaternary" which is divided into two subsections. The older one is named "Pleistocene" and the younger one "Holocene". The Pleistocene period started about 1.8 million years before now and ended just 10,300 years before now. Consequently, the Holocene period covers the last 10,000 years. The Pleistocene is also called Glacial epoch or formerly Ice age.

In order to illustrate this situation with an example, I want to present a figure (Fig.1) which shows the extension of ice caps in northern Europe during the Pleistocene period [1].

As is illustrated by this figure there were three ice ages, named Elster, Saale, and Weichsel, with two warm periods in between. Let us concentrate just on the last ice age, i. e. the Weichsel period.

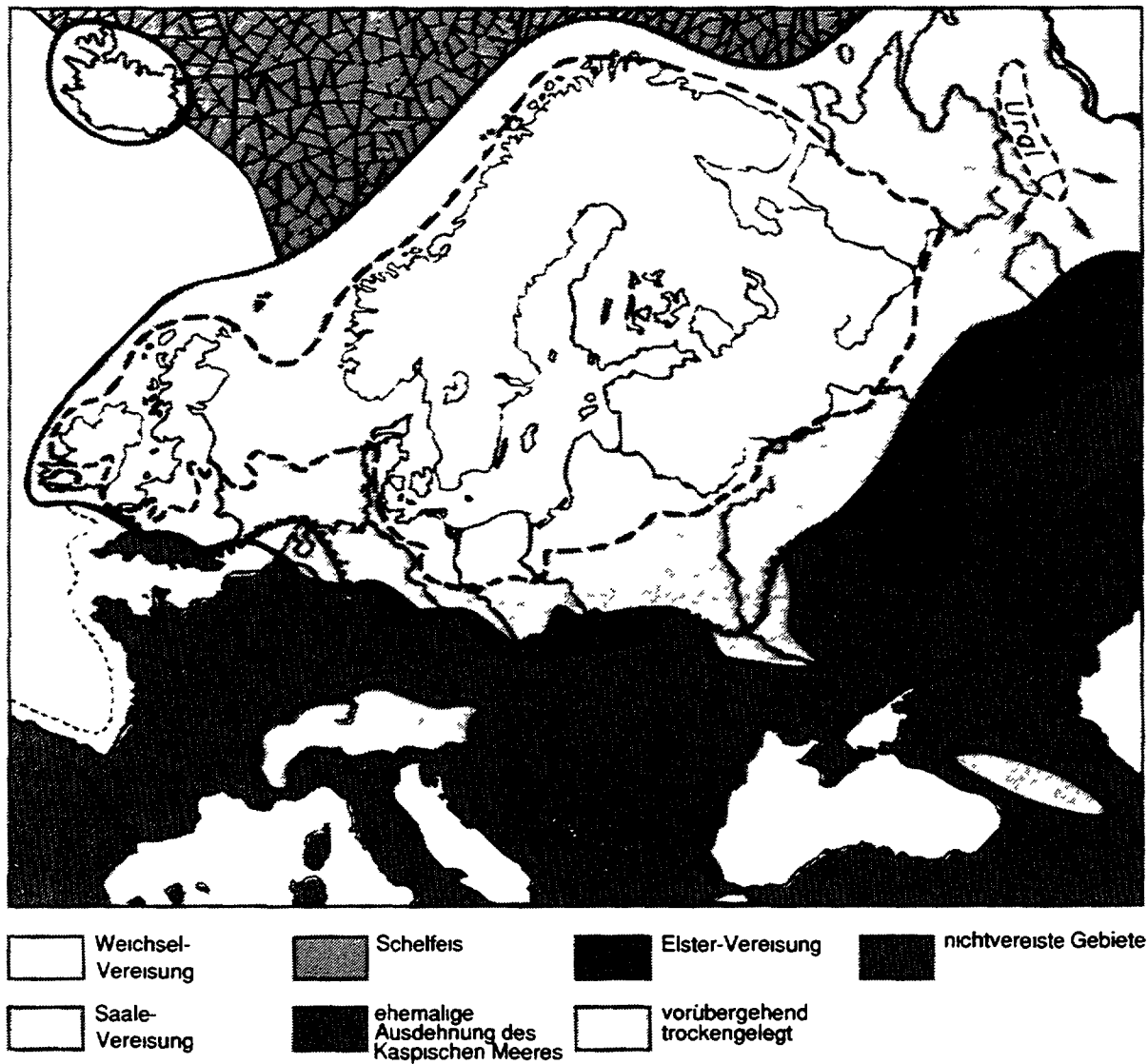


FIG. 1. Extension of glaciation in Northern Europe during Pleistocene [1].

This Weichsel glaciation started about 70,000 years before now. The ice covered whole Scandinavia, about two thirds of the United Kingdom, large parts of Denmark, Germany, Poland and Russia as well as the total area of the North and the Baltic Sea. The most striking fact is, however, that this Weichsel glaciation ended only 10,300 years before now.

I want you to keep this situation in mind when in later presentations, especially by Charles McCombie and by Helmut Röthemeyer, such topics as future generations, time frames, institutional control, record keeping, long-lasting markers, and safeguards will be addressed.

To predict the probability of a new glaciation to come within the next 10 to 20,000 years, seems to be very difficult, especially if we take into account the green house-effect caused by our today's CO₂ production which is so vehemently discussed at present. But also if the contrary phenomenon of polar ice melting with a connected raise of the sea level would occur: this would also be a supra-national issue.

Making these points, I do not want to be misunderstood. My main objective is, however, to underline that geology does not know national boundaries. Nevertheless, I am perfectly convinced that we are able to construct, to operate, and to seal repositories in geological formations, also with the necessary long-lasting safety. This is especially underlined by the fact that those time periods being discussed in connection with the long term safety of repositories, i. e. some hundred thousand up to a million years, are extremely short on the overall geological time scale. The salt of the Gorleben salt dome in Germany for instance, was evaporated from the ocean during the Permian Zechstein area, which means some 250 - 220 million years ago. The salt dome or salt diapir itself was formed during the Cretaceous and the Tertiary periods so that its present form received its final contours roughly 25 million years ago.

For each of the planned repositories in all the different geological settings or formations, long-term safety assessments are being performed. One major constituent of these safety assessments is that relevant events or scenarios might lead to a release of a small fraction of the radionuclide inventory from the repository into the environment. Especially, if the relevant repository is located close to a present national border this might cause a bilateral or even a supra-national problem. The question is, however, if this national border will still exist at the time when the radionuclide release will reach this location.

3. HISTORY

The keyword "institutional control" was already mentioned. Especially the concept of near surface disposal of short lived low- and intermediate-level radioactive wastes is including it as was outlined in the presentation of A. Prasad et al. earlier during this Seminar. The normal time span considered for this institutional control is about 300 years which results from ten half-lives of the isotopes strontium-90 and cesium-137.

In spite of living within relatively solid national boundaries for the last 50 years within the Western Hemisphere, a view 300 years backward into our history teaches us that there were great changes within this time span. The United States of America did not even exist in 1695, Germany was a patchwork of Counties, Duchies, Bishoprics and Electorates, and Russia was just underway to explore Siberia.

Most recent examples of changing national boundaries are the disintegration of the former Soviet Union in 1991, the German Reunification one year earlier and the split of the former Czechoslovakia into the Czech and the Slovak Republic in 1993.

Again, this very brief excursion into our history should not result in the conclusion that we can not realize repositories be it near surface ones or be it ones deep underground. But it clearly underlines that we should not rely too much on institutional control. We should build - as much as possible - long lasting inherent safety into our repository systems. The tools for this approach are available.

4. REPROCESSING AND WASTE MANAGEMENT

After these short comments on geology and history, I would like to address some actual supra-national issues with regard to radioactive waste management.

Interdependencies, cooperation and concentration are progressing with great pace worldwide in all areas of economy. This is also true for nuclear technology: There is a large world market for the construction of nuclear power plants. Reprocessing services for spent nuclear fuel are offered worldwide. A storage facility for vitrified high-level waste is not looking very different in Japan from one in the United Kingdom. But strangely enough, there is one exception: The disposal of radioactive wastes into geological repositories. In this area, every country tries to realize its own concept.

In the 70's and 80's, one main objective in Germany's nuclear fuel cycle policy was the siting and construction of an industrial reprocessing plant for spent fuel. After many violent ups and downs, construction was finally started at the site of Wackersdorf in the Federal State of Bavaria. Only shortly later, the German utilities which were financing these efforts, decided in 1989 to abandon the project for reasons which I will not comment on. Instead of plant construction in Germany, they signed contracts for reprocessing German fuel with France and the United Kingdom. These industrial contracts were backed by bilateral treaties between the governments of Germany and France or the United Kingdom, respectively. In the political discussion this procedure was declared "the Europeanization of reprocessing". The virtual next logic steps - at least in my mind - , namely "the Europeanization of radioactive waste management and especially of disposal" were, however, not performed. The contracts explicitly include a clause that all radioactive wastes originating from reprocessing foreign spent fuel have to be shipped back to the originating country. In France, this intention was even sanctioned in the law of December 30, 1991, on the research for radioactive waste management [2]. Art. 3 of this law reads as follows: "Le stockage en France de déchets radioactifs importés, même si leur retraitement a été effectué sur le territoire national, est interdit au-delà des délais techniques imposés par le retraitement". This might be translated as "The storage in France of imported radioactive wastes even if their reprocessing was performed on the national territory, is forbidden for longer technical periods than those which are caused by reprocessing".

In spite of these originally rigid positions, there seem to be some slight indications of policy change. First, integrated part of the reprocessing contracts was that bilateral - and if you want, you even can call it international - agreement had to be achieved on the specifications of those wastes which have to be taken back by the customers. The confirmation of these specifications has been reached meanwhile. One should not underestimate this procedure and the result because seven nations were engaged, namely France, United Kingdom, Japan, Belgium, the Netherlands, Switzerland, and Germany.

The next promising step comes from UK. The British reprocessing company BNFL proposed recently to substitute the relatively large volumes of low- and intermediate-level wastes originating from reprocessing foreign fuel by an additional amount of vitrified high-level waste to be shipped back [3]. In my personal opinion, this is a very attractive proposal into the right direction, because it does not make much sense to transport large amounts of "contaminated concrete" over many hundreds or even thousands of kilometers from one country into another for their disposal.

There are, of course, still some problems to be solved in the United Kingdom as well as in the customers' countries:

- The British Government must accept BNFL's proposal. (This occurred most recently with some conditions [4])
- The British public must be convinced that the pro's and con's are well balanced.
- BNFL's customers, their respective regulatory bodies and governments must agree.
- An appropriate tool for waste substitution must be established. The "Integrated Radiotoxic Potential (ITP)" has been proposed for this purpose [3-6].

Nevertheless, if this proposal of waste substitution could be commonly agreed upon this would mean for the first time that foreign waste would be disposed of in a national repository.

5. INTERNATIONAL REPOSITORIES

Up to now, there is in all countries the iron clad political rule to consider only national waste disposal schemes with national repositories. Even discussion of international repositories is a political taboo. To a certain extent, one can understand this dominant position taking into consideration all the difficulties which exist in nearly every country to establish a national repository and which we discuss at this Seminar.

On the other hand, one really can ask the question if it does make any sense, for instance in a "growing together Europe" - a beloved and frequently used expression by our top politicians - that every small country, like e. g.

- (1) The Netherlands with two nuclear power plants (0.5 GWe)
- (2) Finland with four nuclear power plants (2.4 GWe)
- (3) Switzerland with five nuclear power plants (3.1 GWe)
- (4) Belgium with seven nuclear power plants (5.8 GWe)

should site, construct and operate an own very sophisticated and expensive underground repository for very small quantities of high-level wastes or spent fuel?

This question is the more qualified because there exists a striking contrary example. A German industrial company is operating since 1972 the geological repository "Herfa-Neurode" into which quite a variety of chemical wastes is being disposed of. Out of the roughly 1 million tons of chemical waste which are disposed of annually, a little more than 10 % originate from other European countries outside the Federal Republic of Germany. This fact is not questioned at all by politicians and regulatory bodies, nor by the media or the public.

So, I hope that we can initiate or at least catalyze through this Seminar political and technical discussions on possible international repositories for radioactive waste. I am well aware that this idea is supported by international institutions, like the Commission of the European Union, the Nuclear Energy Agency of OECD, and also by this Agency. The disadvantage of these international bodies is, however, that they don't have territories. So, we have to convince our national governments and politicians that it is a worthwhile approach to discuss this possibility.

On the other hand, my appeal should in no way mean to stop the ongoing activities in the different nations to locate, construct and operate a repository. We urgently need two, three or four examples in order to demonstrate that the available concepts can be realized and the available tools can be successfully applied. I am also personally convinced that a discussion on international repositories can be executed much easier once one real repository is operating.

One other reason not to neglect or to slow down the national programs for construction and operation of repositories is a possible failure of my idea to install international repositories. In this case each nation will be responsible for the disposal of its own waste and should have available the necessary technologies and sites.

6. INTERNATIONAL COOPERATION AND HARMONIZATION

May be, time is not yet ripe for my proposal. On the other hand there exists a long and very successful history with regard to international cooperation in the area of research and development. There is quite a number of bi-, tri- or multilateral contracts for cooperation. Underground research laboratories were and are used commonly by several nations. You all know the names, like Asse salt mine, Stripa project, Felslabor Grimsel, URL near Pinawa, Äspö Hard Rock Laboratory, just to mention a few. International exchange of results and free, open technical discussions are well established in our field.

What we did not fully achieve up to now is public acceptance, as was and will be mentioned frequently during this Seminar. One step forward in this direction would be achieved in my mind if we can successfully harmonize our regulatory framework. In our scientific knowledge and understanding there is no real difference if the long-term safety goal of a repository is defined as a dose rate of 100, 200, or 300 $\mu\text{Sv}/\text{year}$ to a future person. But for the famous "man in the street", 100 and 300 are two different figures.

I want to make two points with this statement:

- (1) I do not believe that we can educate a typical member of the public to understand the objective meaning of "a radiation dose rate of 300 $\mu\text{Sv}/\text{year}$ " or the "annual deviation width of natural radiation", not to speak of "a risk of $10^{-6}/\text{year}$ ".
- (2) Consequently, we should undertake every possible effort to establish internationally harmonized or even better equal safety standards for repositories which are to be applied in all countries.

Of course, this idea or proposal is not new at all. There exist numerous institutions which try to meet this objective since quite some times. Let me name a few examples:

- (1) In 1992, the radiation protection and nuclear safety authorities of the five Scandinavian countries published their common report: "Disposal of high-level radioactive waste - Consideration of some basic criteria" [7].
- (2) The Commission of the European Union is active in this area since many years, especially through its "Plan of Action-Committee".
- (3) The Nuclear Energy Agency of OECD published among many other reports two collective opinions of its Radioactive Waste Management Committee, one in 1985 entitled "Technical Appraisal of the Current Situation in the Field of Radioactive Waste Management" [8] and another one - most recently in spring of this year - "On the Environmental and Ethical Basis of Geological Disposal" [9].
- (4) The International Atomic Energy Agency finally started its RADWASS-program some four years ago. One main objective of this program is to elaborate and to publish "Safety Standards" for radioactive waste management and disposal.

All these and other not quoted efforts are certainly very necessary and helpful. But they have one disadvantage in common: **They are all based and operating on a voluntary basis with informal, non binding recommendations.**

This statement does not mean that I am not aware of the enormous amounts of difficulties which do exist. I have worked for some decades with and for international organizations. But for the same reason, I believe I can judge the great advantage if we could be successful in internationally harmonizing our safety approach and evaluation for repositories in geological formations. This is really a supra-national issue and challenge!

You are completely right in asking me: What are your proposals to solve this issue? Here are two of them:

- (1) The International Commission on Radiological Protection (ICRP) is well established since about 50 years and accepted worldwide. Its reports on supra-national issues of radiation protection are not only accepted by the scientific community, but are taken over and/or transformed into national and international regulations.

However, it is correct to observe that the ICRP was founded 50 years ago and the then prevailing circumstances were indeed quite different. Nevertheless, the idea to enrich and to complement work on the nuclear waste issue by inputs from genuinely academic groups and institutions continues to be of value. As a matter of fact, the issue of radioactive waste disposal is one of our greater problems and will be with us for still quite some time. In 1993 on the occasion of the GLOBAL '93 Conference in Seattle the proposal was made to create an "International Commission on Nuclear Waste Disposal" (ICND) along such lines. In subsequent discussions this has led to a move which foresees possibly the operation of such a committee (rather than a commission) within the scope of the international "Council of Academies of Engineering and Technical Sciences" (CAETS). Such a move would be in close conjunction with the International Radioactive Waste Management Advisory Committee (INWAC) of the IAEA respectively its successor by appropriate organizational measures. Therefore not a

duplication but an enrichment is foreseen. This move is still underway at present and the outcome is to be seen.

- (2) The IAEA-Member States have agreed on a "Convention on Nuclear Safety" which was presented to this Seminar on Monday by Z. G. Domaratzki. Encouraged by this success, the Agency started an initiative earlier this year to elaborate a parallel "Convention on the Safety of Radioactive Waste Management" which was introduced during the Opening Session by G. A. Webb.

Even if a long list of questions, problems, and issues resulted from the respective first preparatory meeting, the Agency should not be discouraged to consequently follow this way. I also fully support it. But the difficulty which in my mind is inherent to an International Convention is that it cannot establish safety standards by itself, it can only lay the basis for later detailed efforts in this direction.

In summary: One of the most important supra-national issues in my personal opinion is the international harmonization of the safety approach and of the respective regulations for radioactive waste repositories in geological formations. None of such repositories for long-lived and high-level wastes will be operating in this century. So, there seems to be plenty of time to solve the issue. But because this century is nearly over, we all must hurry up in a concentrated effort!

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SAFETY OF REPOSITORIES

(Session III.2)

Chairman

H. RÖTHEMEYER
Germany

OPERATIONAL SAFETY OF A DISPOSAL FACILITY

A. ZURKINDEN

Swiss Federal Nuclear Safety Inspectorate,
Villigen, Switzerland

Abstract

The purpose of a disposal facility is the permanent and safe disposal of radioactive waste. Such a facility has to be operated in a way which ensures protection of the workers and of the public. The doses allowed to workers of a disposal facility should be lower than the dose limits generally set for occupational exposure. The dose constraints for a member of the public should be only a small fraction of the dose limits generally set for public exposure. The risk of fatality from the operation of a disposal facility with respect to potential exposures should not exceed the order of magnitude of one in a million per year. As a means to achieve these protection objectives, design criteria pertaining to normal operation of the facility and to unexpected incidents are outlined. Criteria for the acceptance of waste packages for disposal at a facility should be established on the basis of site specific performance assessments. A comprehensive quality assurance programme should ensure that only waste packages fulfilling the acceptance criteria will be emplaced at the facility. The requirements concerning the emplacement of the waste packages, the documentation on the facility and the preparations for the closure of the repository are discussed.

1. INTRODUCTION

The purpose of a disposal facility is to emplace radioactive waste in a place and in a manner that will provide long-term isolation of the waste from the biosphere. A disposal facility is therefore primarily designed according to the needs for long-term safety. Performance assessments [1, 2] must have demonstrated prior to operation that the particular disposal conditions will ensure protection of human health and of the environment according to the prevailing requirements [3].

A disposal facility is a nuclear installation and has to be operated in a way which ensures protection of the workers in the facility and of the public around the facility. The operational steps at a disposal facility and the possible detrimental effects originating from these operations are briefly described in the following sections 2 and 3. The protection objectives for workers and the public are discussed in section 4. As a means to achieve these protection objectives, criteria pertaining to normal operation and to unexpected incidents as outlined in section 5 should be observed when designing the facility. The requirements concerning acceptance and emplacement of the waste packages are elucidated in section 6. A comprehensive documentation and quality assurance as illustrated in section 7 is of high importance. Operational features directed toward closure of the facility and long-term safety are addressed in section 8. The main conclusions are finally summarized in section 9.

2. OPERATIONAL STEPS

The waste packages handled at a disposal facility contain radionuclides in quantities which may be very high. Generally these packages are not opened at the disposal facility. Radioactive waste intended for disposal is generally conditioned for disposal prior to transportation to the disposal facility. The predisposal management of radioactive waste [4] is not discussed in this paper.

The operations at a disposal facility may be grouped into the following steps:

- (a) reception and check of the waste packages;
- (b) encapsulation of the packages into disposal containers, if needed;
- (c) transfer of the disposal containers to the disposal place; and
- (d) emplacement of the disposal container and backfill of the disposal place.

After the repository is full and no further packages will be emplaced, the remaining cavities are backfilled and sealed (closure of the repository).

3. POSSIBLE DETRIMENTAL EFFECTS

Since the waste packages are not opened at a typical disposal facility, the primary concern is to keep external exposure at a low level. Vitrified high level waste packages may have surface dose rates up to 500 Sv/h even after 40 years of storage and require remote handling. Also intermediate level waste packages may show high dose rates which require shielding and/or remote handling. Because of high volumes, measures to reduce external exposure may be necessary in the presence of low level waste packages which normally do not require additional shielding.

Despite tight containment of the waste, some releases of radionuclides may occur during the operation of a disposal facility. Even under normal operational conditions volatile radionuclides (for instance tritium) may escape from the waste packages. Larger releases may happen as a consequence of accidental damages (crash or fire) to the waste packages. Workers can therefore be subject to internal exposure following inhalation of radioactive substances. Releases from the waste packages will further lead to radioactive effluent discharges from the facility.

Depending on the type of rock within which the repository is built, radon may exhale from the rock in quantities which lead to harmful concentrations within the facility. Despite the fact that radon is a naturally occurring radionuclide, its possible detrimental effects may have to be taken into account for the operational safety of a disposal facility.

4. PROTECTION OBJECTIVES

It is the responsibility of each country in which radionuclides are being produced or used to establish and implement a legal framework for radioactive waste management [5]. This legal framework shall provide for a rational set of safety, radiological and environmental protection objectives [6]. The requirements are generally limited to the protection of human beings, because it is considered that standards of protection that are adequate for this purpose will also ensure that no other species is threatened as a population, even if individuals of the species may be harmed. Both occupational exposure of workers and public exposure of individuals in the vicinity of the facility are addressed.

4.1. Protection of workers

A very large effort to set internationally harmonized standards for radiation protection lead to the publication by the IAEA of an interim edition of the Basic Safety Standards [7]. According to these Basic Safety Standards, the occupational exposure of any worker shall be so controlled that the following limits are not exceeded:

- (a) an effective dose of 20 mSv per year averaged over five consecutive years;
- (b) an effective dose of 50 mSv in any single year;
- (c) an equivalent dose to the lens of the eye of 150 mSv in a year; and
- (d) an equivalent dose to the extremities (hands and feet) or the skin of 500 mSv in a year.

Lower limits are set for apprentices and students of 16 to 18 years of age who are subjected to occupational exposure. No person under the age of 16 years shall be subjected to occupational exposure.

These limits have been set particularly for workers at nuclear power plants. The operations to be carried out at a disposal facility allow for lower exposure, provided adequate technical and organizational measures are taken. Optimization of protection requires such measures to be taken. Accordingly, national regulations may set dose limits for workers in a disposal facility which are lower than the values given above. A sensible design target for the operation of a disposal facility is a limit for the occupational effective dose of 5 mSv per year.

In addition to the control of the individual exposure of each worker of the facility, also the number of persons exposed should be limited in order to keep the collective dose as low as reasonably achievable.

4.2. Protection of the public

The Basic Safety Standards [7] also give dose limits for public exposure. The exposure of members of the public attributable to practices shall not exceed the following limits which apply to the estimated average doses to the relevant critical groups:

- (a) an effective dose of 1 mSv in a year;
- (b) in special circumstances, an effective dose of up to 5 mSv in a single year provided that the average dose over five consecutive years does not exceed 1 mSv per year;
- (c) an equivalent dose to the lens of the eye of 15 mSv in a year; and
- (d) an equivalent dose to the skin of 50 mSv in a year.

In order to ensure that the dose limits for members of the public are not exceeded when the exposure of a critical group for a particular source is added to the exposures of that group from all other sources, the concept of dose constraints has been introduced. Information on the establishment of source related dose constraints for members of the public are given in the IAEA-TECDOC-664 [8]. This document shows which considerations have to be taken into account when setting a dose constraint, and gives examples of the derivation of source related dose constraints. Several countries have already set dose constraints, especially for the nuclear fuel cycle facilities; the values range between 0.1 and 0.3 mSv/a.

It has been recognized (see section 3) that a disposal facility can be operated without large discharges of airborne or waterborne radioactivity. On the other hand the direct exposure from waste packages can easily be controlled. Therefore a low dose constraint for the effective dose to members of the public can and should be set for disposal facilities. A sensible order of magnitude for the dose constraint is 0.1 mSv per year.

4.3. Potential exposure

Workers and members of the public must also be protected against detrimental effects resulting from unexpected but possible accidental situations. Such detrimental effects are called potential exposures, since they are not certain to occur, while not having a negligible probability. The Basic Safety Standards [7] do not set limits for potential exposures. Protection against potential exposures shall be provided through prevention of accidents and mitigation of their consequences. An expert group on potential exposure of the OECD Nuclear Energy Agency concludes [9] that, for the present, risk should be regulated through judicious use of indicators of risk. Establishing numerical values for risk in regulations might occur gradually.

Even if no limit for potential exposure is set in the regulations, a low risk from the operation of disposal facilities should be strived at. An effective dose of 0.1 mSv per year, which is a sensible order of magnitude for the dose constraint, leads to a risk of fatality of five in a million per year. This indicates that the risk from the operation of a disposal facility with respect to potential exposures should not exceed the order of magnitude of one in a million per year.

5. DESIGN FOR SAFE OPERATION

As a way to meet the objectives described in the previous section certain design criteria should be observed while designing a disposal facility. In the case of an underground disposal facility, the conventional mining safety requirements applicable to the actual situation must of course be satisfied.

5.1. Design for normal operation

With respect to safe normal operation, following features should be taken into account in the design of a disposal facility:

- (a) **Delimitation of supervised and controlled areas**
A supervised area is any area where occupational exposure conditions need to be kept under review even though specific protection measures are not normally needed. A controlled area is any area in which such specific protection measures are or could be required. The boundaries of a controlled area depend on the magnitudes of the expected normal exposures, the likelihood and magnitude of potential exposures, and the nature and extent of the required protection and safety procedures.
- (b) **Provision of adequate shielding**
The dose rate in areas needed for routine operation should be maintained at a low level by means of suitable positioning of the installations and shielding of the handled waste packages.
- (c) **Treatment and monitoring of liquid and airborne effluents**
The exhaust air of the disposal facility should be monitored in order to demonstrate compliance with the limits for airborne effluent discharges. Filters for the retention of aerosols may also be foreseen, depending on the specific conditions. Waste water arising from normal operation or as a consequence of an incident or a remedial action should be collected in order to allow a controlled discharge.

5.2. Design against incidents

An appropriate design of the disposal facility should lower the occurrence of disturbing events and facilitate the mitigation of the consequences, should such events occur.

- (a) **External events**
Examples of external events which are not expected, but which could occur and impair the facility are flooding, earthquake and water intrusion. The access to an underground facility must evidently be protected against surface floods. It is sensible to design the surface and underground constructions against an earthquake with a expected frequency of 10^{-3} or even 10^{-4} per year.
- (b) **Internal events**
Examples of internal events which can have radiological consequences are crash of waste packages, fire and explosion. A crash of waste packages when handling or transferring such packages should be prevented by technical and organizational measures. If a crash with a substantial release of radionuclides cannot be excluded, measures to mitigate the consequences should be foreseen. Special care to prevent fire is to be taken when handling inflammable or heat sensitive waste. The accumulation of explosive gas mixtures as a result of gas releases from the waste packages or from the surrounding rock must be prevented.

6. ACCEPTANCE AND EMPLACEMENT OF WASTE PACKAGES

6.1. Waste acceptance criteria

The safety relevant characteristics of the waste packages which are allowed to be disposed of at the facility must be derived from the results of performance assessments. These safety relevant characteristics form the waste acceptance criteria.

Performance assessments to derive waste acceptance criteria should be based on site specific data which have to be gathered by site investigations. They should be done for the operational phase of the disposal facility and for the long-term post closure phase. Normal operation or evolution and unexpected but possible accidental situations must be covered.

The characteristics of the waste packages must be so, that performance assessments show positive results with regard to all the protection objectives. Further to this overall requirement the fulfillment of more specific criteria may be requested, as for instance

- avoidance of criticality in the disposal facility;
- limitation of the thermal loading of the host rock; and
- compliance with IAEA Safeguard Regulations.

6.2. Waste emplacement

The emplacement of accepted waste packages has to be done according to the procedures which have been taken into account in the performance assessments.

If waste packages are damaged, the ability of the damaged packages to be safely disposed of at the facility must be checked. If this ability is put in question, corrective measures may be taken on site to ensure safe disposal of the damaged packages. If such measures are not feasible, the damaged packages will have to be taken out of the disposal place and reconditioned.

Should an incident affecting the disposal facility occur during the construction or operational phase, it has to be checked under which conditions the construction and/or operation of the repository can be continued without jeopardizing especially long-term safety. The effects of such an incident on waste packages already emplaced and on sections of the repository already backfilled should also be assessed. If long-term safety is jeopardized and cannot be restored by corrective measures, the waste packages that have become unsafe should be retrieved from the repository.

7. QUALITY ASSURANCE AND DOCUMENTATION

A comprehensive quality assurance programme should be implemented, which covers design, construction, operation and closure of the disposal facility. This quality assurance programme should ensure that the protection objectives of the operational phase and of the subsequent long-term postclosure phase will be achieved. It should in particular make sure that only waste packages fulfilling the waste acceptance criteria will be accepted for disposal at the facility. It is recommended to develop the quality assurance programme according to an international agreed standard.

Records should be kept on the waste packages accepted and emplaced at the disposal facility. The documentation on each waste package should include its identification, its safety relevant characteristics and the position where it has been emplaced.

A further documentation has to be compiled after the emplacement operations have finished and the repository closed. The documentation which is needed for a near surface repository is presented in the next paper [10].

8. PREPARATIONS FOR CLOSURE

It is worthwhile to compile a comprehensive data base describing the environment of the disposal facility in the undisturbed conditions. For that purpose a measurement programme for the surveillance of sources and radioactivity in the region potentially influenced by the repository should be started before beginning construction.

The behaviour of the sections of the disposal facility already backfilled should be observed during the continuing operational phase until closure of the repository. The aim of these observations is to confirm the predictions and to draw conclusions on long-term safety. These conclusions shall support the final demonstration of long-term safety which is required for the decision to close the repository (see next paper [10]). In order to strengthen the conclusions, the observations may be prolonged for a limited period of time after the end of emplacement operations. The needs or merits of a surveillance period after closure of the disposal facility will also be addressed in the next paper and in paper 21 [11].

9. CONCLUSIONS

Concerning the operational safety of a disposal facility, the following main conclusions are drawn:

- (a) The purpose of a disposal facility is to emplace radioactive waste in a place and in a manner that will provide long-term safety.
- (b) A disposal facility is a nuclear installation and has to be operated in a way which ensures protection of the workers and of the public.
- (c) In application of the optimization principle, the doses allowed to a worker of a disposal facility should be lower than the dose limits generally set for occupational exposure.
- (d) The dose constraints for a member of the public should be only a small fraction of the dose limits generally set for public exposure.
- (e) Criteria for the acceptance of waste packages for disposal at the facility should be established on the basis of site specific performance assessments.
- (f) A comprehensive quality assurance programme should ensure that only waste packages fulfilling the waste acceptance criteria will be disposed of at the facility.

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REQUIREMENTS FOR THE CLOSURE OF A NEAR SURFACE REPOSITORY

J.C. NIEL

Direction de la sûreté des installations nucléaires,
Paris

P. AGALEDES

Institut de protection et de sûreté nucléaire,
Fontenay-aux-Roses

France

Abstract

The objective of safe radioactive waste management is to protect human beings and the environment now and in the future from adverse effects of radioactive waste. Short lived low and intermediate level waste may be disposed of in near surface repositories. At the end of its operation the repository is closed and then may enter into a institutional control period. Even before closure, the elements necessary to monitor and maintain the repository, to perform, if necessary, corrective actions and to understand any accidental phenomena must be gathered and recorded. Moreover the surveillance program and the organization responsible for the institutional control must be defined.

1. INTRODUCTION

In the following paper, we will present the various elements which are necessary before proceeding to the closure of a near surface repository. The paper is divided in three parts :

The first one will deal with the conditions for closure, more or less those conditions are related to the knowledge of the repository (inventory, quality of the various barriers, evolution...)

The second part describes the actions to be taken during the institutional phase (monitoring, maintenance...)

The third part specifies the organization and documents to be developed for the institutional phase.

The objective of a near surface repository is to protect the human beings and the environment now and in the future from the adverse effects of radioactive materials.

Immediate protection is a common feature to all nuclear facilities, the required protection on long term makes the repositories special. In particular, it implies in many cases a restricted phase limited in time after the operational phase. Thus, after the closure, the repository may still be under institutional control for a period adapted to the hazard.

Indeed, confinement of radionuclides has :

- to protect the waste from external effects that could lead to dissemination of radioactivity, mainly through the action of man and water.
- to limit and delay the release of radionuclides and their transfer to the biosphere. This is done by limiting global and specific activity of the radionuclides and by interposing efficient barriers between the waste and the biosphere.

In normal situations, during the operational and institutional phases, the radionuclides are confined by the packages and the engineered barriers. The radiological impact of hypothetical situations is acceptable due to the content of the repository and the properties of the geological barrier.

The advantage of the multibarriers concept is that safety of the repository does not depend on a single barrier whose failure might seriously compromise the two roles of the repository. In this respect the barriers are complementary.

2. KNOWLEDGE ABOUT THE REPOSITORY

The long term safety assessment of the repository with or without institutional control relies mainly on the evaluation of the release process and the transfer of radioactivity to the biosphere. It is then necessary to have a precise knowledge of the content of the repository.

Consequently, the radioactive characteristics of the waste packages, particularly their radioactive content inventory, will have to be recorded. A special attention should be devoted to the long lived radionuclides. The chemical content of the waste packages should be checked first to be able to evaluate the chemical impact and second to limit the quantity of products liable to increase the solubility of the radionuclides or which are liable to form a significant proportion of complexes, reducing the retention of the radionuclides by the containment barriers.

The nature and quantities of gas produced by phenomena such as radiolysis, corrosion, etc... should be determined.

The physico-chemical characteristics of the waste packages are important. For example, mechanical properties may determine the stability of the repository or the nature of the conditioning materials may have consequences on the chemical stability of some forms of the radionuclides. Then, specific gravity, homogeneity, packing fraction, chemical composition, solubility should be evaluated.

To make it possible to assess the containment capacity of the packages and supply the materials necessary for the demonstration of safety and, on the other hand, to estimate the effect of the packages on the containment capacity of the other barriers, these data should be completed by properties of the packages, particularly those associated with their initial radioactive containment capacity and their evolution :

- rate of leaching by ground-water,
- rate of degassing,
- mechanical resistance under pressure conditions representative of the repositories,
- effects of chemical interactions (between waste and matrix, between waste or matrix and engineered barrier materials etc...),
- the effects of alpha or beta/gamma irradiation,
- the effects of micro-organisms.

The position of the packages in the repository and the overall geometry of the repository are important as well, indeed local variation of radioactivity inside the repository may be relevant to the impact. The position and the condition of the engineered barriers, of devices to collect effluents or to release them, of the topography of the cover, if any, and of the monitoring devices must be known.

To enhance the understanding of the releases and release processes of radioactive or toxic materials (either liquid or gaseous) toward the collecting devices or the aquifer, the experience in releases must be precisely evaluated and fed back.

The radiological state in the vicinity of the repository and its evolution in the past combined with the knowledge of the release phenomena should allow to predict the evolution of releases in the future as well as the efficiency of the closure dispositions (watertight cover) and the corrective actions to be taken in case of incident.

The hydrogeological context should be sufficiently precise to allow prediction of the migration of radionuclides in case of releases in the aquifer. It means that discharge points should be localized,

transfer time determined, extreme levels of the watertable evaluated, extent of the retention of radionuclides by the ground precised.

The precise knowledge of the repository is necessary :

- to follow the evolution of the confinement barriers efficiency, for example through the analysis of the radioactivity releases out of the structures ;
- to interpret radioactive releases in order to be able to determine their origin, causes and mechanisms. This should help to control these releases ;
- to assess the impact on environment in the future. This, then, allows to determine the period of the restricted phase. Indeed, the radiological impact is directly linked to the radioactive content of the repository and decreases with time ;
- to guarantee that actions undertaken to close the repository are relevant ; for example, the watertightness of the cover must allow the reduction of the radioactive releases below the desired level ;
- to define the correction actions ;
- to make sure that the actions for maintenance, control and monitoring during the institutional phase will be easily feasible ;
- to transmit in the future the elements to manage the repository, in particular to maintain it, to define the conditions for the post institutional phase ;

Special attention must be given to the conservation of the relevant information which may be useful in the future. This information will have to be recorded on adequate media and duplicated. The quality of the recording must be kept, leading if necessary to copy or use of new media for conservation. The information recorded must allow a safe management of the repository in the future, they contain, at least, the facility design, as built structures, waste inventory including location and physicochemical characteristics, package identification, site characterization, data and relevant plans, engineering drawings and specifications, safety and environmental impact assessment results, methods and computer codes used, environmental monitoring results, and data on the closure of the disposal facility.

3. ACTIONS TO BE PERFORMED DURING THE RESTRICTED PHASE

The main actions to be performed during an institutional phase are the control of the repository and the environment, the management of the releases, the maintenance of the facility, the performance of corrective actions in case of accidental radioactive releases, the record of information and various studies.

3.1 Control of the repository and the environment.

During the restricted phase, the evolution of the site must be checked and compared to predictions. It implies ;

- the physical control of the site to prevent both human and animal intrusion. It can be done, of course, by fences and guarding around the repository ;
- the radiological and toxical control of the site, both the repository and its environment. It consists, mainly, in the measurement of the radioactivity and flow rates in collecting devices, aquifers, discharge points... as well as the radioactivity of the air, plants...
- the radiological control of people working at the repository.
- the ecological control of the site and its environment to check the absence of impact of the repository on animal life and flora ;
- the control of the cover and its watertightness through visual observation, topographical measures, flowrates of collecting devices ;
- the control of the structures (drift, collecting devices, basins...) whose availability is deemed necessary ;

- the control of measures and sampling apparatus which are contributing to the control of the site.

3.2. Management of releases

The water which may have infiltrated the repository and has been collected in the water draining systems must be controlled and evacuated according to precise conditions.

3.3. The maintenance

The maintenance during the institutional phase must maintain the efficiency of the multi barriers system of the repository, it implies that it addresses

- the cover,
- the drifts,
- the collecting and draining system ,
- the ventilation system of the drift,
- the apparatus and devices to perform measures, to monitor the environment, to alarm,
- the fences and detection of intrusion devices.

3.4. The performance of actions in case of accidental radioactive releases

Such actions must be elaborated after analysis of the actual releases. To perform this analysis, in particular to evaluate the origin and the consequences of this release, it is necessary to know the release mechanism.

The efficiency of the corrective actions will have to be assessed and, then, verified. These corrective actions can cover a wide spectrum of actions from increasing the monitoring of the site, through repair of the cover to intervention on packages.

3.5. Record of the information

The information gathered prior to closure must be recorded as well as those from the institutional phase. It is particularly relevant to keep the data from corrective or maintenance actions.

The recording of the information itself may need some maintenance or corrective actions: the information must be up to date, duplicated on permanent media and easily obtained and exploited.

3.6. Studies

During the restricted phase, some studies must continue. The results of the various measures performed for the control of the site must be analyzed and interpreted. A feedback of the experience gained in this process must be carried out as it is done for other nuclear facilities.

Operation prior to the unrestricted phase must be prepared and performed such as back filling drifts, remodelling topography, dismantling useless buildings. However, the post institutional phase could be accompanied by some passive measures like keeping record of relevant information like the position of the repository.

4. ORGANIZATION DURING THE RESTRICTED PHASE

During the restricted phase, a responsible institution is in charge of the various actions described before. This institution will have to be organized to comply with the regulatory requirements.

Indeed, on a long time period this institution will do measurements, monitor the environment, control the site, and interpret the results to verify the absence of significant impact, confirm the predictions of the safety analysis and the performance of the isolation system. If judged necessary, corrective actions which may be important (maintenance of the cover) will have to be performed.

The monitoring (cover, drift...), the measures (radiological, toxical, environmental) are done according to programs elaborated following quality assurance criteria. These programs must, at least, specify the reasons for these actions as well as their nature (location, frequency...) and their expected results in normal situations.

The institution must elaborate a plan for recording the information, including the means to interpret them at any time in the future during, at least, the institutional phase.

The safety report, justifying the expected impact, is reassessed regularly integrating the results of the control, it is completed by operating rules for controlling and monitoring in normal situations and describing the criteria for intervention in case of accidental or incidental situations which will be defined.

Interventions in case of abnormal situations must be described, explained and justified as well.

5. CONCLUSIONS

The requirements for the closure of a near surface repository must guarantee an acceptable impact on the people and the environment in the institutional and post institutional phase. They are related to :

- the knowledge of the repository, of the release mechanisms etc.
- the programs to control and monitor the evolution of the site, to maintain the repository and to perform corrective action,
- the organization of the institution in charge of the repository.

REPOSITORY SYSTEM INTEGRATION AND OVERALL SAFETY

C. DEVILLERS

Institut de protection et de sûreté nucléaire,
Fontenay-aux-Roses, France

Abstract

The overall safety of a deep repository relies on a multi-barrier system and a limited contribution from institutional control. The question of safety indicators is discussed, including the need for societal risk indicators. The process of determining the robustness of a repository system is presented with the selection of adverse situations and the provision for adequate lines of defence, starting at the site selection stage. Performance assessment principles, methodology and sensitivities are addressed and examples of the usefulness of sensitivity studies are shown.

1. INTRODUCTION

While the question of low level waste disposal has found practical answers in several countries, there is to-day no concrete experience available on deep geological disposal of high level or long lived waste. To compensate for the lack of experience, a specially careful safety approach is deemed necessary, in particular at the stages of site selection and deep repository design studies, a major present-day issue. Deep geological repositories will be addressed in this presentation from the point of view of repository system integration and overall safety.

In the terms "repository system", we include:

- the site, comprising areas involved in performance assessments,
- the disposal facility, and
- the waste packages ready for disposal.

Safety objectives, principles and approach being defined by the safety authority [1], the applicant will deploy efforts to develop a deep repository system presenting, with a view to its licensing, a reasonable assurance of a high level of safety, both during operation and after closure. The safety authority will in parallel develop technical capabilities to be able to assess the applicant's proposal and prepare decision making. Because there is no concrete experience or any universal recipe available for designing a deep repository, adequate system integration cannot be achieved without iterative performance assessments.

In the following, we will discuss the issues that we to-day consider as important for the safety authority to form its opinion on the overall safety of a deep geological repository system. This will introduce the next paper devoted to confidence-building measures in the quantification of safety. The next sections deal respectively with:

- fundamental safety objective and considerations on safety indicators,
- important issues for judging the post-closure safety of a deep repository system,
- robustness of a repository system,
- soundness of performance assessment methodology.

2. FUNDAMENTAL SAFETY OBJECTIVE AND CONSIDERATIONS ON SAFETY INDICATORS

The RADWASS draft Safety Fundamentals entitled "The Principles of Radioactive Waste Management" define as follows the objective of radioactive waste management : "The objective of radioactive waste management is to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations".

Within this scope, the fundamental safety objective of a deep repository system for the post-closure period is to protect future societies and the environment from the risk associated with the dispersion of and the exposure to the radioactive material contained in the repository.

This protection has to be assured, taking the present day level as a reference, in all situations considered, as long as the radioactive risk remains significant compared to the natural background level.

In showing compliance with this objective, no allowance shall be made for post-closure maintenance, and no institutional control shall be considered beyond a limited period.

Potential individual and societal risks are the right quantities to consider when assessing the overall safety of a repository. These risks can be characterized by probabilities of events, including disruptive events, and a description of their consequences.

The individual risk is sometimes presented [2] under the form of an aggregated risk function consisting in the mathematical expectation of death for an individual over one year, from all events.

However, it must be realized:

- firstly, that components of risk, i.e. probabilities and doses, are not all easy to quantify; they will be obtained by means of models of different levels of quality and some of them will reduce to crude estimates,
- secondly, that the probabilities and doses may intervene separately in the judgement passed on the acceptability of the potential impacts of a repository.

Therefore, the use of aggregated risk functions as indicators would present serious disadvantages in the loss of information available to the decision maker. Consequently, the assessment of individual risks has to consider all their components and a single number risk criterion would have a limited significance.

In that respect, the ICRP provides guidance [2] concerning the limitation of potential individual risks induced by a repository. The proposed limits bear on individual dose for situations having a high probability of occurrence and on individual risk of fatality for situations having a low probability of occurrence. The first limitation can in our opinion be used as a safety indicator. Most countries have, for high probability situations, defined a limit equal to a fraction of 1 millisievert per year. On the contrary, we feel that the concept of individual risk limitation is more difficult to apply, particularly because reciprocity between probability and consequences is questionable. In this respect we think that the level of potential individual exposures shall be kept below the level likely to result in deterministic health effects, by means of appropriate design options. Provided this condition is met (it can be related to the assumption of no intervention in the long term to protect individuals), it can be accepted that the lower the probability of an "accident", the higher the potential consequences may be. This hybrid dose/risk system can be enforced in a way comparable to the one currently used for assessing the design of other nuclear facilities.

Moreover, additional indicators are necessary to characterize potential societal risks especially those associated with low probability situations. For this purpose, indicators such that the importance of resources potentially affected by radioactive substances (for example, land, forests, surface water, groundwater and raw materials) and the duration of these effects could be utilized, together with the estimated probabilities of such effects.

In any case, safety indicators more directly related to the design should be used to enlighten the overall safety assessments [3] especially during the siting and design optimization phases. Such indicators include for example:

- distribution of groundwater flows from the repository to the different water discharge locations,
- groundwater transit times between repository and water discharge locations,
- radioactive substance transfer time along the same routes,
- radioactive substance fluxes at the interface between geosphere and biosphere,
- concentration of radionuclides in groundwater resources.

3. IMPORTANT ISSUES FOR JUDGING THE POST-CLOSURE SAFETY OF A DEEP REPOSITORY SYSTEM

To form its opinion on the post-closure safety of a deep repository system, the safety authority will generally consider the following aspects:

- robustness of the repository system, depending upon the levels of protection provided in the design against normal and adverse situations originating from the environment, from human intrusions or from the repository itself,
- soundness of the performance assessment methodology used for the safety demonstration, taking into account their logical structures, clarity and sensitivities to uncertainties in data and models,
- quality of the data sets and models important for the performance assessments, in terms of uncertainties of data (measurements, expert opinion elicitation) and bias in conceptual or predictive models.

The applicant, for his part, will also go through that process, with probably several iterations, in order to optimize the repository design, within siting constraints.

4. ROBUSTNESS OF A REPOSITORY SYSTEM

4.1. The multi-barrier system

Current deep repository projects are based on a multi-barrier concept aiming at ensuring the containment of radioactive substances:

- waste packages: they contribute to the containment of radioactive substances,
- engineered barriers of the disposal facility, in which waste packages are emplaced:
 - . they protect the waste packages,
 - . they delay the transfer of radioactive substances released from the waste packages in the long term or in case of package failure,
- host formation in which the disposal facility is located, plus the surrounding geological formations, together constituting the geosphere:
 - . they protect the engineered barriers and the waste packages,
 - . they delay and dilute radioactive substances released from the disposal facility in the long term or in case of failure of packages and/or engineered barriers.

At the closure of the facility, boreholes, shafts and access tunnels are sealed to restore the geosphere properties as well as possible. The geosphere is in contact with the biosphere, made up of surface and subsurface areas and resources easily accessible to human activities.

In addition to its containment function, the multi-barrier system also ensures radiation shielding and helps prevention of criticality.

Radiation shielding is provided, on the one hand by the thick layer of materials isolating the waste packages from the biosphere, on the other hand by preventing intrusion. Note that the irradiation hazard essentially due to short-lived beta-gamma emitting radionuclides decays more rapidly than the ingestion hazard dominated by long-lived radionuclides.

Prevention of criticality in arrays of waste packages containing fissile materials can be obtained both in operational and post-closure periods by safe geometry arrangements of waste packages and engineered barriers. In certain cases it will be necessary to add site specific requirements on nuclide concentration. Sub-criticality must be ensured for any water content and distribution.

4.2. Normal and abnormal situations

The robustness of the multi-barrier system and its above-described safety functions will depend upon its levels of protection against various normal or abnormal situations, a basic notion in the defence

in depth concept. These situations must be defined through a systematic review of features, events and processes likely to reduce barrier effectiveness. Expert opinion elicitation methods might be used for that purpose; however, iteration will be necessary in the light of sensitivity studies.

The situations to take into account depend evidently on the type of geological formation and on the repository concept considered. However, they can be classified in three families, as Table 1 shows for illustration, according to their origin.

TABLE 1. FAMILIES OF SITUATIONS

<p>a. Natural environment</p> <ul style="list-style-type: none">-groundwater movements (flow, velocity) to the repository and from the repository to the biosphere,-undetected major fault or heterogeneity in the geosphere,-groundwater chemical aggressiveness,-<i>in-situ</i> stresses,-transport of radionuclide species with little retention in the geosphere,-effects of earthquakes on hydraulic conductivity,-climate changes (glacial - interglacial cycling),-geomorphological changes (denudation, weathering),-valuable mineral, oil or water resources.
<p>b. Human intrusion</p> <ul style="list-style-type: none">-exploratory drillings, groundwater abstraction, mining, geothermal energy production,-subsurface works (tunnelling, underground shelters).
<p>c. Effects of the repository</p> <ul style="list-style-type: none">-damage to the host medium around shafts and access tunnels,-dewatering,-heat production,-gas production (corrosion, radiolysis, microbial degradation),-short-circuit pathways in shafts or access tunnel seals.

4.3. The protection of the multi-barrier system

Protection of the multi-barrier system against these normal and abnormal situations consists in providing combinations of lines of defence taken among:

- site properties,
- disposal concept features, including those related to a possible retrievability option,
- waste package characteristics, and
- institutional control, including possible post-closure monitoring and interventions (cf. Paper 21),

so that, should one line of defence fail, the other(s) would limit the consequences.

Table 2 shows typical lines of defence currently considered for the protection of a multi-barrier repository against normal and abnormal situations.

Note that the effort put into the quality of activities involved in working out its protection adds to the robustness of the repository system. This is particularly true:

- for geological site investigation, to reduce the probability of undetected major faults or heterogeneities in the geosphere,
- for the development of sealing technology, to reduce the probability of short-circuit pathways in shafts or access tunnels.

TABLE 2. PROTECTION OF A MULTI-BARRIER REPOSITORY AGAINST NORMAL AND ABNORMAL SITUATIONS

Natural environment	Human intrusion	Effects of repository
<i>Site properties</i>		
Unsaturated medium Low hydraulic gradient Low groundwater velocity Low chemical aggressiveness Ease of characterization Depth of host rock formation Distance from large geological faults Good seismic, tectonic and geomorphic stability (≥ 10,000 years)	Absence of resources of exceptional value	Good mechanical and thermal properties Pre-closure monitoring
<i>Disposal concept features</i>		
Horizontal location and depth of repository Adequate location of shafts and access tunnels Efficient and durable shaft and access tunnel sealing Seismic design Limitation of groundwater flow to waste packages Control of groundwater chemistry Retention of radioactive species	Depth of repository Efficient and durable shaft and access tunnel sealing Waste packages physical separation Tagging	Excavating (soft) Gas collecting and control Stress homogenization Pre-closure monitoring and retrievability
<i>Waste package characteristics</i>		
Corrosion resistant container Low solubility matrix Low area/volume ratio Good mechanical resistance Low long-lived radionuclide content Standardization of waste packages	Corrosion resistant container Low solubility matrix Low area/volume ratio Good mechanical resistance Low long-lived radionuclide content Low tendency to form dust	Heat and radiation resistant matrix Low decay heat value Standardization of waste packages
<i>Institutional control (≤ 500 years after closure) ^{a)}</i>		
	Recording Restrictions in soil and sub-soil use	Recording Post-closure monitoring and intervention

^{a)} For safety assessments, the loss of memory of the existence of a repository is assumed to occur 500 years after closure, even if provisions are taken for appropriate recording, regulatory institutional document availability, site tagging over longer periods.

Before licensing a repository system, the safety authority, on the basis of the safety demonstration provided by the applicant, will first of all carry out a qualitative analysis of the set of lines of defence proposed by the latter against a set of selected normal and abnormal situations. This analysis will relate to two aspects: the comprehensiveness of the set of selected situations and the qualities of the lines of defence.

It might happen that the lines of defence against given situations would be judged insufficient: for example, if the possibility of fast-running underground water could not be excluded due to difficulties in the characterization of the host formation, or if a large regional seismic hazard could lead to a reopening of silted cracks. To reduce the probability of rejecting a site, a preselection of site(s) must be performed according to its (their) permeability, stability and ability to be characterized. Furthermore, underground reconnaissance in deep underground laboratories must be carried out to confirm the capacity of the site(s) to host a deep repository. Guidance for siting of geological disposal facilities is available in reference [4].

It may also happen that lines of defence favorable for certain situations present adverse side effects. For example, design provisions such as leaving cavities open to ensure retrievability may complicate later back-filling of cavities. The question of the advantages of post-closure monitoring (detailed recording associated with monitoring allow targeted interventions) must also be discussed against its possible disadvantage in leaving open preferential groundwater pathways.

5. SOUNDNESS OF PERFORMANCE ASSESSMENT/METHODOLOGY

5.1. Principle of performance assessments

The next step in the safety assessments consists in performance assessments relying on modelling the repository and its boundary conditions. Performance assessments are the essential tool to understand, quantify and optimize the respective roles of the different lines of defence of a given repository system. The roles of the different barriers in that repository system can then be explained from the results of performance assessments. Indeed, the roles of the different barriers depend greatly on which radionuclide is considered. Therefore, results of performance assessments obtained with a specific radionuclide spectrum cannot be generalized to any other spectrum.

Performance assessments comprise scenario development and potential impact calculations.

Scenario development aims at generating series of time-histories corresponding to combinations of situations selected from the above-mentioned families, bearing in mind that their effects may accumulate: for example, groundwater movements and climate change, groundwater movements and large earthquakes.

These time histories are then applied as boundary conditions in space and time to repository conceptual models; they constitute scenarios.

Calculations of potential impacts of each scenario consist in simulating the scenario-driven evolution of the repository: thermo-mechanical behavior; underground water circulation; change in chemical conditions; degradation of waste packages, engineered barriers, geosphere, seals; transfer of radioactive substances through the multi-barrier system; dispersion of radionuclides in the biosphere. Results are expressed in terms of safety indicators.

5.2. Integration of modelling into the system

Modelling has two main objectives:

- to represent the repository system, including the regions of the geosphere and biosphere necessary for potential impact calculations, and its boundary conditions,

- to provide computer codes capable of simulating the evolution of the system for different boundary conditions and the potential radiological impact in space and time.

Modelling capabilities must:

- be consistent with the mode of characterization of the barrier components introduced into the model,
- rely on as realistic as possible an understanding of the behavior of barrier components whose levels of performance appear from sensitivity studies to be major contributors to the overall safety of the repository,
- allow sensitivity studies.

Different methods combining in different proportions probabilistic approaches and deterministic approaches are available to-day for scenario development [5] and potential impact calculation.

This is a domain of development, each approach presenting specific merits and specific disadvantages.

Probabilistic techniques are interesting in generating scenarios by means of Markov (climatic change for example) or Poisson (intrusion) models. In general, the difficulty for probabilistic assessments lies in a poor knowledge of probability distribution functions for a number of input parameters.

On the contrary, models currently used for the conceptual representation of the repository, the calculation of the evolution of the system and the potential radiological impact are essentially of a deterministic nature. Attempts are being made to represent the repository by a geostatistical model and to calculate underground water circulation using Monte Carlo techniques. But this seems to be a long term challenge.

Therefore, performance assessments in many countries are still largely based on a deterministic approach. Probabilistic specific verifications should however be made to detect possible weaknesses in the deterministic approach (for example incompleteness of the scenario set). In the deterministic approach, a limited set of scenarios is established to represent in a conservative fashion series of combinations of situations (features, events or processes) — for example, groundwater circulation and a Würm glaciation at 60 000 years. Each scenario must be assigned a "degree of belief" which will intervene together with safety indicators (see Section 2 above) and other factors in the final judgement on the acceptability of the repository. The scenario of highest degree of belief is called the "normal" scenario.

On the other hand, specific scenarios corresponding to events of unpredictable probabilities can be developed to check the robustness of the repository system to such events ("what if" approach). Such specific scenarios may be introduced to represent extreme realizations of situations that generally fall into the "normal" scenario. For example the ageing and progressive loss of effectiveness of shaft and access tunnel seals is assumed, due to lack of qualification, to prematurely allow for a short-circuit pathway in these seals; this case is dealt with as an hypothetical scenario. Another example of a hypothetical scenario comes from the difficulty in very heterogeneous rock formations to correctly characterize the medium from a limited set of measurements; this leads to introducing a hypothetical scenario corresponding to an undetected defect in the host formation.

It is clear that the scenario development, because it implies simplification of reality and its serving as a substitute, in extreme cases, for a realistic modelling evolution, needs to be thoroughly controlled to ensure reasonable conservativeness. Precautions such as the following must be taken:

- pay attention to common mode failures,
- be careful about cumulative effects of multiple adverse situations,

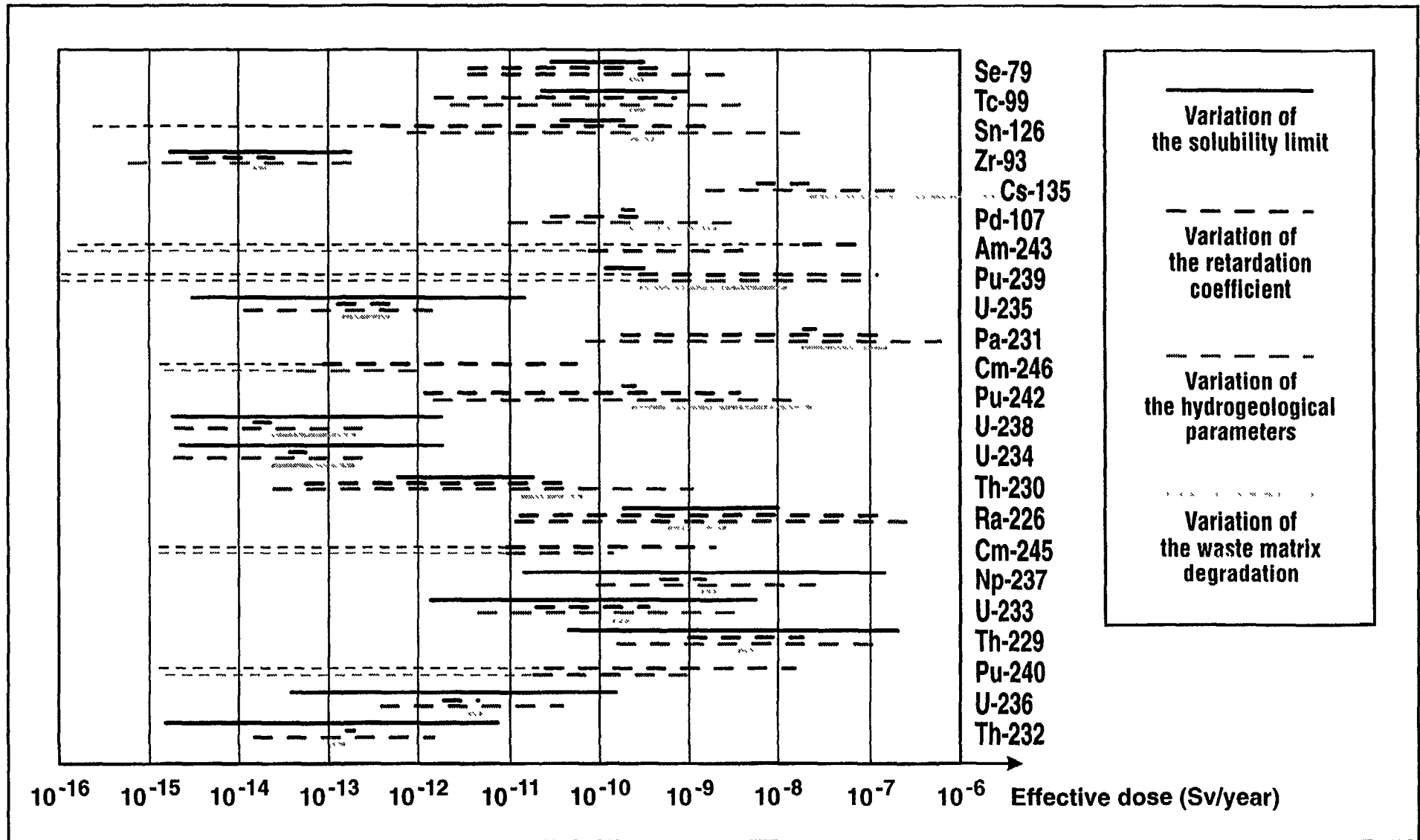


FIG. 1. Variation of the maximum effective dose ($\text{Sv}\cdot\text{y}^{-1}$) for each radionuclide in the case of HLW versus variations on the four main parameters.

- formalize expert opinion elicitation methods,
- cross-check with probabilistic simulations,
- perform peer reviews,
- keep trace of the whole process.

5.3. Sensitivity studies of impact assessments

Impact assessments aim at estimating for each scenario the values of the safety indicators as a function of space and time.

Impact calculations should use input data and models which are as realistic as possible. This concerns the evolution of the repository, the transfer of radionuclides through the multi-barrier system and the biosphere, and the characteristics of critical groups.

Studies of sensitivity to uncertainties in the input data are a fundamental ingredient of safety assessments in that they provide information for:

- understanding which lines of defence are more important for safety,
- balancing the respective roles of these lines of defence,
- orienting data acquisition efforts,
- driving barrier performance improvements, and
- appreciating the possible ranges of variation of the results due to variations in the input parameters.

Examples of impact assessments taken from the European Union Everest exercise give an idea of these variations for an hypothetical repository containing vitrified waste in a granite formation. Figure 1 summarizes, for the normal scenario, the variation of potential individual doses due to different radionuclides, when varying hydraulic parameters of the geosphere, retardation coefficients, matrix solubility, and radionuclide solubilities.

6. CONCLUSION

The overall safety of a deep repository system relies on a multi-barrier concept including the geological barrier.

The level of protection of man and environment provided by a deep repository can be expressed by means of safety indicators. These indicators comprise potential individual exposures. For situations of high probability, potential individual exposures shall be limited to a fraction of a millisievert per year. For uncertain situations, potential individual exposures shall be bounded; in addition, potential societal risk must be taken into account in these situations. This subject should be considered in greater depth.

Safety indicators more directly related to the repository design are of interest in strengthening safety assessments; examples are given in the preceding sections.

As concerns risk, whether individual or societal, appreciation of its acceptability should be based more on its various components than on aggregated risk functions.

Important aspects for judging the post-closure safety of a deep repository are the robustness of the system with respect to adverse situations, the soundness of the safety demonstration as a function of its sensitivity to uncertainties, and the quality of input data and models.

Robustness can be achieved by means of a systematic review of possible situations and of an analysis of the lines of defence incorporated in the system against these situations, with a limited

contribution from institutional control. The role of this contribution in intrusion prevention or in possible interventions should be agreed upon.

Preselection of sites on the basis of their lines of defence against the most adverse situations (fast underground water circulation, high seismotectonic instability) increases the probability of obtaining a safe repository system. However, engineered safety features could, to a certain extent, compensate for weaknesses in the site.

Quality assurance and peer reviews are important aspects in assessing the robustness of a repository system.

Performance assessments are, through scenario development and modelling, necessary to understand, quantify, optimize and assess a repository system both as concerns its intrinsic robustness and from the point of view of the dependence of the safety demonstration to uncertainties. Performance assessments also provide input for:

- uncertainty estimates,
- directing data acquisition efforts, and
- improvements in performances of components important for safety.

Examples taken from the European Union Everest exercise illustrates the usefulness of sensitivity studies.

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SAFETY ASSESSMENT METHODOLOGY AND CONFIDENCE-BUILDING MEASURES

C. McCOMBIE
NAGRA,
Wettingen, Switzerland

Abstract

The paper summarises the various rôles of safety assessment in radioactive waste management and describes progress made over the last 20 years towards development and harmonisation of the assessment methodology. Some key issues still being actively debated in the national and international arenas are discussed at more length. The most controversial topic concerns the building of sufficient confidence in the reliability of the models used in safety assessments. The point is strongly emphasised that even the best modelling must be complemented by use of expert judgement. Consensus extends widely throughout the technical community that safety assessment methodology is sufficiently mature and reliable for use in analysis of long-term repository behaviour; this consensus view must be brought before, and justified to, a wider public. The RADWASS series of reports and the planned Convention on the Safety of Radioactive Waste Management can both provide valuable vehicles for stimulating the debate and for increasing acceptance of geologic disposal concepts.

1. THE RÔLE OF SAFETY ASSESSMENT IN REPOSITORY DEVELOPMENT

1.1. The importance of long-term safety assessments

The design, construction and operation of a disposal facility for radioactive wastes, in particular of a deep geologic repository for long-lived wastes, is a major undertaking presenting challenges in various fields. Important tasks include:

- ◆ application of good science and engineering
- ◆ estimation of costs and other socio-economic impacts
- ◆ project planning for timescales up to a hundred years
- ◆ provision of adequate public information
- ◆ analysis of the expected safety levels at all times out to the far-future.

For the decades since the beginning of planning for waste disposal, however, the prime focus for debate has been the last mentioned issue of long-term safety. Today, this is still the case, as exemplified by the titles of this conference and of its individual sessions.

The intense debates on safety arise despite the fact that a well-designed repository represents a passive system containing a succession of robust safety barriers and no large energy density which might lead to catastrophic hazards. Our present civilisation designs, builds and lives with technological facilities of much greater complexity and higher hazard potential. What, then, are the new or unusual features of repository safety analyses which lead to so much discussion. They are primarily the **long timescales** which are explicitly taken into consideration in the analyses and the **prominent rôle of the geological medium** which has compelled earth scientists who are used to descriptive, deductive reconstructions of the past to aim at quantified, inductive assessments of future system behaviour.

In the current paper I shall, accordingly, concentrate upon the safety assessment methodology for judging the long-term performance of deep repositories and leave it to other contributors to document the efforts continually being made at all phases in the management of all types of radioactive wastes to ensure the achievement of the mandatory high levels of safety for workers and public. Because the paper is intended as an overview for non-specialists, there is no attempt made to

back up specific points by referring to particular published papers. Instead, a short bibliography of useful overview documents which lead to more detailed literature has been appended.

1.2. The requirements on long-term safety assessment

The timescales of concern for deep disposal are so long (hundreds of thousands of years) that **direct** observations or measurements of temporal alterations in system components are of limited value. Assessment of future repository performance must be based upon **modelling** of the physical and chemical processes involved. Is our current knowledge adequate to allow sufficiently realistic predictive modelling over the timescales mentioned? Some important points to be made before answering this question are that:

- ♦ the laws of natural science which govern key processes like corrosion, fluid-flow, mass- transport etc. do **not** change with time
- ♦ the geological database actually extends over very much **longer** timescales (billions of years) than the toxic lifetimes of most wastes
- ♦ **accurate** predictions of actual system behaviour are not required; it suffices to provide conservative estimates of impacts that can be reasonably expected
- ♦ the low levels of release which appear to be achievable imply that **precise** estimates are not needed; even with some orders of magnitude of residual uncertainty we may be clearly within defined safety goals or limits.

Taking these points into account, it has been possible for interdisciplinary teams of safety assessors - including representatives from the fields of engineering, physics, chemistry, earth sciences, mathematics etc. - to develop over the past 20 years a safety assessment methodology capable of providing an **important part of the decision basis** required before implementation of projects for geologic repositories for radioactive wastes. This methodology, its strengths and weaknesses and its practical applications to date, are summarised in the current paper.

However, a **direct** demonstration of the reliability of the methodology or a rigorous and complete **proof** that models are correct are as pointed out above not possible. Accordingly, the societal acceptability of project decisions based, at least in part, upon the results of safety assessments will depend upon the level of confidence placed in the methodology by the technical experts within the implementer and regulator organisations, by political decision makers and by the public. The important subject of confidence-building measures is therefore the second major topic addressed below.

1.3. Applications of safety assessment

Obviously the ultimate use of a sufficiently reliable methodology for safety assessment is to judge whether the safety levels offered by a facility lie within those which are judged acceptable by society and which, therefore, have been embodied in national licensing requirements. In earlier project phases, however, an assessment of the potential influence of numerous specific project choices on achievable safety is an invaluable decision aid. For this reason, iterative safety assessment is also performed to rank conceptual facility designs, to structure data-collection programmes in laboratory and field, to provide input for site-selection, to guide R&D work and to optimise the selection of specific combinations of safety barriers in the repository.

For differing applications, the requirements on reliability or accuracy of the assessments may vary. For instance, **compliance** with a limit may be demonstrated using deliberately **conservative or robust models** which take no credit for less demonstrable safety mechanisms; on the other hand, to allow **optimisation** of a combined safety barrier system, an adequate level of **realism** in the modelling of each component is required. Important nuances of this type will not, however, be discussed further in this summary paper; attention is focused primarily on the ultimate challenge of developing safety

assessment methodology of sufficient quality to provide a decision basis within the regulatory process for licensing of a geologic disposal facility.

2. SAFETY ASSESSMENT METHODOLOGY

2.1. Development and harmonisation of assessment methodology

Over the last 20 years, significant effort has been devoted worldwide to development of safety assessment methodology and also to achieving international consensus on appropriate approaches. This might seem surprising when one considers that most countries will license only one or two radioactive waste repositories, often at very different times and for rather different kinds of waste. One could infer that there is no strong incentive to standardise the methodology. However, the safety issue for nuclear waste has a high international visibility, and the long time period during which the waste must be isolated has heightened international awareness of long-term repository safety. The recognised need for a common understanding of the safety of the different repositories, has during the eighties and nineties, encouraged international discussions on methodologies. A large number of conferences, workshops and meetings have been held to discuss modelling in specific areas or to assure the necessary interaction between experts from different technical backgrounds or to disseminate information on safety assessment to a wider audience.

There exists today an extensive literature documenting the techniques, the applications and the results of safety assessments. This basis makes it feasible to provide guidance and advice on safety assessments for radioactive waste disposal facilities near the surface or at depth. A major part of the IAEA RADWASS documentation is being devoted to this topic.

However, no single approach to assessing safety has yet been identified as optimal. Different assessment groups and different disposal programmes apply methodologies which differ in their broad structure as well as in their detailed modelling. Moreover, in all of the approaches currently in use there are remaining open issues and continuing developments. In the following sections, we shall try to summarise the common basis to safety assessment methodologies, to indicate where different solutions have been developed and to point to the major topical issues still being debated. Detailed descriptions or exhaustive catalogues of individual modelling efforts are neither possible nor necessary in an overview seminar of the present type.

2.2. The modelling process

As pointed out earlier, models are needed in performance assessment to simulate the behaviour of repository systems because of the long time periods and large spatial scales that are of interest. The modelling process itself consists of a series of basic steps (see Fig. 1), each of which requires input information or data:

The initial step in the chain - namely obtaining an adequate understanding of the processes involved - cannot be emphasised enough. Performance assessment modelling must not consist of mechanical "number crunching" using today's advanced computing tools. Scientific understanding and judgement is needed from the outset - and, indeed, throughout the process up to and including interpretation of the numerical results produced by the models.

Only when sufficient understanding of the system has been achieved can we develop the conceptual model which represents our understanding of the features and processes of interest. It is an abstraction of reality which need only include those relationships needed to describe the system for the intended model application. Ideally, the relationships are stated in terms of testable hypotheses. For performance assessment, the relationships of the conceptual model are represented quantitatively in a calculational model. The calculational model may be as simple as a closed-form analytic solution or so complex that only computer solutions are possible.

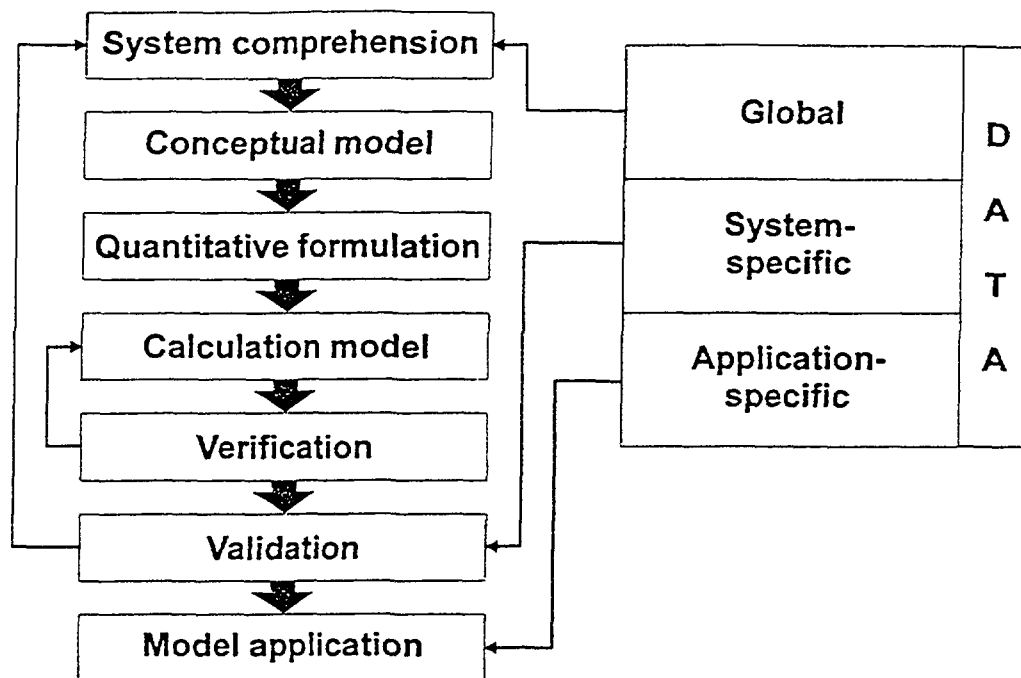


FIG. 1. Stages in modelling for performance assessment.

The next steps, labelled verification and validation, are intended to ensure that the model is adequate for the intended application. These processes remain the subject of intense debate - they are discussed at greater length in Section 3 of this paper.

2.3. Classification of models

Models can be classified according to their intended application; for example, models can be grouped initially into those that represent near-field phenomena and those that represent far-field phenomena. Definitions of the terms near-field and far-field vary, but in general, the distinction is that heat, disturbance of the host rock from construction, and the specific configuration of the repository and its components are important to the near-field but may be largely ignored in the far-field. Within each group, models can be classified by the sub-system or phenomenon that they are intended to simulate.

Models may also be divided into research models and assessment models. Research models are typically complex, detailed models that attempt to provide a relatively accurate representation of the system of interest. In research models completeness and accuracy of the representation are given greater weight than computational speed and efficiency. Thus, research models cannot normally be applied in situations where repetitive calculations are needed such as in estimating performance of the entire repository system over a wide range of scenarios. This gives rise to the need for the simplified assessment models that allow rapid calculation, but present a greater degree of approximation. Because they are normally more approximate and may integrate several processes, assessment models can be more difficult to validate.

A final important classification of models is into the categories deterministic or probabilistic. Deterministic models calculate a specific result from a given input dataset. Because there are always uncertainties in data due to measurement accuracies or to natural variations, it will normally be necessary to run the deterministic models for a variety of different datasets. Probabilistic models refine and automate this process in that data can be input as ranges or as probability density functions,

following which the corresponding ranges of output are generated by appropriate sampling techniques and iterative calculations. The relative advantages of deterministic and probabilistic approaches are briefly discussed below.

2.4. Current topical issues in safety assessments

As already mentioned, several areas in the safety assessment area are still being actively debated. In this section we shall briefly list and comment on the more important of these topics.

Safety indicators, safety criteria and compliance requirements: The most obvious indicators of the safety of a repository are the predicted effects on man and the environment. However, because estimation of radiation effects on man requires speculation on human behaviours, at very far-future times other safety indicators have been proposed. One example is the Scandinavian proposal for comparing radionuclide releases with the flow of natural radionuclides in the environment. Most safety assessments, however, concentrate on comparing estimated doses or risks to man out to far-future times with some acceptability criteria. On the much debated topics of dose criteria vs risk criteria, acceptable bounding levels, and timescales for the assessments there have been no single consensus decisions arrived at. Rather there has been a growing awareness that a multi-faceted approach is needed.

Use of pure dose criteria does not remove the necessity for discussion of associated probabilities and hence of related risks; more complex criteria based on risk considerations or on probable nuclide releases can be understood and put into proper perspective only by looking also separately at potential doses to individuals. The precise limits set for doses or risks are not of great relevance because of the relatively low resolution of the analyses and the conservative approach to safety normally employed. Specification of a fixed time cut-off for quantitative analyses of performance does not obviate the requirement to consider longer times at which releases may still occur. The licensing issue of most concern at present is not what the formal criteria should be, but rather how we can demonstrate compliance with a given set of criteria. As is clear from the text of the previous paper, the task of developing criteria which can be unambiguously used in compliance testing is viewed as a challenging task also by the regulators of radioactive waste disposal.

The most important point to be made is that 100 % proof of compliance will never be possible in waste disposal assessments - or indeed in any other comparable fields. A decision that the predicted safety performance of any technical system (other than simple quality-controlled components) is acceptable when measured against specific criteria has always involved an element of engineering judgement. The imminence of formal licensing procedures - and their increasing tendency to involve legalistic processes in which experts are called upon to deliver their considered opinions on technical questions - has led to intensive discussions on how such judgmental issues can be handled. It is still uncertain how formal compliance issues will be treated in a licensing procedure. Clearly, there will be much technical debate on key issues like uncertainties in performance predictions and model validation. It is important, however, that we do not raise expectations on the technical analysis to an unrealistic, unachievable level. We should openly acknowledge that some uncertainty on the performance and long-term safety of a disposal system will always remain - we should, however, require that judgements on acceptable uncertainties and on residual risks are compatible with those applied in assessment of other technologies.

Scenario selection/analysis: Performance assessment scenario analysis has been defined as "the identification and definition of phenomena which could initiate and/or influence the release and transport of radionuclides from the source to man. Thus scenario analysis provides initial and boundary conditions for subsequent consequence analyses". For scenario preparation, early lists of important processes and events which could initiate release were made and these were repeatedly used while a single overall systematic approach was being sought.

Attempts have also been made to use relatively complex simulation approaches superpositioning the effects of various processes and events. However, the more empirical approach, based on selected combinations of events and processes, has to date been directly applied in more numerous and more specific analyses. Both approaches have run into similar problems when trying to tackle the important issue of assignment of probabilities to single parameters, to overall scenarios, or to calculated risks.

In the simulation approach, parameters are specified by probability distributions which are often difficult - or impossible - to determine directly from measurement or observation. In the scenario selection/event tree approach, assignment of probabilities poses similar problems. Accordingly, strong reliance is always placed upon human judgement. At an early stage, formalised elicitation methods were proposed to structure such judgements and there has been a recent resurgence of this approach. The fundamental questions of ensuring completeness of scenarios and of allocation of probabilities will continue to be problematic issues in safety analysis.

However, this does not disqualify formal performance assessment as a tool for analysing future repository behaviour. It is accepted by the technical community (including regulatory bodies) that analyses can be based upon lists of "credible" scenarios and that a degree of subjective judgement will always be needed. A danger arises when one tries to avoid the difficulties of assessing low probabilities by arbitrarily assuming higher values and then estimating conservative (i.e. pessimistic) consequences for these scenarios; the resulting over-exaggerated estimates of risks must not be used unthinkingly to justify design changes in the repository - especially if these changes may be detrimental in the most probable, reference scenarios. A further problem is that highly unrealistic scenarios with large potential consequences can be introduced into the debate with undue weight if we do not work within a framework which focuses on both consequences and probabilities.

In the area of scenario analysis where so much reliance is placed upon human judgement, the approaches and methodology of the performance assessor must be as transparent as possible to other interested groups. Significant advances have been made here thanks to intense international cooperation and technical exchange.

Modelling approaches: One major issue debated in this area for many years has been the relative merits of deterministic and probabilistic approaches. In most programmes, a combination of the two is now employed, although the weighting varies enormously. Pure probabilistic analyses are intellectually satisfying and more objectively scope the range of potential future system behaviours; the basic problem of assigning defensible probabilities to all relevant events and processes remains a weak point. Simpler, more transparent approaches which deterministically model selected scenarios, on the other hand, inevitably land upon rare events of non-negligible consequence so that the probabilities must be taken into account.

A further topical issue centres upon the rôle of robust, bounding analyses as opposed to more realistic modelling of processes and events. The attractions of using conservative or robust analyses (e.g. in order to reduce validation requirements or to demonstrate that even pessimistic approaches do not lead to catastrophic failures) are recognised; these are particularly appealing features for projects nearing realisation. The down-side to such analyses, however, is that over-conservatism in modelling can lead to illogical or cost-ineffective choices for the barrier system. Optimisation of the overall disposal system is only possible based on reasonably realistic estimation of subcomponent behaviour.

The complexity of models to be used in a performance assessment depends upon the complexity of the governing processes, on the databases which can be built-up and on the computing power available. Today, computing power is still increasing rapidly and data collection methods (particularly in the field) are still developing, so that further progress can be expected towards improved modelling. A key question is whether such major advances are required or are feasible on the timescales of relevance for performance assessments needed for licensing of deep geological repositories.

In practice, near-perfect modelling solutions are neither required at present nor possible on useful timescales. It is much more important that we concentrate on getting a better understanding of the uncertainties in current models and data and on ensuring that our current methods and models do not underpredict the potential releases of radioactive material from a deep repository. The level of subsequent effort which is justifiable for improving methods in order to further reduce residual uncertainties or to more accurately represent real system behaviour will be a subject of recurring debate.

Treatment of uncertainties: This topic is probably the most discussed issue amongst performance assessors at present. Discussion is also included in the preceding paper of this Seminar. The relatively straightforward aspects of treating statistical-type uncertainties in data were tackled early by many groups. The thorny problem at present is the quantification of conceptual model uncertainties. Included here - and often mixed up with one another - are physical conceptual models of a repository site (geological features, flow and transport properties of these, etc.) and also conceptual models of important processes (e.g. flow in fractured media, rock-water interactions). Of course, it can never be possible to completely quantify uncertainties due to one's imperfect understanding of how a physical/chemical system performs. The earlier remarks on the necessity for some reliance on human judgement and the plea to require no more of assessments in our field than in other comparable areas must be again emphasised here. A rigorous quantitative derivation of all uncertainties in the results of safety calculations will not be possible. A more modest goal is to achieve a consensus amongst all parties on reasonable uncertainties to be attributed to components of the total analysis and to develop a traceable methodology for deriving overall uncertainties from these components uncertainties.

Presentation of results of performance assessments: This last issue to be raised concerns the increasingly important question of how to best present the results of a performance assessment. Different readers can react differently to the same presentation. The technical expert when confronted with yet another plot of time-dependent radioactivity releases will realise that time axes which extend up to 10^{23} years or release rates down to 10^{-50} Bq/y (both of which are actual examples from the literature!) are merely indicative of the numerical limits set on the computer run - but the uninitiated may conclude that we really believe ourselves able to predict such nonsensical numbers. The non-expert will be confused by complex, probabilistically expressed results; the specialist will quickly ask the probabilities associated with purely deterministically treated scenarios. No one outside the radiation protection field will fully grasp the (in)significance of extremely low dose predictions if a perspective of their health effects is not provided.

Accordingly, the final reporting of a full performance assessment is an important step which needs careful planning. The overview documents must be sufficiently simple and diversified with respect to display material that they can be grasped by a wider audience; the back-up technical documentation must be traceable and of adequate quality to allow review by regulatory authorities or also within the scope of the increasingly common peer reviews at an international level.

2.5. Applications of safety assessment

It has been pointed out that performance assessment is applied in many of the phases leading from conceptual design through to repository implementation. In earlier years effort was invested in generic scoping studies. This was followed by a second phase of performance assessment applications which involved integrated assessments of total disposal systems; these studies were aimed either at demonstrating basic feasibility or else at guiding future development work. Examples here come from Sweden, Switzerland, Germany, Finland, UK, Canada, the USA and the CEC. Some extremely important points which are stressed in almost all such guiding studies are repeated here. All contain explicit numerical estimates of the possible consequences of a waste repository and most of them compare different options with respect to siting, barrier design etc. In almost all cases, the predicted doses or risks from the repository lie far below regulatory limits but, at these low levels, large variations can result for different options. It is repeatedly stressed that no great importance should be

attached to such differences (a) because the accuracy of the modelling at these levels is limited and, more fundamentally, (b) because the objective of the assessments is commonly to show that the repositories can provide demonstrably adequate levels of safety and not to identify "safest possible" options and (c) because it is of questionable value to discuss further dose reductions at levels far below fluctuations in natural background.

The important application of performance assessment to development of site characterisation programmes has become much more common in recent years because an increasing number of national waste management programmes have reached this stage. It is noticeable in all such programmes that preliminary performance assessment has been used not only to judge the potential suitability of the site, but also to identify the critical geotechnical parameters which sensitively influence performance and which must therefore be measured with special care.

The most challenging application for performance assessment, namely in the licensing procedure, is also being faced in an increasing number of countries. After many years in which only a few disposal facilities existed - and these only for LLW -, new repositories have been developed in, for example, Sweden, Finland, France, Spain and Japan. The next challenge is to complete a performance assessment for licensing of a HLW facility. No country is at this stage and indeed, in most countries, debate is still continuing on some of the key issues to be tackled in HLW projects where the problems of producing quantitative and easily understandable predictions of future repository behaviour are significantly more difficult.

3. CONFIDENCE-BUILDING MEASURES

3.1. Verification, validation and confidence-building

In the early days of developing modelling for safety assessment, the terms "verification" and "validation" were given specific technical meanings which were reflected, for example, in the publications of the IAEA. Verification of a calculational model implies proving that the results calculated are not affected by errors in, for example, computer coding or data-handling. This definition, taken over from computer programming, is still in use.

The use of "validation" has led to more debate. The IAEA official definition makes clear that the objective of validation is to "ensure an acceptable level of predictive accuracy" and notes that this involves judgement based on knowledge of the application in mind. Unfortunately, this reasonable, pragmatic definition is often questioned by more academic scientists who tend to equate the concept of validation to that of "perfect or complete proof". In the writings of such modellers, there are often to be found caveats of the type that "complete validation can never be achieved".

Obviously, definitive proof of the correctness of any theory or model can never be achieved. Simultaneous acceptance of an absolute definition for validation and an absolute requirement for validated models accordingly dooms any modelling approach to failure from the outset. More useful is a pragmatic approach to validation which recognises that models and databases are sufficiently validated for use in a safety assessment when they are good enough to ensure that any remaining inaccuracies will not lead to an erroneous prediction of apparently acceptable repository performance in cases where actual performance would be inadequate.

To avoid the partly semantic disputes raised by the use of the word validation, it is becoming increasingly common to use a more general term, "confidence-building" to include all of the activities which are aimed at showing the reliability of safety assessment modelling as an aid to decision making. An important additional aspect inherent in usage of this term is that sufficient confidence must be shared not just by technical experts but also by a wider public; transparency in procedures and results, clarity in presentation and trust in the competence and the motivation of assessors then assume equally high importance.

3.2. Confidence-building in disposal programmes

Because the importance of validating safety assessment methods is universally recognised, significant efforts are devoted to this activity in national programmes and also within the scope of international projects. One recognised approach is comparison of calculated results with experimental values obtained in the laboratory or in the field. The fact that feasible measurement times are always much shorter than the timescales of relevance for disposal systems is obviously a great limitation here; nevertheless, agreement of calculation and experiments under a range of relevant conditions can enhance confidence in our understanding of mechanisms involved and also give a database for extrapolation. Extensive laboratory programmes have studied the behaviours of all materials in the repository system (waste matrices, container materials, clays and cements, diverse rock types); in the field or in underground research laboratories large experiments have simulated key aspects of rock mechanics, hydrogeology, hydrochemistry, etc. Of special importance are the major in situ radionuclide migration experiments which have contributed significantly to increasing confidence in our ability to model key processes retarding the transport of radionuclides in groundwaters.

To collect validation data of greater relevance for the long timescales to be considered, one can exploit the potential of natural analogue systems - i.e. natural or historical man-made systems whose characteristics can be monitored today and their evolution through time modelled using the same methodology to be used in safety assessments. Useful analogues range from natural ore bodies (like Oklo in Gabon or Cigar Lake in Canada), through specific localised features of relevance (e.g. the alkali springs of Oman), to the study of archaeological artefacts like Roman glasses or ancient metals. In contrast to laboratory experiments with well-defined initial conditions and limited timescales, some analogue systems have evolved over time periods even longer than those of relevance for repositories; however, there are often inherent difficulties in specifying closely the conditions at the outset and throughout the history of the analogue system.

The combination of short-term exact experiments and observations with long-term analogue studies does, however, contribute to elimination of unsuitable models and to increased confidence in those models retained for final safety assessments. There remains, of course, a large element of human judgement in this area, as in most other technical assessments. Accordingly, the "soft-science" approaches to further ensuring quality in technical work and reliability of products are also important.

These approaches include the use of open, wide and objective reviews of technical work. They include also the consideration given to impartial and unbiased elicitation of expert opinion on issues where human judgement remains of key importance. It is no coincidence that the literature in the waste disposal area, generated by old and new journals as well as by innumerable dedicated conferences, has increased so dramatically over recent years. It is rather an expression of the interest of all those involved in disposal programmes to stimulate debate, to make the maximum information available to interested parties, and to seek consensus on issues affecting our confidence in safety assessment methodologies and results.

3.3. Current level of confidence in safety assessment

In their 1991 Collective Opinion on safety assessment methodology, representatives of the NEA-OECD, the IAEA, and the CEC expressed their belief that adequate (although not perfect) methods were available for the assessment of the safety of a waste repository. The critical step towards production of reliable comprehensive assessment of deep repositories was judged to be not the further development of methodology but rather the gathering of sufficient data from site characterisation programmes. However, this opinion, formulated by experts within the waste community, continues to be challenged at the broad level by nuclear opponents. At the detailed technical level, a debate on the validity of specific models continues even within the technical community. It is not surprising that decision makers and public are still to some extent confused by the conflicting input they therefore receive.

Where does the way ahead lie? At the technical level there must be increased recognition that **perfect** solutions are neither possible on repository-relevant timescales nor, indeed, are they required for justifiable project decisions. It is more important that we concentrate on understanding the effects of uncertainties in our current models and data and on providing reasonable assurance that these current approaches will not underpredict potential releases of radioactive materials from repositories.

At the wider level, it is crucial that safety assessment experts communicate their belief that their calculated results, although imperfect, provide sufficiently reliable input for decision makers. Numerical results of analyses extending out to geological times, if presented without sufficient discussion of their significance, lead understandably to accusations of over-optimism, immodesty or even irrationality. On the other hand, failure to emphasise the conservative nature of safety analyses and the existence of a broad base of scientific facts which make estimates scientifically justifiable would deprive decision makers and public of a crucial element determining their confidence in and acceptance of waste repositories.

4. SUMMARY AND CONCLUSIONS

The following conclusions on the status of safety assessment for waste repositories can be based on the preceding discussions:

- ♦ The necessity of modelling the long-term performance of a repository is universally recognised. Quantitative results from assessments can provide the necessary input for decisions throughout disposal system development. The calculated results do not, however, provide hard criteria which obviate the need for human judgement. Safety assessments alone are not the only considerations governing the acceptability of any disposal facility.
- ♦ The feasibility of performing assessments of sufficient quality is accepted by technical experts within the waste management community; this technical consensus has been documented in the international Collective Opinion referred to earlier. A somewhat lower level of confidence exists in wider scientific circles and in limited segments of the public severe reservations are still expressed. Of course, the coupling of the waste disposal issue to the highly politicised and polarised issue of nuclear power production means that certain groups have vested interests in over-emphasising the strengths or the weaknesses of assessment methodologies. Some of the remaining differences in views could be narrowed if assessors made clearer that their aim is not to exactly predict the future but rather to scope the range of potential future behaviours of the repository system.
- ♦ Specific parts of the modelling chain for geologic repositories continue to be developed and refined. The common timescales for implementation of HLW repositories leave many years for potential improvements. These developments may ease the difficulties in future licensing procedures; nevertheless, they will not result in perfect models which produce unquestionably accurate results. The requirements on human judgement and expert opinion will remain.
- ♦ The critical issue with respect to safety assessment is the required or the achievable level of confidence in the results of the analyses. Neither a 100 % level of safety nor a 100 % confidence in the reliability of the assessments is possible. This is a fact which is true also for every other comparable technical undertaking and we must take care that unique, unfulfillable requirements to the contrary are not placed on waste disposal.
- ♦ The extensive technical efforts which are being put into specific validation programmes centred around comparisons of calculations, experiments and observations of analogue objects should be increasingly complemented by further confidence-building measures. These include peer review, more formalised quality assurance, transparent documentation and open discussion with all involved parties.

- The field of safety assessment is extensively documented. The area is sufficiently mature to allow international guidelines or criteria of a generalised nature to be established for the performance of safety assessments. Documents of this type already exist, for example, in the IAEA RADWASS series. However, the specific issue of specifying the precise nature and the appropriate numerical levels for acceptance criteria is still under active discussion; it is therefore more productive to concentrate on confirming the consensus at the broad level rather than to try now to develop common detailed standards and criteria.

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REVIEWING POST-CLOSURE ISSUES

H. RÖTHEMEYER
Bundesamt für Strahlenschutz,
Salzgitter, Germany

Abstract

The study of man-repository-interaction in the post-closure phase is a new field of research. Its evaluation must be based on a proper assessment of the predictive possibilities and limitations of the man-repository-system. Institutional controls would be a way of solving post-closure issues connected with retrievability, human intrusion and safeguards. Their predicted effectiveness is, however, limited to a few hundred years for active and to a few thousand years for passive controls. Therefore the much longer time periods of concern for geological repositories have to be taken into account. Answers to post-closure issues should be based on a rational evaluation of the good and bad aspects of alternative strategies and actions. Such an evaluation reveals tentative answers to post-closure issues. Retrievability: Repository construction and sealing in a way that renders institutional control unnecessary, but not impossible. Human intrusion: Emplacement of unavoidable hazardous waste in deep geological repositories is the best we can do today; alternatives like indefinite storage present higher risks and burdens on future generations. Safeguards: Safeguarding of nuclear material, if considered necessary by future generations, is possible with present day technology. Geological repositories will not enter into a post-closure status before the middle of the next century. Therefore post-closure issues present no urgent problem.

1. INTRODUCTION

The objective of radioactive waste management is to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations. This protection goal is enunciated in the Safety Fundamentals [1] of radioactive waste management. It will be achieved, if the requirements contained in 9 principles of the Safety Fundamentals are met. For post-closure issues, the following principles are of special relevance:

- **Principle 4: Protection of future generations**

Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.

- **Principle 5: Burdens on future generations**

Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.

It is internationally agreed that disposal provides the best option for fulfilling the principles and thus achieving the above objective [2]. Disposal is defined as the emplacement of waste in an approved, specified facility (for example, near surface or geologic repository) without the intention of retrieval [1]. It aims at containing and isolating the waste in a repository in such a manner that residual radioactive substances possibly reaching the biosphere in the future will be at concentrations that are acceptable today. The disposal concepts were originally developed with main reference to scientific/technical arguments which were based on multiple barriers and their interaction with the natural cycles of matter. The above objective can only be achieved, however, if future societies and possible human actions are considered as well. The evaluation process is thus of an unprecedented interdisciplinary nature and dependent on subjective elements. This has led some scientists to consider that to make long-term predictions concerning, for example, the safe isolation of radioactive waste is wishful thinking [3]. A proper assessment of the man-repository-system with possible man-repository-interaction will show whether this conclusion is justified.

2. MAN-REPOSITORY-SYSTEM

Man-machine-systems and man-machine-interactions have been studied for quite a while. It has been of special importance with systems, where improper man-machine-interaction can result in immediate hazards for man and the environment. The interaction between man and nuclear power plants are a good example [4]. The study of man-repository-interaction in the post-closure phase is a new field of research. Its evaluation must be based on a proper assessment of the predictive possibilities and limitations of the man-repository-system.

The possibilities for predictions are strongly dependent on the number and nature of disciplines involved. Predictions of the radioactive decay of waste can be handled by scientific disciplines like physics and chemistry alone; they can therefore be made over practically unlimited time frames with the necessary precision. Predictions of nuclide migration from a repository to the environment necessitate the evaluation of the natural cycles of matter. The disciplines involved, for example geology, are of a descriptive nature. Their predictive capability is based on the premise that present cycles and processes are the key to our understanding of the past and that this understanding again is a prerequisite for predictions. The latter are thus associated with uncertainties. These are considered to be limited as long as the predictions don't cover time spans far beyond those of the respective cycles of matter [5]. Table 1 indicates the orders of magnitude for our predictive possibilities. These results have caused an international group of experts to recommend the use of different safety indicators in different time frames for the safety assessment of underground radioactive waste repositories [6, 7].

TABLE 1. PREDICTIVE POSSIBILITIES AND LIMITATIONS OF MAIN PARTS OF THE MAN-REPOSITORY-SYSTEM

The time scales should be taken as approximate orders of magnitude. The number of disciplines involved in the respective assessments ranges from a few to some twenty disciplines. (Note: The uncertainties associated with the predictions may be large and must be estimated site specifically)

Radioactivity	practically unlimited
Cycles of rock forming material (substantial natural barrier changes)	10^6 years
Climatic cycles (substantial near surface changes)	10^4 years
Passive institutional control (Markers, conservation of information)	10^3 years
Active institutional control (monitoring, surveillance, remedial work, land use control)	10^2 years

Herrmann introduced the scientific base of waste management as early as 1979. He concludes that toxic elements, disposed of close to the earth's surface can be isolated from the biosphere for time periods of the order of one hundred years and those disposed of in repositories for up to millions of years [8].

This isolation potential, however, could only be guaranteed, if disruptive events could be avoided. Proof of these prerequisites will always remain an illusory objective [7, 9, 10]. Therefore

repository designs that allow for long term retrievability of the waste and inadvertent and intentional human intrusions (for example to recover nuclear material) are post-closure issues. They could only be avoided by effective institutional controls. These controls can be active (for example monitoring, surveillance, remedial work, land use control) or passive (for example markers, conservation of information). The assessment of timescales over which these controls can be relied upon involves consideration of changes in society and human behaviour and thus disciplines with a low predictive capability. Respective timescales [11] are also indicated in Table 1. As the long-term potential for harm, especially of high-level waste and/or spent fuel remains for hundred thousands of years, issues connected to retrievability, human intrusion and measures to prevent recovery of nuclear material (safeguards) are of particular concern in the post-closure period.

3. RETRIEVABILITY

Retrievability is defined as the ability to remove waste from where it has been emplaced.

The defining characteristic of the post-closure status is that no further engineering measures are expected to be necessary in order to ensure proper future performance of the disposal facility. In a geological repository, for example, the post-closure phase pertains to the period of time following final shaft sealing and surface facility decommissioning. Retrievability as a design base may thus be in conflict with the post-closure status desired for compliance with the aforementioned objective and principles of radioactive waste management. On the other hand the ethical requirement of not foreclosing decisions and responsible actions including reparability/retrievability of future generations may be easier to meet.

The different views on the subject were expressed at an international workshop on the environmental and ethical aspects of long-lived radioactive waste disposal in 1994 [12]. The extensive discussions held at this workshop show that final conclusions will have to be based on scientific/technical and especially ethical grounds. The workshop provided an important base for the Collective Opinion of the Radioactive Waste Management Committee (RWMC) of the OECD Nuclear Energy Agency on "The Environmental and Ethical Basis of Geological Disposal" [2].

The conclusions of the Collective Opinion concerning retrievability are based on the following scientific/ technical and ethical arguments:

An essential aspect of the waste isolation strategy is that long-term safety of geological repositories must be convincingly presented, and accepted, prior to actual waste emplacement. The feasibility and reliability of such a safety case, including uncertainties unavoidably associated with the assessment of future situations, were addressed and confirmed in a previous international Collective Opinion [13]. Geological disposal should not necessarily be looked at as a totally irreversible process, completely foreclosing possible future changes in policy: Sealing of a site and its access will always require a specific decision; it could be delayed well after the end of waste emplacement operations to facilitate reversibility and allow flexibility in the decision making process. In the extreme case of retrieval from a sealed repository, engineering procedures might be difficult and costly, but not impossible, and somewhat analogous to the extraction of toxic mineral ores (cf. chapter 5). Therefore geologic disposal without the intention to retrieve the waste meets also the ethical requirement of not foreclosing responsible actions of future generations.

4. HUMAN INTRUSION

In 1990 the OECD/NEA established a Working Group on the Assessment of Future Human Actions at Radioactive Waste Disposal Sites. This group published its final report in 1995 [11]. The following review is heavily based on this report. Additionally, use has been made of discussions within the Sub-Group on Principles and Criteria for Radioactive Waste Disposal of the International Radioactive Waste Management Advisory Group (INWAC) of the IAEA.

Possible human intrusions in the post-closure phase may be intentional or inadvertent. They are of concern, if they have the potential to disrupt or impair significantly the ability of the natural or engineered barriers to contain the radioactive waste. Intentional actions can generally be considered the responsibility of the society that takes these actions, especially if they are forewarned of the consequences. Intentional intrusion for gaining access to nuclear material will be considered in the next chapter.

Inadvertent human intrusion and disruptive natural events can result in the same type of consequences. Thus, the general quantitative framework developed for safety assessment involving naturally occurring events and processes is also appropriate for the analysis of human intrusion scenarios. Extensive human judgement is required for the development and modelling of these scenarios (cf. chapter 2).

So far the following basic assumptions have been made for scenario development:

- Drilling a water well (Belgium, Canada, Finland, Sweden, Switzerland);
- (exploratory) drilling (Canada, Germany, Netherlands, UK, US);
- contaminated soil or peat (Canada);
- mine cavern 50 m away from repository (France);
- solution mining (France, US);
- storage cavern in salt (Germany).

The analyses of human intrusion scenarios into or near a geological repository using these assumptions can lead to significant doses to hypothetical future individuals; in some cases they can be higher than those from natural evolution scenarios. The results are not surprising as the radiotoxicity and direct radiation of high level waste or spent fuel in a repository remain potentially harmful for hundred thousands of years. According to the PAGIS-study [14] these scenarios don't, however, provide a dominant contribution to the overall annual risk because of their low probability of occurrence.

Most studies assume future modes of intrusion similar to those of today. They might, however, change significantly in the future. The decline of natural resources in the future, for example, may change drilling frequencies significantly. The subjective element in the development of the scenarios have created concern for important scenarios and their probabilities being forgotten or even deliberately disregarded [3]. There is international agreement, however, that the results of the analysis of human intrusion scenarios can only be illustrative and never complete; they cannot represent a realistic view on what will be in the future.

It is this very dependence of human intrusion analysis on subjective judgement, which have led countries like Germany to refrain so far from specific criteria for judging human intrusion scenarios. On the other hand, the US Environmental Protection Agency regulations provide a range of guidance on drilling likelihood, borehole backfill properties and the effectiveness of institutional controls. In most national regulations, however, the basis for judging risks associated with future human actions in licensing assessment has not been clearly defined. Therefore the Radioactive Waste Management Committee of the OECD/NEA endorsed at its 26 meeting in January 1994 the proposal for a Working Group on the regulatory aspects of judging assessments of future human actions at radioactive waste disposal sites.

The very nature of post-closure issues like human intrusion is not purely technical (cf. chapter 2, 3). Any regulatory approach must be based on philosophical and especially ethical arguments as well. It is a basic requirement of ethics that an evaluation of the good and bad aspects of alternative strategies and actions is needed [2, 12]. This point was strongly stressed in the public enquiry for the Konrad repository [15]. Here human intrusion as an issue was of negligible importance. This agrees with the collective opinion [2], which may be summarised with respect to the human intrusion issue as follows: Emplacement of unavoidable hazardous waste in geological

repositories is the best we can do today to comply with the objective and the principles of radioactive waste management (cf. chapter 1); alternatives like indefinite storage present higher risks and burdens on future generations.

Another ethical requirement is to adhere to the ALARA-principle, even if the overall risk is estimated to be small. Therefore measures may be used to reduce the probability or to mitigate the consequences of future inadvertent human intrusion in a geological repository. The most effective ones would be active institutional controls. As these measures can only be considered to be effective for timescales, which are negligible to the time periods of concern (cf. Table 1) other measures are discussed. They include:

- Siting of repositories away from areas of currently recognised subsurface resource potential. Although this might be considered the most effective measure and has been incorporated into both national and international guidance on siting, in practice other siting factors (e.g., geological formation, local acceptance of the repository) may emerge as being of greater importance. The resource potential or its value for future humans may change, too, during the long time periods of concern.
- Isolation of waste far from the human environment. For deep geologic repositories, the very depth of burial is an important mitigating feature against potentially disruptive human actions. Given that knowledge of the location of a waste repository is lost, the likelihood of direct intrusion is reduced as the depth of the repository is increased. This strategy may have detrimental effects on cost and safe operation and is limited by present mining technology.
- Other criteria for the design of waste repositories (e.g., geometry of disposal, backfilling materials, intrusion barriers) and for the waste form itself (e.g., low tendency to form dust if exposed in open air) can help reduce the consequences associated with disruptive human actions.
- Conservation of information at different levels of society and locations can help to reduce the likelihood of disruptive human actions in the short term of up to several hundred years.
- For comparable or even longer time scales, large-scale physical markers at or near the site may help to reduce the likelihood of disruptive human actions. Recent work suggests that well designed markers have a high likelihood of maintaining their effectiveness for periods on the order of several thousands of years. On the other hand, some argue that far in the future the message concerning the hazard associated with the repository might not be properly understood, and that markers may serve primarily to increase interest in the repository.

In contrast to geological repositories, near surface ones for short lived low and intermediate level waste are usually designed by taking advantage of a post-closure institutional control period of up to a few hundred years. Thus controls maintained after closure contribute to enhancement of the safety of the disposal facility. The controls can be active or passive (cf. chapter 2) or a combination of both [16].

5. SAFEGUARDS

The IAEA is responsible for monitoring adherence to safeguards requirements for fissile material throughout the life-cycle of these materials [17]. So far waste management facilities for direct disposal, including conditioning plants and geological repositories are not addressed by current safeguards approaches. The Agency is therefore assessing whether safeguards agreements covering fissile material might lead to the necessity of applying safeguards to repositories. To achieve this aim a number of Member States have been addressed requesting support in the development of "Safeguards for Final Disposal of Spent Fuel". A Joint Programme of Germany with the IAEA was initiated in 1988. It aims at a "Reference Concept for Nuclear Material Safeguards in a Geological Repository for Spent Nuclear Fuel". In 1993 the USA initiated a multinational task with the IAEA for the development of a safeguards concept generally applicable in all host rock formations.

With respect to the post-closure phase of a repository containing spent fuel, present thinking assumes that safeguards cannot be terminated. The basis for this assumption is the existing safeguards

agreement [18] and recommendations by international advisory groups [19]. This assumption is drawn from an evaluation of the criterion that safeguards can only be terminated, if IAEA determines that the material has been consumed or diluted in such a way that it is no longer usable for any nuclear activities or has become "practicably irrecoverable" (PI). So far, no rigorous definition of PI has been provided in the IAEA documents [20, 21].

The position of not terminating safeguards poses issues concerning compliance with the objective and principles of radioactive waste management. Of special concern is the impact of possible safeguards procedures on the safety of the disposal system, the burden on future generations and the necessary provisions for long lasting continuity of responsibilities and funding requirements. These provisions and requirements are specifically addressed in the Safety Fundamentals [1] and the safety standard "Establishing a National System for Radioactive Waste Management [22].

In 1992, issues like these concerning the interface between nuclear safeguards and radioactive waste management were discussed at a meeting of the Standing Sub-Group of the International Waste Management Advisory Committee (INWAC) on "Principles and Criteria for Radioactive Waste Disposal". The Sub-Group requested that a working paper be prepared to examine the current safeguards position with respect to radioactive wastes, including spent fuel, from a radioactive waste management perspective. This paper [23] represents the first assessment of the interface between safeguards and radioactive waste management (cf. also [10]). With respect to the post-closure phase the following conclusions are drawn:

- Safeguards procedures must be designed keeping in mind that the safety of the isolation system is an absolute priority. In other words, the integrity of the natural barriers should not be threatened, due to surveillance and monitoring;
- A distinction should be made between disposal facilities containing only waste and repositories containing only spent fuel or a mixture of waste and spent fuel.
- At the present time no clear safeguards policy for closed repositories containing only wastes seems to exist. Because of the relatively low concentrations of nuclear materials in the various categories of radioactive wastes and the enormous difficulties of recovering waste from closed, deep disposal facilities, it is considered that there is no need to maintain safeguards requirements for the waste-only-repositories.
- For spent fuel in repositories, the difficulties in recovering material from a closed repository would also be considerable and it is extremely doubtful as to whether it can be regarded as a realistic diversion scenario. However, if it is presently accepted that safeguards must be maintained after closure of such repositories, proposed surveillance techniques such as a combination of satellite imagery and non-intrusive geophysics (e.g. surface based techniques such as microseismic surveillance) would ensure the continuing integrity of the repository and would not affect its safety system.

The paper does not provide answers concerning burdens on future generations and the necessary administrative and financial provisions addressed above. One might even conclude that a technology, producing waste, which has to be monitored for practically indefinite periods of time, cannot be justified especially on ethical and financial grounds.

A tentative answer to these issues can be derived from defining PI in agreement with, for example, the above conclusions concerning waste-only-repositories. Here the enormous difficulty of recovering the waste is addressed. As a recovery is in principle always possible, this argument refers to relative difficulties compared to alternatives. Therefore the question of retrievability has a key role. In chapter 3 it was concluded that retrievability in the post-closure phase might be difficult and costly, but not impossible.

A German study on retrievability of spent fuel in a salt repository provides the following information [24]: Retrieval of spent fuel in the post-closure phase is possible by means of a specially designed mine. It takes about 19 months to recover the first cask. The technical and financial efforts

TABLE 2: SUMMARY OF POST-CLOSURE ISSUES OF GEOLOGICAL REPOSITORIES

Issue	Scientific/technical and ethical issues	Tentative answers
Retrievability	Generally, safety and the limitation of the burdens on future generations require a sealed geological repository without the necessity of institutional control; a perfect technical system, however, does not exist and future generations ought to have the possibility for institutional control including responsible actions like repairability/retrievability.	Repository construction and sealing in a way that renders institutional control unnecessary, but not impossible.
Human intrusion	Human behaviour is least predictable in predictive assessments; impacts on a limited number of people may be high, but difficult to quantify; limitation of human intrusion scenarios to inadvertent actions; measures like institutional control, siting, optimal isolation and special design may present adverse scientific/technical and ethical problems.	Emplacement of unavoidable hazardous waste in deep geological repositories is the best we can do today; alternatives like indefinite storage present higher risks and burdens on future generations.
Safeguards	Fissile materials (e.g. in spent fuel elements) is subject to international safeguards to prevent military use; it may be terminated, if the material becomes "practicably irrecoverable"; this condition is presently not considered to be fulfilled for spent fuel, leading to discussions of not terminating safeguards after repository closure.	Waste packages and/or spent fuel in a repository should be considered practicably irrecoverable, if retrievability of the nuclear material presents - compared to alternatives - a relatively low risk from a safeguards point of view; spent fuel emplaced in a deep geological repository at elevated temperatures can generally be considered to be "practicably irrecoverable"; excavation of a sealed repository cannot be carried out in a short time; therefore periodically obtained satellite images or inspections can principally be made use of, if consensus on the view expressed above cannot be achieved; safeguarding of nuclear material in the post-closure phase is thus possible with present day technology but presents no urgent problem; repositories for e. g. spent fuel are not expected to be closed before the middle of the next century.

are comparable to the erection of the repository, i.e. with costs in the order of billions of DM. The necessary infrastructure and the waste heap prevent an undetected recovery.

These results lead to suggest the following definition of PI: The respective waste package and/or spent fuel is practicably irrecoverable, if retrievability of the nuclear material presents - compared to alternatives - a relatively low risk from a safeguards point of view. Here the uranium option (e.g. uranium deposit, heap leaching) might be a more profitable and convenient alternative. The German Federal Office for Radiation Protection (BfS) and the Swedish Statens Kärnkraftinspektion (SKI) take the position that extremely high demands on inaccessibility from the point of view of safeguards are hardly reasonable bearing in mind the alternatives for producing fissile material which are always available [25, 26, 27].

The above discussion shows a tentative answer to the important post-closure issue of safeguards. To achieve an international consensus, experts in safeguards and waste disposal should work in close cooperation.

6. SUMMARISING REMARKS AND CONCLUSIONS

Post-closure issues are of an interdisciplinary nature. Ethical considerations in the face of uncertainties in predicting the future are the main focus of common interest. Possible measures including safeguarding of nuclear material can be taken so as not to be in contradiction with the safety of the isolating system. Effective institutional controls would be a way of solving post-closure issues. Their predicted effectiveness is, however, limited to a few hundred years for active and to a few thousand years for passive controls. Therefore the much longer time periods of concern for geological repositories have to be taken into account. Answers to post-closure issues should be based on a rational evaluation of the good and bad aspects of alternative strategies and actions with safety as an absolute priority. Such a process will reveal that long term issues are associated with practically all technologies. The issues and tentative answers presented in this paper for radioactive waste management are summarised in Table 2.

The assessment of post-closure issues in this paper leads to a more balanced position concerning the possibilities and limitations of long term predictions as the one expressed in the introduction: On the one hand it would indeed be wishful thinking to view long term calculations as an exact prediction of hazards to humans living in the far future. They are, however, indicators of safety. These indicators provide a high level of confidence that the health and environment detriment from radioactive waste repositories can be planned and regulated to be in agreement with the aforementioned objective and principles of radioactive waste management.

Geological repositories will not enter into a post-closure status before the middle of the next century. Therefore post-closure issues present no urgent problem. The following generations will have to take final decisions. It is the responsibility of the present generation, however, to develop answers to post-closure issues especially on a sound scientific/technical and ethical base. The tentative answers presented in this paper are a further step towards achieving this goal. They should encourage close cooperation of the disciplines involved.

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EXEMPTION, CLEARANCE AND REMEDIATION

G. LINSLEY

International Atomic Energy Agency,
Vienna

A. JANSSENS

European Commission,
Plateau Kirchberg, Luxembourg

Abstract

This paper is concerned with the mechanisms by which materials, wastes and surface areas contaminated to very low levels with radionuclides may be removed from the requirements of regulatory control. The practices of recycle and reuse of slightly contaminated materials from the nuclear industry and the disposal of very low level wastes from various sources are reviewed and the principles and criteria which have been adopted in different countries and internationally for their exemption and clearance from regulatory control are presented. The paper addresses some of the issues which have arisen in the application of exemption principles. Consideration is given to the factors which have to be taken into account in making decisions on the remediation of contaminated land and progress in the development of radiological criteria for guiding decisions is reviewed.

1. INTRODUCTION

Within the nuclear industry materials may become contaminated or activated at varying levels of activity concentration. A large proportion of the materials, for example, of the steels and concrete used in building construction, are contaminated at very low levels and present a negligible risk to health. They can therefore safely be considered as candidates for recycle, reuse or disposal outside the nuclear industry. Low level wastes arise both within the nuclear industry and as a result of the use of radionuclides in medicine and research. Most of these wastes are so low in activity concentration as to be of little health concern and they are suitable for disposal with normal municipal wastes. Before such releases can be allowed it is first necessary to establish appropriate radiological criteria as a basis for judging the acceptability of the practices. The same general considerations apply to land areas which have become contaminated as a result of operations or accidents involving radioactive materials. Such areas may be released from control provided that the levels are sufficiently low or have been reduced to low levels as a result of decontamination/clean-up operations. Again, it is necessary to establish appropriate criteria as a basis for decisions on the release of such areas.

In this paper we first review the practices of recycle and reuse of slightly contaminated materials from the nuclear industry and the disposal of very low level wastes from various sources and then discuss and present the criteria for release which have been used in different countries. Next the criteria which have been developed at the international level are presented and discussed. Consideration is then given to situations requiring environmental remediation and to the development of criteria for releasing such areas from regulatory control.

2. TERMINOLOGY

Various terms relevant to the subject have been defined; they are presented in the following paragraphs.

Radioactive materials emit ionizing radiations and they are, therefore, potentially harmful to health and generally need to be controlled. This is typically achieved by means of a regulatory system which includes notification, registration and licensing [1] or reporting and prior authorization [2].

Some types of sources of ionizing radiation do not need to be subject to regulatory control, either because they are not amenable to control (e.g. cosmic rays at ground level and most natural sources in the environment) and are therefore *excluded* from the regulatory process, or because they present such a low risk that it would be a waste of resources to exercise control by regulatory processes. In the latter case, two types of situation can be distinguished:

- radiation sources which never enter the regulatory control regime, that is, control is not imposed, and
- radiation sources which are released from regulatory control, that is, control is removed.

The first situation is called *exemption*; it typically includes the small sources of radiation such as tracers used in research, calibration sources and some consumer products containing small sources or low levels of activity per unit mass which are not normally regulated. The corresponding levels of activity or activity concentration are called *exemption levels*.

The second situation is called *clearance* (or decontrol); it includes materials formerly under regulatory control which have been processed in such a way that their use no longer presents a significant radiological risk or whose radioactive content has been substantially reduced by decay. Examples are materials for recycle and wastes containing low levels of radioactivity from within the nuclear fuel cycle or from other regulated facilities such as hospitals, research laboratories and industry. When regulatory controls are removed, materials are said to be "*cleared*" from regulatory control. The corresponding levels of activity or activity concentration are called clearance levels.

The distinctions between exclusion, exemption and clearance are illustrated in Figure 1.

3. CANDIDATE MATERIALS FOR EXEMPTION AND CLEARANCE

3.1. Sources candidate for exemption

As explained in Section 2, exemption implies not imposing control because the associated risks are trivial. In most countries regulations for the control of radioactive materials specify those sources which are outside the requirements of the regulations. The sources are generally those involving the small scale use of radioactive materials, such as:

- density gauges (β emitters)
- testing the integrity of semiconductors and leak testing generally (e.g., ^{85}Kr)
- in education (e.g., sealed sources for demonstrating properties of radiation)
- technological application (e.g., ^{63}Ni in gas chronography)
- smoke detectors (e.g., ^{241}Am)
- research laboratories (e.g., ^{14}C and ^{32}P as tracers in biochemical research)
- hospital laboratories (e.g., radio-immunoassay techniques).

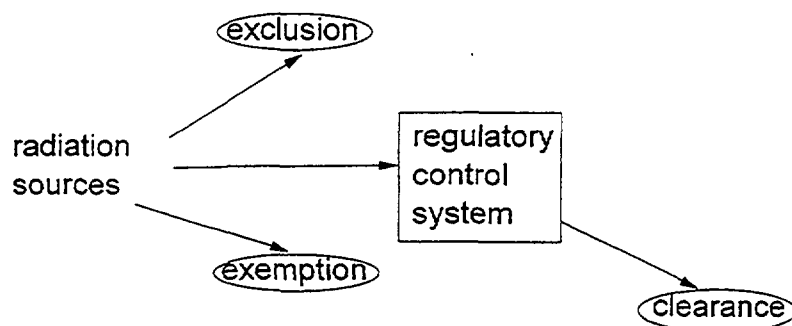


FIG. 1. Exclusion, exemption and clearance - basic concepts.

3.2. Wastes candidate for clearance

The use of unsealed radioactive materials in hospitals for diagnosis and treatment as well as for research in the medical field results in the generation of various kinds of radioactive waste. In general, these include radioactive materials which are no longer useful and are therefore regarded as waste, items which have been contaminated with radioactive materials, such as paper, plastic gloves and covers, counting tubes, glassware, washing liquids and excreta from patients who have been treated internally with radioisotopes.

A wide variety of radioisotopes is used for research in the fields of agriculture, biology, physics, chemistry etc. The wastes generated from such research uses range from more easily handled materials such as contaminated aqueous liquids and combustible materials to less easily handled contaminated materials such as organic liquids, (e.g., liquid scintillation fluid) large animal carcasses and large contaminated equipment. Since many of the radionuclides used in hospitals and research establishments have relatively short half-lives, and can be effectively disposed of through storage to allow for decay to harmless levels, these are generally separated from longer-lived radionuclides.

Much of the solid radioactive waste arising in hospitals and research establishments consists of contaminated paper and plastics. These wastes may be disposed of by incineration or, alternatively, by direct disposal in landfills. At some establishments a proportion of solid waste consists of animal carcasses. These are either treated as combustible waste, macerated and disposed with liquid wastes or collected for burial.

Liquid wastes are generally segregated into aqueous and organic liquids. Organic scintillation liquids constitute a significant proportion of the organic liquids. The aqueous liquids may be discharged directly to the sewage system provided that radionuclide concentrations are sufficiently low. The normal disposal method for organic wastes is by means of incineration.

Wastes of similar types to those described above occur within the nuclear fuel cycle and the same disposal options can, in principle, be applied.

3.3. Materials for recycling and reuse

Waste materials and materials which have the potential to be recycled or reused arise in all parts of the nuclear fuel cycle. Such materials are generated throughout the active lifetime of nuclear facilities but it is at the decommissioning stage when the volumes of metal and concrete with potential for recycle and reuse and for disposal are at their largest. At the present time when many nuclear facilities in the world are approaching, or have arrived at, the decommissioning stage it is important for the possible options for managing the materials from decommissioning to be critically examined.

3.3.1. Quantities involved [3]

Studies have indicated that the total quantity of steel in a large (1000 MW(e)) pressurized water reactor (PWR) or boiling water reactor (BWR) is about 10 000 t. About half of this material (5000 t) has a potential for recycle using currently available decontamination methods. Additional estimates for advanced gas cooled reactors of the 600 MW(e) class indicate that they would also contain about 10 000 t of steel with a similar potential for recycling. Estimates for a Magnox station are that the total quantity of steel resulting from decommissioning would be about 13 000 t. For a Magnox station, about one third, or about 4300 t, would be potentially suitable for recycling.

Concrete makes up by far the largest inventory of potentially contaminated or activated material at commercial nuclear power stations. Although not as economically important as steel or other metals, there exists the potential to recycle some contaminated concrete, which can be used as aggregate in making new concrete for construction. It is estimated that there are about 180 000 t of

concrete in a 1000 MW(e) PWR constructed in 1971. Of this total, about 13 500 t are potentially contaminated and about 900 t are potentially activated. If half of this material could be released for recycle as aggregate in making new concrete, the waste disposal cost savings would be significant.

Other nuclear installations contain significant quantities of steel and other metals, especially uranium enrichment and nuclear reprocessing plants. For example, a uranium enrichment facility utilizing gaseous diffusion will contain thousands of tonnes of steel and aluminium that may be decontaminated and released after the facility is decommissioned. In addition, there are other maintenance operations at nuclear installations that could result in the production of significant quantities of scrap metals and items that could be reused. These may include, for example, fuel flasks used to transport fuel, shielding casks for the interim storage of radioactive wastes and large pieces of equipment from uranium mine/mill facilities.

The most abundant metal used in nuclear power station is carbon steel. It is used as a main structural component and is the main material used in the primary coolant side of the stations, including the reactor vessel and many of the major components. The typical annual production of raw steel worldwide is about 700×10^6 t, consisting of about 56% recycled scrap (from all sources) and 44% from new ores. It is clear that if about 5000 t of recycled steel could be recovered per reactor, the total quantity of steel that could be recovered even from an aggressive worldwide decommissioning programme would be less than 1% of the total feed required for the steel industry worldwide. Although the case is less clear for specialty metals (including aluminium, copper and nickel), there is certain to be a large dilution on average by scrap materials from other sources and from fresh ore feed.

The recycle of concrete occurs in some countries, depending on the specific industrial and economic situation. It is possible that more emphasis will be placed on concrete recycle in the future; however, it is difficult to predict whether this will happen with certainty because of the availability of aggregate from other sources. It seems clear that only a tiny fraction of the global demand for aggregate could reasonably be supplied by concrete recycled from decommissioning. It is also likely that in concrete recycling operations there would usually be a large dilution factor because of mixing of aggregate from a number of sources.

3.3.2. Options

When materials are being considered for recycle or reuse they must satisfy certain specified radiological requirements. In order to achieve these goals, operations designed to reduce the concentration of radionuclides in the material may be applied. They include storage for decay, decontamination and melting.

Material may be deemed to be unsuitable for recycle because of the associated radiation doses, difficulty in conducting verification surveys, decontamination cost, economic worth, or other practical considerations. In these circumstances, the material may be recycled under controlled conditions, or sent for disposal to normal landfills or to controlled sites as low level radioactive wastes.

An option that may be considered in some situations is the controlled use of equipment, parts, tools, or even basic metals. In this option, the material in question may not meet the appropriate criteria for unconditional release, but because of economic or other practical considerations, recycle or reuse may be prescribed for a limited (controlled) purpose. Such materials may be recycled within the nuclear industry if controls can ensure that the radiation exposure of workers within the nuclear industry can be kept to acceptable levels. An example is the potential recycle of contaminated steel for use as canisters for waste disposal.

3.3.3. Benefits from recycle and reuse

The recycle and reuse of materials and equipment have been increasing during recent years, partly because of a recognition of the economic opportunities presented, but also because of an increased societal awareness of the desirability of conserving raw materials and natural resources.

(i) Resource saving

Recycle offers the potential for extending the lifetime of valuable natural reserves and is of particular interest for materials which are in short supply in the world and for materials whose recovery from the Earth's crust is difficult and expensive. [The incentive for resource saving may be enhanced in some countries where little or no natural reserves exist. In other countries, recognition of the finite nature of many of the world's resources has prompted governments to encourage recycling activities even though there may be no immediate shortages in sight.]

It is also argued that environmental pollution can be reduced by recycling, and that recycle often results in energy saving when compared with the alternative of production from natural materials (e.g. metallic ores). However, much depends on the nature of the material being recycled and on the type of recycling and waste disposal practices and options that are considered.

In addition to the benefits from recycle that accrue from the potential savings of raw materials and pollution, the resulting reduction in the volume of wastes produced is also positive feature. By reducing the volumes of waste going to either municipal landfills or regulated low level waste disposal sites, there will be a reduction in the capacity of repositories required for disposal.

(ii) Economic factors

The economic benefit of recycling might accrue from the recovered value of the recycled material, although this may not be the most important factor for steel, concrete, or other relatively cheap construction materials. Of potentially greater value are the potential savings to be achieved in the costs of conditioning, packaging, storage, transport and disposal of large volumes of nominally active material.

On the other hand, the costs involved in reclaiming potentially contaminated materials may be significant when compared with controlled disposal. These costs arise mainly from the decontamination and other procedures which may be necessary in order to bring contamination levels to within radiological standards and also from the costs involved in demonstrating compliance. It is difficult to draw generalized conclusions on the economics of recycle because much depends on the value of the material being considered for recycle, on the costs of waste disposal and on the criteria adopted for unrestricted recycle and reuse. Although the recycle of ferrous metals from the nuclear industry is being practiced on a limited scale in some countries, this may not necessarily indicate that the activities are cost effective on a broader scale. In some cases, the recycling activities are still at the research and technical feasibility demonstration stages. Other factors, such as national policies on resource saving and reuse of materials, may have a strong influence.

3.3.4. Experience with recycle and reuse

Limited amounts of recycle and reuse of materials from the nuclear industry have taken place in western countries. Usually it has been permitted on a case-by-case basis rather than under the terms of a generic national policy. These experiences have included unrestricted reuse/recycle of scrap metals and concrete and the reuse/recycle of metals within the nuclear industry and for specific applications outside the nuclear industry. In addition, there is experience of release of materials for disposal in public dumping grounds in many countries [4, 5, 6].

3.4. Existing clearance criteria

Criteria for releasing materials from regulatory control have emerged in several countries over the past few decades. However while the criteria adopted in these countries are generally of the same order of magnitude there is no international consensus yet on appropriate values at the present time, although, as will be described later, good progress is being made towards this objective. The values are usually expressed in terms of surface contamination (Bq/cm²) and activity concentration (Bq/g) levels. Values which have been used for releasing materials from control in European and North American countries range between 0.4 and 4 Bq/cm² and 0.1 and 5 Bq/g for beta-gamma emitters and about one order of magnitude lower for alpha emitters [4, 5]. Usually a single value is specified for beta-gamma emitters and a single value for alpha emitters. The origins of and bases for the derivation of these values are usually not given.

4. INTERNATIONAL GUIDANCE ON EXEMPTION AND CLEARANCE CRITERIA

4.1. IAEA/NEA guidance on exemption principles

In 1988 an international consensus was reached on the general principles for exemption and from regulatory control. The principles were published as IAEA Safety Series No. 89 [7]. According to these principles, the exemption of a practice or a source from regulatory control (notification, registration, licensing) must be seen in relation to the basic radiological protection principles: justification of a practice, optimization of protection, individual risk and dose limits. For a source or practice which is justified from a radiological protection standpoint, there are two basic criteria for determining whether or not it can be a candidate for an exemption:

- individual risks must be trivial, i.e. sufficiently low as not to warrant regulatory concern;
- the radiological protection must be optimized, taking the cost of regulatory control into account.

In addition, the exemption practices and sources must be inherently safe with no appreciable likelihood of scenarios that could lead to a failure to meet the above criteria.

In Safety Series No. 89, a trivial risk is evaluated: firstly, by choosing a level of risk and the corresponding dose¹ which is of no significance to individuals; secondly, by using the exposure to the natural background, to the extent that it is normal and unavoidable, as a relevant reference level. After evaluating these approaches, it was concluded that for the purpose of exemption, a level of individual dose of some tens of microsieverts in a year could reasonably be regarded as trivial by competent authorities.

Because an individual may be exposed to radiation doses from several exempted practices, it is necessary to ensure that the total dose does not rise above the trivial dose level. Safety Series No. 89 therefore recommends that each exempt practice should contribute only a part of the identified 'trivial dose'. The apportionment suggested in Safety Series No. 89 could lead to individual doses to average members of the critical group in the order of 10 μ Sv in a year from each exempt practice [7].

In relation to the optimization of protection, Safety Series No. 89 recommends that each practice should be assessed as if it were to be subjected to a formal optimization procedure. A study of the available options (including various kinds of regulatory action) should be made and the conclusion reached that exemption is the option that optimizes radiation protection. If, however, a

¹The term 'dose' refers to the sum of the effective dose from external exposure in a given period and the committed effective dose from radionuclides taken into the body in the same period.

preliminary analysis shows that the practice gives a collective dose commitment of less than about 1 man.Sv per year of practice, then the total detriment is low enough to permit exemption without more detailed examination of other options.

As discussed earlier, the basis for clearing sources from regulatory control is trivial risk and the principles for exemption described above are therefore also valid for clearance.

4.2. ICRP guidance

The guidance offered by ICRP [8] on this subject is broadly in line with that given by IAEA/NEA and summarised above. Two grounds for exempting a source are given:

- the source should give rise to small individual doses and small collective doses in both normal and accident situations,
- no reasonable control procedures would be able to achieve significant reductions in individual and collective doses.

The ICRP document points to the difficulty that exemption relates to a practice while the triviality of dose relates to the exposed individual. The document does not give quantitative guidance on establishing trivial doses.

4.3. Guidance in the international standards on radiation protection

The principles for exemption from regulatory control described in 4.1 have been incorporated into the recently revised International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources (BRSS) [1].

The general principles for exemption are reformulated by requiring that radiation risks to individuals and the collective radiological impact are both "sufficiently low as not to warrant regulatory control". In addition, it is stated that practices and sources may be exempted "without further consideration" provided that individual doses do not exceed 10 $\mu\text{v}/\text{y}$ and the collective effective dose committed by one year of the practice is no more than about 1 man.Sv. Compliance with these conditions allows for "automatic exemption".

The Draft EC Directive [2] does not address the issue of exemption in general terms. However, it contains exemption levels derived on the basis of Safety Series 89 criteria, with an additional criterion of 50 mSv equivalent dose limit to skin.

4.4. Summary on international consensus on exemption principles

The radiological guidance on exemption principles given in IAEA Safety Series No. 89 [7] has been widely adopted and most recently it has been incorporated in the BRSS and also used as a basis for the derived quantities in the draft EC Directive. At the national level the guidance has been adopted by some countries and, in others, used as a basis for evaluating the adequacy of existing national exemption/clearance levels. In the USA, the attempt by the USNRC to institute a general policy on 'Below Regulatory Control', similar to that of Safety Series No. 89, failed mainly due to public opposition although it is understood that 'case by case' exemptions are issued.

5. DERIVED CRITERIA FOR EXEMPTION AND CLEARANCE

The international guidance discussed in the previous sections is in terms of radiation dose and risk. This guidance must be converted into practical quantities such as activity concentration (Bq/g) and surface contamination (Bq/cm²) levels in order to permit verification by measurement.

TABLE 1 EXEMPTION AND CLEARANCE LEVELS

Radionuclides	Exemption Levels from BRSS [1] and EU draft BSS [2]		IAEA draft Unconditional Clearance Levels [11] (range)	EC draft Clearance Levels [12]		
				metal scrap recycling		direct reuse
	Bq	Bq/g	Bq/g and Bq/cm ²	Bq/g	Bq/cm ²	Bq/cm ²
H-3	1 x 10 ⁹	1 x 10 ⁶	10 ³ -10 ⁴	10 ³	10 ⁵	10 ⁴
C-14	1 x 10 ⁷	1 x 10 ⁴	10 ² -10 ³	10 ²	10 ³	10 ³
Na-24	1 x 10 ⁵	1 x 10 ¹	10 ⁻¹ -10 ¹			
S-35	1 x 10 ⁸	1 x 10 ⁵	10 ³ -10 ⁴			
Cl-36	1 x 10 ⁶	1 x 10 ⁴	10 ² -10 ³			
Ca-45	1 x 10 ⁷	1 x 10 ⁴	10 ³ -10 ⁴			
Cr-51	1 x 10 ⁷	1 x 10 ³	10 ¹ -10 ²			
Mn-54	1 x 10 ⁶	1 x 10 ¹	10 ⁻¹ -10 ⁰	10 ⁰	10 ¹	10 ¹
Fe-55	1 x 10 ⁶	1 x 10 ⁴	10 ² -10 ³	10 ⁴	10 ⁴	10 ³
Co-60	1 x 10 ⁵	1 x 10 ¹	10 ⁻¹ -10 ⁰	10 ⁰	10 ¹	10 ⁰
Ni-63	1 x 10 ⁸	1 x 10 ⁵	10 ³ -10 ⁴	10 ⁴	10 ³	10 ³
Zn-65	1 x 10 ⁶	1 x 10 ¹	10 ⁻¹ -10 ⁰	10 ⁰	10 ²	10 ¹
Sr-90	1 x 10 ⁴	1 x 10 ²	10 ⁰ -10 ¹	10 ¹	10 ⁰	10 ¹
Nb-94	1 x 10 ⁶	1 x 10 ¹	10 ⁻¹ -10 ⁰	10 ⁰	10 ¹	10 ⁰
Tc-99	1 x 10 ⁷	1 x 10 ⁴	10 ² -10 ³	10 ²	10 ³	10 ³
Ru-106	1 x 10 ⁵	1 x 10 ²	10 ⁰ -10 ¹	10 ⁰	10 ¹	10 ¹
Ag-110m	1 x 10 ⁶	1 x 10 ¹	10 ⁻¹ -10 ⁰	10 ⁰	10 ¹	10 ⁰
I-125	1 x 10 ⁶	1 x 10 ³	10 ¹ -10 ²			
I-129	1 x 10 ⁵	1 x 10 ²	10 ¹ -10 ²			
Cs-137	1 x 10 ⁴	1 x 10 ¹	10 ⁻¹ -10 ⁰	10 ⁰	10 ²	10 ¹
Ce-144	1 x 10 ⁵	1 x 10 ²	10 ¹ -10 ²			
Pm-147	1 x 10 ⁷	1 x 10 ⁴	10 ³ -10 ⁴	10 ³	10 ³	10 ³
Ir-192	1 x 10 ⁴	1 x 10 ¹	10 ⁰ -10 ¹			
Au-198	1 x 10 ⁶	1 x 10 ²	10 ⁰ -10 ¹			
Pb-210	1 x 10 ⁴	1 x 10 ¹	10 ⁻¹ -10 ⁰			
Th-232	1 x 10 ³	1 x 10 ⁰	10 ⁻¹ -10 ⁰			
Ra-226	1 x 10 ⁴	1 x 10 ¹	10 ⁻¹ -10 ⁰			
U-238	1 x 10 ⁴	1 x 10 ¹	10 ⁻¹ -10 ⁰	10 ⁰	10 ⁻¹	10 ⁻¹
Np-237	1 x 10 ³	1 x 10 ⁰	10 ⁻¹ -10 ⁰	10 ⁰	10 ⁻¹	10 ⁻¹
Pu-239	1 x 10 ⁴	1 x 10 ⁰	10 ⁻¹ -10 ⁰	10 ⁰	10 ⁻¹	10 ⁻¹
Am-241	1 x 10 ⁴	1 x 10 ⁰	10 ⁻¹ -10 ⁰	10 ⁰	10 ⁻¹	10 ⁻¹
Cm-244	1 x 10 ⁴	1 x 10 ¹	10 ⁻¹ -10 ⁰	10 ⁰	10 ⁻¹	10 ⁻¹

5.1. Exemption levels in the international standards

In an Annex of the BRSS, radionuclide specific "automatic" exemption levels are tabulated. They are derived on the basis of the criteria given in Safety Series No. 89. The levels were developed in collaboration with the Commission of the European Communities (CEC) in connection with the revision of its own standards. The intention of the cooperation has been that both standards should contain the same exemption criteria, expressed in terms of activity (Bq) and activity concentration (Bq/g), to ensure international consistency and compatibility in this subject area.

The methodology used for deriving the exemption levels in the BRSS is described in reference [9]. Exempted sources and practices are those involving the small scale use of radioactive materials, such as the examples given in Section 3.1.

The scenarios considered in evaluating the exempt quantities are briefly summarised below:

- The Normal Use (workplace) scenario represents the use of small amounts of radionuclides in industry, etc. in the manner for which they are intended, and involves external exposure and inadvertent intakes of radioactive materials.

Exposures to the public arising from normal releases of activity are adequately covered by this workplace scenario.

- The Accidental (workplace) scenario represents abnormal procedures or incidents that might occur during the routine use of small amounts of radionuclides. These situations may lead to exposures via a range of external, inhalation and ingestion pathways.
- The Disposal (public) scenario represents a member of the public becoming exposed after subsequent disposal of the source. This situation may lead to external, inhalation and ingestion pathways. Both normal and accidental situations are considered.

In the analysis of these latter scenarios, account is taken of the probability that an exposure event will occur.

The exemption levels derived from this analysis are listed in Table 1 for selected radionuclides.

The following notes apply:

- (i) The exemption values in Table 1 represent the lowest values calculated, using a conservative approach, in any of the scenarios listed above.
- (ii) The exemption levels are expressed in terms of total activity (Bq) and activity concentration (Bq/g). Exemption is permitted if levels are below the total activity or activity concentration levels. This allows for the exemption of sources with high activity concentration but low total activity, e.g. smoke detector sources.
- (iii) For comparison it may be recalled that the exempt activity concentrations given in previous international standards were 100 Bq/g for all radionuclides except for those in naturally occurring radioactive materials for which it was 500 Bq/g. The new values are thus more restrictive for most radionuclides and less restrictive for others.

5.2. International guidance on clearance levels

The concept of clearance from regulatory control implies a removal of restrictions so that the cleared materials can be treated without any consideration of their radiological properties. However, the removal of restrictions may not always be complete; there is also the possibility of clearing

material under specified conditions. Thus, two types of clearance can be identified: 'unconditional' and 'conditional' clearance.

The full and complete clearance of a material requires that all reasonably possible exposure routes are examined and taken into account in the derivation of the clearance levels, irrespective of how that material is used and to where it may be directed. Such clearances are called 'unconditional clearances'.

Alternatively, the clearances may be constrained in some way, usually because the fate of the material being considered in the clearance is known, so that only a limited number of reasonably possible exposure routes have to be considered in deriving the clearance levels. The clearance may then be granted with certain conditions, for example, it may prescribe a definite fate for the material being considered. Such clearances are called 'conditional clearances'.

The concept of clearance is recognised in the BRSS and the draft EU Directive but no practical guidance is given. IAEA and EC working groups have, in the past, developed guidance on methods for deriving clearance levels and have given limited guidance on clearance levels for particular circumstances [3, 9, 10]. In these studies, consideration has been given to the low level waste streams from the nuclear industry, from the use of isotopes in medicine and research, and to the practice of recycling and re-use of materials, metals in particular, contaminated to very low levels arising from the decommissioning of nuclear facilities.

At the present time international recommendations on clearance levels are being developed by IAEA and EC.

5.2.1. IAEA unconditional clearance levels [11]

The basis for the IAEA draft guidance on unconditional clearance levels is the reports of 14 separate national and international studies which had been directed towards the low activity streams of material generally considered to be the most likely candidates for clearance. These are:

- low level solid wastes from the nuclear fuel cycle;
- slightly contaminated metals and concrete which may arise in the decommissioning of nuclear installations;
- low level wastes generated during the application of radioisotopes in industry, hospitals and research laboratories.

In the studies reviewed, individual radiation exposures were evaluated for a range of scenarios linked to each of the practices considered.

The main scenarios considered were the following:

- | | | |
|-------------------|---|---|
| Landfill disposal | - | transport workers |
| | - | landfill site workers |
| | - | disturbance of the site after closure |
| | - | radionuclide transfer via groundwater |
| | - | fires in the landfill |
| Incineration | - | operators |
| | - | emissions |
| | - | ash (to landfill) |
| Recycling (steel) | - | scrap transport workers |
| | - | scrap processing workers |
| | - | workers at smelter, and fabrication plant |
| | - | consumer use |

- emissions
- use of slag

similar groups of scenarios were considered for non-ferrous metals and concrete).

- | | |
|-------|--|
| Reuse | <ul style="list-style-type: none"> - small tools and equipment - large equipment - buildings (use and renovation) |
|-------|--|

The clearance levels were derived by reviewing the results of all available studies. IAEA expert groups developed a method of analysis which, while avoiding selecting the most restrictive value obtained for any particular radionuclide, ensured that there would be a small probability of the $10\mu\text{Sv/y}$ dose criterion being exceeded from application of the selected clearance level value irrespective of the use or application of material after its release. The values were derived assuming the equal possibility of disposal, incineration, recycling or reuse. Furthermore, it is assumed that the cleared materials could be used anywhere, e.g. in another country as a result of transboundary movement. The analyses of potential radiological impact are, therefore, necessarily generic and conservative.

The results are presented in Table 1 and should be interpreted as follows:

- (a) The uncertainties in the results of studies used to develop the classification do not allow a single number to be attached to each radionuclide but only categorization by order of magnitude.
- (b) Where a single value of the clearance level is required by regulators, the log-mean values for each category are proposed for use as representative clearance level values. The clearance levels are then 0.3, 3, 30, 300 and 3000 Bq/g for the five classes.
- (c) The levels in Table 1 are those below which the unconditional clearance of material containing the relevant radionuclides from facilities under regulatory control may be allowed.
- (d) In the absence of other guidance, the clearance level values for surface contamination (Bq/cm^2) may be taken to be the same in unit terms as for activity concentration (Bq/g). Where appropriate, mass and surface criteria should be applied simultaneously, for example for metal objects and buildings. For many materials it will only be possible to apply activity concentration values, for example for materials with uneven, rough or porous surfaces.

5.2.2. EC Clearance levels for metal scrap recycling and reuse [12]

The clearance levels described in the following paragraphs have been derived assuming a particular use and destination of the material and therefore they are termed 'conditional clearance levels' as discussed above.

The radiological assessment of individual doses resulting from recycling of cleared scrap in the EU takes into account the entire sequence of scrap processing, starting with transport and handling of the scrap metal up to exposure from consumer goods made of recycled metal. The assumed exposed population consists essentially of workers employed in the scrapyards, smelter or refinery, or manufacturing industry. Workers are exposed to external radiation essentially from the scrap heap, to inhalation of resuspended dust upon handling and cutting of the scrap or of fumes in the foundry. Secondary ingestion through hand contamination is allowed for. Workers are also assumed to be exposed as a result of the disposal of slags and dust on landfills. The radioactivity content of materials can be enriched following melting as a result of element-specific distribution of radionuclides among fumes, slags and metal. Appropriate distribution factors were established by means of experimental studies. The possible enrichment is in many cases largely compensated by the fact that for a variety of reasons scrap is never processed as a single batch. Scrap of different origin and feed material are mixed for metallurgical reasons. An important factor is also the capacity of the furnaces compared to single loads of scrap of nuclear origin.

The radiological assessment thus involved a detailed analysis of the recycling industry and precise data on the flow of materials.

As indicated in Section 3.3 and borne out by the EC study, scrap of nuclear origin represents only an extremely small fraction of the entire metal scrap market. As a result of these considerations dilution factors were introduced in the EC study reflecting either dilution in terms of exposure time over a year or physical dilution in a batch of product material. The choice of dilution factors was considered very carefully, favouring a prudently realistic rather than an excessively conservative approach.

The implications of the dilution parameter are most relevant when estimating individual doses from exposure to final products. The selected dilution parameters, pertaining to mass-specific clearance levels for those nuclides that are both gamma emitters and dominantly recovered in the final product (e.g. ^{60}Co) are the following:

Metal group	Dilution parameter
Steel and iron	0.1
Stainless steel and steel alloys	0.2
Aluminium and aluminium alloys	0.2
Copper and copper alloys	0.3

The study examined in great detail the doses and corresponding clearance levels in terms of mass and surface activity concentrations for the three metal categories considered. In fact it turned out that different metals did not yield significantly different results. In terms of surface activity concentration it was concluded that direct reuse of equipment should be considered separately. In this case, no reduction in activity content of cleared scrap occurs as a result of mixing with scrap from non-nuclear sources.

Clearance Criteria for Metal Scrap Recycling

The nuclide specific clearance levels shown in Table 1 are the lowest values from all the metals studied. Regulatory control can be relinquished if activity concentrations are below these levels, when applied as set out below:

- (a) The mass specific clearance levels are the total activity per unit mass of the metal being released and are intended as an average over moderate amounts of metal.
- (b) The surface specific clearance levels are the total surface activity concentration, fixed plus non-fixed, and are intended as an average over moderate areas.
- (c) The mass specific and surface specific clearance criteria apply simultaneously. Any exceptions to this should be investigated by the competent authorities.
- (d) The recommended clearance levels are not intended for composite materials like electrical cables.
- (e) The recommended clearance levels do not apply to metal items or scrap which were, before clearance, melted under regulatory control.

Clearance Criteria for direct reuse of equipment

The nuclide specific clearance levels in Table 1 apply to metal components, equipment or tools for which direct reuse is foreseen. The recommended clearance levels are the lower of the recycling and reuse clearance levels and are valid for all metals. The following conditions apply:

- (a) The surface specific clearance levels are the total surface activity concentration, fixed plus non-fixed, and are intended as an average over moderate areas.
- (b) Mass specific clearance levels are not required if for gamma-emitting nuclides the emissions entering the detector from the item are counted as surface activity and for alpha- and beta-emitters the activity hidden under surface layers, for example under paint corrosion or rust, are included as surface activity.

5.3. Comparison and discussion of the exemption and clearance levels

- (i) Clearance levels are given in terms of activity concentration (Bq/g) and surface contamination (Bq/cm²). The clearance levels are lower than or equal to the exemption activity concentrations (Bq/g) for all radionuclides considered, although the radiological basis for derivation is the same. This is due to the different natures of the sources being considered. It is evident from the examples of sources being considered for exemption and clearance respectively given earlier in this document that the masses and volumes of the material for clearance are considerably greater than those for exemption. In the analysis of exposure scenarios this difference leads to higher doses per unit activity concentration from the materials for clearance as compared to those for exemption.

In the BRSS [1] and EU draft BSS [2] it is pointed out that in order to avoid legal and regulatory problems, clearance levels should not be greater than the prescribed exemption activity concentrations. This is to ensure that a source, once cleared from regulatory control, does not immediately become liable for regulation once more.

- (ii) The IAEA [11] and EU [12] clearance levels for activity concentration are generally consistent with each other. Since the IAEA study was concerned with unconditional clearance it considered a wider range of release scenarios than the EU study which was only concerned with clearance of metal scrap for recycling (conditional clearance). The IAEA range encompasses the EU values for activity concentration with one exception (⁵⁵Fe). The agreement is less satisfactory for the surface contamination concentration values (Bq/cm²). However, it is recognised in the IAEA study that the data available at the time of the study was insufficient to give firm guidance. The EU study draws on more recent results.
- (iii) Following the guidance of Safety Series No. 89 [7], it is also necessary to ensure that radiation protection is optimized before a source or practice can be exempted or cleared from regulatory control. For practices giving rise to collective doses of 1 man.Sv per year or less, the optimization requirement can be considered to be automatically met. On the basis of the estimates which have been made in deriving the exemption and clearance levels, either the collective doses are very low or substantial quantities in terms of mass would have to be involved before collective dose commitments or more than 1 man.Sv per year would be delivered.
- (iv) The exemption activity concentrations for naturally occurring alpha emitters are in the range of 1 to 10 Bq/g. This has prompted the concern that many previously unregulated practices involving the use of naturally occurring radionuclides would need to be brought under regulatory control. Under the BRSS, such practices may be *excluded* from regulatory requirements if the associated radiation exposures are considered *unamenable to control*. In cases where it is judged that exposures are too high and warrant remedial actions they would

then be treated as being intervention situations under the terms of the BRSS. In the EU draft BSS it is envisaged that competent authorities may identify which industries and workplaces shall be subject to controls, both in view of worker's exposure and in terms of population exposure resulting from gaseous or liquid effluents of such work activities.

5.4. Exemption and the Transport Regulations

At the present time the IAEA Regulations for the Safe Transport of Radioactive Material [13] are being revised. One aspect under consideration is to replace the existing definition of "radioactive material - as any material having a specific activity greater than 70 Bq/g" with nuclide specific values based upon the BRSS exemption levels. At present, a majority in the relevant working groups preparing the revised Transport Regulations favour accepting the BRSS exempt activity concentrations (Bq/g) (see Table 1) but not the total activity values (Bq) owing to difficulty in application. Acceptance of the activity concentration values has been assisted by an analysis of exposure scenarios relevant to the transport of radioactive materials. Another point of relevance is a recommendation to bring the surface contamination limits for excepted packages (0.4 Bq/cm² for beta/gamma emitters and low toxicity alpha emitters and 0.04 Bq/cm² for all other alpha emitters) in line with the values used for other packages which are higher by an order of magnitude. A study has shown that there is no justification for the lower values of the existing standard on radiation protection grounds. The revised Safety Standard is planned to be submitted to the IAEA's Board of Governors for approval in 1996.

5.5. Public perception aspects

While the concepts of exemption and clearance can be readily justified technically, it has to be recognised that the subject may be viewed differently by non-technical persons and by the public in general. It is often difficult to explain that the risks associated with very low levels of radioactive waste are trivial. To many people radioactive waste of any kind is hazardous and undesirable.

The problems encountered in the USA over the 'Below Regulatory Concern' policy were mentioned earlier. For similar reasons a policy of 'zoning' in the French nuclear industry is being proposed, in which some areas are declared as containing radioactive materials and others are defined as being free from radioactive materials. The disposal of materials and structures within the radioactive zones will be managed without release from the zones, with the intention of avoiding the need for exemption and clearance. However, even with this approach it will be necessary to define what is "radioactive" and what is not.

6. ENVIRONMENTAL REMEDIATION

This section of the paper deals with the issue of environmental clean-up and the release of land areas from regulatory control. Of particular interest in the context of this Seminar are areas which have become contaminated as a result of operations in the nuclear fuel cycle and which have to be decontaminated as part of decommissioning. Land areas may also become contaminated as a result of accidents in the nuclear fuel cycle, nuclear weapons testing, the production of nuclear weapons, and previous poor practices inside and outside the nuclear fuel cycle. An issue for consideration is whether all types of contamination situation should receive the same regulatory treatment.

Options for remediation include removal of surface soil, fixation to prevent mobilization by processes such as wind resuspension, amendment to reduce radionuclide transfer to plants and animals, covering with uncontaminated soils to reduce external radiation dose rates and to reduce uptake into plants and animals. Other potential courses of action include administrative measures to limit the uses of the land, for example, so that it is not used for human habitation, thereby reducing exposures or to exclude access completely.

6.1. Factors influencing decisions on remediation

The main technical reason for remediating land is to reduce the radiation exposures received by those who would live or work on the land to acceptable levels. The choice of an appropriate level for deciding when remediation is necessary may be influenced by several factors including the potential benefits, in terms of dose reductions, the costs of remediation, and this would include consideration of the size of the area needing remediation and the costs of waste disposal. In addition to considering radiological factors, the decision to remediate may be influenced by a concern for the ecological damage that may be caused by the remediation actions, consideration of the value and the location of the land, and public concern and anxiety about land contaminated with radioactive material.

Decision making has to accommodate all of these factors and to weight them appropriately. Some of them can be evaluated and quantified but others tend to be subjective and are difficult to include in a generic analysis.

6.2. Experience with environmental clean-up

Over the last forty years there have been numerous examples of environmental clean-up operations in different countries. They include the plutonium clean-up operations following the US military aircraft crashes in Palomares, Spain and Thule, Greenland, the large scale environmental remediations after the Kyshtym reprocessing plant and Chernobyl nuclear power plant accidents in the former USSR and the clean-up of the town of Goiania in Brazil after the spread of radiocaesium from a medical therapy source. In addition to these rather large scale events there have been smaller clean-up operations in many countries associated with mining and milling operations, historic radium manufacturing operations and applications and poorly controlled release practices. A good summary of many of these events and of the subsequent remediation actions is contained in the proceedings of an international symposium held in Antwerp in 1993 [14].

The criteria used for judging an acceptable clean-up level in the remediation situations which have occurred to date have varied. Much has depended on the local circumstances and the scale of the contamination event. Recently, clean-up standards have been developed in Germany to deal with the land contamination left by the extensive uranium mining and milling operations in the former East Germany [14]. The basic criterion is that for radiation doses, in addition to those from natural background, of less than 1mSv/a the area can be released from regulatory control. For implied doses of more than this, remediation may be implemented depending upon the outcome of an optimization procedure. In the USA, which is currently faced with a legacy of contaminated sites mainly as a result of its nuclear weapons programme, guidance is being developed by the Federal Agencies. The draft proposals of the EPA envisage that sites can be released from regulatory control if doses are not greater than 0.15mSv/a [14]. If this is not feasible, they may be released with active control measures, for example, institutional controls, engineered barriers, provided that in the event of failure of the active control measures the dose would not exceed 0.75mSv/a. This guidance is being developed in cooperation with the NRC and the draft proposals are very similar [16]. The NRC draft guidance places stronger emphasis on the need for it to be demonstrated that further reductions in residual radioactivity are not technically achievable, would be prohibitively expensive, or would result in net public or environmental harm, before release would be permitted.

6.3. The development of international guidance

Guidance on criteria for the remediation of contaminated land is being developed by IAEA [17]. The approach being used is to apply the principles of the ICRP relevant to practice situations and to interventions. A practice is any activity that increases the exposure or the likelihood of exposure of people, while an intervention is any action intended to reduce or avert exposure or the likelihood of exposure to sources which are not part of a controlled practice or which are out of control as a consequence of an accident. Situations involving contaminated areas may fall into either

of these two categories, and in some cases it may not be clear which is more appropriate. For example, the clean-up of a licensed nuclear site as part of decommissioning is clearly a part of that practice, and the clean-up of contaminated areas from a major accident would clearly be intervention, but clean-up of contamination left behind from a previously discontinued practice does not fall so clearly into either category. These distinctions are being examined for the variety of contamination situations that exist as part of the IAEA study.

For areas identified as being part of a practice, the clean-up would be subject to the same considerations as any other routine activity within the practice, that is, the clean-up operation would have to be optimized by weighing the costs of clean-up against the benefits. The optimized solution would be constrained by appropriate dose constraints. In principle, the concept of clearance is also relevant here although it seems likely that the environmental concentrations derived on the basis of trivial doses will be too low to be of practical application in this context.

In cases identified as intervention situations, the radiation protection principles for intervention will apply, that is, the proposed intervention should do more good than harm (justification) and the form, scale and duration of the intervention should be optimized so that the net benefit of the reduction in dose is maximised. Normal dose limits do not apply in the case of interventions.

The study aims to develop generic clean-up criteria for both of the situations discussed above. The approach being taken involves carrying out scoping calculations using generic data - where possible obtained from real situations. The criteria developed by these approaches will indicate the doses, or the range of doses, at which clean-up is justified on radiological grounds in the two types of situation - recognising that the results will be generic and could be modified if site specific information were available.

6.4. Summary on criteria for clean-up

To date clean-up activities have been carried out in several countries using radiological criteria developed on a 'case by case' basis. In the past, the approach has been to use judgement based on comparison with existing standards derived for other purposes and/or with naturally occurring levels of the radionuclides. More recently criteria have been developed at the national level by applying the intervention concepts introduced by ICRP but the development of an internationally accepted approach to deriving clean-up criteria for the wide range of situations for which they are needed is still in its early stages.

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REGULATION AND COMPLIANCE

(Session III.3)

Chairman

S. NORRBY
Sweden)

FORMULATION OF REGULATORY AND LICENSING REQUIREMENTS

S. NORRBY, S. WINGEFORS
Swedish Nuclear Power Inspectorate (SKI),
Stockholm, Sweden

Abstract

In general there is international agreement on what issues that are important safety factors in radioactive waste management disposal? Experience in radioactive waste management, mainly related to low- and intermediate level radioactive waste, exist in many countries. Can we learn from this experience how regulatory requirements may be formulated? What rôle could safety assessments have in the formulation of regulatory requirements? These issues and related issues are discussed in the paper.

1. INTRODUCTION AND SCOPE

The objectives and methodology for regulation of radioactive waste management (RWM) depend on several factors, the most important of which are,

- the legal basis for regulation, above all the assignment of responsibilities between waste generator, operator (of radioactive waste facilities) and regulator
- size of the national nuclear programme and its matureness.

This presentation is based on the Swedish regulatory experience, complemented with views and comments relating to other national programmes. Regulation and overseeing of R&D work and a financing system for RWM are not treated in this paper. Licensing requirements are seen as a part of the regulatory framework.

2. REGULATORY PHILOSOPHIES AND DEVELOPMENT OF REQUIREMENTS

Regulatory requirements for RWM have normally been developed in a continuous process starting in the early stages of a nuclear programme in the 1950's. It is, however, a fact that even if it was realized from the beginning that there is a need for handling and disposal of radioactive waste from waste generating activities all implications were not fully understood. This is also true for nuclear power production. Much of the treatment technology and disposal strategies accepted at that time are no longer accepted. There is an increasing understanding that the full acceptance of nuclear power requires a high quality waste management system and a regulatory system in which the responsibilities and competence of the bodies involved in the RWM process is defined and that this process itself is carried through.

During recent years public involvement in the RWM process has been more and more pronounced. Also requirements on R&D work as well as on the financing of future costs have been more pronounced. These aspects are not treated in this paper, however.

So, even if the development of regulatory requirements for RWM started several decades ago it is not until later that the implications were fully apprehended. One result of this understanding is the decision by the IAEA to set up a special programme on Radioactive Waste and Safety Standards (RADWASS) a few years ago.

In the regulation of RWM two different philosophies can be seen,

- detailed specifications are provided by the regulators. Such requirements must be feasible and some responsibility rests with the regulator;
- detailed specifications are elaborated by the operator and reviewed and decided by the regulator.

Even if a regulatory system without detailed requirements on a RWM system is developed before the implementation of the system, rather detailed requirements may later be defined in the licensing of RWM facilities.

Both philosophies have their advantages and disadvantages. Detailed regulatory requirements given early in the RWM process, if unduly restrictive, may hamper the development of techniques and procedures within the RWM system. In R&D such requirements tend to direct focus on the separate components of, e.g. a disposal system, while an integrated view might have been more appropriate for allocation of resources. On the other hand, this philosophy provides clear messages both to the implementor and to the general public. This could no doubt have advantages.

A philosophy without detailed requirements could be beneficial for the development of technical procedures, but may on the other hand leave too much of the interpretation of the overall objectives to the implementor. The lack of rigor and particular requirements might give an impression of insufficient control from the authorities. Another drawback might be difficulties in keeping of a stable level in the demands and conditions issued by the authorities in particular matters.

In most cases the national RWM regulations are a combination between these two principal philosophies. Clearly defined roles for regulator and implementor is a prerequisite for a defendable and transparent RWM regulatory system.

In the RADWASS programme two top documents are the Safety Fundamentals "The Principles of Radioactive Waste Management" [1] and the Safety Standard No.1 "Establishing a National System for Radioactive Waste Management" [2]. Together these documents present the principles and recommendations that should be the basis for a national RWM system. These principles and recommendations build on ideas and views that to a great extent have been accepted and applied earlier. However, the documents give a presentation that is logical and structured so as to facilitate the comprehension of supporting motivations.

The Safety Fundamentals "The Principles of Radioactive Waste Management" presents nine principles covering ethical, administrative and technical aspects on RWM. It includes principles on the protection of man and the environment, now and in the future, within national borders as well as outside. It also addresses the need for having the appropriate facilities for RWM.

The Safety Standard No.1 "Establishing a National System for Radioactive Waste Management" presents a number of recommendations all addressing issues relevant in the establishment of a national system for RWM. These recommendations include aspects on the legal framework, the regulatory body, responsibilities of waste generators and operators of waste management facilities, licensing process, etc.

As pointed out earlier, even if these principles and recommendations have been agreed and published recently, very much of the content in the publications referred to is since long accepted as the basis for national RWM systems.

Evidently there are numerous ways of classifying regulatory requirements, e.g. according to kind of facility or type of radioactive waste. Perhaps the most obvious requirements are those *technical requirements* provided for ensuring nuclear safety, including radiation protection, during operation of waste handling facilities and also for the long-term in case of repositories. In the first place, such requirements puts demands on equipment, processes or packages, e.g. on mechanical strength, specifications on operational parameters (technical specifications), or content of radionuclides. Technical requirements on this level are not sufficient, however, but must be supported by requirements on management, common to all nuclear facilities, e.g. on a quality system, education of personnel and reporting of incidents.

In general, the development of technical requirements related to operational safety of waste handling facilities has gone smoothly since much of the experience and practices from operation of nuclear reactors could be relied upon. On the other hand, formulation of requirements on waste packages, and, thus, on the processes for treatment and conditioning of waste, is a question where more consideration is needed. Since the waste package is the common denominator for all steps in the RWM system it has become the reason why the different steps in RWM are interlinked to each other: generation of waste, pre-treatment, treatment, storage and disposal of radioactive waste. This also means that when requirements on a separate part of the RWM system is defined consideration must be given to the other parts.

Thus, licensing of facilities and waste packages should also be interlinked. The difficulty might be that it could then be regarded illogical to license a waste package for production when not all subsequent handling steps/facilities are defined or licensed - and *vice versa*. This difficulty may only be overcome by regarding the development of a RWM system as an iterative process, e.g. by assigning "typically desirable" characteristics and requirements to procedures and products not yet decided and implemented. However, already the very awareness of these potential difficulties is a major step towards finding acceptable solutions.

Another class of requirements applies to the *licensing procedures*, e.g. on the development and content of an environmental impact statement (EIS), or on a final safety report for a facility. Requirements on the licensing of types of waste packages also belong to this class. Closely related to the latter are the *requirements on documentation*, i.e. on the characterisation of waste, description of a type of waste package, or on registration of waste packages. Documentation of waste is an increasingly important issue, since it must be ensured that background knowledge is not lost, e.g. when decommissioning nuclear facilities. Obviously, the interest here is focused on "historical waste", and where the magnitude of the issue may be very different in different countries.

3. LICENSING OF FACILITIES

As stated earlier, a prerequisite for the acceptance of practices giving rise to radioactive waste should be the safe management and disposal of the radioactive waste.

Facilities for waste conditioning and storage are to be licensed as parts of a total RWM system. Basic requirements relate to the safety of workers and the public. However, another basic requirement is that the waste must be treated, conditioned and handled in a way that makes it suitable for further conditioning, handling, transport and disposal.

Repositories for waste above a certain level of short- and long-lived radionuclides should be based on the multibarrier principle and they should provide protection of man and nature in the future to a degree not less than acceptable today from similar activities. For HLW and spent fuel deep geological repositories are foreseen [3]. For low- and intermediate level radioactive waste with a small content of long lived alpha activity near-surface facilities are normally judged acceptable [4].

The safety of repositories must be demonstrated by performance assessments using "validated" models and site specific data [5]. Preferably the safety analysis report should be outlined according to a prescribed format. The long term safety should be demonstrated for as long time as necessary considering the total potential hazard of the waste. Increasing uncertainties in the long term cause a need for larger margins between predicted consequences and applicable safety criteria.

The safety and the environmental effects from a repository for spent nuclear fuel should be evaluated for very long time periods, typically hundreds of thousands of years. For time periods until the next glaciation, or similar expected drastic changes of the biosphere, the individual dose received by members of a hypothetical critical group could be calculated and assessed with some confidence. For longer time periods similar predicted doserates are used as "safety indicators" together with

predicted concentrations of radionuclides in the biosphere and possibly also fluxes of radionuclides into the biosphere. The latter two can be compared with corresponding natural levels [6].

Whatever safety assessment methodology is used the uncertainties in the evaluation of long-term effect will be considerable. This is true not only for HLW repositories but also for low- and intermediate level waste that often contain also a long-lived component which calls for safety assessments covering thousands of years. These evaluations will never be easy and straight forward. A considerable amount of expert judgement will always be necessary. An open and transparent licensing process is needed to achieve credibility and eventually public acceptance of the practice and the RWM facility.

Operational requirements should be defined for all kinds of RWM facilities and should comprise:

- quality assurance system
- documentation of waste packages
- technical specifications
- reporting of incidents
- quality control and other measurements.

It should be noted that operational requirements must take into account the requirements on waste form and waste package that can be derived from the long-term requirements on the repository system. Normally these different aspect will not be in conflict as remote handling technology can be utilized in the operational phase.

The complete RWM system, including final disposal should be evaluated. This then includes the operational phase of all RWM facilities but also the long-term phase of the repository. Even if a strict optimization process for the complete system is not achievable one should try to balance the requirements on different parts of the RWM system in a reasonable way. In this process retrievability of waste canisters, human intrusion, safeguards of fissile materials etc should be taken into account. Because of the complexity of the complete RWM system e.g. the final repository, and the advantage in building on operational experience, the development of a RWM system and sometimes also the development of individual components of such a system should be an iterative process that allows for repeated technical improvements and evaluations of the RWM system.

4. LICENSING OF WASTE TYPES

Development of waste acceptance criteria is an iterative activity. In the beginning of a nuclear programme waste packages will necessarily have to be robust and permit a wide flexibility in subsequent handling steps since no repository will (normally) be available. As stated earlier the planning of activities giving rise to radioactive waste should however include also planning for a RWM system. Later on in the programme the detailed layout of the RWM system is known and the design of new waste types could be adjusted accordingly. Ideally a full license of a specific type of waste package should only be given based on a existing disposal system, including a licensed repository.

General and quantitative requirements on waste packages are difficult to define, since any quantification of such will evidently depend on the actual waste origin, conditioning, handling sequence and disposal method. Thus, requirements have to be defined on an individual basis for each type (and producer) of waste packages. A logical way to proceed in formulation of such requirements is to start defining functional requirements - requirements posed on the package by the system. Functional requirements are defined for each step in the handling sequence: treatment, conditioning, storage, transport, disposal. From functional requirements on intrinsic properties are derived, e.g. mechanical strength, maximum allowed surface dose rate etc. A list of general requirements has been produced for LLW and ILW to be disposed of in the Swedish SFR-1 repository [7].

Situations similar to the Swedish have been experienced in many other countries e.g. UK, France [8] and Finland. In Germany, on the other hand, requirements on waste packages have been derived from the detailed safety assessment of the Konrad repository [9].

Little or no difficulty has been experienced from the presence of mixed waste. In the licensing of SFR-1 limits on the content of non-radioactive pollutants are given. However, only relatively small amounts of hazardous chemicals are handled by producers of radioactive waste in Sweden. Anyway, due to non-specific and flexible regulation of both conventional and radioactive waste the presence of mixed waste has been of little concern.

Even if this issue has not been of great concern in the SFR-1 facility in Sweden this question in general should be given attention and the issue is of great concern in many countries. The general ideas applied for radioactive waste are applicable also for hazardous waste (waste minimization, total systems approach etc) [10].

5. CONCLUSIONS

Regulatory requirements and methods as described in, e.g. the RADWASS documents, did not exist at the time when many countries started up nuclear programmes or other practices giving rise to radioactive waste. Steps and actions had to be taken to solve immediate problems without access to a complete RWM system, which later simply had to be adapted to accommodate what was achieved earlier in terms of, e.g. waste packaging.

Experience has shown that the absence of detailed regulations on technical matters in the early phases of nuclear power did not necessarily lead to unsatisfactory solutions, e.g. waste produced before the development of a complete RWM system could be accepted within a complete RWM system, notably repositories. Even if detailed technical regulations do not exist the safety will eventually have to be ensured by detailed (sub-system) criteria and conditions given in licences. More important than giving detailed technical regulations is the regulatory system in general, with a special emphasis on legislation and clear assignment of responsibilities.

Experience gained is now incorporated into the RADWASS documents, which should be of great value to countries now planning to start up activities that will generate radioactive waste.

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COMPLIANCE WITH REGULATORY REQUIREMENTS

E. RUOKOLA

Finnish Centre for Radiation and Nuclear Safety,
Helsinki, Finland

J. ANDERSSON

Swedish Nuclear Power Inspectorate,
Stockholm, Sweden

Abstract

The paper discusses how compliance with regulatory requirements is ensured in the various phases of the implementation of waste management facilities. The discussion is focused on, but not restricted to, waste disposal facilities. There are a number of examples of successful regulatory processes related to waste management facilities. Demonstration of the compliance with the regulatory requirements for a waste disposal facility, however, involve some special features that lie beyond established regulatory control procedures; those issues are identified and discussed in the paper.

1. INTRODUCTION

Most countries have adopted a stepwise licensing procedure for waste management facilities, where the licensing steps constitute the main regulatory checkpoints. This set of licencing steps may include a general licence, a construction licence, an operating licence and a closure/decommissioning licence. Besides that, there are regulatory instruments by means of which compliance with the regulatory requirements is verified between these checkpoints. Fig. 1 gives an example of such interaction between implementation and regulatory control in a repository development project. The discussion below is focused on disposal facilities with references in particular to the implementation of repositories for low and intermediate level wastes (LILW) in Finland (see Fig. 2) and to the Swedish spent nuclear fuel disposal programme. However, the discussion is not restricted only to waste disposal facilities but most of the text is also applicable to waste management facilities of other kind.

2. CHOICE OF THE BASIC CONCEPT

It seems that in most cases the initial ideas for waste management concepts have been selected without any open, formal and thorough safety evaluation of alternatives, though such evaluations have in some cases been made at the later stages of the concept development process. For instance, the choice of the basic concepts for disposal of LILW have predominantly been based on national geological and environmental conditions and on experiences from other countries.

Nevertheless, there has been re-evaluation of the selected concepts. Due to the more stringent regulatory requirements adopted for shallow land disposal in some countries in the 1980's, the modern concepts provide much better isolation by means of engineered barriers than those introduced a few decades ago.

On the basis of expert discussions, the most common concept for disposal of LILW, shallow ground disposal, was rejected in Sweden and Finland mainly due to unfavourable geological and climatic conditions, and disposal into rock cavities was introduced instead.

In Sweden, the KBS concept for disposal of spent nuclear fuel or high level reprocessing waste, was developed in a short time due to the provisions of the so called Stipulation Act. Based on a series of safety evaluations of the KBS concept and on reviews of these, the Swedish Government concluded in 1984 that safe disposal of spent nuclear fuel and other high level waste is feasible in the

Steps of implementation		Regulatory actions
Choice of concept	1980	
Site investigations, R&D		Surveillance
Siting report	1983	Review
Preliminary design		Policy decision
Site confirmation	1986	Draft safety regulation
Re-design		Review
PSAR		
Start of construction	1988	Construction licence
		Surveillance
	1991	Final safety regulations
FSAR		Review
Commissioning	1992	Surveillance
Start of disposal operations		Operating licence
		Surveillance

FIG 1. Steps of implementation and related regulatory control of the Finnish VLJ-repository.

Swedish bedrock. However, it was also concluded that much additional research and development work were needed before the KBS concept could be realized. The view that the KBS concept can be used as the main alternative in the industry's R&D programme has been reconfirmed in the later reviews of Swedish and Finnish spent fuel disposal programmes [1,2]. It is also clear that before starting to construct the actual facilities, the safety of the selected concept and of its viable alternatives will be thoroughly evaluated.

Another example of assessment of the basic concept for spent fuel disposal is the Canadian case, where the concept for spent fuel disposal is currently subject to comprehensive regulatory and societal reviews [3].

3. SITE CHARACTERIZATION AND OTHER RESEARCH AND DEVELOPMENT

Site selection is an urgent issue for disposal facilities in particular, because the characteristics of the site may contribute crucially to long-term safety. The siting of a disposal facility is generally a matter of great interest to society, thus a number of aspects must be considered and reconciled in a siting process.

For LILW disposal, the geological characteristics of a site are not necessarily the most determining factor and preference may be given to other suitability factors. For instance, in Sweden and Finland, bedrocks of NPP sites were selected and, based on subsequent site characterization studies, approved as the locations for LILW repositories.

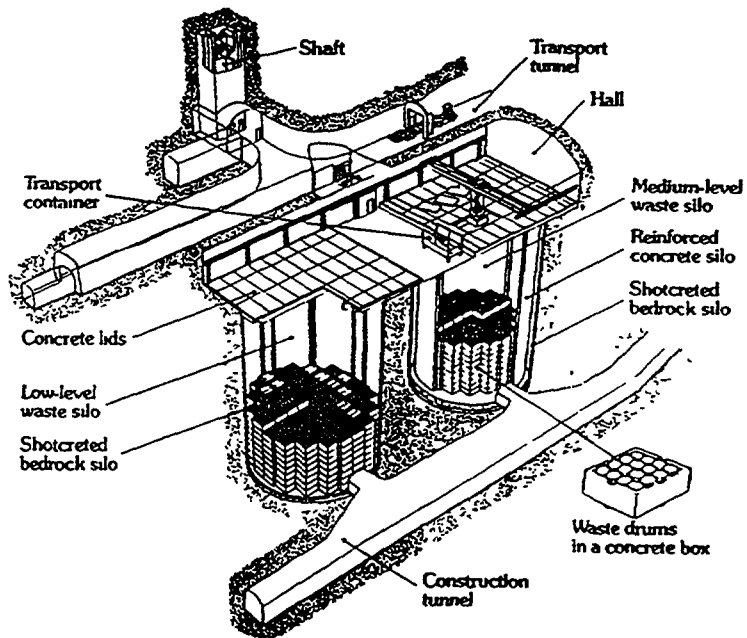
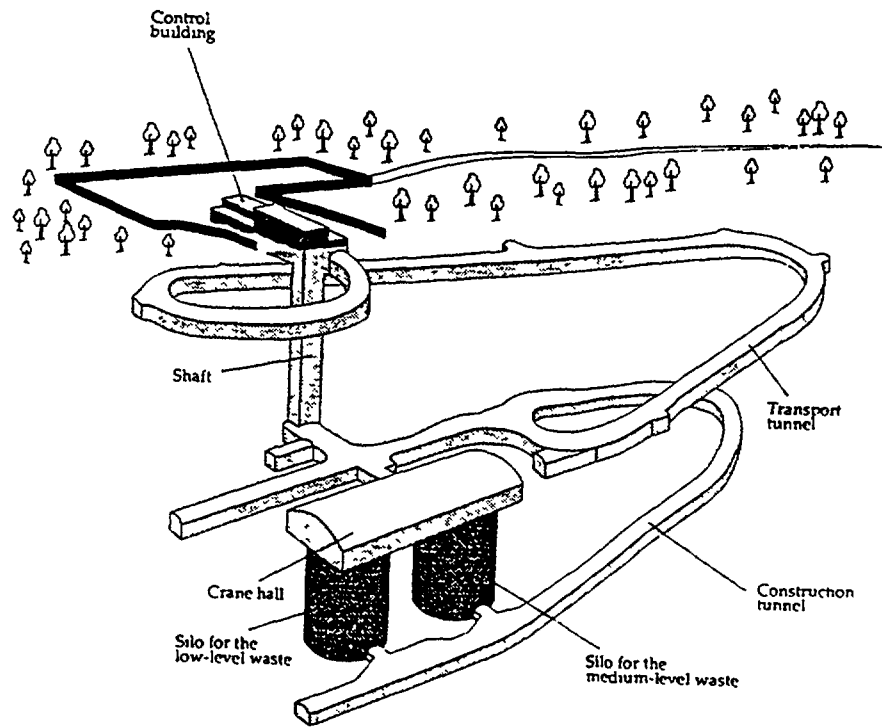


FIG 2. Lay-out of the Finnish VLJ-repository.

There is no unique strategy for the siting of a repository for HLW. Some countries, Finland among them, have initially identified a large number of potential areas and, on the basis of further site characterizations and other considerations, gradually narrowed this list of potential sites. Regulatory "feedback" is ensured by defining a few reporting-review milestones for the siting programme. Swedish and French utilities have looked for "volunteer" communities for the identification of a short list of potential areas. USA, Germany and Belgium have, at an early stage of the siting process, nominated one specific site with likely favourable characteristics and studies are focused on the confirmation of the suitability of this site e.g. by sinking an exploratory shaft to the planned disposal depth.

Other research and development related to waste management may also be subject to regulatory control. In Sweden the nuclear industry, which is fully responsible for finding safe solutions to the handling and disposal of nuclear waste, shall every third year submit to the Government a R&D programme on waste management. The Swedish Nuclear Power Inspectorate (SKI) which is authorized to conduct the review of the programme, submits it also to a large number of other reviewing bodies in Sweden. SKI's statement and other documents on the matter will be submitted to the Government. In its latest review of the programme [1] SKI suggested conditions on the future R&D work, canister design and manufacturing, methods for safety analyses and on the strategy of site selection. These conditions were later confirmed by the Government.

In site characterization and other research related to waste disposal, novel and non-validated investigation methods must occasionally be employed. It is then difficult to fulfill all the requirements of quality assurance. However, one should adhere to good planning and documentation of experiments in order to facilitate later traceability of the results.

4. GENERAL LICENCE

In many countries, nuclear or other legislation calls for the obtaining of a general licence of some kind for a major nuclear facility before proceeding to the construction licence phase. The Environmental Impact Assessment process is often coupled to this licensing stage. The main issues in this stage are the general societal acceptability and siting of the facility. Consequently the scope of the review in this licensing stage is not limited only to radiological and technical issues but is much broader. However, a preliminary design for the facility and a generic safety assessment should be available in this licensing phase as a background material for the regulatory review.

Such a general licensing stage was included also in the implementation of the Finnish VLJ-repository (see Fig. 1). The regulatory authority deemed the proposed site suitable to host a repository but had objections to the preliminary design of the disposal facility. This resulted in the re-design of the facility.

The Swedish Government has recently declared, based on SKI's review, that prior to the issuance of a licence to start constructing the encapsulation facility (the first facility of the KBS disposal system), industry needs to evaluate the short and long term safety of all facilities needed for the disposal concept. So, it would not be sufficient to evaluate only the operational safety of the facility for which an actual construction licence is sought for. There will be similar demands for a licence to start the detailed investigations at a potential disposal site as such investigations, in fact, are viewed as the first stage in the construction of the repository itself.

5. CONSTRUCTION LICENCE

For the regulatory review, the most important document to be included in a construction licence application is the preliminary safety analysis report (PSAR). It should define the design bases for the facility and include a detailed description of the site, facility and its operation. The PSAR should also include a safety assessment that is based on the design bases and specifications of the plant, site specific data and safety regulations and guidelines, if available. Occupational and public

exposures and other significant environmental effects should be assessed for the expected behaviour of the facility and for realistic unexpected events.

It is recognized that, in particular, assessment of the long-term performance of disposal facilities involve substantial uncertainties due to the difficulties in predicting future conditions, validating conceptual models and other assumptions, and in obtaining site specific data. In the regulatory decision-making these uncertainties should be considered in an appropriate way. More discussion of this issue is included in [4].

6. CONSTRUCTION PHASE

Regulatory control during construction of a nuclear facility aims to ensure that the facility is built according to design specifications and licence conditions and that applicable regulations are observed. For a disposal facility, these may include mining rules or rules concerning underground works. The regulatory control should be commensurate to the safety function of each structure or system. For this purpose, a safety classification system may be introduced. For instance, the concrete silo of the VLJ-repository (see Fig. 2) was ranked into a higher safety class than most other structures due to its importance to long-term safety. Accordingly very detailed design specifications and stringent quality control during construction were required for that structure.

The construction phase may be divided into subphases so that a new phase cannot commence before the regulator e.g. has approved the detailed plans for some important structure or system to be implemented. During the construction of a repository, it is advisable to ensure the quality of host rock around the planned disposal area by performing an at-depth reconnaissance programme as soon as the access tunnel or shaft has reached the planned disposal depth. Relocation of the disposal rooms or holes should be considered if these investigations indicate unexpectedly poor rock quality.

The construction process should be transparent to the regulator. Frequent on-site inspections and meetings with the representatives of the regulator and the implementors help in achieving this goal.

Commissioning tests serve to demonstrate that a waste management facility is built and operates according to the design. The regulator should review the commissioning test programme, witness the tests and review the test reports.

7. OPERATING LICENCE

The documentation for the operating licence application includes an updated version of that enclosed in the construction licence application. The final safety analysis report (FSAR) should be based on the actual design of the facility, further specified site data and regulatory requirements, if available. The FSAR for a disposal facility should also contain rather detailed plans for the closure of the repository. Other documents to be included in the operating licence application, if not included in the FSAR, may include waste acceptance requirements and other operational technical specifications, a programme for in-service testing, inspections and monitoring, operating instructions, administrative rules, a training programme, an environmental monitoring programme, emergency response arrangements and an operational quality assurance programme.

8. OPERATING PHASE

Operation of a waste management facility shall comply with the operating conditions defined in the operating licence or other documentation approved by the regulator. For disposal facilities, the waste acceptance requirements constitute an important set of operating conditions. The waste acceptance requirements for a repository should be derived from its design basis and from the results of the performance assessment. They may address e.g. the physical and chemical characteristics of

waste form, its radioactive and fissile content and the properties of containers. The waste acceptance requirements for the Swedish repository for LILW are discussed in [5].

Compliance with the waste acceptance requirements is ensured by means of a waste package quality control programme. This programme may be based on the qualification of the conditioning method and the checking of the documentation of waste packages when received at the disposal facility. The regulator may carry out independent checks by inspecting the conditioning process and by randomly testing waste packages. If the conditioning process is non-qualified or the records of waste packages are inadequate, there are higher demands concerning the methods and frequency applied for testing individual waste packages. Even destructive sampling of waste packages may then turn out to be necessary.

Environmental and in-plant radiation monitoring should be carried out during the operating period of a waste management facility. The vital structures and systems of the facility should be subject to in-service testing, inspections and monitoring in order to ensure that their performance is maintained. For a geological repository, these structures include also the host rock; deformations and changes in hydrology and stress field may be monitored.

On the basis of experiences and monitoring data obtained during the operating period, periodic safety related reviews should be made. Even updating of the performance assessment during the operating phase may be necessary if some crucial new information appears.

Maintenance of documentation for the facility is important. The operator of a repository should create a record of disposed waste that forms a basis for the register to be long-term archived.

9. CLOSURE AND DECOMMISSIONING

The transition from the operating phase to the closure of a major waste management facility can be regarded as the fourth major licensing step. For the closure of a waste treatment facility, a detailed decommissioning plan with a waste management plan should be submitted to the regulator for approval. Replacement of the operating licence by a special decommissioning licence may be required, if the decommissioning phase is long-lasting.

A considerable part of materials and structures at nuclear installations to be decommissioned contain so little activity that they could be cleared from regulatory control. A prerequisite for this is that clearance levels have been established by the regulator and that compliance with the clearance levels can be reliably shown by means of a monitoring programme. All clearances of radioactive materials and structures should be subject to strict regulatory control that includes review of clearance applications and other documentation, inspections of monitoring practices, promulgation of regulatory guides and quality assurance. The clearance issues are further discussed in [6,7].

The closure of a disposal facility is crucial to the long-term performance of the repository as it involves actions, such as backfilling and sealing, aimed at finalizing the isolating system. The final closure plan and an updated safety assessment, based on experiences and observations gained during the operating period, should be submitted for regulatory review. The closure of a repository should be subject to similar regulatory control than that during the construction phase.

After the closure of a disposal facility, the responsibility for the facility may be transferred to a permanent organization, e.g. to the state. Before that, the regulator should ensure that the closure has been done in a proper manner and that there are no remaining liabilities. The permanent organization should also arrange the long-term archiving of information about the repository.

The safety of some repository concepts is essentially based on long-term monitoring and other institutional control beyond the closure phase. These issues are discussed in [8].

10. CONCLUSIONS

There is much experience of how to ensure successfully compliance with regulatory requirements in context with the implementation of waste management facilities, including repositories for low and intermediate level wastes. For waste treatment facilities, same kind of implementary-regulatory interaction as for other nuclear facilities, can generally be followed. Waste disposal facilities, however, involve some special features that must be considered in the regulatory process. Issues deserving further discussion include e.g.

- (1) Regulatory approach to the siting process of HLW disposal
- (2) Validation of performance assessments to be included in licensing documentation
- (3) Derivation of and verification of compliance with waste acceptance requirements
- (4) Application of quality assurance to site characterization and to R&D related to repository development.

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STATUS OF INTERNATIONAL CONSENSUS
(Session IV)
SUMMARIES OF SESSIONS AND DISCUSSIONS

PLANNING FOR SAFETY

F. PARKER (USA),
A.C. LACOSTE (France)

1. PAPER No. 1 "RADIOACTIVE WASTE MANAGEMENT AS PART OF ENVIRONMENTAL PROTECTION" by T.P. GRUMBLY (USA)

1.1. Cost of USA's cleanup programme

Mr. Grumbly showed a figure from the recent DOE Report *Estimating the Cold War Mortgage* showing a mid-range cost of $\$230 \times 10^9$ over a 75 year period using present techniques and present cleanup levels for remediation of the DOE sites.

This estimate does not include most ground water cleanup nor cleanup of the Nevada test site, nor is it based on complete information. Not all sites have yet been characterized. It does not allow calculation of tradeoffs - what is the cost if 1% of waste is left in the tanks versus 5%, and what is the difference in risk for the different levels of cleanup?

1.2. Prioritization

Mr. Grumbly has set six goals for the Department of Energy. The first deal with truly urgent risks. Some are easy, such as the Hanford tanks which have the potential but did they really have the probability of duplicating the Kyshtym accident? An objective study showed that such an explosion at Hanford was highly unlikely. The temperatures were too low and there was too much water in the system to create explosive conditions though the same chemical constituents were present. This is a case where the technical community mislead itself and the public.

How should the Department of Energy prioritize? They have embraced risk analysis in contrast to the previous department position that in cases of budgetary shortfall, there should be proportional reduction in funding for all. This is not a wise nor efficient choice but was adopted under pressure because it offended the least number of participants. However, getting good risk estimates has turned out to be far more difficult than originally thought. The Department has embraced the contents of a National Academy of Sciences report entitled *Building Consensus Through Risk Assessment and Management of the Department of Energy's Environmental Management Program*. One of the key recommendations in that report was to involve members of the public at the earliest stages including defining the scenarios to be studied and to have them participate in its analysis. Further, the report emphasized the false distinction between supposedly value-free risk assessment and value-loaded risk management. Risk assessors have values that are included in their choice of scenarios and input numbers. This emphasis on value affected risk assessment may revive the vigorous discussion of yesterday on models. Do we use standard man as it was asked yesterday or do we take into account the different dietary habits of the "critical group?" The report highlighted the importance of bringing different points of view into the discussion and of answering the questions that trouble the public - not just those that are scientifically interesting to us. I repeat the question I asked in my talk, does it make sense, for example, to spend more money on the scientific understanding of flow through fractured rocks when the bounding cases already calculate doses orders of magnitude below any regulatory limits? I ask this not in an anti-science sense, but in an attempt to put HLW underground more quickly. Technological development is a different question - can we emplace backfill as well as we predict? and can we weld copper canisters as well as we predict?

2. PAPER No. 2 "DEVELOPMENT OF NUCLEAR SAFETY PHILOSOPHY"
by A.P. VUORINEN (Finland)

Mr. Vuorinen touched upon but did not elaborate on the ability of the public to make objective judgements on nuclear waste matters. In the past three days we have heard numerous cries of despair about the difficulty of educating the public. Perhaps we should recognize that the problem is not in the alignment of the stars, but ourselves. As Pogo said in the American comic strips, we have met the enemy and it is us. If we cannot persuade the public that our views are the correct views - whom should we blame? This is akin to killing the messenger who brings bad news. Instead of lamenting the public's ignorance and bias, perhaps we should ask what are we doing wrong?

3. PAPER No. 3 "SOCIO-POLITICAL CONSIDERATIONS"
by J.M. KINDELAN (Spain)

It is peculiar to me that Mr. Kindelan's paper that raised many of these issues invoked little comment. He said, "the achievement of higher levels of equality and the adoption of solidarity as a practice still constitutes a driving force for the programs of mankind and a reasonable utopia at which to aim. This is undoubtedly the fundamental political issue for the coming century." I think he was absolutely right. We live in political society, overwhelmingly a democratic society, and not a technocratic society, and should behave that way.

Though we continue to flog the public and the media, objective analysis of media content in the United States over and over again does not indicate the massive bias attributed to it. Though all of us can cite our own individual horror stories - would we accept such anecdotal evidence in our scientific work? Whose fault it is when Bowman's allegations get such a big press, his or the media's? Ethics is an issue - what do we do with such apparently irresponsible and refuted allegations? Do we declare the individuals responsible, pariahs?

As Mr. Kindelan has said, "coherent, serious and technically founded activity in relation to local public opinion, accompanied by economic incentives," has made the low-level waste facility a reality.

I call your attention again to the fact that the recent NEA/OECD Collective Opinion on Environmental and Ethical Aspects of Long Lived Radioactive Waste Disposal said not a word about intragenerational equity. All of us want to be treated fairly. So why would members of the public accept the pronouncements of these members of a technological elite?

4. PAPER No. 4 "NUCLEAR POWER PLANT SAFETY CONVENTION"
by Z.G. DOMARATZKI (Canada) and
PAPER No. 5 "PRINCIPLES AND OBJECTIVE OF RADIOACTIVE WASTE MANAGEMENT"
by E. WARNECKE (IAEA)

I have spent relatively little time on these papers, not because they are not of interest, but because they are descriptions of historical facts on the development and maturation of Nuclear Safety Philosophy, the Nuclear Power Plant Safety Convention, and the principles and responsibility in Radioactive Waste Management and left little room for editorializing.

5. PAPER No. 6 "RESEARCH AND DEVELOPMENT ON RADIOACTIVE WASTE MANAGEMENT" by W. BALZ (European Commission)

I will refer to Mr. Balz's excellent description of the status of R&D in Radioactive Waste Management, and would like to emphasize the fundamental question that he says is yet unanswered - "whether the certainly valuable scientific/technical results from R&D programs necessarily contribute to the information needed by decision makers and licensing authorities for a repository in deep geological formations or by the public to gain confidence in the concepts and techniques used for safe long-term disposal of radioactive waste?" Should we not be applying the techniques of decision

theory and see whether further information would change our decision and whether the cost of the information is more than the improvement in the decision?

We demand from the authorities and the public, answers to questions as how clean is clean enough, and how safe is safe enough? Should we not also demand of ourselves how much characterization and R&D is enough?

I hope these comments will engender some discussion with the authors of the papers and with members of the audience on my interpretation of what was said.

6. DISCUSSION

The comments led to vigorous discussion on many of the points. In addition, suggestions were offered for additional “defining moments” or “milestones.” They included:

- (1) The establishment of SKB (Sweden), ANDRA (France) and NAGRA (Switzerland).
- (2) The opening of SFR (Sweden).
- (3) Subseabed studies (NEA).
- (4) Study of natural analogues (NEA).
- (5) Repository assessment programs of NAGRA (GEWAEHR) and of CEC (PAGIS).
- (6) Development of Gorleben HLW site (Germany).
- (7) Hearings on Konrad LLW site (Germany).

EXPERIENCE IN THE SAFE MANAGEMENT OF RADIOACTIVE WASTE

*C. McCOMBIE (Switzerland),
A. LOPEZ (Spain)*

The session was structured to provide an overview of high level waste management extending from a historical perspective of the past (paper by F. Parker), to comprehensive reviews of the status in the key application areas of L/ILW (A.N. Prasad et al.), HLW (W. Thomas) and mining and milling wastes (P. Brown and R. Pollock). The question addressed then by A. Duncan et al was whether the RADWASS documents of the IAEA and in particular the "Safety Fundamentals" documents do indeed provide a proper framework for these waste management activities. An added presentation by G.E. Dials and L.G. Eriksson summarized progress towards taking the WIPP facility into operation; as this may be the first operation disposal facility for long lived wastes, it was of interest to see which issues were regarded as of key importance. In the discussion on the session and in this written summary the papers by A.N. Prasad et al., W. Thomas and P. Brown and R. Pollock were separated out from the other contributions to the session.

Some of the (deliberately) provocative points raised by F. Parker in order to initiate discussion are highlighted here:

- Should we be concentrating to such a degree on nuclear power plant wastes when environmental remediation is in many countries a bigger problem?
- Is there too much reliance placed on mathematical modelling (cf. the quotation from Dostoevski)?
- How can one reconcile the statements in the paper (a) that it is a "myth" that no solution to waste disposal exists, and (b) that there are "philosophical and technical misgivings" about the feasibility?
- It is true that the Bowman/Veneri explosion hypothesis is "not yet laid to test"?
- Does the ethics issue neglect "fairness" to those generations living at present?
- How much agreement was there on the statement in the paper that "the search for higher technology solutions is futile (if the aim is) to reduce opposition" to disposal?

In the paper by A. Duncan et al the question being addressed is how the safe requirements for radioactive waste management are linked to, or can be derived from, the safety fundamentals or to a general Convention based on these. Some of the key points emphasized were as follows:

- A waste management system should be a comprehensive structured aggregate which is coherent with that in other countries. A centralized, uniform system is, however, not necessary.
- Although there is broad agreement on the concepts of risk or potential exposure, there is less consensus on how to apply these concepts in regulation.
- Predisposal issues in waste management are relatively straightforward. Decommissioning is an important area; plans should be made from the outset and reviewed periodically.
- In the disposal area one problem concerns extended institutional controls. Are these incompatible with RADWASS because they place a burden on future generations?

In the limited time available for discussion, several participants confirmed that the Bowmann/Veneri hypothesis had led to additional studies in their national programmes, despite the fact that the criticality issue had already been covered at a technical level. There was some debate on the value of looking for ever more sophisticated technical solutions to disposal problems when the principle objections being raised are socio-political. Several participants felt that high technology approaches were also needed in order to enhance the confidence and credibility of waste management in the scientific/technical community. In the area of safety regulation, the value of consistent approach was recognized but the IAEA was cautioned against giving too detailed guidance to Member States.

RADIOACTIVE WASTE MANAGEMENT ISSUES: MANAGEMENT STRATEGIES

A. DUNCAN (United Kingdom)

1. The following points could be highlighted from the paper on "*Waste Management Perspectives*" by R. Rometsch (Switzerland):

- It is important not to be judgemental about public perception, to be prepared to join the debate in a constructive and informative way and to ensure that our waste management systems and national arrangements take account of this requirement.
- The idea of an international repository is taboo although there might be increasing acceptance of the idea as national HLW repositories began to be commissioned and to operate safely. It was thought that such acceptance might even develop after commissioning of long lived ILW repositories.

2. The paper on "*Remediation Issues and Activities*" by R.G. Lightner stressed the following points:

- US experience, and no doubt others' experience, of the consequences of early nuclear operations emphasizes or demonstrates the wisdom of the RADWASS requirement for considering waste management at the planning stage.
- During the floor discussion another interpretation on Mr. Parker's reference to "regulation following practice" was raised, by suggesting that experience of the consequences of such practices led to regulation which ensured that such practices were not repeated!

3. On G.J. Allan's paper on "*Disposal Concepts and Disposal Alternatives*" it should be stressed that underground disposal was both feasible and ethical and that concepts such as actinide transmutation do not eliminate the need for facilities for disposal of waste with long lived activity. There was nothing contentious.

4. From K. Kühn's paper on "*Supra-national Issues*" the following points should be highlighted:

- It is to be noted that, despite the taboo of the international repository, we already have international co-operation by way of the arrangements for reprocessing spent fuel. Attention was drawn to the fact that this removed some of the flexibility of national waste management systems (i.e. those of BNFL and COGEMA customers) by fixing, in essence, the waste package specification. It was also suggested that a disposal safety case in such a situation would have to be robust against the possibility of the waste specification not being entirely within national control.
- Mr. Kühn raised the issue of an International Commission for Nuclear Waste Disposal (ICNWD). There is clearly some resistance to the idea of such a body taking over or duplicating the work of the IAEA and it was suggested that a compromise might be possible. An ICNWD might establish basic principles and ethics and the IAEA, for example, could develop standards, guides, etc. for implementation of such principles.

RADIOACTIVE WASTE MANAGEMENT ISSUES: SAFETY OF REPOSITORIES

H. RÖTHEMEYER (Germany)

1. GENERAL APPROACH

The objective of radioactive waste management is to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations. The proof of this objective being achieved at a given site is generally based on safety indicators which can be compared to quantitative safety criteria.

The overall performance assessment for the repository system (overall geological situation, mine, waste package) must prove (operational phase) and give reasonable assurance (post operational phase) that the quantitative safety criteria are met. The long term safety assessment consists of the identification and description of potential pathways of radionuclide release, migration and exposure. The establishment of waste acceptance requirements based on the compliance of the performance assessment results with the safety criteria is the last step before a disposal facility can be licensed and operated.

2. NEAR SURFACE REPOSITORIES

Near surface repositories for LILW-SL are usually designed by taking advantage of a post-closure institutional control period of up to a few hundred years. No issues have been identified with respect to their operational safety and requirements for the institutional control period. The duration of institutional control and unforeseen changes in the stability of the society might be further discussed.

3. OPERATIONAL PHASE OF A DEEP REPOSITORY

The performance assessment of the operational phase including (design basis) accidents can in principle follow the same approach as for other nuclear facilities; this includes the application of the radiological protection principles and objectives.

4. SAFETY INDICATORS

The assessed long-term consequences of disposal systems must be considered as indicators of safety that can be compared to safety criteria. Dose and risk are generally used as indicators for radiological safety. Indicators for societal risks and for the environment have to be further developed. The IAEA-TECDOC-767 (Safety Indicators in Different Time Frames for the Safety Assessment of Underground Radioactive Waste Repositories) gives valuable guidance. (Environmental protection scientists have recently introduced environmental indicators to describe aspects of the environment influenced by humans.)

5. TIME FRAMES

The interpretation of performance assessment results as indicators of safety reflects the uncertainties associated with predictive modelling. The IAEA-TECDOC-767 recommends different indicators for different time frames (possibly in support of a safety case based on dose or risk). Some countries have introduced a fixed time cut-off for quantitative performance assessment to account also for the uncertainties. The concept of safety indicators may thus render a time cut-off unnecessary. Predictions beyond about a million years, however, seem to be meaningless even as an indicator of the possible future behaviour of the repository system (i.e. safety assessment). Releases possibly occurring after these long times may indicate a well chosen and designed repository system.

6. SAFETY ASSESSMENT

Present and further improved future performance assessments can and shall never aim of predicting the future, but of scoping the range of potential future behavior of the repository system.

It is recognized that a complimentary use of deterministic and probalistic approaches may be appropriate for reasonable assurance of safety.

The requirements on human judgement and expert opinion will remain. Confidence building measures like peer reviews, formalized quality assurance and open discussions are necessary parts of a confidence building process. The role of natural analogues in the confidence building process has hardly been discussed. German experience with the projects Gorleben and Konrad show that these analogues are of utmost importance in the public confidence building process.

The demonstration of compliance with a given set of (national) criteria is still a much debated issue.

7. POST-CLOSURE ISSUES

The following tentative answers to the post-closure issues associated with retrievability, human intrusion and safeguards have been accepted as possible: Answers to post-closure issues should be based on a rational evaluation of the good and bad aspects of alternative strategies and actions. Such an evaluation reveals tentative answers to post-closure issues. **Retrievability:** Repository construction and sealing in a way that renders institutional control unnecessary, but not impossible. **Human intrusion:** Emplacement of unavoidable hazardous waste in deep geological repositories is the best we can do today; alternatives like indefinite storage present higher risks and burdens on future generations. **Safeguards:** Safeguarding of nuclear material, if considered necessary by future generations, is possible with present day technology.

RADIOACTIVE WASTE MANAGEMENT ISSUES: REGULATION AND COMPLIANCE

S. NORRBY (Sweden)

1. From the panel discussion on *Exclusion, Exemption and Clearance of Materials from Regulatory Control* it appeared that even if a considerable development of knowledge and harmonization of views has occurred since the publication of IAEA Safety Series No. 89 (1988) further work is needed to reach consensus on clearance of materials from regulatory control. Still there are different views as regards the basic concept of clearance/exemption and also on the implementation of the principles. There is a need for harmonized regulation in different countries especially as some of the problems concern transboundary movements. Also from the point of view of the Convention on Radioactive Waste now being discussed in an expert group there may be a need to define the concept of exemption/clearance.

2. The key messages of the paper on *"Formulation of Regulatory and Licensing Requirements"* can be summarized as follows:

In general (qualitatively) there is agreement on what issues are important safety factors in RWM including disposal, although it is difficult to give quantitative requirements (content of organic materials, gas forming substances, etc).

If radioactive waste is produced and treated before the final repository is defined there may still exist a possibility to accommodate the waste in a repository system provided the repository can be properly adjusted to the specific waste types. In some cases the waste may be further treated or given an overpack. In any case it is important to have a good documentation on all waste types.

There is international consensus on the possibility to evaluate the safety of a repository system for radioactive waste. However in the very long time perspective uncertainties increase and quantitative results of performance assessments should be regarded as safety indicators than exact figures.

More important than giving detailed technical regulations is the general requirements on a legal framework and a clear definition on the responsibilities of the different organizations involved in RWM (waste producer, operator and regulator).

3. The paper on *"Compliance with Regulatory Requirements"* is focussed mainly on final disposal and summarizes the possibilities to demonstrate compliance with regulatory requirements in different steps of the development of a repository system. The main message of the paper is that demonstration of compliance is possible in many cases but that there are issues that deserve further discussions, for example:

- regulatory approach to the siting process of HLW disposal,
- validation of performance assessments to be included in licensing documentation,
- derivation of and verification of compliance with waste acceptance requirements,
- application of quality assurance to site characterization and to R&D related to repository development.

In the floor discussion it was underlined that it is sometimes valuable to free oneself from old customs and views. As regards radioactive waste a comparison was offered between the amount of radioactivity dispersed in the environment (atmospheric, terrestrial, aquatic) from nuclear weapons production and testing - which has not significantly altered the natural background radiation - and the total inventory of radioactive waste existing globally; these two entities probably being of comparable radiological significance. Thus, the principle of concentrating radioactive waste and making their disposal potentially harmful for possible intruders perhaps being worth reconsideration. There was immediate reaction in the audience and it was claimed that the inventory of radioactive materials in

spent fuel was two orders of magnitude bigger than the material from nuclear weapons production and testing.

The audience was also reminded that there are two basically different ways to regulate:

- (1) Allowed is all that is not forbidden.
- (2) Forbidden is all that is not allowed.

The importance of having a high Safety Culture was also stressed in the discussion.

With respect to the International Convention on the Safe Management of Radioactive Waste a few crucial issues for the convention were mentioned:

- spent fuel (should it be included in the convention?),
- past practices (now being a real problem),
- clearance (further clarification needed).

The view that the Convention must have a balance between issues being of different character (technical - social/political) was also expressed.

PANEL DISCUSSIONS

IMPLICATIONS OF TREATING SPENT FUEL AS HIGH LEVEL WASTE

Summary by R. ROMETSCH (Switzerland)

Panel Participants: R. ROMETSCH, Chairman (Switzerland)
C.J. ALLAN (Canada)
J. PAHISSA-CAMPA (Argentina)
S. NORRBY (Sweden)
D. GRAHAM (United Kingdom)
G.A.M. WEBB (IAEA)

1. STATEMENTS BY THE PANELISTS

R. ROMETSCH

Mr. Rometsch, after introducing the panelists, in his opening statement enumerated four groups of major questions posed by treating spent fuel as waste: (1) How to evaluate economics or what has to be included in the comparison of fuel cycle costs; (2) Is the long-term radiological safety of a spent fuel repository acceptable; (3) How important is the conservation of energy resources and how to cope with the nuisance value of contained fissile material and (4) How should the treating of spent fuel as waste be taken care of in the radioactive waste safety convention. He also noted that the introductory statements of the panelists might raise or re-formulate further questions.

C.J. ALLAN

Mr. Allan pointed out that nuclear industry has shown environmental leadership by storing radioactive waste safely, either after fuel reprocessing or, like in Canada, within the used fuel. This could continue for many decades, but it is recognized that there is a need for long-term isolation based on passive safety, i.e. disposal. Both, disposal of spent fuel and of high level waste from reprocessing are technically and economically feasible. Deciding between them is not fundamentally a waste management issue: it involves ethical, political, economic and technical considerations. The size and cost of deep geological repositories for both concepts will be very much the same as it depends mainly on the heat generation of the disposed material. For Candu fuel it is of the order of 400 m² and for LWR-fuel with 3 times the burn-up and double the content of plutonium it is 600-1200 m² per TWh electricity. Costs are also influenced by the geological setting and the overpack or encapsulation system adopted.

He cited a recent NEA study which concluded that there is little difference in total fuel cycle cost for a PWR when comparing prompt reprocessing and recycling with direct disposal, and commented that considerable differences may occur from country to country; in Germany, for instance, one has found disposal of spent fuel cheaper than reprocessing followed by disposal of reprocessing waste. In Canada, where the estimated disposal cost is US\$ 100 per kg heavy metal, this is certainly also the case.

Mr. Allan further noted that presently spent Candu-fuel contains half the amount of plutonium as could be separated from LWR fuel and would, if separated, be significantly more expensive than freshly mined uranium. However, the Candu reactor system is flexible; direct recycle of LWR fuel and LWR plutonium is possible. If Canada should at some future date begin to reprocess spent fuel, it could even decide to retrieve Candu fuel from the repository and convert its strategy to high-level waste disposal. The important point from waste management perspective is that both options exist, both are feasible and both meet the objective of protecting human health and the environment.

J. PAHISSA-CAMPA

Mr. Pahissa-Campa observed that uranium resources are not as great as originally estimated. He emphasized the nuclear energy being essential for at least the coming 50 years and that one must not squander uranium reserves as it was done with petroleum. This means that the spent fuel should be considered not as a common waste but as potentially reusable material. Safe, reliable and retrievable storage should be the approach until a definitive decision is taken.

He informed that Argentina has adopted this "wait and see" policy. In the meantime spent fuel is considered an asset to be safely stored. Taking into account both approaches, direct disposal and reprocessing, recycling fissile material and disposal of high-level waste, Argentina is studying the disposal site for the future geological repository in proximity of which an interim storage for spent fuel could be constructed.

Due to the low burn-up of the fuel from the pressurized heavy water reactors, storage in transport containers has been chosen. Design studies for reinforced concrete casks with stainless steel lining indicate cost of around US\$ 45 per kg uranium. At present pools and concrete silos assure the interim at-reactor storage. If reprocessing is decided, then the plant would also be installed in the proximity of the disposal site to minimize risks and costs of transportation.

Likewise, combined cycles PWR/Candu are being studied together with Brazil. Preliminary results show that the ideal blending ratio of PWRs and Candus would allow both substantial savings of uranium and a considerable reduction of waste arisings.

Therefore, Mr. Pahissa-Campa emphasized that spent fuel should not be considered as waste, however it should be included in the safety convention on waste management.

S. NORRBY

Mr. Norrby indicated that in the discussion on an international convention on safe management of radioactive waste the issue has been raised how to consider spent fuel. Many countries wish the convention to have a broad scope allowing to cover spent fuel. The Nordic Countries proposed that the convention should cover both radioactive waste and spent fuel. To avoid a lengthy discussion on the definition of radioactive waste, spent fuel should be included in the title of the convention.

He pointed out that safety requirements on storage, transport and disposal should take the actual properties of spent fuel or high-level reprocessing waste into account and the safety objective set for their treatment. This causes no problems. However, differences between spent fuel and high-level reprocessing waste affect the long term safety in final disposal, they are :

- specific heat generation in the short and in the long term;
- radionuclide inventory (long lived radionuclides);
- geometric properties of waste packages; and
- matrix in which radionuclides are incorporated.

Mr. Norrby noted that there is international agreement that emplacement in deep geological repositories is the preferred disposal option. Retrievability of the spent fuel will be possible, at least for crystalline host rock. The long-term performance of a repository for spent fuel and/or high-level waste can be evaluated. It should not rely on institutional control which may be regarded as an extra "bonus".

Safeguards requirements are well defined for storage and transportation of spent fuel but may need special consideration for a closed repository. The Swedish Nuclear Power Inspectorate (SKI) is evaluating this question. According to existing agreements safeguards can only be terminated when

the nuclear material can be regarded as "practicably irrecoverable". This expression needs interpretation. SKI expressed the view that also alternatives to intrusion in a repository for access to fissile material should be considered. As long as the possibility of retrieval is recognized it seems acceptable to leave it up to future generations to decide when and how safeguards should be terminated.

In conclusion, Mr. Norrby repeated that the Swedish position is clearly that spent fuel should be covered by the waste safety convention.

D. GRAHAM

Mr. Graham informed that the current nuclear scene in UK is based on the following types of reactors: Magnox (3350 MWe), AGR (8380 MWe) and PWR (1175 MWe). Any additions will need to come from private industry. No FBR or MTR is now in operation in UK. There are some low power University reactors and a TRIGA reactor at Imperial Chemical Industries. Spent fuel reprocessing is undertaken at Sellafield and Dounray.

All spent fuel arising from the UK Magnox reactors during their lifetime will be reprocessed at Sellafield. Besides the new Thermal Oxide Fuel Reprocessing Plant (THORP) is now actively commissioned. AGR fuel arisings will be reprocessed there. Much of it is already in the storage facility awaiting the reprocessing decision. There are also commitments for foreign fuel reprocessing.

At Dounray the Material Testing Reactor Fuel Reprocessing Plant has almost finished all MTR fuel. The Prototype Fast Reactor Reprocessing Plant is being reprocessing the remaining oxide fuel from PFR.

Magnox uranium has been recycled through AGRs. For economic reasons recycling of uranium from THORP in AGRs is now proposed. Recycle of plutonium to fast reactors is the preferred option. However with the demise of the Dounray PFR the possibilities are now limited to use in thermal reactors.

Mr. Graham described further the UK radioactive waste and spent nuclear fuel policy. The Government's White Paper "Review of Radioactive Waste Management Policy", July 1995, has been framed within the context of international guidelines and regulations including RADWASS. The safety principles set out in the IAEA safety fundamentals have been fully reflected in the White Paper. The aim is to ensure a sustainable development and to protect humans and the environment now and in the future.

With regard to spent fuel the selection between early reprocessing, delayed reprocessing and disposal will be one of commercial judgement by the owner of the fuel subject to meeting regulatory requirements. In accordance with IAEA definitions spent fuel is not categorized as waste; it is considered an asset. Wet or dry long term storage of spent fuel is regarded as a sound engineering solution. Again, decisions on need and siting will be a matter of commercial judgement of operators.

Government policy has been to store vitrified high-level waste for 50 years to allow some decay. Though the storage will last well into the next century the Government has decided to take a proactive interest in disposal now. Research programmes will also consider spent fuel disposal.

Finally, Mr. Graham touched the issue of the classification and reclassification of spent fuels. It has to be considered that there is a wide range 'spent fuel'-type materials. In the UK the highly irradiated spent fuel from nuclear power plants is regarded as a resource. Less irradiated spent fuel, scraps and debris can not be compared with high level waste but are, in fact, comparable to intermediate level waste. Any reclassification of existing spent fuel will have implications arising from the change-of-use. Therefore, he concluded, there is a need to proceed very carefully on the classification and licensing issue.

Mr. Webb noted that there are clearly differences between spent fuel and high level reprocessing waste, but there is not any reason for basic safety requirements for either spent fuel or high level waste to be different, whether in store or disposed in a repository. He observed that the principles in the Safety Fundamentals for radioactive waste are very general. Requirements will have to be developed in a quantitative numerical form so that compliance can be demonstrated, for example, through predictive modelling. Quantitative requirements will have to be consistent with the IAEA Basic Safety Standards for radiation protection. For waste storage facilities, the requirements will be closely linked to current safety requirements for any other nuclear facility.

In the convention context, there is agreement that the safe disposal of either spent fuel or high level reprocessing waste would be covered so that these different wastes would be treated the same way from a safety viewpoint. Also storage of high level waste should be covered.

However, when considering the storage of spent fuel, there is discussion as to whether its inclusion should be dependent on its intended future use. If this is disposal it is by definition covered as waste. But if it is intended for reprocessing, it is by definition useful material and it could be argued as being outside the scope of a convention on radioactive waste. Then a given spent fuel store could flip into and out of the scope depending on the current national intention. In particular, the question would arise, what is the status of a "wait and see" store with respect to the convention?

There is the matter of continuous safety coverage. Unless it is specifically included in the waste management safety convention in some way, storage of spent fuel intended for reprocessing will be a "gap" in the conventions. In Mr. Webb's view it is dubious that it is worth a separate convention. As a way to solve the problem, he suggested to face it head-on and say that, even though it may not always be considered as waste, spent fuel should come under the scope of the waste management safety convention.

2. DISCUSSIONS

Discussions, though reflected to a certain extent all major questions raised in the Chairman's and other panelists statements, were focused mostly on reprocessing of spent fuel and the inclusion of spent fuel into the convention on radioactive waste. There was, however, a broad spectrum of arguments and approaches in the presentation of and the views on both issues.

In the discussion of whether to reprocess or not to reprocess, economic, radiological and environmental advantages and disadvantages, such as mill tailings, safeguards, scientific, technical and socio-political aspects, etc. were brought to the attention. In particular, it was pointed out that during the last General Conference, at a half day session of experts' meeting, a conclusion was made that economy is the only factor that speaks in favour of disposal of spent fuel and that energy resource, radiation protection, safety and safeguards related questions speak for reprocessing and recycling, especially taking into account mill tailings, which are considered a major factor in the global exposure. This was noted to be consistent with conclusions of other international bodies such as UNSCEAR, however, inconsistent with the view of some panelists that with regard to radiation protection and nuclear safety the two options should practically be the same.

With respect to that particular point it was stressed that the safety requirements for storage or disposal of spent fuel or high level reprocessing waste should be equivalent. In the introductory statement Mr. Webb did not mean that the overall radiological impact of a reprocessing fuel economy and a disposal fuel economy were the same. They are different and, as it was indicated, the uranium mill tailings are a major contributor to the radiological impact of the once through cycle. The comparison is, however, not simple.

Some speakers argued that they could not imagine that uranium would lack in the future because already at \$40 per kg it would be economically interesting to separate it from phosphate ores the reserves of which are absolutely enormous. So the argument that spent fuel could be considered as an energy resource is, to their opinion, just an argument to avoid decision. Is depleted uranium a waste? Is plutonium from reprocessing a positive value or a burden? Can the structure of reprocessing waste be as good for disposal as the structure provided by the unreprocessed spent fuel? These questions, they argued, should also be discussed when comparing the fuel cycle options.

Mr. Allan reiterated his position by commenting that the issue of safety has to be covered primarily. Spent fuel intended for reprocessing contains valuable material and material identified as waste. Within the nuclear safety convention which covers operational plants and the convention on safe management of radioactive waste, the spent fuel will in fact be covered one way or other and the fundamental objectives of safety and radiological protection of public health and the environment will in fact be met.

Another comment was that economic aspects will probably change with time. But the essential properties of material will not change. In that context a substantial radiation safety difference between the options of disposal of spent fuel and reprocessing waste was emphasized. If the convention is being based on the fundamental safety principles, it must lead to the selection of the best option from the radiological point of view. Are such policy arguments to be included in the convention? Or, will the discussed economic issues determine the selection of options? These were the questions of concern.

With regard to the scope of the convention, the view was expressed that there was not only a technical/scientific aspect but also a linguistic aspect. The linguistic aspect is as follows. Waste is defined as something that has no use or is not planned to be used any more. This is where the problem comes in. Spent fuel to be reprocessed cannot be waste because it is intended to be used. There was quite an active discussion in the convention meeting which led to some agreement that the safety be ensured for all that material - whether it is called spent fuel or waste. This cannot be done easily because of the wording of the definitions. But on the idea, there was no disagreement.

The discussions confirmed that though there were some difficulties, for example, with definitions, the participants of the seminar did not see any major reasons why spent fuel should not be covered by the convention. There are fuels which will not be reprocessed. One can imagine such fuel in interim storage in the same facility where other fuel is awaiting reprocessing. From the safety point of view the same considerations should be applied.

Another view on the question whether to reprocess spent fuel and the scope of the radioactive waste convention was also expressed. On the former, it was noted that the UK for example went through a major exercise some two years ago in connection with the Sellafield reprocessing plant. It showed that the decision to reprocess is not radiation protection, or economics, or sustainability, or safeguards, or transport, or employment, it is all of these items and the decision makers have to be able to weigh all of them in a proper balance. And of course the UK government policy is that it is for the owners of the spent fuel to decide whether to have their fuel reprocessed or not. Clearly, there is no option, if there are no suppliers of reprocessing services and those are pretty few in the world.

On the second point whether spent fuel should or should not be considered as radioactive waste or somehow incorporated in the proposed convention, it was noted that some of the arguments are somewhat unconvincing and of an administrative nature. The decision that the group preparing the convention will have to face is whether one is talking about a radioactive waste convention or indeed a nuclear materials convention. Concern was expressed if the convention were too wide. It would dilute its content. During the preparation of the nuclear safety convention, radioactive waste was taken out of the scope so that it could focus on the nuclear safety aspects and a separate convention on radioactive waste had to be developed.

In a discussion on retrievability and recoverability some experts noted that, once the conceptual decision of disposal is taken, be it for waste or spent fuel, one should not any more talk of retrievability which is contradictory to the safety of the repository but of recoverability. There is always some possibility of recoverability. One can mine again into a repository. If long term storage of spent fuel for later use is considered, storage of spent fuel at the surface is easier and cheaper than disposal in geological formations.

Panelists argued that it is not the intention to retrieve but the possibility to retrieve is important for the acceptance of a repository. Retrievability gives future generations a possibility to do something which we perhaps do not foresee. If retrievability can be included into the design of the repository in a way that it will not be threatening safety, there should be no conflict.

Concerns were expressed by some participants over a potential difficulty posed by the safeguards question. It was pointed out that in accordance with the principle 4 of the RADWASS safety fundamentals one should not put burdens on future generations. One can see a potential conflict regarding the safeguards regime as it could be argued that direct disposal of spent fuel would not be in accordance with the safety fundamentals.

A part of the discussion was about reprocessing and recycling as compared with recycling of other materials like glass, aluminium, etc. It was pointed out that aluminium is not recycled any more; it is too expensive. But, on the other hand, glass is continued to be recycled although in some countries glass recycling is subsidized because of its surplus. These examples show that there are various other aspects than those purely based on economics. Therefore, in some countries the decision to reprocess or not to reprocess would be a political decision. Technical, scientific, economic, radiological protection decisions are based on processes that have some similarity: if a variable increases in value, it becomes more interesting and vice versa, and so forth. Political decisions are very often based on mildly rational arguments, or sometimes not visibly rational arguments which means that they are not predictable. They have also another aspect, that is they can be changed - and in fact they change quite often. What may be politically the right thing to do today may be exactly the opposite in 5 years. So one cannot say for the long term that it is obvious whether reprocessing is a preferred option or not. Only if one is not talking about political aspects one can keep the distinctions of rational factors being considered. The political issue is one that should probably be left aside completely when one wants to discuss reprocessing and recycling rationally.

The Chairman closed the meeting by observing that discussion deviated to some extent from the question of "implications of treating spent fuel as waste" and focused on the questions of "reprocessing" and the "convention". With regard to the convention, one conclusion from this panel discussion, he would like to retain, is that there seems to be general agreement that both radioactive waste and spent fuel, when considered as waste, should be covered by the waste safety convention. The inclusion of conditioned spent fuel would meet also the tendency of the UK not to broaden the convention beyond waste management.

RESIDUES FROM PAST ACTIVITIES AND ACCIDENTS

Summary by R.G. LIGHTNER (USA)

Panel Participants: R. G. LIGHTNER, Chairman (USA)
D. QUENIART (France)
M. AKHMETOV (Kazakhstan)
I. PETR (South Africa)
S. V. KAZAKOV (Ukraine)
G. LINSLEY (IAEA)

1. STATEMENTS BY THE PANELISTS

R.G. LIGHTNER

The chairman of the panel summarized the possible topics relevant to the subject of radioactive residues from past operations and accidents. Among these were:

- Environmental restoration of contaminated areas from military applications.
- Country-specific and international experiences in restoration.
- Future use of contaminated land.
- Should contamination be considered waste, if a decision is made to deal with it in place?
- How should naturally-occurring radioactive contamination in non-nuclear activities be addressed?
- Which topics should be included in the present effort to draft a convention on waste safety?

The chairman then introduced the panel members and their affiliations. He then asked Mr. Linsley to briefly discuss the present IAEA direction to contamination cleanup and clearance levels.

G. LINSLEY

Mr. Linsley pointed out that internationally-accepted criteria for the cleanup of contaminated areas have not been developed, but that ICRP Publication 60 and the Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (IAEA Safety Series No. 115-I) provide a basis for developing guidance.

There are two international working groups studying the subject at the present time (one is an IAEA effort; the other an ICRP effort). Mr. Linsley focused on the IAEA effort. The approach is to divide contamination situations into 3 broad categories:

- Contamination as a result of decommissioning - this would be treated as a practice.
- Contamination as a result of accident situations - this would be handled as an intervention.
- Residues from previous operations - application of practice or intervention would depend on the specifics of the individual situation.

As an example of the latter category, he indicated that a former radium luminising operation could be dealt with as a practice, but if contamination were discovered, which was the result of some previous radium operation whose owners were not known, it might be considered as an intervention situation. He summarised ICRP Principles for practices (justification, optimisation and dose/risk limits and constraints) and for intervention (justification and optimisation). He pointed out that dose limits may be counter-productive for intervention, because this could limit the justification principle. The underlying philosophy is to do more good than harm.

He cited radiological and non-radiological factors affecting remediation decisions. These included exposures resulting from occupancy, doses averted by remedial actions, the number of people involved, doses to workers, costs of remedial action options and other radiological considerations. Non-radiological factors such as public reaction and attitudes and ecological impacts should also be considered. The basic three options in remediation consist of: decontamination (complete or partial), restriction of access/use and no action.

Mr. Linsley summarised national criteria either proposed or in place for three countries: the USA for weapons production sites, Germany for uranium mining and milling contamination and Russia for the Chernobyl accident affected areas.

Mr. Linsley summarised his presentation by noting that:

- Land contamination is a serious problem in some countries,
- Solutions can be expensive,
- Remediation decisions are influenced by non-radiological considerations also,
- Public pressure can force disproportionately resource consumptive strategies, and
- International guidance on radiological cleanup criteria is still under development.

The chairman noted that the greatest hazard to remediation workers can be from industrial - not radiological - accidents.

D. QUENIART

Mr. Queniart observed that the French approach to cleanup of contamination is a function of the specific situation. In particular, he was not in favor of a, a priori, generic activity levels under which there would be no restrictions regarding land use. Each situation has to be managed with one organisation responsible for proposing actions and another organisation responsible for review and approval of any such actions. Where the contamination exists within a nuclear facility's area of control, there is a clear assignment of responsibility for characterising the extent and type of contamination, as well as for dealing with it. The problem occurs when contamination is found outside of a facility's zone of control.

Mr. Queniart listed the general process of dealing with such situations; the parties involved in executing the process would depend on the situation. He stressed the general steps in dealing with contamination and cleanup problems:

- an exhaustive inventory of the contaminated areas should be performed,
- there should be clear delineation of responsibilities and functions,
- each situation should be clearly managed and controlled,
- the policy should promote the means to final disposal for each type of waste, with sufficient continuity.

I. PETR

Mr. Petr indicated that the residues from past mining and milling in South Africa were products of nuclear material exploitation and byproducts from the processing for other valuable metals (e.g., gold and platinum). The mining/milling activity is responsible for a significant portion of the total annual activity in radioactive wastes. So he restricted his presentation to slime dams (tailings), scrap metal and rock wastes associated with mining and milling. In terms of solid waste volumes these three types of mine wastes total over 35 Megatonnes per year.

Mr. Petr discussed the source term found in mining wastes, as a function of components of the U-238 decay chain and the relative equilibrium between U-238, Ra-226, and the contribution from the Th-232 series. Contaminated items (e.g., scrap metals) can be characterised by using approximate mass to surface specific activity ratios.

Mr. Petr focused on slime dams and identified three significant factors (political, technical and financial) which fundamentally support recycling of slime dams materials, depending on the actual levels of contamination, as a reclamation strategy. Along with ore content recycling, using the materials for construction is one of the strategies considered. In addition to disposal and recycling in a licensed facility, two other options are considered for recycling of scrap metal contaminated with naturally-occurring radioactive material. These are:

- Recycle in any smelter, if unconditional clearance conditions apply (10 $\mu\text{Sv/a}$ to an individual of the critical group and 1 manSv/a collective dose limits).
- Recycle in an identified (unlicensed) smelter if conditions for unconditional clearance are not applicable, but conditional clearance provisions can be applied (individual dose does not exceed 100 $\mu\text{Sv/a}$, which must be optimised if collective dose exceeds 1 manSv/a).

M. AKHMETOV

Mr. Akhmetov indicated that one of the types of radioactive waste contamination in Kazakhstan resulted from uranium mining and milling activities. He observed that uranium extraction had begun in 1953, which has resulted in the identification of 50 uranium deposits in 6 uranium mining and milling areas. Two deposits proved to be especially suited for insitu or solution mining. Presently the primary form of uranium recovery is of this type of operation.

The presently existing quantity of mine rock dams and tailings ponds is approximately 200 million tonnes. For mining operations, remediation is under way in the form of soil covers and coordination with all ecological requirements. The effort is hampered by the dissolution of the former Soviet Union's regulatory and control infrastructure and the lack of responsible ownership or title of the materials. Furthermore, mine rock has been used for road and building construction, and there is little government allocation for restoration of such use.

Tailings ponds include 2 large mill sites covering in excess of 15 square kilometers. The reduced uranium production has resulted in the drying of previously water-covered portions, which has led to windblown erosion and transport of radioactive material offsite. Dust suppression activities are under way, and restoration of ground-water from insitu leaching operations is being pursued. The ground-water contamination concern is primarily of a non-radiological character.

The other form of contamination originated in nuclear weapons testing. Although no accidents have been reported, over 450 nuclear explosions occurred in Kazakhstan. The majority of the nuclear explosions were underground. Significant areas of the Semipalatinsk Test Site were contaminated by Cs-137, and plutonium has not yet been characterised. Radioactive contamination has also spread from water flowing through fractures in the explosion cavities. Cleanup levels and strategies for test sites have not yet been established.

S.V. KAZAKOV

Mr. Kazakov discussed problems associated with contamination from the Chernobyl nuclear accident. The first problem is in characterising what portion of the contaminated material in the exclusion zone should be considered radioactive waste and how to deal with it: remove it or possibly use materials for construction. Consideration of the extent to which contaminated materials should be removed, as radioactive waste, presents a problem as well. This is related to the second problem in properly characterising the total inventory of the radioactive waste. The waste is characterised at temporary locations of radioactive waste (TLPRW) and radioactive waste burial sites (RWBS). Although there is a great deal of documented information on the locations, volumes and activities, it is unclear whether to categorise the radioactive waste by specific activity, volume or presence of transuranic and fissionable elements in the radioactive waste.

Radioactive contamination and migration outside of the exclusion zone is a problem that has also been studied. Mr. Kazakov enumerated sources of contamination migrating through the Pripyat River and possible pathways of impact. An estimate of 7400-14800 GigaBq/a of Sr 90 is migrating through the Pripyat River, which composes 40-60 percent of the flow to the Dniپر River. No dose limits have been set for drinking water from "Chernobyl" origin; this has hampered water protection efforts.

Furthermore, there has been no designated disposal site for the burial of high activity radioactive wastes. For those areas, cleanup would be unlikely without such a designated disposal site. Remediation of inadequate RWBS, as well as their use for collection areas for other radioactive waste, has led to problems with defueling the Chernobyl nuclear power plant. No plans have been established to bring the RWBS to environmentally sound conditions, in lieu of radioactive protection norms and governmental coordination. At present no migration of radionuclides from these RWBS has been detected.

2. DISCUSSION

There were some concerns voiced regarding the omission of a dose limit in the application of intervention. Some expressed the opinion that the value of restored land was a more valid factor to the intervention and that averted dose was a specious argument. It was acknowledged that application of a practice at one location and an intervention at another similarly contaminated or nearby location could cause confusion, especially from the public perspective. In deciding upon a remediation strategy, it has to be ensured that pursuit of that strategy incurs no higher risks than would be the case if the site were left as is.

A concern was raised regarding the idea of reuse of slime dam materials (mill tailings) for construction purposes. Mr. Petr had indicated in his introductory statement that the execution of such options would have to address the controlled manner in which the materials would be used after additional processing, which will include some degree of decontamination (e.g., road bedding versus home construction), as well as the level of contamination of the materials.

Mr. Quenart reiterated the French approach of case-by-case decisions, especially with respect to the importance of non-radiological considerations.

In response to the chairman's question on contamination migration through the ground-water regime, it was specified that current measurements showed that the cumulative movement of contaminants from weapons testing in the ground-water ranges from 15 to 500 meters.

A concern was raised regarding the generational inequity of allocating, in the present time frame, such excessive measures to deal with what may only be a potential risk for or dose to future generations. It was pointed out that many of the cleanup programs are mandated by regulations, where little flexibility is available to permit factoring such value judgments into the decision strategy. By such excessive measures equity of generations may be compromised, which would be inconsistent with the spirit and provisions of the RADWASS programme. It was also noted that the problem goes beyond immediate cost/benefit considerations. The management of nuclear waste is of value for improving public appreciation of nuclear energy, which could be beneficial in the long term.

It was suggested that many of these considerations may need to be factored into the deliberation for the radioactive waste safety convention.

Integrated planning was cited as a very important concept in establishing a nuclear program. Past experience has shown the difficulties associated with nuclear programmes in which an ultimate disposal site has not yet been established. Remediation is an easier proposition, if a disposal site is available along with the necessary infrastructure. Public acceptance will be enhanced, if there is a place to take contaminated soils for disposal. It was also pointed out that a temporary storage site was

not reassuring public acceptance, since the natural tendency has been to convert storage sites into permanent holding or disposal sites.

A point was raised with regard to the adequacy of relying solely on radiotoxic limits for managing wastes from mining and milling applications, especially when the hazards associated with the non-radioactive constituents were of greater concern. Remediation should take both radiological and non-radiological hazards into account and provide a comparable level of protection. This was acknowledged and a preference was also indicated for taking out whatever material value remains in the tailings, for extracting negative constituents that could be reasonably extracted and then using the remaining tailings in a controlled manner; for example, for road construction, building of industrial complexes, or backfill. The hazard ratio of the toxic to radiological components of the tailings was also discussed. More is known regarding the impacts of the radioactive components. The acid drainage from the pyritic component of uranium ore is known, but not well quantified in terms of its impact to the public health and environment in contrast to the radiological impact.

Following the discussion on the poor conditions of past practices at the mines and mills, it was asked whether current or planned facilities will meet the RADWASS or waste convention specifications. It was reported that some form of regulation has been in place in South Africa for about 10 years and that these regulations are being presently reconsidered for operating facilities. Furthermore, it was pointed out that the draft RADWASS Safety Standard (under preparation) recognizes that the level of safety associated with mining and milling cannot reach the same level of protection as afforded by deep geologic disposal.

The chairman adjourned the meeting by observing that there was no clear consensus of the pathway to cleanup past residues, which apparently is site specific. But he acknowledged the value of hearing of various experiences in dealing with this problem.

EXCLUSION, EXEMPTION AND CLEARANCE OF MATERIALS FROM REGULATORY CONTROL

Summary by A.P. VUORINEN (Finland)

Panel Participants: A. VUORINEN, Chairman (Finland)
L. BAEKELANDT (Belgium)
C. DEVILLERS (France)
K. SCHALLER (European Commission)
A. GONZALEZ (IAEA)

1. STATEMENTS BY THE PANELISTS

A. P. VUORINEN

In his opening statement the Chairman said that there is a clear economic incentive for the clearance of certain materials from regulatory control, even though the risks might be slightly higher if the material were recycled rather than sent for disposal. He stressed the need to have international agreement on criteria so as to avoid situations like that after Chernobyl where different criteria for food intervention levels existed in each affected country. Also, in the context of the Radioactive Waste Safety Convention now being prepared, there is a need to agree on terminology. He referred the panelists to the issues proposed for discussion by Mr. Linsley during his paper presentation on this subject; these were:

- (1) Is there a need for exemption and clearance?
- (2) Will the global recycling of materials increase risks of radiological accidents?
- (3) The problems associated with applying exemption criteria to naturally occurring radionuclides.

L. BAEKELANDT

Mr. Baekelandt raised a number of issues. Firstly, he referred to the discrepancies which exist in the definitions of the term "practice" in Safety Series No. 89, ICRP and the IAEA Basic Safety Standards (Safety Series No. 115-I). Next, he commented that, with the change in the ICRP basic dose/risk factor in ICRP publication 60, a reconsideration of the trivial dose level recommended in IAEA Safety Series No. 89 might be required. There is also a difference between the treatment of potential exposures in ICRP publication 60, IAEA Safety Series No. 89 and the IAEA Basic Safety Standards.

He noted that it is being suggested that the exemption levels (activity concentrations) of the Basic Safety Standards should be adopted in the revised IAEA Transport Regulations. This would relieve many problems of inconsistency related to international movements of exempted materials. The term "clearance" is now being used but was not discussed in Safety Series No. 89. With this, he raised the question "Is there a need to revise Safety Series No. 89?"

C. DEVILLERS

Mr. Devillers addressed the position of the French regulatory authorities about clearance levels.

He noted that the cost of large volume very low level waste disposal in Centre de l'Aube is too expensive and that other solutions are being sought. Limited experience exists in France of metal recycle internal to nuclear industry - it has been handled on a "case by case basis" - there is no national scheme for handling such wastes. He discussed press reactions to radioactive sources found

in municipal landfills. All these considerations have led the regulatory authority to decide that a more rigorous control system is needed. He outlined a policy which emphasizes maintaining a record of all wastes generated, collecting wastes from non-nuclear users, defining waste pathways so as to have complete traceability of the wastes. The policy includes dedicated disposal or recycle within the nuclear industry and then if sufficient experience has been obtained, of controlled recycling outside the nuclear industry. All wastes must be thoroughly characterised, with information such as radionuclide content, identification of high specific activity parts of it, chemical content, origin of waste and history of originating installation (including records of incidents or accidents).

Finally Mr. Devillers summarised his concern about (unconditional) clearance levels: (a) lack of traceability after release; (b) presence of activity (alpha emitters) that could escape detection; (c) possibility of diluting wastes to allow clearance.

K. SCHALLER

Mr. Schaller began his statement by noting that there is, at present, a great diversity of clearance level values being used in the 15 countries of the European Union. On the other hand it is a completely open market allowing essentially free movement of materials from country to country. He then described a number of hypothetical scenarios involving possible movements of cleared materials between countries from points of origin to a scrap dealer in another country. He concluded that it is desirable to have the same or similar criteria in all countries and that this control has to extend to wastes/materials containing naturally occurring radionuclides.

A. GONZALEZ

Mr. González' statement was in the form of a commentary on the points raised by the previous speakers. He said that the time for analysis of this issue is over. Now is the time when previous work should be synthesized for inclusion in the Waste Safety Convention. He stressed that this is not an exact science but requires a lot of judgement - there is no exact proof or perfect set of numbers.

It should be recognised that sources of radiation which cannot be controlled should not be put into regulations (exclusion). The regulatory authorities should not be burdened with trivial, but should concentrate on more important things. A framework for deciding on exemption of trivial sources is available. This approach, whatever its defects, is better than an arbitrary choice of values and has led to an internationally agreed trivial dose value.

Mr. González commented on the models used for deriving practical exemption/clearance levels and, citing the example of ICRP reference man model, questioned the need for the detailed modelling of all possible scenarios - a robust conservative approach should be sufficient for most purposes.

2. DISCUSSION

Following an earlier comment that the purpose of exemption/clearance is mainly to save regulatory effort, a view was expressed by several members of the audience that the relief of the burden on the operators is probably more important.

Concern was expressed over the possible confusion that can exist between "clearance" which is an administrative measure to avoid having to deal with trivial matters, and "authorised release" which is a technical question to be decided by applying radiation protection principles.

In a discussion on naturally occurring radionuclides the opinion was presented that this is an issue for exclusion and not exemption. Others were not convinced of this, citing the case of radon in houses where controls are applied. Opinions were requested on whether naturally occurring

radionuclides should be inside or outside the Waste Safety Convention. Those who answered took the view that naturally occurring radionuclides should not, in general, be regulated, but there are cases where naturally occurring radionuclides do require control, for example, in uranium mining and milling or if they are enriched in processing materials, for example in the phosphate industry. It was noted, however, that even if controls were to be applied the nature of the controls should be adapted to the extent of the radiological risks presented.

It was suggested that reaching agreement on what is "trivial" is very difficult and that attempting to define what is "significant" might be easier. The opinion was also expressed that there is no need to be relieved of the requirement for maintaining controls on wastes and other materials by clearance.

The Chairman, in summing up, said that exclusion, exemption and clearance are concepts on the "easy side" (that is predisposal) of waste management, the difficult side being high level waste disposal. He was therefore surprised that this panel session had attracted so much interest and discussion.

LIST OF PARTICIPANTS

- Abtahi, M. United Nations Educational, Scientific and Cultural Organization
Liaison Office in Vienna (D1231)
Wagramerstrasse 5, A-1400 Vienna, Austria
- Aebersold, M. Federal Office of Energy
CH-3003 Bern, Switzerland
- Agaledes, P. Institute de protection et de sûreté nucléaire (IPSN)
BP 6, F- 92265 Fontenay-aux-Roses Cedex, France
- Akhmetov, M. Atomic Energy Agency of the Republic of Kazakhstan
Republic sq. 13, Almaty 480013, Kazakhstan
- Al-Taifi, I.M. Permanent Mission of Saudi Arabia to the IAEA
Formanekgasse 38
A-1190 Vienna, Austria
- Allan, C.J. Environmental Sciences and Waste Management
Atomic Energy of Canada Ltd
Whiteshell Laboratories, Pinawa, Manitoba ROE 1LO, Canada
- Aly, H.F. Atomic Energy Authority
101 Kasr El-Eini Street, Cairo, Egypt
- Andersson, J. Swedish Nuclear Power Inspectorate (SKI)
Klarabergsviadukten 90, S-106 58 Stockholm, Sweden
- Ando, Y. Power Reactor and Nuclear Fuel Development Corporation (PNC)
Sankaido Building, 9-13, 1 Chome, Akasaka
Minato-ku, Tokyo, 107 Japan
- Ayala Jiménez, R.E. Dirección General de Energía Nuclear
24 Calle 21-12, Zona 12
Apto, Postal 1421, Guatemala, C.A. 01812, Guatemala
- Bäckblom, L.G.S. Swedish Nuclear Fuel and Waste Management Co. (SKB)
Box 5864, S-102 40 Stockholm, Sweden
- Baekelandt, L.L.M. National Agency for Management of Radioactive Waste and
Enriched Fissile Materials (NIRAS)
Madouplein 1, Bte. 25, B-1030 Brussels, Belgium
- Baer, A.J. Federal Office of Energy
CH-3003 Berne, Switzerland
- Balz, W. European Commission
Rue de la Loi 200, B-1049 Brussels, Belgium
- Bayat, I. Waste Management Department
Atomic Energy Organization of Iran
P.O. Box 11365-8486, Tehran, Islamic Republic of Iran

Beiersmann, R.-R. Technischer Überwachungsverein
Südwestdeutschland e.V.
Dudenstrasse 28, D-68167 Mannheim, Germany

Berner, U.R. Paul Scherrer Institute
CH-5232 Villigen, Switzerland

Boyle, Ch.B. AEA Technology, 424.4, Harwell Laboratory
Didcot, Oxfordshire OX11 0RA, United Kingdom

Bradshaw, I.A. Nuclear Safety Division
Health and Safety Executive, St. Peters House, Balliol Road
Bootle, Merseyside L20 3LZ, United Kingdom

Breza, M. Slovenske elektrarne, s.a.
Atomove elektrarne Bohunice, o.z.
SK-919 31 Jaslovske Bohunice, Slovakia

Brown, P. Natural Resources Canada
Science and Technology, 580 Booth Street
Ottawa, Ontario K1A 0E4, Canada

Brown, S.R.A. H.M. Inspectorate of Pollution
Department of the Environment
Romney House, 43 Marsham Street
London SW1P 3PY, United Kingdom

Brücher, H.P. Forschungszentrum Jülich GmbH
ISR 3, D-52428 Jülich, Germany

Buitron, S.M. A-Calderon 150 y Shyris
Adf. Huayna Capac Dep. 30, Quito, Ecuador

Buteau, P. NUSYS
9, Rue Christophe Colomb
F-75008 Paris, France

Butragueno Casado, J.L. Consejo de Seguridad Nuclear
Justo Dorado, 11, E-28020 Madrid, Spain

Carnino, A. Division of Nuclear Safety
Department of Nuclear Energy and Safety
International Atomic Energy Agency
P.O. Box 100, A-1400 Vienna, Austria

Cavuoto, U. Agency for New Technologies, Energy & Environment (ENEA)
Viale Regina Margherita, 125
I-00198 Rome, Italy

Chen, D.T.Y. Dammstrasse 5
CH-5400 Baden, Switzerland

Cholerzynski, A. Radioactive Waste Management Department
Institute of Atomic Energy
PL-05-400 Swierk-Otwock, Poland

Claughton, S.L. H.M. Inspectorate of Pollution
Department of the Environment
Romney House, 43 Marsham Street
London SW1P 3PY, United Kingdom

Clein, D.A. Comision Nacional de Energia Atomica
Avenida Libertador 8250
1429 Buenos Aires, Argentina

Comerio, G. Oceanic Disposal Management Inc.
7, via Landriani, CH-6900 Lugano, Switzerland

Crowe, C. Anderson Consulting
c/o Mr. K. Wilson
Maulbertschg. 12, A-1190 Vienna, Austria

Dayal, R. Ontario Hydro Technologies
800 Kipling Avenue
Toronto, Ontario M8Z 5S4, Canada

de Grauwe, P.G.M. Ministerie van Tewerkstelling & Arbeid
Arbeidsveiligheid
Belliardstraat 51, B-1040 Brussels, Belgium

Devillers, C. Institute de protection et de sûrete nucléaire (IPSN)
BP 6, F-92265 Fontenay-aux-Roses Cedex, France

Dials, G.E. U. S. Department of Energy
Carlsbad Area Office, 101 West Greene Street
Carlsbad, New Mexico 88220, United States of America

Dobschütz, P. Ch. von Federal Ministry of Environment (BMU)
Postfach 12 06 29, D-53048 Bonn, Germany

Domaratzki, Z.G. Atomic Energy Control Board
P.O.Box 1046, Station "B"
280 Slater Street, Ottawa, Ontario K1P 5S9, Canada

Dubovsky, P. Slovenske elektrarne, s.a.
Atomove elektrarne Bohunice,o.z.
SK-919 31 Jaslovske Bohunice, Slovakia

Duerden, P. Permanent Mission of Australia
Mattiellistrasse 2
A-1040 Vienna, Austria

Duncan, A.G. H. M. Inspectorate of Pollution
Department of the Environment
Romney House, 43 Marsham Street
London SW1P 3PY, United Kingdom

Ehn, L. Nuclear Power Plant Mochovce
SK-935 39 Mochovce, Slovakia

Eid, A.T.	Ministry of Environment P.O.Box 8013 Dep. N-0030 Oslo, Norway
Eletti, G.	Agenzia Nazionale per la Protezione dell'Ambiente Via Vitaliano Brancati 48, I-00144 Roma, Italy
Erastov, A.A.	Minatom of Russian Federation Committee on International Relations Staromonetny pereulok, 26 Moscow, Russian Federation
Eriksson, L.G.	Advanced Sciences Inc. 101 E. Mermod Carlsbad, NM 88220, United States of America
Fekete, I.	National Commission for Nuclear Activities Control 12 Libertatii Blvd., Bucharest - 5, Romania
Fernique, J.C.	Agence nationale pour la gestion des dechets radioactifs (ANDRA), BP 38, F-92266 Fontenay-aux-Roses Cedex, France
Gaal, P.	National Institute of Hygiene and Epidemiology Trnavska 52, SK-821 08 Bratislava, Slovakia
Giunta, G.	Oceanic Disposal Management Inc. 7, via Landriani, CH-6900 Lugano, Switzerland
Gnugnoli, G.N.	Division of Nuclear Safety Department of Nuclear Energy and Safety International Atomic Energy Agency P.O. Box 100, A-1400 Vienna, Austria
Golicheff, I.	Institut de protection et de sûreté nucléaire (IPSN) BP No. 6, F-92265 Fontenay-aux-Roses Cedex, France
González de la Huebra, A.	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas Avenida Complutense, 22, E-28040 Madrid, Spain
González, A.J.	Division of Nuclear Safety Department of Nuclear Energy and Safety International Atomic Energy Agency P.O.Box 100, A-1400 Vienna, Austria
Graham, D.	AEA Fuel Services Building D1226, Dounreay, Thurso Caithness KW14 7TZ, United Kingdom
Gravier, S.	Institute de protection et de sûreté nucléaire (IPSN) BP 6, F-92265 Fontenay-aux-Roses Cedex, France
Gray, J.	British Nuclear Fuels plc Hinton House, H479, Risley, Warrington Cheshire WA3 6AS, United Kingdom

Grumbly, T.P. Office of Environmental Management
U. S. Department of Energy
Washington, DC 20585, United States of America

Guentchev, G. Committee on the Use of Atomic Energy for Peaceful Purposes
69 Shipchenski prokhoz Blvd., BL-1574 Sofia, Bulgaria

Haegg, N.C. Swedish Radiation Protection Institute (SSI)
S-171 16 Stockholm, Sweden

Hammerstrom, M. Swedish Nuclear Fuel and Waste Management Co. (SKB)
Box 5864, S-102 40 Stockholm, Sweden

Harries, J.R. Australian Nuclear Science and Technology Organization
PMB 1, Menai, NSW 2234, Australia

Hezzah, S.Y. League of Arab States Mission in Austria
Grimmelshauseng. 6, A-1030 Vienna, Austria

Hone, C. Radiological Protection Institute of Ireland
3 Clonskeagh Square, Clonskeagh, Dublin 14, Ireland

Horyna, J. State Office for Nuclear Safety
Slezska 9, CZ-12029 Prague 2, Czech Republic

Huizenga, D. Office of Environmental Management
U. S. Department of Energy
Washington, DC 20585, United States of America

Ilberg, D. Licensing Division
Israel Atomic Energy Commission
P.O.Box 7061, Tel Aviv 61070, Israel

Issler, H. National Cooperative for the Disposal of Radioactive Waste
(NAGRA), Hardstrasse 73, CH-5430 Wettingen, Switzerland

Janssens, A. European Commission, DG XI/C/I, WAG C/347
Plateau du Kirchberg, L-2920 Luxembourg

Jurina, V. Ministry of Health
Limbova 2, SK-83343 Bratislava, Slovakia

Kawakami, Y. Office of Safety and Control
Japan Atomic Energy Research Institute
2-2,2-Chome, Uchisaiwai-Cho, Chiyoda-ku
Tokyo 100, Japan

Kazakov, S.V. Research and Industrial Association, "Pripyat"
255 602 Chernobyl, Kiev Region, Ukraine

Kazi, O.A. Nuclear Safety & Radiation Control Division
Bangladesh Atomic Energy Commission
4 Kazi Nazrul Islam Avenue, GPO Box No. 158,
Ramna, Dhaka-1000, Bangladesh

Khalifa, S.M.M. Atomic Energy Authority
101 Kasr El-Eini Street, Cairo, Egypt

Khial, W.K. League of Arab States Mission in Austria
Grimmelshauseng. 6, A-1030 Vienna, Austria

Kindelán, J.M. Consejo de Seguridad Nuclear
Justo Dorado 11, E-28020 Madrid, Spain

Kosako, T. Research Center for Nuclear Science and Technology
The University of Tokyo
11-6, 2-Chome, Yayoi, Bunkyo-ku, Tokyo 113, Japan

Kotovitch, V.V. Institute of Radioecological Problems
220109 Sosny, Minsk, Belarus

Krajc, T. DECOM Slovakia, s.r.o.
Jana Bottu 63, SK-917 01 Trnava, Slovakia

Krishnamurthi, T.N. Health and Safety Division, Atomic Energy Regulatory Board
Vikram Sarabhai Bhavan, Anushaktinagar,
Bombay 400 094, India

Kühn, K. GSF - Forschungsbergwerk Asse
D-38319 Remlingen, Germany

Kutbi, I.I. Nuclear Engineering Department
King Abdulaziz University
P.O.Box 90 27, Jeddah 21 413, Saudi Arabia

Lacoste, A.C. Ministère de l'Industrie et Ministère de l'Environnement
Direction de la sûreté des installations nucléaires (DSIN)
99 rue de la Grenelle, F-75353 Paris, France

Langer, M.F.B. Federal Institute for Geosciences and Natural Resources
Stilleweg 2, D-30655 Hannover, Germany

Lantes, B. Electricité de France, EPN/DSRE
6, rue Ampère, B.P. 114
F-93203 Saint-Denis Cedex 1, France

Lee, D.J. AEA Decommissioning and Radwaste
Winfrith Technology Centre
Dorchester, Dorset DT2 8DH, United Kingdom

Lightner, R.G. Office of Environmental Restoration, EM-45/Cloverleaf
U. S. Department of Energy, 19901 Germantown Road
Germantown, MD 20874-1290, United States of America

Linsley, G. Division of Nuclear Fuel Cycle and Waste Management
Department of Nuclear Energy and Safety
International Atomic Energy Agency
P.O. Box 100 A-1400 Vienna, Austria

Lokner, V. APO - Hazardous Waste Management Agency
Savska Cesta 41/IV, 10000 Zagreb, Croatia

Loose, A. Agency for Radwaste Management
Parmova 53, SL-61113 Ljubljana, Slovenia

López García, A. Empresa Nacional de Residuos Radiactivos (ENRESA)
Emilio Vargas 7, E-28043 Madrid, Spain

Lucas, M. Nuclear Electric Plc., Barnett Way, Barnwood
Gloucester GL4 7RS, United Kingdom

Malik, S.A. Malaysian Institute for Nuclear Technology Research (MINT)
Bangi, 43000 Kajang Selangor, Malaysia

Maravic, H. von European Commission, XII-F-5
200, Rue de la Loi, B-1040 Brussels, Belgium

Martin, S. COGEMA
2, rue Paul Dautier, B.P.No.4
F-78141 Velizy-Villacoublay Cedex, France

Martynov, Yu. All-Russia Nuclear Power Plant Research Institute
Franskaya str. 25, 109507 Moscow, Russian Federation

Masson, H. COGEMA
2, rue Paul Dautier, B.P.No.4
F-78141 Velizy-Villacoublay, Cedex, France

Matunov, A.I. National Joint Stock Company (KATEP)
168, Bogenbai Betyr Street, 480012 Almaty, Kazakhstan

McCombie, C. National Cooperative for Disposal of Radioactive Waste (NAGRA),
Hardstrasse 73, CH-5430 Wettingen, Switzerland

Misra, S.D. Waste Management Projects Division
Bhabha Atomic Research Centre
Trombay, Bombay 400 085, India

Mollah, A.S. Institute of Nuclear Science and Technology
Atomic Energy Research Establishment
Ganakbari, Savar, GPO Box 3787
Dhaka-1000, Bangladesh

Nanias, M. Slovenske elektrarne, s.a., Atomove elektrarne Bohunice,o.z.
SK-919 31 Jaslovske Bohunice, Slovakia

Neerdael, B. Nuclear Energy Research Centre (CEN/SCK)
Boeretang 200, B-2400 Mol, Belgium

Niel, J.-Ch. Ministère de l'Industrie et Ministère de l'Environnement
Direction de la sûreté des installations nucléaires (DSIN)
99, rue de Grenelle, F-75353 Paris, France

Norrby, S. Swedish Nuclear Power Inspectorate (SKI)
Klarabergsviadukten 90, S-106 58 Stockholm, Sweden

Novikov, V. International Institute of Applied Systems Analysis
A-2361 Laxenburg, Austria

Nyanda, A.M. National Radiation Commission
P.O.Box 743, Arusha, United Republic of Tanzania

Pahissa-Campa, J. Comisión Nacional de Energía Atómica
Avenida del Libertador 8250, 1429 Buenos Aires, Argentina

Palmai, I. Paks Nuclear Power Plant
Pf. 71, H-7031 Paks, Hungary

Parker, F.L. Civil and Environmental Engineering
Vanderbilt University
Nashville, TN 37235, United States of America

Pérez Fernández, S. Division of Nuclear Safety
Department of Nuclear Energy and Safety
International Atomic Energy Agency
P.O.Box 100, A-1400 Vienna, Austria

Pescatore, C. OECD Nuclear Energy Agency
Le Seine St-Germain
F-92130 Issy-les Moulineaux, France

Petr, I. Council for Nuclear Safety
P.O.Box 7106, Hennopsmeer 0046, South Africa

Pichurin, S.G. Research and Industrial Complex, "Vector"
255 602 Chernobyl, Ukraine

Plourde, K.J. Transport Canada, Transport Dangerous Goods Directorate
Canada Buidling, 14th floor, 344 Slater Street
Ottawa, Ontario K1A 0N5, Canada

Pollock, R. Low Level Radioactive Waste Management Office
Suite 700, 1595 Telesat Court
Gloucester, Ontario K1B 5R3, Canada

Prasad, A.N. Bhabha Atomic Research Centre
Trombay, Bombay 400 085, India

Protopapas, A.P. Molten Metal Technology, Inc., 51 Sawyer Road
Waltham, MA 02154, United States of America

Queniart, D. Institute de protection et de sûreté nucléaire (IPSN)
BP 6, F- 92265 Fontenay-aux-Roses Cedex, France

Ramoutar, S. The Uranium Institute, Twelfth Floor, Bowater House
68, Knightsbridge, London, SW1X 7LT, United Kingdom

Rehman, R. Directorate of Nuclear Safety and Radiation Protection
P.O.Box 1912, Islamabad, Pakistan

Richardson, Ph. 17 Ashby Road
Moira, Swadlincote, Derbyshire DE12 6DJ, United Kingdom

Richter, D. Gesellschaft für Nuklear Service mbH
Hollestrasse 7 a, D-45127 Essen, Germany

Rodríguez Beceiro, A. Empresa Nacional de Residuos Radiactivos (ENRESA)
Emilio Vargas 7, E-28043 Madrid, Spain

Rometsch, R. Châlet Tiger
Terrassenweg, CH-3818 Grindelwald, Switzerland

Rosen, M. Division of Nuclear Safety
Department of Nuclear Energy and Safety
International Atomic Energy Agency
P.O.Box 100, A-1400 Vienna, Austria

Röthemeyer, H. Bundesamt für Strahlenschutz
Bundesallee 100, D-38116 Braunschweig, Germany

Rozdjalovskaya, L.F. Committee for Supervision of Industrial and Nuclear
Safety of the Ministry for Emergencies
6 Chkalov Str., 220039 Minsk, Belarus

Ruokola, E. Finnish Centre for Radiation and Nuclear Safety (STUK)
P.O.Box 14, FIN-00881 Helsinki, Finland

Sabik, F. Nuclear Power Plant Mochovce
SK-935 39 Mochovce, Slovakia

Salzer, P. Nuclear Regulatory Authority of the Slovak Republic
Okružna 5, SK-91864 Trnava, Slovakia

Schaller, K.H. European Commission
Rue de la Loi 200, B-1049 Brussels, Belgium

Sedliak, D. Nuclear Power Plant Mochovce
Dept. 520, SK-935 39 Mochovce, Slovakia

Semenov, B. Department of Nuclear Energy and Safety
International Atomic Energy Agency
P.O.Box 100, A-1400 Vienna, Austria

Servaes, I.M.A. AIB Vincotte Nuclear
Koningslaan 157, B-1060 Brussels, Belgium

Simionov, V. Cernavoda Nuclear Power Plant, National Power Utility
CP 18, Str. Medgidiei No. 1, R-8625 Cernavoda, Romania

Soerlie, A. Norwegian Radiation Protection Authority
P.O.Box 55, N-1345 Østeras, Norway

Subasic, D. APO - Hazardous Waste Management Agency
Savska Cesta 41/IV, 10000 Zagreb, Croatia

Suzuki, H. Radioactive Waste Regulation, Nuclear Safety Bureau
Science and Technology Agency,
2-1, 2-Chome, Kasumigaseki, Chiyoda-ku, Tokyo 100, Japan

Takasu, A. Nuclear Safety Research Association
2-2, 1-Chome, Uchisaiwai-Cho, Chiyoda-ku, Tokyo 100, Japan

Tauber, J. Department of Waste Management
Austrian Research Centre Seibersdorf
A-2444 Seibersdorf, Austria

Thomas, W. Gesellschaft für Reaktorsicherheit mbH
D-85748 Garching, Germany

van Enst, J.W.A. Ministry of Economic Affairs
Bezuidenhoutseweg 30, P.O.Box 20101
NL-2500 EC Den Haag, Netherlands

Varjoranta, T.T. Finnish Centre for Radiation and Nuclear Safety (STUK)
P.O.Box 14, FIN-00881 Helsinki, Finland

Vilkamo, S.A.M. Ministry of Trade and Industry
P.O.Box 37, FIN-00131 Helsinki, Finland

Vira, J. Teollisuuden Voima Oy, Nuclear Waste Management
Annankatu 42 C, FIN-00100 Helsinki, Finland

Vovk, I. Division of Nuclear Safety
Department of Nuclear Energy and Safety
International Atomic Energy Agency
P.O. Box 100, A-1400 Vienna, Austria

Vrsic, S. IBE Elektrorprojekt, Consulting Engineers
Hajdrihova 4, P.O.Box 204
SL-61000 Ljubljana, Slovenia

Vuorinen, A. Finnish Centre for Radiation and Nuclear Safety (STUK)
P.O.Box 14, FIN-00881 Helsinki, Finland

Wang, W. Molten Metal Technology, Inc.
51 Sawyer Road
Waltham, MA 02154, United States of America

Warnecke, E. Division of Nuclear Safety
Department of Nuclear Energy and Safety
International Atomic Energy Agency
P.O.Box 100, A-1400 Vienna, Austria

Webb, G.A. Division of Nuclear Safety
Department of Nuclear Energy and Safety
International Atomic Energy Agency
P.O.Box 100, A-1400 Vienna, Austria

Weiser, G.I.	Nuclear Research Center Negev P.O.Box 9001, Beer-Sheva, Israel
Westerlind, M.	Swedish Radiation Protection Institute (SSI) S-171 16 Stockholm, Sweden
Wilson, K.	ARD Environmental Maulbertschgasse 12, A-1190 Vienna, Austria
Wlodarski, J.A.	National Atomic Energy Agency ul. Krucza 36, PL-00 921 Warsaw, Poland
Xue, Weixian	Division of Nuclear Materials National Nuclear Safety Administration P.O.Box 8088 Beijing 100088, Peoples' Republic of China
Yabe, I.	Technology Research Department Nuclear Safety Research Association 2-2, 1- Chome, Uchisaiwai, Cho., Chiyada-ku, Tokyo 100, Japan
Yamkate, P.	Office of Atomic Energy for Peace Vibhavadi Rangsit Rd., Chatuchak, Bangkok 10900, Thailand
Yatim, S.	Radioactive Waste Management Technology Center Kawasan Puspipstek, Serpong Tangerang 15310, Indonesia
Zhang, Yansheng	China Institute for Radiation Protection P.O.Box 120 Taiyuan, Shanxi, Peoples' Republic of China
Ziggel, H.F.	Universität Bremen, Fachberich 1 P.O. Box 330 440, D-28334 Bremen, Germany
Zrubec, M.	Nuclear Power Plant Mochovce Dept. 520, SK-935 39 Mochovce, Slovakia
Zurkinden, A.	Division principale de la sécurité des installations nucléaires (HSK) CH-5232 Villigen, Switzerland

LIST OF AUTHORS, CO-AUTHORS AND SPEAKERS

- Agaledes, P. Institute de protection et de sûreté nucléaire (IPSN)
BP 6, F- 92265 Fontenay-aux-Roses Cedex, France
- Ahlquist, A.J. Office of Environmental Restoration, EM-45/Cloverleaf
U.S. Department of Energy, 19901 Germantown Road
Germantown, MD 20874-1290, United States of America
- Akhmetov, M. Atomic Energy Agency of the Republic of Kazakhstan
Republic sq. 13, Almaty 480013, Kazakhstan
- Allan, C.J. Environmental Sciences and Waste Management
Atomic Energy of Canada Ltd.
Whiteshell Laboratories, Pinawa, Manitoba ROE 1LO, Canada
- Andersson, J. Swedish Nuclear Power Inspectorate (SKI)
Klarabergsviadukten 90, S-106 58 Stockholm, Sweden
- Ando, Y. Power Reactor and Nuclear Fuel Development Corporation (PNC)
Sankaido Building, 9-13, 1 Chome, Akasaka
Minato-ku, Tokyo, 107 Japan
- Baekelandt, L.L.M. National Agency for Management of Radioactive Waste and
Enriched Fissile Materials (NIRAS)
Madouplein 1, Bte. 25, B-1030 Brussels, Belgium
- Balz, W. European Commission
Rue de la Loi 200, B-1049 Brussels, Belgium
- Brown, P. Natural Resources Canada
Science and Technology, 580 Booth Street
Ottawa, Ontario K1A OE4, Canada
- Carnino, A. Division of Nuclear Safety
Department of Nuclear Energy and Safety
International Atomic Energy Agency
P.O. Box 100, A-1400 Vienna, Austria
- Devillers, C. Institute de protection et de sûreté nucléaire (IPSN)
BP 6, F-92265 Fontenay-aux-Roses Cedex, France
- Dials, G.E. U.S. Department of Energy
Carlsbad Area Office, 101 West Greene Street
Carlsbad, New Mexico 88220, United States of America
- Domaratzki, Z.G. Atomic Energy Control Board
P.O.Box 1046, Station "B"
280 Slater Street, Ottawa, Ontario K1P 5S9, Canada

Duncan, A.G.	H.M. Inspectorate of Pollution Department of the Environment Romney House, 43 Marsham Street London SW1P 3PY, United Kingdom
Gerusky, T.M.	Office of Environmental Restoration, EM-45/Cloverleaf U. S. Department of Energy, 19901 Germantown Road Germantown, MD 20874-1290, United States of America
González, A.J.	Division of Nuclear Safety Department of Nuclear Energy and Safety International Atomic Energy Agency P.O.Box 100, A-1400 Vienna, Austria
Graham, D.	AEA Fuel Services Building D1226, Dounreay, Thurso Caithness KW14 7TZ, United Kingdom
Grumbly, T.P.	Office of Environmental Management U. S. Department of Energy Washington, DC 20585, United States of America
Janssens, A.	European Commission, DG XI/C/I, WAG C/347 Plateau du Kirchberg, L-2920 Luxembourg
Kawakami, Y.	Office of Safety and Control Japan Atomic Energy Research Institute 2-2,2-Chome, Uchisaiwai-Cho, Chiyoda-ku Tokyo 100, Japan
Kazakov, S.V.	Research and Industrial Association, "Pripyat" 255 602 Chernobyl, Kiev Region, Ukraine
Kindelán, J.M.	Consejo de Seguridad Nuclear Justo Dorado 11, E-28020 Madrid, Spain
Kühn, K.	GSF - Forschungsbergwerk Asse D-38319 Remlingen, Germany
Kumra, M.S.	Waste Management Division Bhabha Atomic Research Centre Trombay, Bombay 400 85, India
Lacoste, A.C.	Ministère de l'Industrie et Ministère de l'Environnement Direction de la sûreté des installations nucléaires (DSIN) 99 rue de la Grenelle, F-75353 Paris, France
Lightner, R.G.	Office of Environmental Restoration, EM-45/Cloverleaf U.S. Department of Energy, 19901 Germantown Road Germantown, MD 20874-1290, United States of America

Linsley, G. Division of Nuclear Fuel Cycle and Waste Management
Department of Nuclear Energy and Safety
International Atomic Energy Agency
P.O. Box 100 A-1400 Vienna, Austria

López García, A. Empresa Nacional de Residuos Radiactivos (ENRESA)
Emilio Vargas 7, E-28043 Madrid, Spain

McCombie, C. National Cooperative for Disposal of Radioactive Waste (NAGRA)
Hardstrasse 73, CH-5430 Wettingen, Switzerland

McMurry, J. Environmental Sciences and Waste Management
Atomic Energy of Canada Ltd.
Whiteshell Laboratories, Pinawa, Manitoba ROE 1LO, Canada

Misra, S.D. Waste Management Projects Division
Bhabha Atomic Research Centre
Trombay, Bombay 400 085, India

Niel, J.-Ch. Ministère de l'Industrie et Ministère de l'Environnement
Direction de la sûreté des installations nucléaires (DSIN)
99, rue de Grenelle, F-75353 Paris, France

Norrby, S. Swedish Nuclear Power Inspectorate (SKI)
Klarabergsviadukten 90, S-106 58 Stockholm, Sweden

Pahissa-Campa, J. Comisión Nacional de Energía Atómica
Avenida del Libertador 8250, 1429 Buenos Aires, Argentina

Parker, F.L. Civil and Environmental Engineering
Vanderbilt University
Nashville, TN 37235, United States of America

Petr, I. Council for Nuclear Safety
P.O.Box 7106, Hennopsmeer 0046, South Africa

Pollock, R. Low Level Radioactive Waste Management Office
Suite 700, 1595 Telesat Court
Gloucester, Ontario K1B 5R3, Canada

Prasad, A.N. Bhabha Atomic Research Centre
Trombay, Bombay 400 085, India

Queniart, D. Institute de protection et de sûreté nucléaire (IPSN)
BP 6, F- 92265 Fontenay-aux-Roses Cedex, France

Rometsch, R. Châlet Tiger
Terrassenweg, CH-3818 Grindelwald, Switzerland

Röthemeyer, H. Bundesamt für Strahlenschutz
Bundesallee 100, D-38116 Braunschweig, Germany

- Ruokola, E. Finnish Centre for Radiation and Nuclear Safety (STUK)
P.O.Box 14, FIN-00881 Helsinki, Finland
- Schaller, K.H. European Commission
Rue de la Loi 200, B-1049 Brussels, Belgium
- Suzuki, H. Radioactive Waste Regulation, Nuclear Safety Bureau
Science and Technology Agency,
2-1, 2-Chome, Kasumigaseki, Chiyoda-ku, Tokyo 100, Japan
- Thomas, W. Gesellschaft für Reaktorsicherheit mbH
D-85748 Garching, Germany
- Vuorinen, A. Finnish Centre for Radiation and Nuclear Safety (STUK)
P.O.Box 14, FIN-00881 Helsinki, Finland
- Warnecke, E. Division of Nuclear Safety
Department of Nuclear Energy and Safety
International Atomic Energy Agency
P.O.Box 100, A-1400 Vienna, Austria
- Webb, G.A. Division of Nuclear Safety
Department of Nuclear Energy and Safety
International Atomic Energy Agency
P.O.Box 100, A-1400 Vienna, Austria
- Wingefors, S. Swedish Nuclear Power Inspectorate (SKI)
Klarabergsviadukten 90, S-106 58 Stockholm, Sweden
- Yabe, I. Technology Research Department
Nuclear Safety Research Association
2-2, 1- Chome, Uchisaiwai, Cho.,
Chiyada-ku, Tokyo 100, Japan
- Zurkinden, A. Division principale de la sécurité des installations nucléaires (HSK)
CH-5232 Villigen, Switzerland

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