A COMMON FRAMEWORK FOR THE SAFE DISPOSAL OF RADIOACTIVE WASTE

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Abstract. Various industrial, research and medical activities give rise to waste that contain or are contaminated with radioactive material. In view of the potential radiological hazards associated with such waste they have to be managed and disposed of in such a way as to ensure that such potential hazards are adequately managed and controlled in compliance with the safety principles and criteria. Over the past few decades experience in radioactive waste management has led to the development of various options for radioactive waste management and has also led to the development of principles which the various waste management options should satisfy in order to achieve an acceptable level of safety. International consensus has evolved in respect of the principles. However, complete consensus in respect of demonstrating compliance with the requirements for managing and disposing of the whole range of waste types is still developing. This paper identifies the various waste types that have to be managed, the prevailing safety principles and the disposal options available. It discusses the development of a common framework which would enable demonstration that a particular disposal option would meet the safety principles and requirements for the disposal of a particular waste type.

1. INTRODUCTION

Various industrial, research and medical activities give rise to waste that contain or are contaminated with radioactive material. In view of the potential radiation hazards associated with such waste they have to be managed and disposed of in such a way as to ensure that such potential hazards are adequately controlled. The different associated processes including disposal are generally referred to as radioactive waste management. Over the past few decades experience accrued in radioactive waste management has led to the development of various options for such management and has also led to the development of principles which the various waste management options should satisfy in order to achieve a good level of safety. International consensus has evolved in respect of the principles. However, complete consensus over the actual requirements for managing and disposing of the whole range of waste types is still developing.

One of the main generators of radioactive waste is the nuclear fuel cycle, this is the sequence of steps in the nuclear energy generation process starting with the mining of ores rich in naturally radioactive uranium and thorium. These elements have radioactive half-lives comparable to the age of the earth and make up on average some ten parts per million of the earth's crust. As with many other elements there are localized concentrations in the earth's crust and mineralized deposits comprising up to twenty percent uranium have been found to exist. Concentrations ranging from around a few hundred parts per million upwards have been commercially exploited for the extraction of uranium. Mined ores go through mineral extraction processes which include crushing, milling and metallurgical extraction. The concentrates are then usually transported in the form of uranium oxides to refining and conversion facilities where the purified uranium is converted to uranium hexafluoride for enrichment. The enriched uranium is subsequently converted, usually to uranium dioxide, which is then fabricated into nuclear fuel, the exact fuel design depending on the reactor type in which the fuel will be used. Spent nuclear fuel is removed from reactors and placed in storage for decay pending subsequent disposal. The spent nuclear fuel contains the highest concentrations of radioactive materials and repositories for its final disposal are still in the process of development. Whilst the concentrations of radioactive materials are greatest in the spent fuel, each step in the nuclear fuel cycle gives rise to radioactive waste in one form or another. These vary widely in radionuclide type and content, and in physical and chemical form and in quantity.

Nuclear energy may be exploited in nuclear power stations to produce electricity, it may also be exploited in research and radioisotope production reactors. In the latter, the nuclear fission process is used to produce radiation beams for purposes of research and development or for the production of radioactive material which are used for a broad range of applications. Radionuclides can also be produced in accelerators and together with reactor produced radionuclides are referred to as artificial radionuclides. Such radionuclides can be fabricated into sealed radiation sources or used in an unsealed form and both find widespread applications in industry, medicine and research. Again the manufacture and use of these sources gives rise to the generation of radioactive waste and again the characteristics of the waste can vary widely depending on the particular radionuclides involved, their associated radioactive half lives and the activity of the sources. The nature of the use for which the source was employed will also greatly influence the physical and chemical characteristics of the waste and the amounts of material involved.

In addition to the various activities discussed above where materials are exploited for their fissionable properties, such as uranium, or their radioactive properties in the case of radiation sources, other activities involving materials containing elevated levels of naturally occurring radionuclides generate radioactive waste. As with the former activities, the latter also give rise to a broad range of waste types with varying radioactive, physical and chemical characteristics.

The one aspect in common with all radioactive waste, regardless of their type or origin is their radioactive nature and their potential to give rise to radiological hazards, albeit of widely varying magnitude. Nevertheless, they all need to be managed as radioactive waste, with appropriate levels of control, if their safety is to be assured.

The safety principles developed for radioactive waste management and the various technologies developed to ensure these principles are met have largely been based on consideration of waste arising from the nuclear fuel cycle and largely on the waste arising from the back-end of the cycle i.e. operational waste and spent nuclear fuel arising from nuclear power stations. More recently a number of anomalies have become more evident in application of the principles to the broader range of waste types and the circumstances of their generation and management, particularly in respect of waste arising from the front end of the nuclear fuel cycle, those associated with naturally occurring radioactive materials and in the disposal of spent or disused radiation sources. In order to address these anomalies and to ensure that all radioactive waste are managed in an acceptably safe manner, it has been suggested that a common framework should be established to provide for the safe management of all radioactive waste types. The common framework should identify all radioactive waste types, the agreed safety principles, the issues to be considered in their management and how the safety of a particular disposal option can be can be reasonably assured.

2. RADIOACTIVE WASTE TYPES AND CHARACTERISTICS

The broad range of waste types that are generated can be managed in a variety of ways and it is convenient to classify waste for which particular management arrangements are appropriate. The determination of what management arrangements are appropriate requires consideration of a number of factors including the radiological, physical and chemical properties of the waste, the amounts and timeframes of waste generation, the processing capabilities available and the disposal options available. Nevertheless, it is possible to identify a number of generic disposal options that are or could be made available and a few broad categories of waste types that with appropriate processing would logically be compatible with a particular disposal option. The waste types and their characteristics are tabulated below.

Waste Type	**Origins**	**Characteristics**
Residues and waste from mining and processing of radioactive ores	• Uranium mining • Thorium mining • Minerals sands mining • Minerals with elevated concentrations of naturally occurring radionuclides – phosphates, copper, fluorspar, coal etc.	Large volumes Low specific activities Very long radioactive half lives Radon gas generation Contaminated scales Contaminated equipment – metal, timber, plastic etc. Adventitious concentrates
Waste containing higher concentrations of longer lived alpha emitting waste	• U refining, conversion, enrichment and fuel fabrication • Minerals processing – rare earth extraction, oil refining, fertilizer production, water treatment etc.	Chemical residues – sludges, resins, carbon Filters Process tailings Scales Contaminated equipment – metal, plastic Contaminated bricks and concrete Long half lives Adventitious concentrates
Spent fabricated radiation sources with short radioactive half live < 1 year	Industry, medicine and research	Small size Short half lives High specific activity Sealed /unsealed
Spent fabricated radiation sources with radioactive half lives > 1 year < 30 years	Industry, medicine and research	Small size Medium half lives High specific activity Sealed
Spent fabricated radiation sources with longer radioactive half lives > 30 years	Industry, medicine and research	Small size Long half lives High specific activity Sealed
Operational waste from nuclear installations and other industrial/medical/research activities containing primarily radionuclides with radioactive half lives shorter than 30 years and with activity concentrations not requiring significant radiation shielding.	• Nuclear power stations • Research reactors • Nuclear fuel cycle facilities • Research laboratories • Hospitals	Resins Filters Chemical concentrates and sludges Contaminated consumable – clothing, plastic etc. Contaminated equipment Decommissioning waste Fission and activation products Medium to low specific activities
Operational waste from nuclear installations and other industrial/medical/research activities containing primarily radionuclides with radioactive half lives shorter than 30 years and with activity concentrations requiring radiation shielding.	• Nuclear power stations • Research reactors • Nuclear fuel cycle facilities • Research laboratories • Hospitals	Filters Chemical concentrates and sludges Contaminated consumable – clothing, plastic etc. Contaminated equipment Decommissioning waste Fission and activation products Medium to low specific activities Biological waste
Spent nuclear fuel and high level waste from reprocessing of spent nuclear fuel	• Nuclear power stations • Research reactors • Re-processing facilities	High specific activity Fission products, actinides

3. SAFETY PRINCIPLES

A number of bodies have played a role at an international level in the development of safety principles for radioactive waste safety. Prime amongst these bodies are the International Commission on Radiological Protection and the International Atomic Energy Agency. The former is an independent international commission which makes recommendations based on prevailing scientific knowledge and the IAEA is a specialist UN Agency within whose mandate it is to establish international consensus on safety standards for radioactive waste safety together with radiation and nuclear safety. To assist the IAEA in these functions it has established a Commission on Safety Standards (CSS) with supporting specialist committees e.g. Waste Safety Standards Committee (WASSC), and an International Nuclear Safety Advisory Group.

3.1. IAEA Principles

In 1995, the Agency issued a Safety Fundamentals publication entitled "Principles of Radioactive Waste Management". These principles are referred to in the following sections and are derived from a stated objective of radioactive waste management, namely:

"*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 principles that are particularly relevant to the discussion in this document are as follows:

Principle 1: *"Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health."*

This has generally been interpreted simply to mean that, in general terms, radioactive waste is to be managed according to the normal system of radiation protection for practices. This is typically qualified by noting that waste management on its own does not require justification, but that the justification of the practice or intervention that gives rise to the waste should include consideration of the management of the waste.

Principle 2: *"Radioactive waste shall be managed in such a way as to secure an acceptable level of protection of the environment."*

The extent to which this has been interpreted as distinct from Principle 1 varies. Of interest to this paper is the statement, in elaborating upon the text of the principle itself, that: "The preferred approach to radioactive waste management is concentration and containment of radionuclides rather than dilution and dispersion in the environment. The most recent ICRP recommendations are less supportive of such a preference.

Principle 4: *"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."*

Variants of this principle are widely used in national and international recommendations, but this formulation is more explicit than most (other versions refer, for example, to a level of protection at least equivalent to that provided today). Regardless of the wording, this principle has most commonly been interpreted to mean that the same numerical criteria (limits or constraints) should be applied for all times in the future. Firstly, it should be noted that even this quite rigid interpretation leaves a very large degree of uncertainty as to the level of assurance needed. We have a relatively good idea of the doses that people actually receive at present, but the doses to individuals in future generations are so dependent upon aspects of their environment and behaviour which have such large associated uncertainties as to be not "predictable" in any meaningful sense. Furthermore, there is no certainty that a given dose will have the same impact on health in the future. Typically, however, the practical interpretation has been to estimate doses to hypothetical humans with all the characteristics existing today transferred into the future. Although this is a convenient method for obtaining a quantitative measure of the "predicted impact", it is not at all clear what the results really mean. Secondly, the measures used to represent the "levels of impact that are acceptable today", such as the dose constraint applied to discharges, do not fully represent the level of protection that exists today. The present generation may experience radiological impacts not only from the planned operation of current practices, but also from the residues of past practices and from accidents that might occur in current practices (although there are mechanisms in place to intervene if necessary to mitigate the effects of accidents). It is not a straightforward task to determine what situation in the future, viewed from the perspective of the present day, would be equivalent to this. Clearly, the difficulties in applying this principle increase as the time periods of concern increase, and so are particularly pertinent to the management of very long-lived waste.

Principle 5: *"Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations."*

This principle is intended to relate to non-radiological "burdens". It has been generally understood to mean that the present generation should do as much as it can to provide for the safe long term management of the waste it generates, leaving as little as possible for future generations to do. One example quoted in the safety fundamentals is that "*the management of radioactive waste should, to the extent possible, not rely on long term institutional control as a necessary safety feature*". In practice, however, consideration of long term institutional control has tended to focus more on the reliance that can be placed on it than on whether it represents an undue burden. This raises fundamental questions in relation to the disposal of very long-lived waste in places where, in the absence of institutional control, they could relatively easily reach the human environment.

There are four remaining principles that are not relevant to the present discussion. For completeness, these are listed below:

Principle 6: *"radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions."*

Principle 7: *"generation of radioactive waste shall be kept to the minimum practicable."*

Principle 8: *"interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account."*

Principle 9: *"the safety of facilities for radioactive waste management shall be appropriately assured during their lifetime.*

3.2. INSAG principles

The IAEA has established an International Nuclear Safety Advisory Group (INSAG), formed by well known experts, which has the function of providing advice to the agency's director general. The eleventh INSAG report draws together the three safety fundamentals publications in the safety series dealing respectively with the safety of nuclear installations, radioactive waste and radiation sources.

Due to its brevity the report cannot provide much detail, but, regarding the disposal of radioactive waste, none of the relevant principles described in section 3.1.1 is in any way contradicted. In general terms the point is stressed that disposal options need to be commensurate to the activity level and the longevity of the radiological hazard. In particular paragraph 91 says:

> *"for waste disposal the objective is to achieve an ultimately passive solution with, as far as possible, no long term requirements for intervention by humans or for continuing institutional control. Disposal thus seeks to isolate the waste from the environment for sufficiently long periods of time so that the risks to humans from such disposal, including any risk from inadvertent human intrusion, would be very small."*

This can be interpreted as supporting at once several of the principles quoted above. Then the report goes on to stress the importance of defence in depth and quality control.

3.3. Recent Developments in ICRP Recommendations

Since publication of the IAEA safety fundamentals, ICRP has issued three publications relevant to waste disposal that extend and expand on the system of protection recommended in ICRP Publication 60. These publications are:

(1) Radiological Protection Policy for the Disposal of Radioactive Waste, ICRP Publication 77

(2) Radiation Protection Recommendations as Applied to the Disposal of Long-lived Solid Radioactive Waste, ICRP Publication 81

(3) Protection of the Public in Situations of Prolonged Radiation Exposure, ICRP Publication 82.

The important aspects of these publications are discussed below followed by a summary of their implications for the management of radioactive waste in general.

3.3.1. Summary of ICRP Publications

In publication 77, ICRP deals with specific policy issues that arise from application of its system of protection to the disposal of radioactive waste whether in the form of gaseous or liquid discharges or as solids. ICRP reaffirmed that the principles of protection for practices would normally be applied to the controlled disposal of radioactive waste and that the main issues concern exposure of the public. In the context of waste management strategies, ICRP considers that 'the dispersal of radioactive waste should not be automatically regarded as less suitable than retention'.

The main implications of this publication concern optimization of protection and use of the quantity collective dose. In publication 77, the process of optimization of protection is considered to have a strong subjective element being 'more subtle and judgmental than is implied by differential cost–benefit analysis'. Constraints should be applied during the optimization of protection and ICRP recommends an upper value for the dose constraint for members of the public from waste management operations of 0.3 mSv/a. Constrained optimization is considered to be the means for controlling public exposure from waste management operations.

In connection with the quantity collective dose, ICRP considers that estimates for time periods longer than several thousands of years into the future should be viewed with caution. One purpose for calculating collective dose is to estimate possible numbers of health effects (referred to by ICRP as 'health detriment'). Taking account of the fact that the currently understood relationship between dose and risk might not be valid for future generations, ICRP takes the view that forecasts of health detriment over periods longer than several hundreds of years into the future should be viewed critically. Overall, in the context of protection of future generations from decisions taken today, ICRP suggests that estimates of doses or risks to individuals in future critical groups will provide a basis for deciding on the appropriate level of protection.

ICRP's policy, as enunciated in Publication 77, was developed in the context of disposal of long lived solid radioactive waste in Publication 81, taking account of ICRP's previous recommendations in this area. Publication 81 also applies some of the principles developed in Publication 82 which is described later.

Publication 81 states that the principal objective of disposal of solid radioactive waste is the protection of current and future generations from the radiological consequences of waste produced by the current generation. Furthermore, ICRP acknowledges the basic ethical principle that individuals and populations in the future should be afforded at least the same level of protection from actions taken today as is the current generation. This parallels at least one principle in the safety fundamentals. In evaluating the level of protection being afforded future generations, ICRP concludes that two broad categories of exposure situations must be considered: natural processes and inadvertent human intrusion.

In the first case, estimated doses and risks should be compared with a dose constraint of no more than about 0.3 mSv/a or its risk equivalent. In the case of human intrusion, ICRP recommends that the consequences of intrusion are assessed in terms of doses to exposed individuals using one or more stylized human intrusion scenarios. It is pointed out that it is not appropriate to compare these assessed doses with the dose or risk constraints for natural processes because by definition 'intrusion will have by-passed all of the barriers which were considered in the optimization of protection'. Instead, ICRP recommends that they are compared with current criteria used to establish whether intervention is necessary; if human intrusion could result in doses 'to those living around the site sufficiently high that intervention on current criteria would almost always be justified, reasonable efforts should be made during the design and development of the repository to reduce the probability of intrusion or to limit its consequences'. The criteria for deciding whether intervention would be justified are taken from Publication 82.

Publication 81 addresses the issue of institutional controls. Whilst acknowledging that *'it cannot be assumed that future generations will have knowledge of disposals undertaken by the current generation'* ICRP points out *'that institutional controls maintained over a disposal facility after closure may enhance confidence in the safety of the disposal facility particularly by reducing the likelihood of intrusion'*. Of particular relevance to the present discussion, ICRP goes on to state that *'there is no reason why these controls may not continue for extended periods of time and, therefore, may make a significant contribution to the overall radiological safety of shallow facilities in particular. Furthermore, for surface or near surface disposal of uranium mill tailings, these controls may be relied upon for long periods of time in situations where, if the controls fail, consequences will be generally lower than those associated with other long-lived radioactive waste.'*

Developing on the points made in Publication 77, it is considered that estimates of doses and risks can only be regarded as measures of health detriment for times up to around several hundreds of years into the future. For longer time scales they only represent indicators of the protection afforded by the system. This point is taken up by ICRP in considerations of compliance with numerical criteria such as dose or risk constraints where it is stated that *'as the time frame increases, some allowance should be made for assessed dose or risk exceeding* *the dose or risk constraint'*. again, the quantity collective dose is regarded as having little or no role to play.

Constrained optimization is considered to be the key to establishing the radiological acceptability of a waste disposal system. Publication 81 further extends the judgmental approach to optimization of protection noted in Publication 77. Publication 81, in the context of disposal of long lived solid radioactive waste, states that *'optimisation of protection is a judgmental process with social and economic factors being taken into account....the goal is to ensure that reasonable measures have been taken to reduce future doses to the extent that required resources are in line with these reductions'*. ICRP makes further use of the idea of reasonableness in its concluding recommendations on the evaluation of the radiological acceptability of a disposal option by stating: *'provided reasonable measures have been taken both to satisfy the constraint from natural processes and to reduce the probability or consequences of inadvertent human intrusion, and technical and managerial principles have been followed, then radiological protection requirements can be considered to have been complied with'*. This statement is only relevant if calculated exposures remain below some standards, for example intervention levels.

Publication 82 deals with the application of ICRP's system of protection to radiation exposure from natural sources and long lived residues. It derives criteria from, amongst other things, consideration of natural background levels, for deciding whether intervention may be justified in such situations: in circumstances where exposures are above 100 mSv/a, intervention is considered to be almost always justified, conversely in situations where exposures are below 10 mSv/a intervention is probably not justified. (these criteria are also used in Publication 81 to assess the significance of inadvertent human intrusion into a waste repository — see above). The report discusses some issues of relevance to the management of a particular category of waste, *i.e.* waste with elevated levels of naturally occurring radionuclides. It emphasizes that residues remaining from past activities should be treated within an intervention framework. For proposed new facilities generating such waste, application of optimization of protection within dose and risk constraints is recommended with the proviso that in some cases the application of low dose constraints may be too restrictive.

3.3.2. General Implications for the Control of Radioactive Waste

The ICRP recommendations described above, seem to justify the following general radiological protection framework for the control of radioactive waste.

Assessed doses and risks to appropriate critical groups provide an adequate basis for evaluating the protection being afforded future generations. Collective doses play only a minor role even in the process of optimization of protection.

The assessed doses and risks can be regarded as measures of health detriment for time periods up to several hundreds of years into the future only. Beyond this time they should be regarded as indicators of safety.

Assessments being undertaken to evaluate the degree of protection being afforded future generations should consider two broad categories of exposure situations: natural processes and inadvertent human intrusion. The term 'natural processes' covers all processes leading to exposure of humans other than human intrusion, i.e. pathways where human action has degraded one or more of the containment barriers.

Doses and risks assessed for natural processes should be compared with the appropriate constraints for protection of the public from controlled practices. However, it is inappropriate to compare doses assessed for human intrusion with constraints developed for application in controlled practices because for inadvertent human intrusion to have occurred, control over the repository must have been lost, at least to some degree.

The significance of doses assessed for inadvertent human intrusion can be evaluated by comparison with the range of doses experienced in various situations today. This approach is suggested instead of ICRP's approach of linkage to intervention criteria, to avoid possible misunderstandings that could arise from the simultaneous use of practice criteria and intervention criteria (in fact, the approach adopted in this report and ICRP's approach result in the same numerical criteria). Annual doses from natural background provide a useful barometer against which to judge the significance of doses. Typically on a worldwide basis, annual doses from natural background range up to about 10 mSv with a maximum in a few small areas of about 100 mSv. If the assessed dose for a particular disposal system is lower than around 10 mSv/a, the radiological consequences of human intrusion can be considered to be broadly tolerable provided there are no straightforward means for their reduction. If the assessed doses are higher than this value, consideration should be given in the design of the repository system to reduce either the probability of intrusion (by, for example locating the repository at a greater depth) or its consequences (by, for example, dilution of the waste). The target is to reduce intrusion doses to below 10 mSv per year. If the assessed dose is greater than 100 mSv then it must be established that all reasonable steps have been taken to mitigate the implications of human intrusion.

The process for achieving an acceptable level of protection of human health in the future from the management of radioactive waste should be constrained optimization with emphasis on taking all reasonable steps to achieve protection instead of relying solely on compliance with numerical criteria. Furthermore, the fact that specified numerical criteria may be assessed as being exceeded at some time in the future may not in itself imply rejection of the disposal option: the decision making process is judgmental particularly when considering the implications of doses assessed for time periods greater than several hundreds of years into the future.

3.3.3. Implications for the Interpretation of the Principles of Radioactive Waste Management

The new recommendations from ICRP focus on protection of the public; other issues such as protection of the environment, transboundary implications, the implications for national legal frameworks and matters relating to waste generation are not specifically addressed. Therefore, these new recommendations are of most relevance to the interpretation of principles 1, 4 and possibly 5 of the safety fundamentals (see Section 3.1). The main difficulty concerns the interpretation of principle 4 which is addressed at the protection of future generations and so this will be discussed first.

As stated in section 3.1, principle 4 is commonly interpreted as meaning that the same numerical criteria (limits and constraints) as are applied today should be applied at all times in the future. The implications of the ICRP recommendations are that for natural processes, dose projections in the far future indicating doses in excess of these levels should not necessarily be seem as contra indicators to acceptability. This is 'justified' by ICRP on the basis of the conservatism inherent in the calculations and so does not conflict greatly with the conventional interpretation of this principle.

It is in the consideration of inadvertent human intrusion that more serious issues arise. The conventional approach to protection of future generations in this context has often been to assess annual risks from intrusion, taking account of the assessed probability of such intrusion and of the corresponding health effects, and to compare the result with a risk constraint equivalent to the corresponding dose constraint. However, there is no consensus in this regard. The ICRP approach is to look at the consequences of intrusion in terms of dose. In judging the acceptability of this assessed dose ICRP refers to criteria for intervention on the basis that control over the source has been lost. If uncontrolled exposures resulted from a source today, the situation would be addressed using the system of protection for intervention and so it can be argued that this approach provides an appropriate level of protection for future generations. However, in applying this recommendation to a near surface facility for long lived waste it could be argued that as control is almost certain to be lost at some time in the future and so intrusion is almost certain to occur, essentially intervention criteria are being applied to the control of a practice. There is no clear answer to this issue and differences in interpretation seem to be unavoidable as discussed further in section 5.

Turning to Principle 5, which concerns undue burdens on future generations: the implications of the ICRP recommendations are that institutional control should not necessarily be regarded as an undue burden on future generations. This possibly is in accord with current thinking in this area although as was pointed out in section 2, the main issue is for how long one can rely on controls and not whether they are an undue burden or not. Concerning Principle 1 — securing an acceptable level of protection for human health — there do not appear to be any implications from the ICRP recommendations other than those noted under Principle 4 insofar as the two principles overlap.

3.3.4. Application to Disposal of Longer Lived Waste in Near Surface Facilities

These principles could be applied to the specific case of disposal of longer lived waste in near surface facilities, particularly mining and minerals processing waste in the following way. Any chosen option should comply with the dose or risk constraints for natural processes. This may require containment barriers to be monitored and at some stage in the longer term repaired. Facility designs should be robust and simple to repair in order not to place undue burdens on future generations but nevertheless the implications are that to achieve the level of safety required in the longer term, institutional controls will be necessary. The time period over which institutional controls are likely to remain effective cannot be guaranteed although every effort should be directed at their maintenance on an ongoing basis.

Assessed doses from human intrusion are likely to be important determinants in deciding whether waste are suitable for surface or near surface disposal. Appropriate stylized intrusion scenarios should be selected. For surface or near surface disposal of mining and minerals processing waste these are likely to include consideration of exposure to radon in dwellings constructed on or near the repository. In circumstances where the assessed doses are greater than 100 mSv/a modifications should be made to the repository concept to reduce either the probability of intrusion or its consequences. If the high doses are from radon exposure in dwellings, this could be achieved by either diluting the waste within the repository or disposal at greater depth.

If the assessed doses from intrusion are less than 100 mSv per year, it should be demonstrated that mitigation cannot be achieved without disproportionate use of resources by applying optimization procedures. If the assessed doses are less than 10 mSv/a, this requirement is relaxed and a simple check that straightforward measures will not bring about improvement is all that is required. Thus, an annual dose of 10 mSv can be viewed as a target in the optimization process in respect of intrusion considerations.

The radiological protection framework outlined above in respect of near surface disposal of longer lived waste is consistent with new ICRP recommendations. However, it may have significant implications in respect of mining and minerals processing waste. It implies that ongoing institutional control will be necessary and it implies that mining and minerals processing waste above certain concentrations would be contra indicated for near surface disposal or would require dilution to levels that could not give rise to intrusion doses above 100mSv. In supporting such an approach comparison with situations giving rise to exposures from naturally occurring background radiation may be helpful.

4. ISSUES IN ESTABLISHING A COMMON FRAMEWORK

4.1. General issues

There are several issues of a general nature which may influence the choice of which option may be appropriate to dispose of a particular waste type. The following sections discuss these and provide some general understanding of how these issues may affect the decision-making process. Further details will be provided in the specific discussion of each waste type in relation to each disposal option.

4.2. Institutional control

The role of institutional control is to reduce the probability of intrusion into disposed waste, to reduce the magnitude of the consequences if intrusion does occur, to expedite intervention activities after intrusion has taken place and to help achieve societal confidence. Monitoring and inspection are particular forms of institutional control and are very important part of generating societal confidence. The term "institutional control" refers to that period after "normal" operation of a repository has ceased even though there is continuous involvement of institutions during all stages of any waste facility.

The half lives of radioisotopes can be clustered into groups of: short lived — less than 1 year, intermediate lived — up to about 30 years and long lived — typically a few thousands of years or more. Ten half lives decay reduces the source activity concentration by a factor of one thousand, for large sealed sources, twenty half lives gives a reduction of a million times. Thus an institutional control period of 300 years would allow most radioactive waste to decay to trivial levels. The exceptions being large sealed sources, high level waste/spent fuel and naturally occurring isotopes. For very long lived radioactive waste such as that containing the primordial naturally occurring radioactive species in the uranium and thorium decay chains no reasonable period of decay would allow activity levels to decay significantly.

The concept of institutional control changes over time. The "practice" period could lasts up to 50 years or more and includes the operating period and the closure phase. Post closure starts after this but there can be an intermediate period referred to as the Post Operational Pre-closure Phase (POPC) during which extended monitoring can be undertaken to ensure facility performance is satisfactory. At some point there is a shift in emphasis and this may also be reflected in a change in ownership and the facility (usually to a government body) as well as a change in the degree of regulatory control.

For near surface disposal facilities containing low and intermediate level waste of short or intermediate half life and limited amounts of longer lived waste, it would seem reasonable from a radiation protection perspective to rely on institutional controls to achieve safety.

Generally this has been considered to be reasonable for a limited period of time (up to several hundred years) and also for this sort of time period that institutional controls can also be thought of as additional or complementary safety barriers which work with the other natural and engineering barriers to ensure safety. Institutional controls do not constitute an "undue" burden from a radiation protection perspective. They are a burden, but are seen by society as acceptable in the context of managing other types of hazardous chemical waste. The important issue, and maybe burden, is that the current generation pass on to the next generation the knowledge, skills, records and societal judgements that led to the existing decisions as well as any financial resources needed to cover work that was intentionally deferred. This would allow the next generation to make the decisions it regards as being appropriate and acceptable to it. This might include stopping any further action, reversing past actions or continuing to pass information on to its immediate next generation. It is not possible, reasonable or practicable for this generation to impose its will on future generations. It is the responsibility of each generation to consider, to decide and to act. Thus there is perhaps limited value in a philosophical discussion on what might happen in the next few hundreds or thousands of years.

Regarding geological disposal facilities institutional controls are not regarded as being necessary to ensure safety. They are complementary to other barriers but could help to build societal confidence. Radiological monitoring is undertaken to facilitate societal confidence as there are no expected consequences that can be observed for very long times. Markers and passive land use controls may be considered to be appropriate and passing of records and other design and decision-making information should be carried out. Safeguards will need to be maintained for spent fuel or other fissile material as determined.

For long lived and naturally occurring materials, institutional control of near surface disposal facilities is necessary to prevent intrusion into the waste and to prevent diversion of the waste – an issue often of concern for mine tailings and waste rock dumps. There is no limit to the time period where this is needed, it is analogous to the way society deals with long lived chemically hazardous waste. Robust mechanisms are needed to ensure that transfer of information between generations is maintained. Where practicable, such radioactive waste should be disposed far enough bellow the surface to avoid the need for open ended institutional controls. Monitoring/ inspection are important to identify barrier degradation and to undertake repairs as needed and to determine if there are direct effects on the immediate environment and to allow prompt intervention if intrusion occurs.

Safeguards are a specific form of institutional control. They apply only to spent fuel where the amount of fissile material is above the level considered to be practically irrecoverable under the Non Proliferation Treaty. It would also apply to weapons grade plutonium if it were to be considered as waste and placed into a repository. The key issue for safeguarding waste is to ensure that no measures that are taken to verify the materials significantly compromises the overall safety of the repository. Thus safety has priority over safeguards. This usually results in maintaining the integrity of the barrier systems and thus safeguards activities are proposed which rely on remote sensing and site monitoring. As there is currently technology available to do this, having a safeguards regime in place does not impose any special constraint of the choice of how such waste is disposed.

4.3. Intrusion

Intrusion can be defined as human actions that are not intentional which give rise to consequences from a waste repository or other form of waste management facility. Intentional intrusion is specifically excluded. In order to determine what effect intrusion may have on the choice of disposal option for any given waste, it is necessary to first consider some related aspects such as: how to evaluate the consequences which may arise in the future from human intrusion, how to judge the acceptability of the consequences which might arise given that they will have a probabilistic nature (they are not certain to arise) and that they may have a magnitude that would not be acceptable if they where to occur in a normal practice situation today, how to reduce both the likelihood of the intrusion occurring and the magnitude of the consequences if it does?

In terms of evaluating the consequences, given the long time frames and the associated uncertainties, only an indication of consequence is reasonable and appropriate. It would appear to be reasonable to use a few generic stylized scenarios as a basis for indicating what the consequence might be. Scenarios should be somewhat conservative , but not unreasonably so. This approach is somewhat analogous to the use of "reference man" in the radiation protection context. It is generally considered that analysis should not be overly complex since that would imply an unreasonable level of precision and understanding in the light of future changes in social habits and biosphere evolution. Three basic intrusion situations have been suggested: direct access and immediate exposure to waste giving rise to high doses (driller being exposed to spent fuel from a core sample), direct access to waste and prolonged exposure to low level doses (waste is removed from the repository and people live on or near the waste.) and indirect exposure to low doses from a leaking repository whose barriers have been degraded by the intrusion. Exposures are received sooner than expected from natural evolution processes. (a well penetrates a contaminant plume from a degraded barrier system due to the intrusion).

In terms of judging acceptability of the consequences the approach recommended by ICRP can be adopted. The thinking infers doses are potential in nature and would occur at a time when the waste repository is no longer a "practice", but rather would be considered an "intervention" if it where to occur today. Doses would be estimated from the three generic stylized scenarios as well as their probability (the dis-aggregated approach). Doses above 100 mSv should not be allowed and every effort be made to reduce the consequences or the likelihood of occurrence. Doses of less than 10 mSv would likely be acceptable if all practicable and reasonable measures have been taken to reduce/optimize exposures or their likelihood. Doses less than 1 mSv would be acceptable and require no further action.

There are a number of possibilities to reduce both the likelihood of intrusion and the possible consequences. The likelihood can be reduced by increasing the depth of disposal, adding markers to ensure that any intrusion sees "made ground" and by maintaining records and other passive institutional controls. The consequences could be limited by elimination of hot spots in the repository, by dispersing the waste in the repository to reduce the specific activity or by selecting a site with inherently good containment capacity to reduce dependency on engineered barriers which could be penetrated.

4.4. Reversibility and retrieveability

The benefit of having a waste repository which can have one or all of its various operations reversed is that less emphasis has to be placed on having to demonstrate that all aspects of the design are adequate from the outset. The knowledge that the disposal process can be reversed could help generate confidence on the part of the various interested parties (stakeholders) within a society, although it should not relieve the developer or operator of the repository of the obligation to demonstrate with a high degree of likelihood that the repository will be safe.

It is not surprising that society is not generally willing to accept a waste facility which cannot be repaired and which it is claimed does not need to be repaired. This runs counter to human experience where failures occur and mistakes are made on a regular, if not frequent basis. Claims that the understanding of repository systems and their behaviour over long periods at the early stages of development have little credibility and can antagonise public sentiment.

For any short lived waste, it is unlikely that reversibility is an issue as they will decay in time periods that would allow the waste to be left in place even if it were not found to have been placed in an optimum situation. Thus reversibility will only be an issue for waste that are long lived such as spent fuel, high level waste and uranium mine tailings. Of these, waste placed on or near the surface are inherently very accessible and are thus inherently retrieveable without special measures being needed to enhance or facilitate access. Thus in general the only waste that need to be considered specifically from a reversibility perspective is long lived waste placed into a deep geological repository.

The key question is whether measures which are taken to facilitate reversibility are likely to degrade barrier systems used to isolate and contain the waste and thus to reduce the safety of the facility. It is generally considered that safety should be the primary consideration. Studies have shown that the safety can be maintained even when provisions are made to enhance access to the waste to facilitate reversibility. In addition the cost of such provisions is not usually very significant when compared to the overall cost of a repository. The main constraint which these studies reveal is that good institutional controls must be maintained to ensure that the waste is not allowed to flood and that the repository is ultimately closed in accordance with its initial design. If either of these conditions are not met, then there is a likelihood that a significant reduction in safety can occur. This is seen to be unacceptable and thus any delay in closing a repository should be reduced to the minimum and be accompanied by a strong institutional control framework. There is however no fundamental reason from a safety perspective not to allow for reversibility and ultimate recovery of waste placed in a disposal repository.

4.5. Making the safety case

Whilst it is generally recognised that quantitative performance and impact assessment is important in the design of disposal facilities, in establishing operational controls and limitations and in associated regulatory processes, it is not enough to provide the levels of assurance necessary in the overall safety of facilities and the associated decision making processes both regulatory and at a broader political level.

A safety case should be developed for a repository which addresses the logic and soundness of the overall system design and a range of aspects which provide confidence in the design and the more quantitative aspects of safety impact assessment. It should address the robustness of the design explaining the passive safety features adopted, the mechanisms that will provide for containment of the waste and for isolation form the accessible environment. It should address the reliability of the various natural and engineered design features and their assessed performance. The safety case should explain how the concept of defence in depth has been employed and what features provide multiple barriers or levels of safety. It should also address the safety margins designed into the facility. The integrated performance assessment of the repository should feature in the safety case which due consideration of uncertainties. The adequacy, appropriateness and validation of the modelling process and models used in the assessment should be addressed. The level of confidence associated with the safety of the repository should be addressed as relevant to a particular stage of the repository development.

Aspects such as natural analogues, alternative indicators of safety to dose and risk and monitoring should be included.

5. APPLICATION OF A COMMON FRAMEWORK

The basic reason for developing a common framework for disposal of radioactive waste is in recognition of the fact that a range of radioactive waste types exist and are continuing to be produced, the majority of which need to be disposed of in order to ensure compliance with the internationally agreed waste safety fundamentals. A number of disposal options are available and have been utilised in the past. In reviewing past waste disposals practices and when looking at proposed disposal practices for the future, there are clearly some areas where anomalies exist. There is a clear need to find safe and cost effective disposal solutions for spent radiation sources in countries which are not engaged in nuclear programmes to any significant degree or with limited infrastructure and resources. Borehole disposal could be such an option. There is also a need to rationalise the near surface disposal of mine tailings with the accepted waste disposal principles and to identify acceptable options for disposal of NORM waste.

The coming into force of the Joint Convention on the safety of Spent Fuel and the Safety of Radioactive Waste management will no doubt raise the focus on these and related issues. The development of an internally endorsed common framework for disposal of all radioactive waste types will assist in decision making in this area particularly is such a framework can enable a clear and justifiable safety argument to be developed for the disposal of all types of radioactive waste in cost effective, safe and appropriate disposal facilities.

Such a common framework must for each waste type, processing and disposal option systematically test all the waste and radiation safety principles and determine congruence and compatibility.

6. CONCLUSION

The principles of radioactive waste safety are now sufficiently developed to structure a framework against which waste types and disposal options can be tested. A systematic mechanism needs to be developed for structuring and applying such a framework.