ASSESSMENT OF RADIOACTIVE AND NON-RADIOACTIVE CONTAMINANTS FOUND IN LOW LEVEL RADIOACTIVE WASTE STREAMS

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ABSTRACT

This paper describes and presents the findings from two studies undertaken for the European Commission to assess the long-term impact upon the environment and human health of non-radioactive contaminants found in various low level radioactive waste streams. The initial study investigated the application of safety assessment approaches developed for radioactive contaminants to the assessment of non-radioactive contaminants in low level radioactive waste. It demonstrated how disposal limits could be derived for a range of non-radioactive contaminants and generic disposal facilities. The follow-up study used the same approach but undertook more detailed, disposal system specific calculations, assessing the impacts of both the non-radioactive and radioactive contaminants. The calculations undertaken indicated that it is prudent to consider non-radioactive, as well as radioactive contaminants, when assessing the impacts of low level radioactive waste disposal. For some waste streams with relatively low concentrations of radionuclides, the potential post-closure disposal impacts from non-radioactive contaminants can be comparable with the potential radiological impacts. For such waste streams there is therefore an added incentive to explore options for recycling the materials involved wherever possible.

INTRODUCTION

Historically, regulations for radioactive and non-radioactive waste disposal within European Union (EU) Member States have been kept strictly separate, with some exceptions for certain types of landfills in some Member States, where co-disposal of very small amounts of radioactive material is currently allowed. Non-radioactive waste regulations neglect the fact that waste can contain natural radioactivity, sometimes in concentrations enhanced by industrial processes, and that the adverse health effects from natural radioactivity are the same as those from artificial radioactivity. Indeed, studies have shown that enhanced levels of radioactive tritium can be found in leachate from certain non-radioactive waste disposal sites. On the other hand, radioactive waste from the nuclear industry, hospitals and research institutes may contain non-radioactive contaminants. Various studies have shown that leachate from radioactive waste disposal sites can contain non-trivial levels of heavy metals. However, very few long-term safety assessments of low level radioactive waste (LLW) disposal have included quantitative evaluation of the environmental impacts of the non-radioactive contaminants in the wastes since it is usually assumed that their impacts will be small compared with those of the radioactive contaminants. To test this assumption, two studies have been undertaken for the European Commission.

THE INITIAL STUDY

The aim of the study was to demonstrate how disposal limits for non-radioactive contaminants in LLW could be derived to support decisions concerning appropriate disposal options (1). In order to ensure that a thorough and quantitative assessment of the impacts, the eleven step Safety Assessment Comparison (SACO) methodology was used (Figure 1). The SACO methodology had been developed under the European Commission’s R&D Programme on Management and Storage of Radioactive Waste (1990-1994) (2,3) specifically to allow the quantitative assessment of both radioactive and non-radioactive wastes.

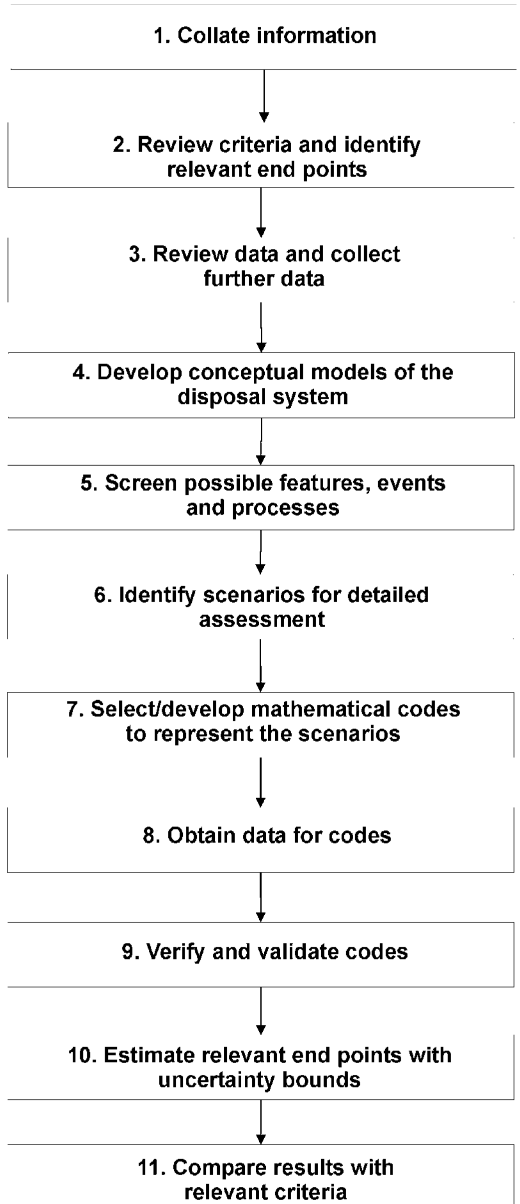

Fig. 1. Steps in the SACO methodology

The eleven steps can be grouped into five main stages which are presented below:

- collate background information;
- develop conceptual models of, and scenarios for, the disposal facilities considered;
- perform scenario and contaminant screening;
- perform detailed calculations for key scenarios and contaminants; and
- derive disposal limits.

Collation of Background Information

The first phase of the project (Steps 1 to 3 of the SACO methodology) involved the collation of background information concerning the disposal of the non-radioactive contaminants of LLW. The following three tasks were undertaken.

First, a review of low level radioactive waste streams was undertaken and representative waste streams and associated non-radioactive contaminants were identified. Non-radioactive contaminants in radioactive waste are generally considered in two main categories: organic and inorganic (mainly heavy metals). Particularly useful lists of potentially significant contaminants are provided in (4) and (5). Using these initial lists, a review of the non-radioactive contaminants in European and North American solid LLW was undertaken to determine the inventories of such contaminants. The review emphasised the observation made by other researchers, that little information is generally available for the levels of non-radioactive contaminants in LLW, especially non-radioactive organic contaminants. Nevertheless, it was possible to devise a list of non-radioactive organic and inorganic contaminants for consideration in the project (Table I).

Table I. Non-radioactive Contaminants Considered in (1)

Inorganic Contaminants: Metals: Ag, B, Ba, Be, Bi, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Sn, Te, Th,Ti, Tl, U, V, Zn Asbestos
Organic Contaminants: Phenols: Phenol, 2-4-5 Trichlorophenol, 2-4-6 Trichlorophenol Mineral Oil PAH: Napthalene Volatile Hydrocarbons: Acetone, 1-2 Dichlorobenzene, 1-3 Dichlorobenzene, 1-4 Dichlorobenzene, 1-2 Dichloroethane, Diphenylethyl, Methylethyl Ketone, Toluene, Trichloroethane, 1-1-1 Trichloroethane, 1-1-2 Trichloroethane, O-xylene, M-xylene, P-xylene Volatile Chlorinated Hydrocarbons Other Chlorinated Hydrocarbons Trichlorotrifluoroethane PCBs: PCB1016, PCB1232, PCB1232, PCB1242, PCB1248, PCB1254, PCB1260 Complexing Agents: EDTA Surfactants Pesticides: DDT, Lindane Mirex

The information obtained from the review was also used to collate a list of representative waste streams in LLW (Table II). Some of these are quite well defined (for example, those with large quantities of Pb, Cu and asbestos), while others should be regarded as illustrative only.

The **second** task was the characterisation of five representative disposal facilities into which disposals were assumed to occur. The terms of reference of the study required consideration of disposal in facilities with increasing levels of engineering:

- a shallow facility suitable for the disposal of inert waste (least engineered);
- a shallow facility suitable for the disposal of solid municipal waste (MSW);
- a shallow facility suitable for the disposal of hazardous waste;
- a shallow facility suitable for the disposal of radioactive waste; and
- a deep underground facility suitable for the disposal of non-nuclear industrial waste (most engineered).

Table II. Inventories of Inorganic Contaminants in LLW considered by (1)

Waste Stream	**Volume (m^3)**	**Inorganic Contaminant**	**Total Mass (t)**	**Concentration ($kg\ m^{-3}$)**
Operational LLW	200000	Cd	4	0.02
		Hg	4	0.02
		Be	20	0.1
		Se	8	0.04
Lead bricks	-	Pb	500	-
Decommissioning steels	50000	Cr	3000	60
		Ni	1700	34
		Mo	100	2
		Co	75	1.5
BNFL fuel flasks	1400	Pb	3500	2500
		Mo	76	54
Copper cables	-	Cu	2000	-
Galvanised drums	40000	Zn	400	10
Evaporator concentrates	3300	B	150	45
Ion Exchange Resins	1000	Cr	0.5	0.5
		Ni	0.8	0.8
Soil and rubble	69000	Asbestos	0.5	140

In order to allow calculations to be undertaken for each facility, information describing the characteristics of the relevant wastes, disposal facilities, geospheres, and biospheres had to be specified. This information was drawn from a number sources with the aim of providing generic rather than site-specific data. Where appropriate, the same geosphere and biosphere data were used for one or more of the disposal options to facilitate intercomparison of results.

A common biosphere based upon the BIOMOVS II Complementary Studies biosphere (6) was assumed for all five facilities. The geosphere surrounding the deep facility was based upon the granite Auriat site from the PAGIS exercise (7); the facility itself was based upon a single 5000 m^3 storage room from the Herfa-Neurode Underground Waste facility plant, Germany (8). The common geosphere for the shallow facilities was based upon the NSARS Test Case 1 (9). Each shallow facility is assumed to represent a single 5000 m^3 trench or vault operated using current best practice. Figure 2 shows the general shallow facility conceptual model. The four shallow cases differ in the details of the engineering of each facility. The inert waste facility concept was of an unlined, soil capped trench; the MSW facility concept was of lined, clay capped, compacted waste cells overlying low permeability unsaturated material; the hazardous waste facility was similar, but the waste was assumed to be drummed and backfilled; the radioactive waste facility conceptual model had supercompacted, drummed, grouted waste in a backfilled, concrete walled vault, with overlying clay cap and underlying low permeability unsaturated layer (Figure 3).

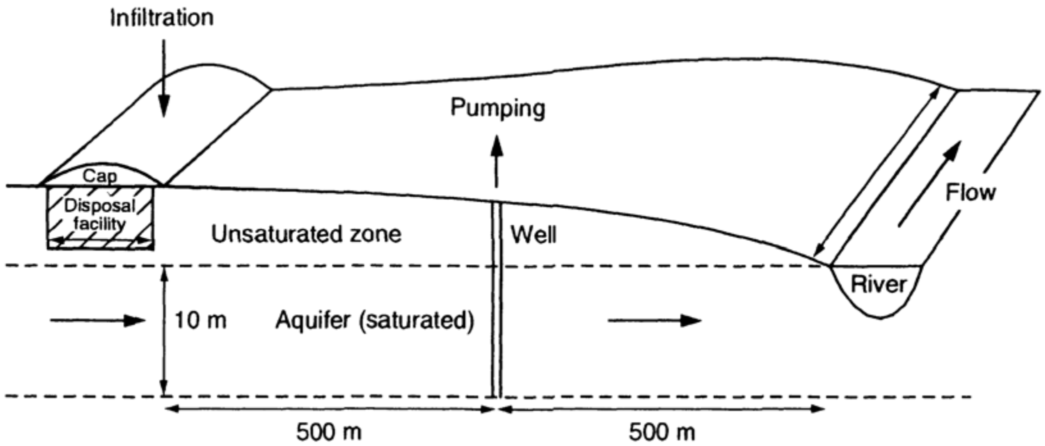

Fig. 2. The shallow waste disposal system

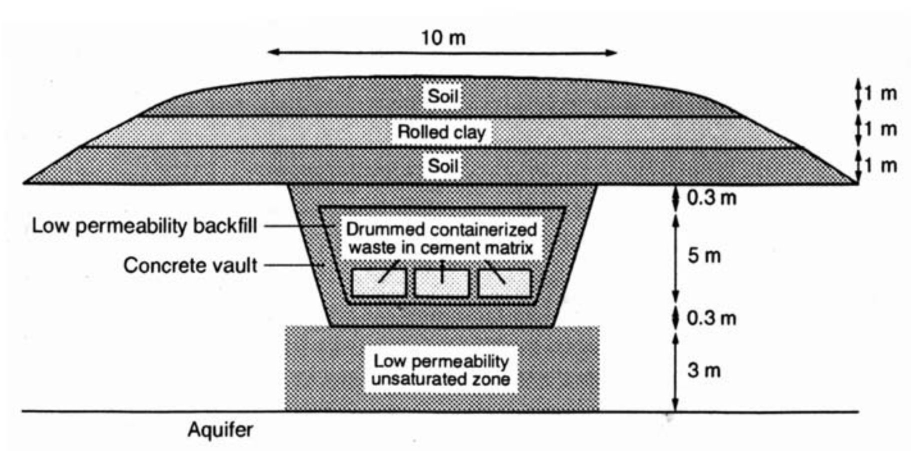

Fig. 3. The radioactive waste disposal facility

The **third** task was the identification of assessment end points to be considered when calculating the environmental impacts of the disposal of the non-radioactive contaminants. The terms of reference for the study required the assessment of the post-closure individual risks against a risk limit of 10^{-6} y^{-1} for risks from the inventory of a disposal facility. For carcinogens, the factors given in the 1994 Health Effect Summary tables (HEAST) of the United States Environmental Protection Agency (USEPA) were used (10) to allow the calculation of risk from a given level of intake via inhalation and ingestion of certain non-radioactive contaminants. However, data were sparse and therefore risk calculations could only be undertaken for certain contaminants and exposure modes. In the absence of direct risk data, other surrogate quantities were used (intake limits for contaminants and environmental quality standard data).

FEP, Scenario and Conceptual Model Identification

A review of the features, events and processes (FEPs) and scenarios used in previous assessments of radioactive waste disposal was carried out (11, 12, 13, 14). Additional FEPs and scenarios peculiar to the non-radioactive component of mixed waste were also identified. When considering and constructing scenarios, the following were ruled out: deliberate intrusion, with knowledge of the waste facility contents (because such deliberate intruders should be able to take any necessary safety precautions, should they feel this necessary); and disasters such as war, meteorite strike or explosions which could damage the facility (because the human health consequences of the disaster outweigh the effects of the release of contaminated waste).

Nine scenario groupings were derived for the shallow facilities, and six parallel scenarios for the deep facility. The FEPs identified in the scenarios were then checked against those in (15) to ensure that no key FEPs had been excluded.

A subset of the scenarios, designed to cover all the main routes by which contaminants could leave the disposal facilities and contaminate the accessible environment, were then identified:

1. Leaching to groundwater including non-aqueous phase transport (shallow and deep facilities);
2. Bathtubbing, where a facility saturates and overflows through the overlying cover (shallow facilities only);
3. Intrusion - risk to site dweller (building excavation for shallow facilities or nearby mining for deep facility);
4. Intrusion - risk to intruder (drilling for shallow facilities, or mining for deep facility);
5. Environmental change (gradual erosion exposing shallow facilities or reducing deep facility cover);
6. Environmental disaster - earthquake enhancing contaminant transport (shallow and deep facilities);
7. Gaseous release (of non-radioactive gases) to overlying buildings (shallow and deep facilities).

The aim in the choice of scenarios was not to be complete, but to include a sufficient number of the different types of scenario and pathway combinations that risks from disposals were unlikely to be underestimated.

Each of the scenarios outlined above implies an underlying conceptual model of the features and processes within the waste disposal system under consideration. For each scenario, conceptual models were identified for the three zones of the system - the waste disposal facility, the geosphere and the biosphere. In each case, the conceptual model identified: the contaminant release and transport media and mechanisms; the primary and secondary biosphere receptors; and the human exposure mechanisms.

Scenario and Contaminant Screening

A series of simplified analytically soluble equations were developed on a spreadsheet system for undertaking scoping calculations with the following aims:

- to define which of the selected scenarios were likely to be most significant in terms of impact for each type of disposal facility;
- to determine which contaminants were unlikely to pose any significant risks when allowance was made for the actual quantities of material which could realistically be disposed of in the types of facility under consideration; and
- to define a more detailed set of calculations to be undertaken on a reduced set of contaminants and scenarios to determine acceptable disposal quantities.

Conservative parameter values were used to ensure that the calculation end points (peak contaminant concentrations in air, soil and water; peak human ingestion and inhalation levels of each contaminant; lifetime health risks from one year's exposure to each contaminant at peak concentration) were not underestimated. Independent sets of parameter values were used for each scenario. The end points were calculated regardless of the timescale involved before the peak values were reached. In each case, the calculations assumed unit mass (1 kg) of contaminant to be contained within each facility. From a comparison between the calculated end point (for unit mass disposal of contaminant) and the regulatory criterion, a limiting disposal mass was calculated, and hence by using the total mass of the waste within the facility, a disposal concentration limit.

For the initial scoping calculations, it was conservatively assumed that the organic contaminants did not degrade prior to reaching the biosphere. Calculations illustrated that only those scenarios where little or no degradation was assumed to take place in the biosphere were potentially significant. Assumed degradation rates were sufficiently fast that degradation periods of a year or more were enough to reduce concentrations to insignificant levels. Thus for most scenarios there was no practical limit to the concentration of the organic contaminant for any of the facilities in terms of impacts considered in the study. It was concluded that there was no need to undertake any more detailed calculations for the organic contaminants. It should be noted that the presence of certain organics (such as EDTA) can significantly affect the mobility of radioactive and non-radioactive contaminants in the disposal facility. However, consideration of such effects was beyond the scope of the study.

From the inorganic scoping calculation results, it was found that:

- with the algorithms and parameter values employed, the leaching, bathtubbing and environmental change scenarios were the most limiting scenarios for the four shallow facilities;
- there would be no practical limit to the concentration of most inorganic contaminants in waste disposed to a deep facility;
- no single exposure pathway was dominant in the various scenarios calculations undertaken; and
- the limiting average disposal concentrations derived from the scoping calculations were generally one to three orders of magnitude more restrictive than disposal limits given in existing criteria.

Detailed Calculations

In light of the scoping calculation results, two sets of more detailed calculations were undertaken for inorganic contaminants in the shallow facilities.

The scoping calculations identified the need to look at these three related scenarios in a consistent way. The main aim of the additional calculations was to determine whether the derivation of the limiting concentrations in wastes for the inorganics obtained from the scoping calculations was pessimistic or biased because of the independent treatment of these scenarios. The approach taken was to use the same basic algorithms used in the scoping calculations for the three scenarios, but to combine these into a single consistent calculation for any given choice of model parameters.

Deterministic and probabilistic calculations were undertaken for the hazardous waste facility using the QUEST computer code (16). They supported the view that the independent treatment of scenarios in the scoping calculations did not result in any significant bias in the derivation of disposal limits. They also confirmed the potential importance of the bathtubbing scenario, which gave higher environmental concentrations than leaching through the base of the facility.

It was considered that more detailed calculations were needed for the leaching scenario for the shallow facilities in order to investigate further the degree of pessimism inherent in the scoping calculations and investigate potential differences in the impacts of the four shallow facilities. The scoping calculations identified that the four most limiting inorganic contaminants were cadmium, mercury, nickel and zinc. The geochemical properties and biosphere accumulation behaviour of these four metals were then considered further. This allowed the selection of cadmium and nickel for detailed modelling of leaching scenarios. It was decided to consider disposals to the inert and radioactive waste facilities since these represented two extremes in terms of the level of engineering of the shallow facilities.

The Safety Assessment Comparison (SACO) code (3) was chosen to undertake the detailed calculations for the leachate scenario because of its ability to represent all components of the disposal system (the disposal facility, the geosphere and the biosphere) at an appropriate level of detail. Furthermore, both deterministic and probabilistic calculations could be performed. The calculations confirmed the conservative nature of the scoping calculations, even though the scoping calculations considered only a simplified biosphere representation. Calculated intake levels of contaminants from the scoping calculations were about an order of magnitude higher than those from the SACO calculations. Deterministic and probabilistic results also showed that the magnitude and timing of the peak intake levels for contaminants disposed of in the inert facility were an order of magnitude higher/earlier than those for contaminants disposed of in the radioactive facility (Figure 4). This reflects the more engineered nature of the radioactive facility.

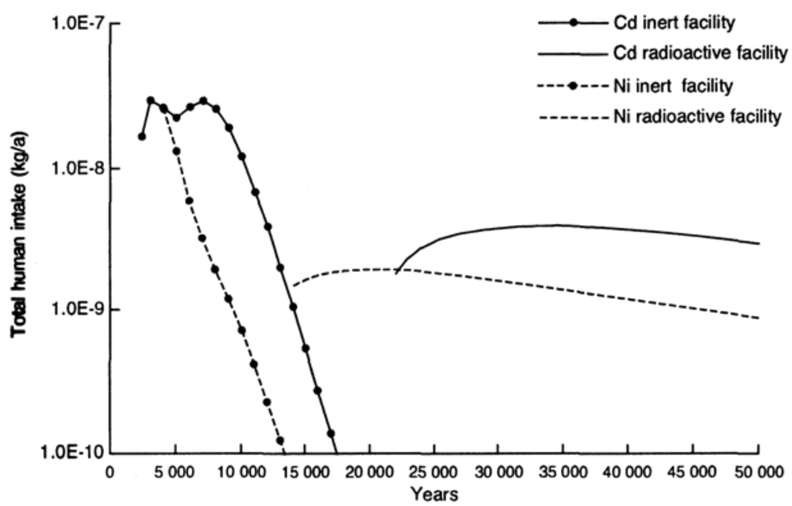

Fig. 4. Intake of Cd and Ni from deterministic SACO calculations

Derivation of Activity Limits

The scoping calculations showed that for most post-closure scenarios considered there was no practical limit to the concentration of any of the organic contaminants in waste disposed of any of the facilities. This conclusion holds if generally accepted organic degradation rates are applied and it is assumed that any degradation products do not pose an environmental hazard. It also ignores the potential impact of some organic contaminants on the mobility of radioactive and non-radioactive contaminants.

The first column of concentration data in Table III gives the limiting concentration in wastes calculated for each inorganic contaminant by the scoping calculations for the shallow facilities considered. This column can be regarded as *de minimis* values. If concentrations of inorganic contaminants are below these values, one can state with a high level of confidence that risks to individuals from shallow disposal will be acceptable. It must be borne in mind that these concentrations refer to values averaged over the facility; it is not necessary for each waste stream to meet these concentrations individually. Furthermore, if concentrations in the wastes are above these values, it is not necessarily the case that deep disposal of the wastes is required.

Table III. Limiting Concentrations of Inorganic Contaminants for Shallow and Deep Disposal

Inorganic	Scoping Calculation Derived Shallow Disposal Limit (kg kg^{-1})	SACO Derived Shallow Disposal Limit (kg kg^{-1})	Scoping Calculation Derived Deep Disposal Limit (kg kg^{-1})
Ag	1E-6	2E-4	2E-2
As	7E-7	8E-4	2E-2
B	2E-6	1E-2	5E-1
Ba	3E-5	8E-4	4E-1
Be	1E-7	4E-5	3E-2
Bi (a)	-	-	-
Cd	2E-7	3E-5	5E-3
Co	3E-6	2E-3	2E-1
Cr	1E-6	7E-5	8E-3
Cu	2E-5	3E-4	2E0
Hg	1E-8	5E-6	1E-4
Mo	3E-6	2E-5	4E-2
Ni	1E-6	1E-3	2E-2
Pb	3E-6	4E-3	1E-1
Sb	2E-8	2E-3	3E-4
Se	1E-6	2E-5	8E-2
Sn	5E-5	3E0	2E0
Te	5E-4	-(b)	2E1
Th (a)	-	-	-
Ti	4E-3	-(b)	9E1
Tl	2E-5	2E-4	4E-3
U	2E-4	-(b)	1E3
V	3E-7	1E-4	2E-1
Zn	1E-5	6E-3	8E-1
Asbestos	1E-9	2E-6	3E-3

Notes:
(a) No risk, intake or EQS data available to allow derivation of limit.
(b) No risk, intake or EQS data available to allow derivation of limit for pathways considered in SACO calculations.

The detailed SACO groundwater transport calculations for cadmium and nickel showed that when release from the wastes is modelled in more detail, one obtains significantly higher limits for the inert and radioactive waste facilities. Therefore, it was decided to undertake SACO calculations for unit (1 kg) disposals of the remaining inorganic contaminants to the most heavily engineered facility, the radioactive waste facility. The second column of concentration data in Table III brings together the calculated limiting concentrations in wastes based on the SACO leaching scenario calculations assuming results from unit calculations can be scaled linearly. If the average concentrations of inorganic contaminants in the relevant shallow disposal facility exceed these values, it is likely that deep disposal will need to be considered. A waste and site-specific assessment would have to be undertaken to determine if this was in fact the case.

The third column of concentration data in Table III give the concentration limits, derived from the scoping calculations, above which it is likely that detailed waste and site specific assessments will be needed to assess whether disposal in a suitable deep facility would lead to acceptable risks. Concentrations below these limits would suggest that deep disposal would not present any unacceptable risks.

The above disposal limits for inorganics were compared with typical non-radioactive contaminant concentrations in the nine representative low level and exemptible radioactive waste streams identified in Table II. It was found that only one waste stream (ion exchange resins) had concentrations below the *de minimis* limits. Five of the remaining eight waste streams had concentrations that would allow shallow disposal, but a waste and site specific assessment would have to be undertaken to determine the appropriate level of facility engineering required. The remaining three waste streams might need to be disposed of in a deep facility. A waste and site-specific assessment would have to be undertaken to determine if was the case.

THE FOLLOW UP STUDY

In light of the conclusions from the initial study that more detailed waste and disposal system specific calculations could be expected to show that most waste streams were likely to be acceptable for disposal in an appropriately sited and/or engineered shallow facility, a follow up study was undertaken using more detailed waste and facility specific calculations (17).

Approach

The follow up study followed the basic philosophy of the initial study, but the broad simplifications employed were replaced by more waste and disposal system specific data and more detailed assessment modelling was undertaken. In addition, the impacts of both radioactive and non-radioactive contaminants were considered.

The LLW streams considered were taken from those that had been shown to be potentially problematic in terms of disposal to a shallow facility in the initial study, namely:
- decommissioning steels;
- evaporator concentrates;
- redundant fuel flasks; and
- a large volume operational LLW stream.

Inventories were derived for each LLW stream, for both non-radioactive and radioactive contaminants, which were adequate to define the waste characteristics required for the post-closure safety assessment calculations to be undertaken. Inorganic non-radioactive contaminants were considered for all four waste streams, and potential concentrations of some organic non-radioactive solvents were included for the operational low level waste stream. In the case of decommissioning steels, the waste stream was divided into two sub-streams according to whether the radioactivity was due to surface contamination or activation throughout the volume of the waste.

Consistent with the initial study, four categories of shallow land disposal systems were identified with increasing levels of containment. Unlike the generic disposal systems considered in the initial study, the disposal facility, geosphere and biosphere characteristics considered were based on real sites in the United Kingdom and Italy. However, it should be noted that none of the illustrative disposal systems have actually received the LLW waste streams identified, and so the assessment calculations undertaken must be seen as being purely hypothetical.

In order to calculate the impacts of the LLW waste stream contaminants on humans and the environment, the following assessment end points were considered:

- contaminant concentrations in air, water and soil;
- exposure rates of humans; and
- human cancer risks.

Six scenarios and associated FEPs were selected:

- a groundwater scenario;
- a bathtubbing scenario;
- a gas scenario;
- an intruder scenario;
- a site dweller scenario; and
- an erosion scenario.

Conceptual models associated with each of the scenarios and disposal systems were derived. In each case, the conceptual model identified the contaminant release, transport media and human exposure mechanisms.

An integrated approach for calculations was developed that allowed for system and waste specific factors to be taken into account for liquid, gaseous and solid releases from the disposal facilities.

Results and Discussion

The results of the assessment calculations showed that, whilst the disposal of contaminants in one or more of the LLW streams could give rise to potentially unacceptable impacts for the disposal systems with lower levels of containment and engineering, disposal to the system with the highest level of engineering was considered to be generally acceptable due to the higher degree of isolation of the waste and associated contaminants from humans and the surface environment. This supports the conclusion drawn from the initial study that more detailed waste and system specific calculations could be expected to show that concentrations of non-radioactive contaminants in most LLW streams are likely to be acceptable for disposal in an appropriate shallow facility.

Through the use of an "Exceedance Quotient" approach[1], it was possible to compare the impacts of radioactive and non-radioactive contaminants. The impacts were generally greater for the non-radioactive

[1] The Exceedance Quotient is calculated by dividing the calculated value of the assessment end point (e.g. concentration in a medium; human intake; human dose; cancer risk) by the acceptable limit for the

inorganic contaminants for the four LLW waste streams considered. This is due to a number of factors including:

- the more persistent nature of the non-radioactive inorganic contaminants resulting in their greater importance for the long-term scenarios assessed (groundwater, bathtubbing and erosion);
- the potentially more restrictive nature of the assessment end points for non-radioactive contaminants which explicitly rather than implicitly consider impacts upon non-human biota and the wider environment as well as humans; and
- differences in the treatment of uncertainties in exposure-human health effects for radioactive and non-radioactive contaminants.

The scenario associated with the highest impact varied depending upon the combination of the disposal system and waste stream, although the erosion and intruder scenarios most frequently resulted in exceedances. This highlights the need to consider each disposal system separately and to consider a range of scenarios rather than limit consideration to a single generic disposal system and one or two scenarios. The probability of the scenario occurring and the timing of the peak impact from the scenario should also be considered. In certain cases, implied timescales could extend over thousands of years. In such cases, the applicability of the calculational approach adopted and results generated must be carefully reviewed.

The results generally indicated that greater engineering of the disposal facility reduces the impacts of contaminants on humans and the environment. However, care must be taken to ensure that the degree of engineering is appropriate, not only for the operational phase of the facility but for the long-term post-operational phase. Delaying the release of certain contaminants to the surface environment, through the use of additional engineering measures, can have limited effect on their associated impacts, especially if these are dominated by long-term scenarios such as the erosion scenario. In extreme cases, greater isolation might possibly result in slightly greater impacts - this reflects the “dilute and disperse” versus the “isolate and contain” argument. Thus care must be taken to ensure that increased isolation does not potentially lead to greater impacts.

The results also showed that the more detailed system and waste stream specific calculations generally imply less restrictive disposal limits for the non-radioactive contaminants than those derived from the initial more generic study. Typically the limiting disposal levels derived were between a factor of two and one hundred less restrictive than those derived previously. This is because an attempt was made to ensure the conservatively derived shallow disposal levels calculated in the initial study were levels “below which one could be confident that shallow disposal would not result in any unacceptable risk”. This has shown to be true for the vast majority of cases considered, however there are two exceptions. These resulted from differences between the systems considered in the initial study (1) and the follow up study (17). This highlights the need to use limiting levels derived from the assessment of generic systems with care, and the need to use site-specific levels in preference. This is especially the case if the limiting scenario is associated with the leaching of contaminants into groundwater. Different disposal facilities, geospheres and biospheres can offer radically different degrees of attenuation and dilution resulting in differing disposal limits based on the groundwater scenario.

DISCUSSION

The two studies undertaken for the EC have shown that there is a need to ensure that the impacts of the non-radioactive, as well as the radioactive contaminants, are assessed when deciding upon suitable disposal options for such waste streams. This is particularly true for wastes arising from the

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assessment end point (e.g. environmental quality standard; intake level; dose constraint; risk target). The acceptable limit is exceeded if the Exceedance Quotient is greater than unity.

decommissioning of nuclear facilities; many decommissioning waste streams will have non-trivial concentrations of non-radioactive contaminants. For some waste streams with relatively low concentrations of radionuclides, the potential post-closure disposal impacts from non-radioactive contaminants can be comparable with the potential radiological impacts.

These considerations provide added incentives for the recycling and reuse of relevant materials wherever possible. There is extensive experience in the recycling of decommissioning materials in several countries, for example at the Greifswald site in Germany (21). In some countries there is public resistance to the practice of such materials entering the unrestricted public domain. An alternative to unrestricted release is for materials to be 'tracked' through the manufacturing chain, with end use within the nuclear industry. This has been referred to as 'provenance tracking' (22). Where materials are to be reused within the nuclear industry, less onerous standards for decontamination may be appropriate than for unrestricted release. This process may not be as economically advantageous as unrestricted release, but may still be more economical than disposal. An example of the economic benefits of recycling contaminated nickel within the nuclear industry is given in (22).

CONCLUSIONS

The two studies have shown how a safety assessment approach can be successfully used to derive illustrative disposal limits for non-radioactive and radioactive contaminants found in low level radioactive waste streams. They have also demonstrated that, if a consistent approach is to be taken to radiological and other contaminant hazards, there is a need to ensure that the potential impacts of the non-radioactive, as well as the radioactive contaminants, are assessed when deciding upon suitable disposal options for such waste streams. Such waste streams are likely to be a significant source of waste for future disposals to LLW disposal facilities throughout the world and it will be important that disposal options are selected mindful of both the radiological and non-radiological impacts that might potentially arise.

For waste stream where the post-closure impacts of non-radioactive contaminants can be comparable with potential radiological impacts there is an added incentive to explore options for recycling the materials involved. For some materials this may best be undertaken by reusing the materials within the nuclear industry.

There remains scope for further work on a number of issues in order to facilitate the comparison of the impacts from radioactive and non-radioactive contaminants. These include:

- reducing the uncertainties associated with contaminant inventories, especially the inventories of non-radioactive contaminants - as national inventories of radioactive waste are revised and updated, there is scope to include additional information concerning non-radioactive contaminants; and
- considering the health impacts of radioactive and non-radioactive contaminants on a more directly comparable basis - various national and international studies are already underway to allow the estimation of the impact of radionuclides on non-human biota which will facilitate this process (18, 19, 20).

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