BIOPROTA

Key Issues in Biosphere Aspects of Assessment of the Long-term Impact of Contaminant Releases Associated with Radioactive Waste Management

Scientific Basis for Long-term Radiological and Hazardous Waste Disposal Assessments

Report of an International Workshop

Version 3.0
13 February 2014

PREFACE

BIOPROTA is an international collaboration forum which seeks to address key uncertainties in the assessment of radiation doses in the long term arising from release of radionuclides as a result of radioactive waste management practices. It is understood that there are radio-ecological and other data and information issues that are common to specific assessments required in many countries. The mutual support within a commonly focused project is intended to make more efficient use of skills and resources, and to provide a transparent and traceable basis for the choices of parameter values, as well as for the wider interpretation of information used in assessments. A list of sponsors of BIOPROTA and other information is available at www.bioprota.org.

The general objectives of BIOPROTA are to make available the best sources of information to justify modelling assumptions made within radiological assessments of radioactive waste management. Particular emphasis is to be placed on key data required for the assessment of long-lived radionuclide migration and accumulation in the biosphere, and the associated radiological impact, following discharge to the environment or release from solid waste disposal facilities. The programme of activities is driven by assessment needs identified from previous and on-going assessment projects. Where common needs are identified within different assessment projects in different countries, a common effort can be applied to finding solutions.

This report describes presentations and discussions held during an international workshop on 22nd to 24th May 2013. The workshop was hosted by ARAO in Ljubljana, Slovenia. Technical support was provided by a wide range of organisations via presentations and discussions, as described in the report. The financial support provided for the project by ANDRA (France), ENSI (Switzerland) GEN Energija d.o.o., (Slovenia), LLWR (UK), NRPA (Norway), NUMO (Japan), NWMO (Canada), Posiva, (Finland), RWMD (UK), and SKB (Sweden) is gratefully acknowledged.

Version History

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Executive Summary

Environmental impact and human health assessments are used to support decisions on the management and disposal of radioactive and hazardous waste. These assessments have to address a wide range of protection objectives related to different ecosystems and timeframes. This creates significant challenges to the design of such assessments and in the provision of corresponding relevant scientific support.

The objective of the workshop described in this report was to provide a forum for discussion and comparison of the scientific basis for such assessments. Through the sharing of experience on the above topics, it was intended to develop ideas for complementary, consistent appropriate scientific support in different assessment contexts.

A wide range of presentations were made covering radioactive waste, hazardous waste, and waste consisting of a mixture of these hazards, including naturally occurring radioactive material (NORM) wastes. The topics addressed included:

- Different assessment techniques and tools for radioactive and hazardous waste disposal:
    - Models,
    - Interpretation of input data,
    - Application to decision making;
- Site investigation and characterisation methods; and
- Scientific techniques available for more detailed investigation.

Substantial information was made available and opportunities for bi-lateral exchange were taken up.

The following points were identified from presentations and discussion.

There are a number of synergies and areas of commonality, particularly in terms of assessment issues, between hazardous and radioactive waste disposal assessments. For both hazardous and radioactive wastes, assessments can be of value at all stages of waste management including the determination of compliance with protection objectives and derivation of waste acceptance criteria for disposal facilities. However, protection objectives, and hence assessment endpoints and criteria for different types of wastes, are sometimes unclear and inconsistent internationally, and at the national and local level. For example, the timeframe for assessment of the impact of radioactive waste disposal is typically a lot longer than for hazardous waste disposal.

With the lack of harmonisation in protection objectives and assessment criteria, different parties can adopt different assessment methods and points for comparison. A more integrated approach could promote proportionate radioactive and hazardous waste management, supported by common assessment methods. This could be especially relevant to wastes which present both types of hazard. In terms of points of comparison, there can be differences in terms of scientific endpoints (e.g. what level constitutes an impact on an ecosystem) and regulatory compliance endpoints. In addition, there can be differences in the types of people who are intended to be protected, and the period for which protection is both intended and needed. Harmonisation is seen as a good thing in terms of the use of best science and techniques, but it may be inappropriate to harmonise in terms of criteria since there are varied views internationally and nationally on the appropriate protection objectives. Furthermore, final decisions on waste disposal are not only dependent on the assessment of long-term impacts, but

need to take into account many other factors including operational safety, transport and future land-use planning.

There are concerns regarding understanding of synergistic effects and how they should be prioritised and addressed within assessments. The combination of some contaminants may result in impacts which would not be apparent if present separately. Combinations of materials may also increase the various possible risks; organic contaminants can, for example, mobilise radionuclides in some circumstances, facilitating transport to the biosphere.

There are differences in the strategies taken toward hazardous waste and solid radioactive waste safety assessments and in different countries. For radioactive wastes, containment is a key priority to allow for natural decay and, hence, risk reduction over time while the contaminants are isolated from the environment. For hazardous wastes containment is also of significant interest, though the timescale over which containment is required to be assured can be different. In addition, in some circumstances, controlled dilution is adopted. Bringing the different assessment communities together could help support a proportionate approach to assessments and hence to waste management in general.

Engagement and cooperation between operators and regulators and other stakeholders can be mutually beneficial. Gaining the trust of stakeholders is important so that stakeholders will have confidence in technical judgements. Nonetheless, stakeholders often want to hear about technical issues and effective communication of these issues is therefore very important. Effective communication is not only useful in itself, it adds to credibility. Transparency of the value judgement aspects of an assessment is important and stakeholder input to such decisions may be helpful.

There may be benefit in harmonising the application of assessment techniques and tools, although it is acknowledged that, even with the same tools, different results can arise. Harmonisation can be resource efficient by avoiding unnecessary 'reinventing the wheel', but there is the potential for over-simplification in terms of application, for example, if important factors of a site specific problem are overlooked. At least some degree of local site investigation is important in this regard, in ensuring an appropriate balance between site-specificity and application of harmonised assessment tools.

In summary, the following key messages arose from presentations and discussion:

- Ideally radionuclides and hazardous materials should be assessed on a common risk management basis. Some differences in application may be necessary, but there should at a minimum be an understanding of the basis of the approaches to allow differences to be understood and communicated.

- It could be beneficial for a common set of protection objectives and hence assessment endpoints and time frames to be developed for the different waste types, to support coherent risk management and allow alternative options to be compared on a comparable basis. Similarly, development of a common language to addressing issues would be very beneficial to avoid use of different terms that can be confusing and lead to errors and mistrust.

- Waste disposal assessments should be considered holistically rather than hazardous materials being something of an afterthought to radioactivity, or vice versa. This should not be taken to mean that there should not be any differences in how the assessments are made, but that the differences should be transparent, and the reasons for them should be explained. A holistic approach should support the proportionate application of resources to the different hazards presented by a waste, in line with national policies and safety standards.

In order to address the points and issues identified previously, the following activities were suggested.

- Further development of the interfaces between assessment communities concerned with hazardous waste disposal, NORM management and disposal, and post-disposal safety for radioactive waste is seen as beneficial. This could be implemented by further technical forums such as that described here. One possible subject area for a further technical forum would be to consider how the EU Groundwater Directive is applied in different countries and its implications for radioactive and hazardous waste disposal assessments.

- Analysis of the differences in protection objectives and assessment endpoints for radioactive and other hazardous disposal. Understanding of the rationale for differences could be used to promote closer harmonisation where that appears appropriate and provide and support the need for differences, again, where that is appropriate.

- Assessing different hazards independently does not allow multi-stressor effects to be considered, although it is acknowledged that this is a challenging issue. Synergistic issues could however be evaluated in terms of long-term assessments and conflicts in approaches could be identified.

- Optimisation techniques for radioactive and hazardous waste assessments could be evaluated and compared in terms of how assessments help to select between options. It may not be possible to fully combine approaches due to distinctions between hazardous substance characteristics, but the possibility of harmonisation could be evaluated: where distinctions are arbitrary there would be scope to bring assessments onto a common ground.

CONTENTS

1. INTRODUCTION

Environmental impact and human health assessments are used to support decisions on the management and disposal of radioactive and hazardous waste. These assessments have to address a wide range of protection objectives related to different ecosystems and timeframes. This creates significant challenges to the design of such assessments and in the provision of corresponding relevant scientific support.

1.1 OBJECTIVES AND SCOPE OF THE WORKSHOP

The objective of this workshop was to provide a forum for discussion and comparison of the scientific basis for assessments of radioactive and hazardous waste disposal, taking into account:

- assessment methodologies for disposal of radioactive and other hazardous waste;
- assessment endpoints (quantities assessed as a measure of environmental and/or human health impact);
- the key processes which dominate the release and disposition of radionuclides and other pernicious pollutants within the environment, following disposal;
- timeframes for assessment and approaches to dealing with environmental change;
- methods for assessing effects on human health and the environment;
- assumptions for human behaviour and land use, and how that affects the potential for impacts both on human health and on the environment;
- approaches to addressing uncertainties; and
- approaches to addressing low probability events which have high consequences.

Through the sharing of experience on the above topics, it was intended to develop ideas for complementary, consistent appropriate scientific support in different assessment contexts.

1.2 PARTICIPATION

The workshop, hosted by ARAO in Ljubljana, Slovenia, was attended by 33 participants from 12 countries, representing a range of operators, regulators, researchers and technical support organisations. Participants and their organisations are listed in Appendix A.

1.3 REPORT STRUCTURE

Section 2 summarises the presentation from workshop participants and associated discussions. Areas of commonality and key issues and lessons learned are then presented in Section 3, along with recommendations for future activities to address key areas.

2. SUMMARY OF PRESENTATIONS AND DISCUSSIONS

The information provided here necessarily does not include all the information presented. Readers are encouraged to contact authors for more information.

2.1 ENDPOINT ISSUES FOR LONG-TERM ECOLOGICAL IMPACT OF RADIATION

Presented by Graham Smith on behalf of Francois Brechignac (IRSN).

Today's concept of environmental protection from the effects of radiation is based on reference animals and plants (RAPs) or reference organisms, as discussed in ICRP Publication 108. The need for such points of reference arises because it is not practical to learn and understand everything about all species.

The reference organism approach can be considered as biocentric. Radiation exposure can be represented by linear transfers, but there is a need to understand what that means in terms of effects and such effects will differ for each reference animal and plant due to differences in radiation exposure and radiosensitivity. The assessment approach is focussed on individual organisms and the conceptual method is therefore built entirely on individual organism responses. Dose assessment tends to focus on a physics perspective rather than taking into account ecological understanding and results are interpreted through the application of derived consideration reference levels (DCRLs) to relate exposure to effect. The DCRLs are derived from expert judgement on available effects data, most of which comes from isolated organism tests performed under ideal experimental conditions. There are also constraints on the organisms used; these are often inbred populations or cell cultures and so are very distant genetically from those present in the wild. Individual effects endpoints of interest relate to morbidity, mortality, reproduction and chromosomal damage, but there is a need to then relate these effects on individuals to effects at the population level. The biocentric approach therefore partially meets environmental protection objectives, but it is not comprehensive since ecology is not at the forefront of the assessment concept: the approach is grounded on individual responses and does not consider higher levels of organisation, interactions between species and trans-generational effects. A focus upon populations rather than individuals is therefore required and an ecosystem approach has been proposed by the IUR (www.iur-uir.org). An ecosystem approach is applied to environmental protection in a number of domains outwith the radiation field so it is questioned as to why assessments are being approached differently with regards radiation exposure.

An ecosystem approach considers all aspects of the environment, including water, air, soils, sediments and other media, and the food chain from primary producers up to man. It therefore takes into account higher levels of organisation than the biocentric approach and more endpoints (direct and indirect) are considered in an integrated approach. It is effectively an ecotoxicology approach. It is acknowledged that there are differences in the resilience of different ecosystems to stressors and responses may therefore vary. Development of a more integrated approach with functional endpoints that expand beyond the organism level and incorporate a more ecological context is therefore recommended. To support the development of an ecosystem approach for radiation, more research is required and a number of research priorities have been identified. These include considering impacts at the overall ecosystem level (a top down approach) for example through field studies in contaminated areas, but also improving studies at the level of the individual (a bottom up approach). A questionnaire has been distributed and many responses received. Responses have indicated that more ecology is required in assessments in the future. Environmental protection should be constructed in terms of ecological impacts as opposed to effects on individuals. In particular, a greater number of species and the interactions between them should be considered rather than the currently limited number of RAPs. However, more dose-effects information is required, to support an ecosystem approach, and, due to non-linearity and chaotic behaviour, it may be difficult to jump from an organism approach to an ecosystem approach. Communities are complex with each community being governed by different rules of engagement so that even similar communities behave quite differently and responses will also differ. In terms of assessments for people, there is a distinction made between change, damage, harm and detriment with harm and health detriment being the key foci. In terms of the environment however, there is no clear mind set as to when changes in organisms or communities lead to deleterious effects on the system as a whole.

It was noted that, for protected habitats, there is an assessment framework available in the UK that aims at protecting the overall habitat rather than individual plants and animals within (see for example Webb et al. 2010)[a]. Whilst focussed more to conventional pollutants and stressors, the LLWR in the UK is applying this type of framework to evaluate site impacts on local protected habitats and incorporating radioactivity assessment within this.

A working group has been established within the IAEA MODARIA programme that is looking at population modelling and how changes in parameters such as age structure effects and predator-prey relationships affect populations. The work follows on from that undertaken within the EMRAS II programme. There are indications that there are tipping points in the models at which populations become affected. A series of papers has been published that provide information on the approaches, which forms the reading list of MODARIA working group 9. The need to consider more than two species when undertaking population modelling was highlighted: the starting point should be a full consideration of the ecology of the system of interest with simplification then occurring once that understanding has been attained. A consensus view on what constitutes a community would be useful input to discussions within the group in this regard.

It is recognised that the lack of current understanding on how radiation affects populations represents a large challenge in terms of ecosystem modelling. Without this understanding it will be difficult to demonstrate that models are representative and validation will be challenging.

2.2 ASSESSMENT OF THE NON-RADIOLOGICAL HAZARD ASSOCIATED WITH A DEEP GEOLOGIC REPOSITORY IN CRYSTALLINE ROCK

Neale Hunt of the NWMO (Canada) presented.

Most of the effort of the NWMO safety assessment function is focussed on radiation consequence analysis. However, consideration is also given to the effects of non-radiological hazards on both people and the environment. The approach used to determine these non-radiological hazards was the subject of this presentation.

It is projected that there will be some 4.6 million bundles of CANDU fuel produced by existing and refurbished reactors within Canada. Used fuel is currently placed in interim storage at 7 licensed sites, with the majority located in Ontario (90%). Other storage locations are Quebec, New Brunswick and Manitoba.

The regulatory framework for the long-term management of used nuclear fuel in Canada is non-prescriptive. Regulatory expectations are provided in a guidance document (G-320 - *Assessing the Long Term Safety of Radioactive Waste Management*, available from the Canadian Nuclear Safety Commission (CNSC) website). Amongst other things, it specifies that a post-closure safety assessment

[a] Webb, J.R., Drewitt, A.L. and Measures, G.H. (2010). Managing for species: Integrating the needs of England's priority species into habitat management. Part 1 Report. Natural England Research Report NERR024.

should be performed, the timescale of which should include the predicted period of maximum impact. It further specifies that results should be interpreted in terms of justified and scientifically defensible acceptance criteria to be proposed by the applicant. Both the radiological and non-radiological effects on people and the environment are to be considered.

In deriving protection criteria for the non-radiological (i.e. hazardous) substances, the NWMO has applied a tiered approach to data sources. Federal Government and then Provincial Government guidelines are the preferred sources with others being drawn upon as required to address data gaps. Where multiple data are available, the lower values are selected. This approach is also applied to chemical species such that data for the most restrictive form are selected unless that species is known not to persist in the environment. The initial focus has been on developing a complete set of criteria for surface waters; however, where data do not exist, criteria have not been developed. Note that toxicity data are not readily available for all elements of interest, and there is added uncertainty due to a lack of knowledge around the form in which these substances would be released.

While the NWMO continues with the siting process, generic post-closure safety assessments are produced. The post-closure safety assessment for a conceptual repository at a hypothetical crystalline rock site was published in December 2012 and is available on the NWMO website. The assessment has also been submitted to the CNSC for regulatory review. Regulatory feedback will inform on further development areas, both in terms of the overall assessment approach and assessment criteria.

The conceptual used-fuel container is based on that of SKB reference design (KBS-3), but with a small size variation due to the different fuel type. Each container in the generic safety assessment will hold 360 fuel bundles.

The post-closure safety assessment is not aimed at predicting the future; rather scenarios are considered that range from likely through to unlikely. The reference scenario is based around assumptions for Normal Evolution of the repository and biosphere. Disruptive Events are then the unlikely scenarios that could give rise to penetration of barriers.

To reduce the large number of elements and radionuclides to a manageable number, a screening analysis is performed as the first step in the assessment. The starting point is to consider everything present in the fuel, the Zircaloy sheath materials, and the copper and associated impurities in the used fuel containers. Steel, bentonite and concrete have not been considered since they are widely disposed of in near surface facilities without precaution. Manual pre-screening is initially performed whereby the half-life of radionuclides and their daughters, leading to stable elements, are considered. All radionuclides with half-lives longer than 0.1 years as well as radionuclides with half-lives longer than one day if they have a parent with a half-life longer than 0.1 years are included. This results in a total of 251 radionuclides and 96 stable elements input to the screening model. After the screening model was run, 16 elements and 21 radionuclides (for in-growth concerns) were selected for the non-radiological hazard assessment. Two further non-screened-in elements were added: arsenic for historical reasons and copper because of its abundance due to the used fuel containers. The acceptance criteria for the 18 elements are shown in table 2.1.

Table 2-1: Acceptance Criteria for the Non-Radiological Hazard Assessment

Chemical Hazard Criteria				
Element	**Groundwater [ug/L]**	**Surface Water [ug/L]**	**Soil [ug/g]**	**Sediment [ug/g]**
Ag	0.3	0.1	0.5	0.5
As	13	5	11	5.9
Cd	0.5	0.017	1	0.6
Ce	-	22	53	19000
Co	3.8	0.9	19	50
Cr	11	1	0.4	26
Cu	5	1	62	16
Eu	-	10.1	50	4700
Hg	0.1	0.004	0.16	0.17
I	-	100	4	-
La	-	10.1	50	4700
Nd	-	1.8	50	7500
P	-	4	-	-
Pb	1.9	1	45	31
Pr	-	9.1	50	5800
Te	-	20	250	-
U	8.9	5	1.9	-
Y	-	6.4	50	1400

The Reference Case considers that there could be 3 containers placed in the repository with undetected defects of radius 1 mm. This relates to a 1 in 5,000 defect frequency. Since the objective is to be conservative, the worst placement sites for the defective containers have been selected. A constant temperate climate has been assumed with glaciation effects considered in separate analyses.

Since the assessment is based on a hypothetical geology, there is no knowledge around the position of fractures. As such different realisations of fracture systems were considered and a single system selected for analysis. This assumes a variety of intersecting fractures at the surface with fewer, but larger fractures at depth.

For the radiological hazard assessment, a self-sufficient farming family with a co-located well is assumed. The sensitivity of results to varying parameters has been evaluated, including degraded barriers (leading to a larger defect), increased solubility or lower sorption, increased geosphere permeability and the presence of fractures and their location in relation to the repository. Disruptive Events include Inadvertent Human Intrusion, Poorly Sealed Boreholes, Shaft and Fracture Seal Failures, Undetected Faults in the Geosphere, and Container Failure. All Containers Fail at 60k years is also considered, together with a sensitivity case in which the container failures occur at 10k years.

For the non-radiological hazard assessment, the focus is on the Reference Case with a few variants such as Reduced Sorption in the Geosphere and the All Containers Fail Scenario. A separate assessment is undertaken in relation to the copper.

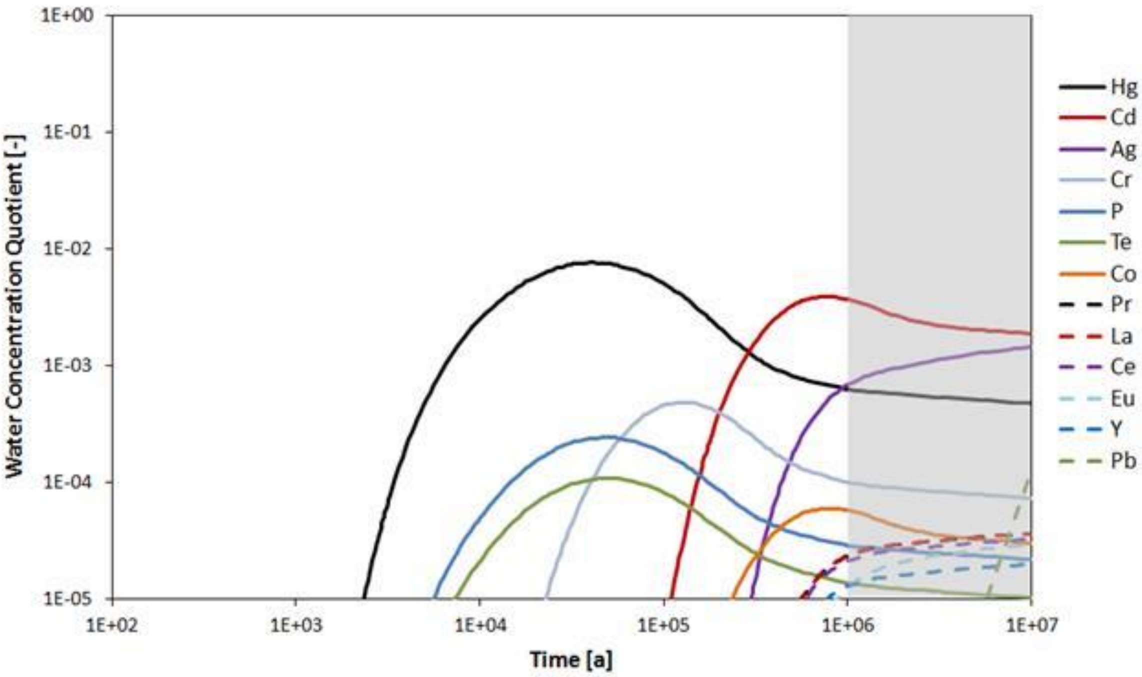
The biosphere is also treated in a generic manner. Groundwater rises from below giving rise to sediment and overburden contamination. Both aquatic and terrestrial discharge points are considered. For the non-radioactive hazard assessment, concentrations in sediments, soil, groundwater and surface water are computed and compared against the derived acceptance criteria, with concentration quotients being computed. Where these are below 1.0, the conservatively determined consequences are within the guideline limits.

For the Reference Case (Figure 2-1), all concentration quotients are below 1.0 (upper figure below) throughout the 1 million year assessment timeframe. For the All Containers Fail Scenario, mercury, lead and cadmium quotients slightly exceed 1.0 (lower figure below). These small exceedances were judged acceptable due to the conservatisms within the assessment.

Copper is treated differently because the copper originates from the outer shell of the used fuel containers and not from the used fuel. The assessment considers the release of copper at its solubility limit from each container position and subsequent transport to the biosphere. The copper concentration quotient is well below 1.0.

The post-closure safety assessment is available from the NWMO website www.nwmo.ca/.

Reference Case:



All Containers Fail (60,000 year) Case:

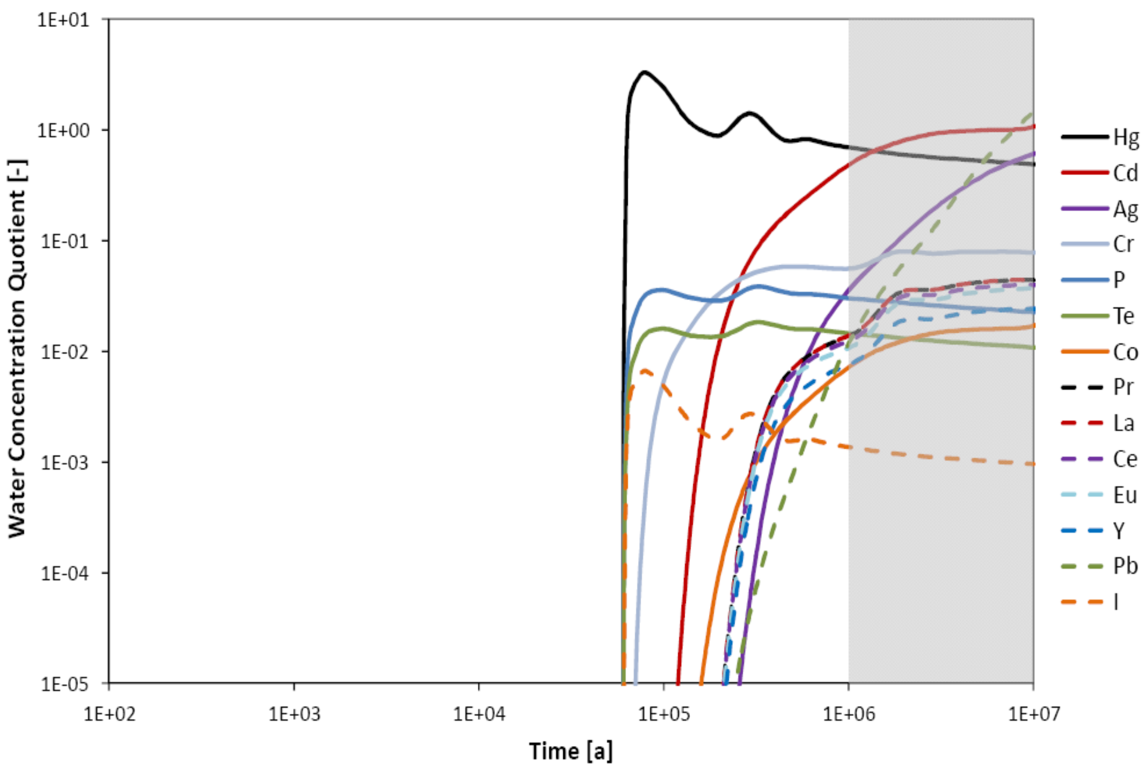


Figure 2-1: Concentration Quotients for the Reference Case and All Containers Fail Scenario

2.3 RESRAD APPLIED TO THE BELLEZANE TAILINGS REPOSITORY IN FRANCE

Thierry Doursout presented work performed as part of the IAEA EMRAS II programme.

The focus of the assessment was a uranium tailings pile in France arising from historical mining and milling activities. There are 4 tailings sites in close proximity: the Bellezane tailings site was selected for assessment. The site is comprised of two former open pit mines with a river located to the north, 3 brooks and an artificial water connection between the Bellezane tailings site and another local site. There are several water treatment basins and the site has undergone some remediation works. Several villages are located nearby.

The reference exposure scenario was based around the current situation whereby transfer pathways are meant to be under control. The site is private property that is owned by AREVA and has a surrounding fence to prevent intrusion into the tailings. The reference exposure group is thus inhabitants of the nearest village and includes adults living and working in the village with a diet partly comprised of local produce. Vegetables can be irrigated by groundwater.

A future exposure scenario assumes the transfer of the site from AREVA that is coincident with budget restrictions that result in the loss of site surveillance and, ultimately the construction of a dwelling on the tailings repository. The family occupying the dwelling are assumed to grow vegetables in their garden with groundwater from a well being used for irrigation.

The pathways of interest to the scenarios are all available in RESRAD-Offsite. Transport both in air and water of radionuclides can be evaluated. The modelled source term took into account the density of the tailings (1,200 kg/m^3), total mass (1.5 megatonnes) and waste rock cover (around 300,000 m^3) within a total repository area of around 5 ha. The repository itself was simplified to a 3-D rectangle that comprised 0.1 m depth of topsoil, 5.8 m depth of waste rock and a tailings layer of 25 m[a]. The orientation in the landscape was consistent with the actual repository. In terms of inventory, no detectable radioactivity was present in vegetation cover, but for waste rock a concentration of 0.5 Bq/kg U-238 (with progeny in equilibrium) was selected and in the tailings layer the concentration of U-238 was 1,600 Bq/kg. Due to limitations in RESRAD-Offsite, modelling has to be performed in steps.

Site monitoring data are available for groundwater, surface water, air, fish, soil, vegetables, milk and sediment. However, most data are for the period from 1994 to 2006 and insufficient data are available for animals. Those data that are available from the monitoring programme represent annual averages and many are reported as being below detection limits.

For the current scenario, there were substantial time variations in the pathways contributing to dose due to slow transport of radioactivity in groundwater. A peak dose of 1.8 mSv/y after 100k years was calculated, although this may not represent the actual peak since this is the maximum simulation time of RESRAD-Offsite. The dose impact was trivial for the first 80,000 years (although this assumed that the site situation remains stable throughout the simulation period which is not realistic). Only water-borne transport pathways were evaluated. The ability of the model to predict the activity concentrations

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[a] In France, the operator in charge of the remediation of uranium mining sites considered waste rock as clean cover and hence topsoil depth had not necessarily to be very great: this surface layer was primarily meant to ease landscape redevelopment. The Bellezane site is also in a topographically low area and thus erosion rates are low, again supporting use of a small topsoil layer that may be considered unsustainable in other areas.

at the discharge point (prior to water treatment) varied according to the assumed hydraulic conductivity: the default value was not representative of site conditions due to mining tunnels below the site that increase water flow. A further difficulty encountered was in discriminating between natural and anthropogenic activity, which may account for observed differences between modelled and measured activity concentrations.

For the future exposure situation the total dose at beginning of the simulation (up to around 800 years) was 20 mSv/y resulting from radon and short-lived progeny from both tailings and waste rock. After this time, water-related exposure pathways dominated and a maximum dose of 155 mSv/y was calculated, with Po-210 being the key radionuclide. Rn-222 is calculated, by default in RESRAD, to enter buildings by diffusion through porous media (e.g. concrete slab).

A sensitivity study on rates of erosion and effects on the tailings cover was also performed. The default value for erosion resulted in the cover remaining intact at the end of the simulation period (after 100,000 years), but a more conservative assumption on rate of erosion led to total loss of cover after 17,500 years and tailings then eroding after 70,000 years. The maximum dose rate for the increased erosion scenario was around 650 mSv/y. Further sensitivity studies looked at the sensitivity of results to parameters such as Kd, hydraulic conductivity, Rn-222 diffusion coefficient and media porosity.

Further work is planned within the IAEA MODARIA programme. More complex exposure scenarios will be considered and there will be greater analysis of sensitivities and uncertainties in a probabilistic approach.

2.4 ASSESSMENT OF NEAR-SURFACE DISPOSAL OF RADIOACTIVE ASBESTOS AT THE LLWR

Trevor Sumerling presented.

The LLWR is a near-surface disposal site for low level radioactive waste that is located at a distance of around 5 km from Sellafield. The site is vulnerable to coastal erosion and is expected to be subject to erosion within a period of a few hundred to a few thousand years from present. The uncertainties in timing are due to uncertainties around global climate change and the effect on ice sheet melting rates. Whilst timing is uncertain, the expectation that the site will be subject to coastal erosion is not.

Total imports of asbestos into the UK amounts to around 600 million tonnes from the early 1900’s until the mid-1990’s: the hazard associated with asbestos was not initially recognised until the mid-1980’s at which point imports significantly reduced. Asbestos, is a naturally occurring fibrous mineral that occurs in a variety of forms. Amosite (brown asbestos) and Crocidolite (blue asbestos) are the most hazardous forms and were banned from use at an earlier time than white asbestos (chrysotile), which is the form that has been most widely used. Blue and brown types have more brittle structures and the hazard is associated with inhaling inert fibres that frustrate lung clearance processes. Inhalation can ultimately lead to mesothelioma, lung cancer and asbestosis. Man-made mineral fibres such as rock wool can irritate skin and nasal passages, but there is no evidence for cancer induction.

The epidemiological evidence indicates that lifetime risk of mesothelioma and lung cancer is linked to cumulative exposure to asbestos fibres, but also increases with time since exposure. The risks from mesothelioma are substantially greater than those from lung cancer or asbestosis.

Lifetime risk factors for mesothelioma, based on occupational exposures have been produced (Figure 2-2). The risk factors are related to the age at which exposure occurs and are non-linear.

Cumulative exposure (from age 30, over 5 yrs)	Mesothelioma – Lifetime Risk per 100,000 exposed		
Fibre/ml.years	Crocidolite	Amosite	Chrysotile
100	40000 (Up to 2-fold uncertainty)	6500 (Up to 2-fold uncertainty)	200 (Up to 3-fold uncertainty)
10	4000 (Up to 2-fold uncertainty)	650 (Up to 2-fold uncertainty)	20 (Up to 3-fold uncertainty)
1	650 (Highest arguable estimate 1500 lowest 250)	90 (Highest arguable estimate 300 lowest 15)	5 (Highest arguable estimate 20 lowest 1)
0.1	100 (Highest arguable estimate 350 lowest 25))	15 (Highest arguable estimate 80 lowest 2)	(Highest 4)
0.01	20 (Highest arguable estimate 100 lowest 2))	3 (highest 20)	
0.005	about 10 (Highest arguable estimate 55, lowest "insignificant"))	about 2 (highest arguable 15)	
0.00007		Highest arguable becomes insignificant	
0.000006	Highest arguable becomes "insignificant"		
Note that the above risks all apply to exposure starting at age 30. The cumulative exposure "year" is an occupational year – assumed to be about 2000 hours. The cumulative exposures in column 1 can be converted to cumulative exposures in fibre/ml.hours by multiplying by 2000; for example 0.01 fibre/ml.years = 20 fibre/ml.hours.			

(After Hodgson and Darnton (2000), table 11)

Figure 2-2. Lifetime risk factors for mesothelioma.

Due to the propensity for use, particularly for high voltage electrical shielding and thermal shielding applications, any nuclear plant built prior to the 1990's will certainly contain substantial quantities of asbestos. Depending upon the areas in which it has been used within a plant, there is potential for radioactive contamination. As such there is a need to consider how radioactively contaminated asbestos should be disposed and to establish relevant associated waste acceptance criteria (WAC).

The forward waste inventory for LLW suitable for disposal at the LLWR amounts to a raw volume of around 500,000 m^3, of which 13,000 m^3 may include at least some asbestos. The total volume of asbestos within these LLW waste streams is calculated to be 1,000 m^3. Larger amounts of asbestos are associated with VLLW and the volume of VLLW that may bear asbestos in the forward waste inventory is some 190,000 m^3: however, it is expected that this waste can be disposed of to conventional landfill. The concern is therefore on the disposal of radioactively contaminated asbestos that falls within the category of LLW[a].

Asbestos is classified as a hazardous material and regulations are in place to control use and disposal. The Environmental Permitting Regulations 2010 (EPR) and Control of Asbestos Regulations 2012 (CAR), both apply, as do associated Approved Codes of Practice (ACOP) for the conditioning of asbestos wastes. In particular, ACOP 24 requires "… asbestos waste … be placed in suitable, labelled bags, wrapping or packaging as it is produced which … ensures no asbestos fibres are released … this

[a] In the UK, waste with specific activity less than 200 Bq/g is classed as VLLW and may be routed to licensed landfill or for reuse/recycle. LLWR capacity will be reserved for LLW requiring engineered disposal, i.e. with activity above 200 Bq/g.

shall not apply to intact asbestos cement sheeting in good condition and textured coatings firmly attached …". Regulations on the safe transport must also be complied with.

The Environment Agency of England and Wales has indicated that they will not apply more stringent conditions to the disposal of radioactively contaminated asbestos within the LLWR than would apply to disposal of non-contaminated asbestos in a hazardous waste landfill. However, the LLWR is considering whether they should do more, since ACOP disposal conditions are not robust in terms of LLWR assessment timescales. The ACOP disposal conditions can be varied, but any variation must be justified.

Within the LLWR Environmental Safety Case, the objective is for asbestos hazards to be assessed in a way that is as consistent with the assessment of radiological hazards. The assessment considers the natural evolution of the site whereby the repository is eroded within a period of a few hundred to a few thousand years, leading to exposure of local beach users and other groups. Human intrusion scenarios are also considered following release of the site from regulatory control. The exposure of intruders and post-intrusion site users are evaluated. Due to the nature of the hazard, only inhalation is considered for asbestos with calculation cases being selected that have the potential for the highest inhalation hazard.

The relationship between the concentration of asbestos in air relative to soil has been calculated from asbestos experiments where soils were doped with asbestos fibres and the air concentration measured. Committed lifetime risk from annual exposure has been derived to bring the assessment in-line with the approach taken for radioactivity and calculated risks compared with the risk guidance level radioactive waste disposal (10^{-6} per year).

The mixture of asbestos types within the waste that will be received to the LLWR is not known. For the purposes of the assessment therefore, a ratio has been calculated based on the ratio of imports to the UK, but made more cautious with regard to amount of the more pernicious forms. Risk levels have then been evaluated corresponding to human intrusion, worker and public risk levels. Exposure to fibres/ml air on the beach can exceed the risk value, but when relevant processes, such as wetting factors associated with the environment and the waste form (blocks), the likelihood of exposure, and hence risk factor, is reduced.

The assessment has indicated that an agreement on the disposal of contaminated asbestos at the LLWR is likely to be achievable, but there may be conditions placed on disposal with regard to the engineered barriers (to ensure that they are at least as protective those required for conventional asbestos disposal facilities). Whilst risks from human intrusion are low, the emplacement strategy would be optimised to reduce risks (e.g. by ensuring that containers are not all stacked at one location).

Overall, it is considered that the LLWR can accommodate the amount of asbestos waste that would be classed as LLW, avoiding the waste being classified as an orphan waste, which is not desirable. The protection level that would be offered by disposing of this waste at the LLWR would be above that afforded to asbestos that is disposed of to conventional hazardous waste sites due to the containment offered by metal container and grout: the different conditioning treatment that could be applied will be considered in future work.

2.5 POTENTIAL BENEFITS OF PROCESS-BASED MODELS FOR LONG-TERM ASSESSMENT

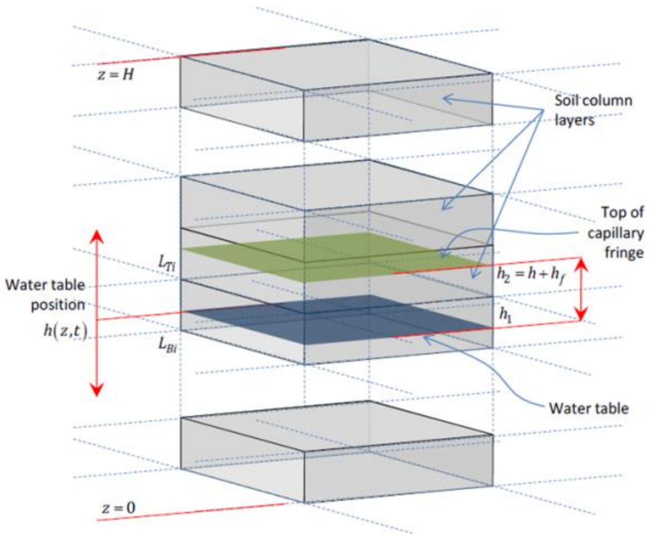
Danyl Perez-Sanchez presented.

There is considerable interest in developing biosphere models appropriate for assessment of the radiological impacts of solid radioactive waste disposal. However, large uncertainties arise concerning the nature, timing, magnitude and spatial extent of any such releases over the timeframe of interest. Simple prognostic models based on empirical relationships developed from short-term observations of present day radionuclide releases may not always provide the level of confidence desired for longer-term assessments. A more detailed process based modelling approach may therefore be more appropriate in these circumstances.

A major challenge is to identify where the greatest advantages can be gained in:

- reducing model uncertainty and understanding variability,
- developing criteria to identify when the additional research required to parameterise dynamic-mechanistic models is warranted,
- identifying the level of model complexity needed for specific exposure scenarios.

The features of the simple soil-plant system one or two compartment models most commonly used in previous repository assessments were noted, as illustrated in the example reference biospheres in IAEA-BIOMASS-6, and compared with those of more advanced models. These allow consideration of detailed site specific information such as landscape evolution, multiple linked biosphere objects, local hydrology including seasonal variation and the dynamics of plant uptake and bioavailablity. These tend to be represented in models with 10 or more soil layers allowing for spatial and temporal variation in depth dependent characteristics (see example illustrations in Figures 2-3 and 2-4 which relate to models developed for CIEMAT and SSM). Note that the GEMA 10 model takes specific account of conditions which can be anticipated at Swedish sites. Other models are under development by other organisation that take into account such site conditions.



The soil is divided into a column of 10 compartments. The flow calculations are required to provide water flows into and between these soil compartments and water content for each of them.

A 1D soil column is used. This soil column is considered either to drain from its base or to receive an upward groundwater flux from below.

Considers root-depth distribution and root-depth uptake

Figure 2-3. CIEMAT Model to represent the behaviour of Se-79 and U-238 series in soils and plants.

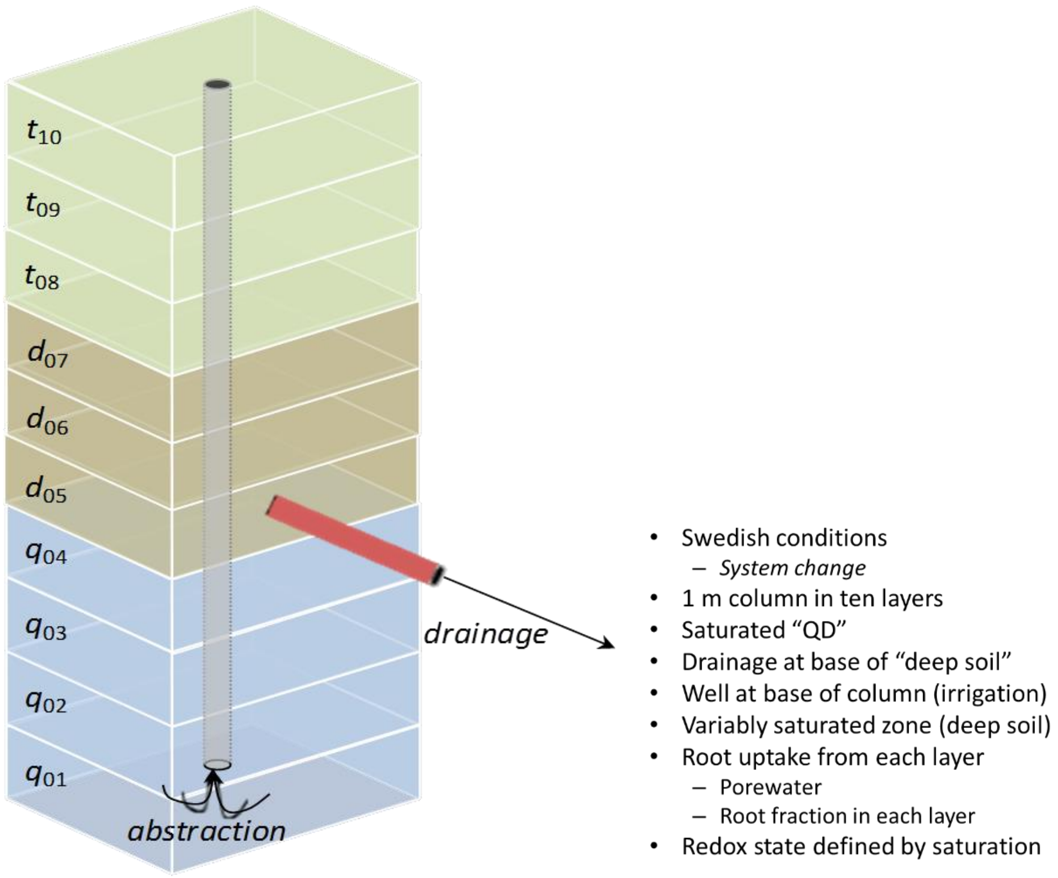


Figure 2-4. GEMA 10 Model developed for SSM

Growing experience in the application of these models can be used to determine the significance of different processes and the effects of more, or less, detailed temporal and spatial averaging. Figure 2-5 illustrates the effect of increasing the number of soil layers for the GEMA 10 and the CIEMAT (PS) model for a continuous release to the biosphere of Ra-226 accounting for annual average and monthly variation in hydrology. Figure 2-6 shows the corresponding results for Se-79, which is more redox sensitive and therefore more significantly affected by the effects of hydrological variation due to the assumed relation between saturation and sorption. As far as Se is concerned the simple model and equilibrium CR/Kd approach would appear to significantly underestimate the uptake compared to the dynamic model. This is true for each of the four combinations of hydrology and averaging. These results can be understood in the degree to which the models are able to recycle radionuclides from the deeper layer to the soil column and by the uptake from the different layers in the soil either coded by the root-fraction or the root distribution function.

A range of other examples of model testing was presented.

These kinds of investigations help to identify where and when more detailed modelling and experimental research could improve confidence and understanding, and this could, in turn, support the more appropriate focussing of characterisation activities, in the later stage of site investigation.

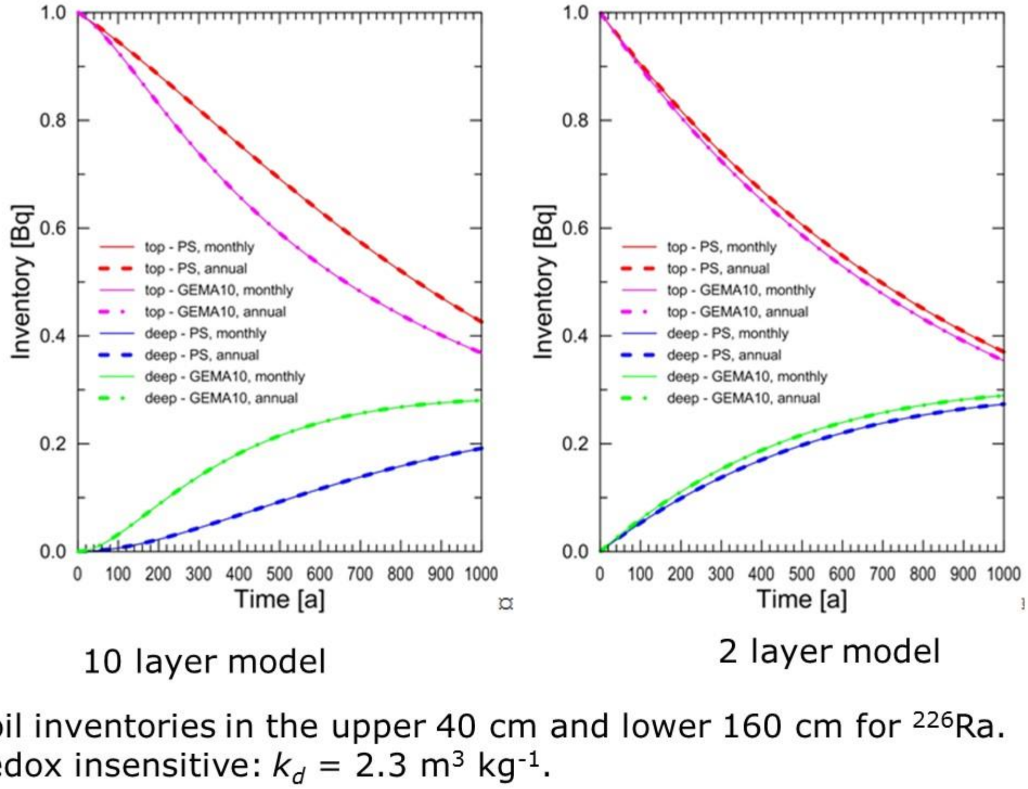


Figure 2-5. Illustration of the effect of increasing the number of soil layers for the GEMA 10 and CIEMAT (PS) model

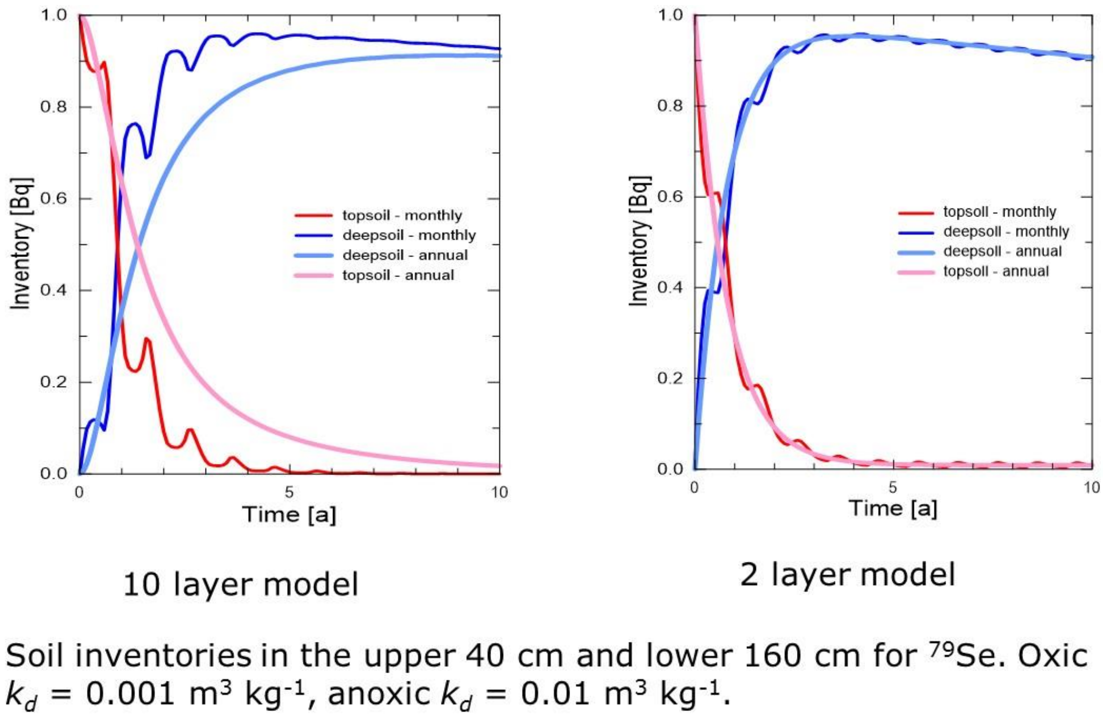


Figure 2-6. Illustration of the effect of increasing the number of soil layers for the GEMA 10 and the CIEMAT (PS) model.

2.6 BSA-2012 BIOSPHERE ASSESSMENT AND ENDPOINTS

Thomas Hjerpe presented

In Finland, spent nuclear fuel is planned to be disposed of within a deep geological repository in crystalline bedrock on Olkiluoto Island. According to national regulations, it is only required that radiological impacts are evaluated. The evaluation must consider the dose to the most exposed people and the rest of the population with annual effective dose being the assessment endpoint. Dose constraints are stipulated for both assessment groups. However there are a number of assessment scenarios that require consideration and, with the more extreme disturbance situations (also very unlikely) such as human intrusion into the facility, doses must be calculated, but do not need to be compared against dose constraints.

The assessment timeframe is at least several millennia, which has been interpreted as 10,000 years. Over this timeframe, it is not possible to predict human behaviour and the regulator has therefore stipulated that constant current human habits can be assumed. Similarly, climate type and nutritional needs can be assumed to remain consistent with those of the present time.

Beyond 10,000 years, constraints are stipulated, but these are evaluated according to activity fluxes into the biosphere and, as such, detailed biosphere assessment is not required for longer timeframes.

The derivation of dose to the most exposed people is consistent with the representative person concept of the ICRP. There is however also a need to demonstrate that doses to other people are below a second criteria. Mean annual doses to all exposed people, including the most exposed are therefore derived based on cautious assumptions around route of exposure. There is a Government Decree, which also stipulates that the exposure of plants and animals to radioactivity is also assessed. This requirement has been incorporated into STUK regulatory guidelines, although no quantitative criteria are stipulated.

The landscape model used in the assessment consists of numerous hydrologically connected compartments that evolve over time to allow for post glacial land uplift, that provides a 4-dimensional view of the distribution of radionuclides with both space and time components. The output of the landscape model in terms of environmental activity concentrations is combined with site-specific information on edible productivity, concentration ratios and other key parameters to calculate exposure. The exposure characteristics, in line with regulatory requirements, are based on local habits of the present day. However, the import/export of food is not incorporated such that the dose assessment is conservative in respect of the population in the modelling area; all food and water that is contaminated is assumed to be utilised by the local population. Food utilisation is based on a constant energy demand of an individual. Landscape doses are calculated according to the dose that people can receive through the utilisation of a landscape object: one person is assumed to obtain all their energy and water requirements from the most contaminated object(s) and subsequent people then utilise what is remaining until the dose to 6,000 people has been evaluated (equivalent to population density at the current time). The 20 persons (“a family or a small village”) receiving the highest doses are taken as the most exposed group with the remainder being categorised as ‘others’ in terms of compliance demonstration.

A similar approach is taken for biota. ERICA is used as the basis for the assessment (to derive dose conversion coefficients for representative species) with site data on such species being applied where available. Representative species have been identified through careful consideration of current food webs and niches. Area weighted average dose rates for representative plants and animals in all relevant biotopes are calculated to give a typical dose rate, as required according to regulatory guidelines.

Results of the reference case, which assumes a single small undetected hole that starts to leak 1,000 years after emplacement, indicate that the most exposed person received their dose primarily from consumption of fish and from drinking water from a contaminated well (Figure 2-7). Once fish as a source of food has been fully utilised, other foodstuffs are consumed by the population and doses reduce. External dose is only a minor contribution to total exposure and the location of dwellings is therefore of little concern. However, regulations require that a small village is considered, hence a group of 20 individuals has been assumed as the most exposed group. The average dose to this group is 2E-7 mSv. For 'other' people, drinking water from a lake is the dominant exposure pathway since the majority of contaminated food has been consumed by the most exposed group: food ingestion accounts for less than 0.01% of the average dose to 'others'.

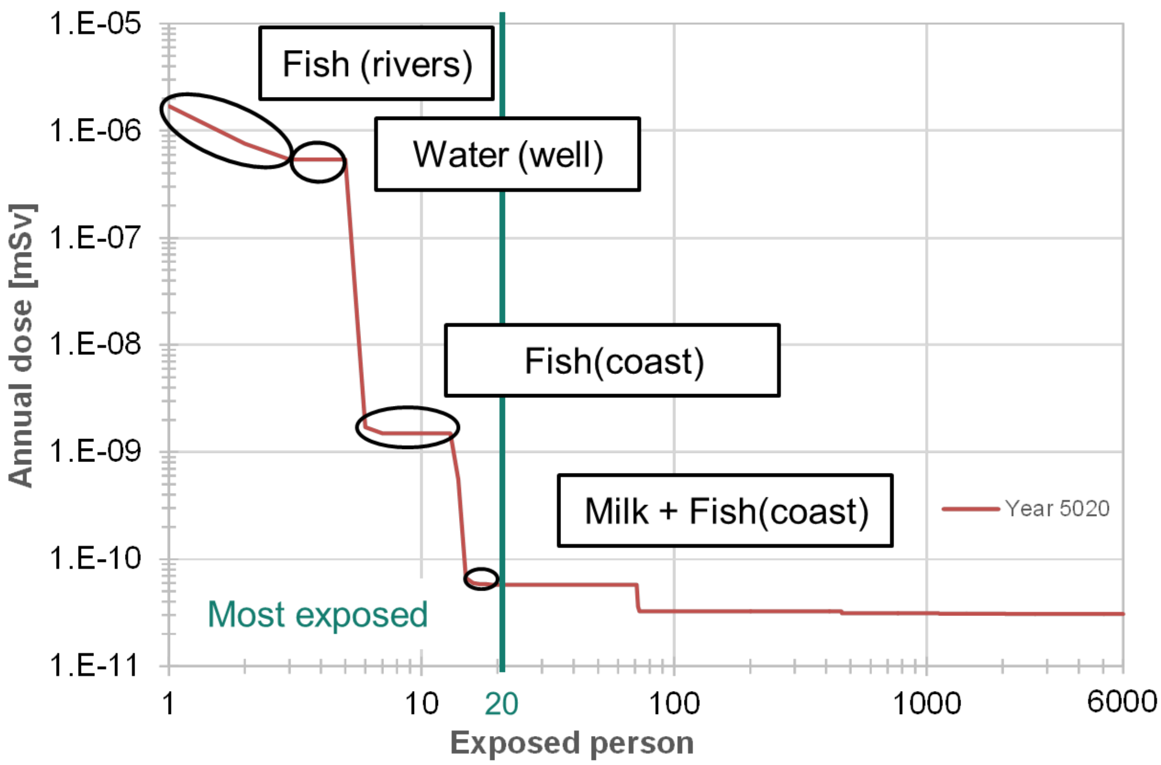


Figure 2-7. Annual dose to individuals and source of exposure in the Reference Case.

For plants and animals, dose rates were assessed to be about 9 orders of magnitude below the ERICA screening value (10 µGy/h) in the Reference Case: freshwater plants and animals are the most exposed with dose rates of around 1E-7 µGy/h. Geometry is a key factor affecting dose to freshwater biota due to C-14 being the dominant radionuclide contributing to dose. Of all calculation cases, the 'habitat' case was the most limiting. This calculation case assumes that plants and animals remain within the single most contaminated biosphere object they can reasonably be assumed to inhabit. Whilst dose rates were greatly increased above the Reference Case, they remained an order of magnitude or more below the ERICA screening value.

As noted previously, after 10,000 years, the flux of radioactivity to the biosphere is computed and compared against flux constraints that have been calculated by the regulator. The regulatory approach to calculation of flux constraints has not been documented in an official report, but the approach is understood to have been to back-calculate from the public dose limit using SR-97 biosphere models. The flux constraints are substantially lower than fluxes linked to phosphate mining and processing in

Finland and elsewhere, see discussion in POSIVA 2012-11, Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto: Complementary Considerations 2012.

2.7 SURFACE ECOYSTEMS IN THE ASSESSMENT OF RADIONUCLIDE WASTE

Ulrik Kautsky presented.

The biosphere is an important focus in safety assessments. It is the area in which people live and, because people have access to the area, unlike the geosphere, they know what it looks like and can therefore relate to information being presented. It is therefore necessary to demonstrate knowledge of the biosphere to gain trust from the public, but due to the complexity of the biosphere it is also necessary to simplify the system to allow assessments to be undertaken.

Defining the biosphere is not simple. In some views, the biosphere extends down to underlying rock whereas for others, it extends further to the deep geosphere, i.e. including near-surface rock. In SKB the preference is to consider the biosphere as the surface ecosystem, which is that overlying rock.

Within the safety assessment, radiological hazards are summarised in terms of dose and compared against regulatory criteria that are set on the basis of what may be considered an acceptable risk level (a risk level of 10^{-6} equates to a dose of around 14 µSv). However, the surface system is not only considered in terms of the assessment of dose, it is also used as a means of optimising the repository system through consideration of how the surface system affects the deeper geosphere. Non-radiological effects on the surface system, such as the effects of construction, should also be considered.

The assessment timeframe for SKB extends as far 1 million years. There is a legal requirement to undertake a realistic assessment for the first 1,000 years post-closure, but up to 100,000 years a risk limit can be used and, at times beyond 100,000 years, indicative indicators can be applied. It will take around 1,000,000 years for the radiotoxicity of the waste to reach natural levels. Release from the near-field will take 100,000 years or more with release to the biosphere occurring after this time. The total dose from internal and external exposure is substantially below the regulatory limit, which is itself set lower than the dose associated with background radiation.

Concerning dietary intake, diets vary both between and within countries and it can be difficult to couple population size to food intake. The approach of SKB in the SR-Site assessment, which is similar to that applied in the recent assessment by Posiva, has focussed on energy requirements in terms of carbon consumption: reference man eats around 110 kgC per year. Everything produced within a biosphere object is considered to be used as food, based on the estimated productivity of a unit area of land: production of food is thus spatially constrained. The approach has the benefit of being based on primary production, which varies globally by as little as a factor of 10. Land productivity and carbon-consumption requirements have been used to compute landscape dose factors that enable dose to people to be evaluated. The remaining issue is then how to evaluate where the radionuclides will enter the surface environment and how they then behave.

The approach to addressing this issue at Forsmark has been to estimate discharge areas and to connect biosphere objects hydrologically. Movement of radionuclides from environmental media (soils, sediments, water etc.) into the food chain could be by use of concentration factors. This provides a simple means for computing activity concentrations in foodstuffs; however there is a large variation in literature data and it is not easy to understand what drives this variability. The variability can be reduced through site measurements, but there are issues around the extent of measurements that can be made such that data gaps will remain. The concentration factor approach is also not appropriate for all elements (e.g. carbon) and requires assumptions of steady state which is not the case in many systems.

The SKB approach has therefore been to consider ecosystem models that evaluate biomass production and consumption across the foodchain in terms of the flow of carbon. Elements are also considered in terms of flow alongside carbon, but taking into account the behaviour of different elements. This approach allows the transfer of radionuclides into food produced and consumed to be computed and can also be applied to evaluate the uptake of radionuclides into plants and animals for biota dose assessment. The approach is data intensive, but makes maximum use of site data derived from extensive characterisation activities.

In the early assessment stages (prior to site selection) lack of data was an issue, particularly in terms of model development. However, by compiling data and considering data gaps it was possible to design the site investigation programme, which included measuring element fluxes and undertaking wildlife surveys.

The site investigation programme was not performed solely to gain data for the assessment; it was also undertaken with the objective of demonstrating understanding of the site which was considered important in gaining the trust of stakeholders and the public, and to obtain data that would be applied in an environmental impact assessment. The investigation programme also established a baseline against which actual impact can be evaluated. The data obtained will be used in future safety assessments that are required at intervals of around 10 years.

With the long assessment timeframe, climate change is an important consideration and a reference glacial cycle has been established. The cyclical period of importance is determined according to whether the disposal facility is located deep in the geosphere or is near to the surface. In the case of the near-surface SFR facility, the first 50,000 years of the glacial cycle are the most important whereas for SR-Site the full glacial cycle is repeated around a dozen times. The glacial cycle affects landscape evolution: shoreline displacement following the last glaciation continues to affect the landscape with the Baltic Sea coastline evolving into an enclosed bay that will eventually become terrestrialised, forming agricultural land and/or forest. As the landscape develops, water flows are affected. Gradually the bay will shrink and water turnover will be restricted, which will in turn affect salinity, reducing it over time. Different land use assumptions are considered according to climatic conditions. For example, under permafrost conditions there will be reduced agriculture leading to a greater coverage of forest. Possible evolution of the landscape is informed from knowledge of the past evolution of the site to present day conditions, with this evolution then being projected to the future. Sediment typology is used to evaluate potential land use. Numerous ecosystem reports are available from www.skb.se that present SKB's ecosystem understanding, process descriptions and data compilations.

Once understanding of how the surface system works has been gained through site characterisation activities, the release of groundwater and associated radionuclides to the surface system was investigated, with discharge points being clustered around water bodies. Upon reaching the surface, water and element migration is investigated through the application of hydrological models. The surface system itself has been divided into distinct biosphere objects that are interconnected within water basins. Radionuclide transport within each biosphere object is modelled to evaluate transport between different media and each object can evolve from one state to another to allow for landscape evolution. Peak activity concentrations are evaluated and, since each biosphere object is known in terms of size and productivity, the number of people an object can support can be determined.

In addition to evaluating impacts on people, the impacts on plants and animals has also been evaluated. The Forsmark site is located in a region that has several protected features and species; a number of red list species have been identified during site surveys. However, the number of species identified is likely a function of effort rather than there being a higher density of such species in the area compared to elsewhere in Sweden. Evaluating impacts on protected features and species is difficult in terms of long-term safety assessments however as land evolution leads to a constantly changing environment that will itself affect habitats and species.

A similar assessment approach to that of SR-Site is being applied in the current SFR assessment that is due to be submitted at the end of 2013. Work is also starting on SFL, a disposal facility for intermediate level waste with that assessment being due at the end of 2014. The SR-Site assessment is currently under review by the authorities and questions arising during the review are being addressed. A research programme plan is also due to be submitted in September 2013. This will detail research undertaken during the last 3 years and provide the forward plan for research activities over the next 3 years. Part of the research plan includes further exploring data derived from site investigations. It is also hoped that collaborative work with Posiva can be established to collectively look at site data gathered during characterisation programmes. Much of the work from the last 3 years has recently been published as a special issue in the journal AMBIO (volume 42(4), May 2013).

From the experience gained throughout the SR-Site programme, it is recommended that site investigations are started early in a programme, even prior to site selection, to allow experience to be gained in drawing together generic data for assessment models and to train those that will undertake field work. The development of competencies is not only important for the assessment team, but also for authorities that will review the assessment upon submission.

2.8 ENVIRONMENTAL RELEASES AND VERY LOW LEVEL WASTE MANAGEMENT AT ANDREEVA BAY

Graham Smith presented on behalf of Anna Filonova, Federal Medical Biophysical Center (FMBC).

FMBC is a technical support organisation that is linked to the Federal Medical Biological Agency of Russia (FMBA).

For legacy issues in Russia there is a need to develop an enhanced regulatory framework. One important legacy site is Andreeva Bay. It is designated as a site for temporary storage of spent fuel and radioactive waste, arising from submarine operations primarily in the 1970s and 80s. However, containment has not been 100% successful and some materials are significantly degraded, and leaking storage facilities have resulted in local contamination of soils and other media. As part of a regulatory cooperation programme with the Norwegian Radiation Protection Authority, a threat assessment was undertaken to identify what needs to be improved in terms of regulatory guidance and a lot of preparatory work has been done in terms of how stored fuel and radioactive waste should be moved and managed thereafter. The major spent fuel recovery operations are due to take place over the next few years with subsequent transfer to Mayak PA. Low and intermediate level radioactive waste is due to be transferred to a site at Saida Bay, and once conditioned, it is planned that storage will be for a period of 70 years, alongside submarine reactor compartments.

Once spent fuel and the more active radioactive waste have been removed, site clean-up will be required. The bulk of radioactive waste generated in clean-up is expected to be only slightly above clearance levels, and so could be categorised as very low level waste (VLLW) requiring less stringent management than that provided for wastes consigned to Saida Bay. The plan is to bury this waste at the site, in accordance with a newly developed VLLW guidance document. The guidance is specific to the site, but provides a model that could be applied to other legacy sites. The final remediation strategy will determine volume of waste to be disposed. This is in turn dependent upon the understanding of the residual contamination source term, taking account of current contamination levels and the potential for changes during recovery operations and the on-going migration, for example from the land to the adjacent marine environment. Work is on-going to characterise the contamination and its potential for migration, alongside the development of software for visualisation and prognostic assessment.

2.9 LAND UPLIFT AND ECOSYSTEM DEVELOPMENT IN BSA-2012

Ari Ikonen, Ville Kangasniemi and Lasse Aro presented.

Olkiluoto was selected as the site for the Finnish repository for spent nuclear fuel in 1999 and a license application for the construction of the facility was submitted in December 2012. Olkiluoto is a 'young' island that is subject to land uplift. It is surrounded by the Baltic Sea; a brackish water body that is progressing toward becoming freshwater.

Regulatory requirements stipulate that the safety assessment for the repository should have an assessment timeframe of several millennia (10,000 years) and should take account of environmental changes resulting from changes in ground level relative to the sea.

Around 5,000 years ago the coastline was some 30 to 40 km from the site and has gradually progressed over time to its current position. This historical coastline progression has been modelled and is projected into the future to look at how the future coastline might progress. The model indicates that the Bothnian Bay will eventually become isolated from the rest of the Baltic Sea, forming a large lake. This isolation will occur toward the end of the assessment timeframe, around the year 12,000.

Other lakes will also form in the assessment area over time. These are not currently present on the island and, as such, reference lakes have had to be identified that are representative of the type of lakes expected to form. Similarities are ensured by checking that overburden types, climate and vegetation zones are similar.

Since the landscape is continually evolving as new areas emerge from the sea, the interface between the geosphere and biosphere also evolves. Olkiluoto Island has emerged from the Baltic Sea quite recently, which is reflected in the overburden types. The coastline tends toward rocky till with soft sediments being washed away. However, in more sheltered areas where wave action does not contribute to erosion, leaf litter and fine sediments build up and, in wetter areas, mire formation is initiated due to development of peat-forming vegetation. The age of soils varies considerably in the region: sandy till is the dominant soil type.

The continued land uplift affects the groundwater table with a move from sea-dominated gradients to topography-dominated gradients over time. Currently there are areas where the groundwater table is above the surface, but over time, as soils develop and build and land continues to rise, the groundwater table will lower relative to the surface. Formation of mineral soils is an important process with most areas being subject to podzolisation. It can take up to 2,000 years for sand and sandy till soil profiles to form; the soils currently present on Olkiluoto range for 0 to 2,800 years old. The age of soils will affect radionuclide behaviour that will be reflected in assessment parameters such as Kd. To investigate how such parameters are affected by soil age, different soils are being investigated, including throughout the wider reference area. The pH of soils on Olkiluoto Island is more acidic than in older soils throughout the reference area. Organic matter content is also lower in younger soils. The soil properties within the reference area can therefore help in determining the range of conditions that could occur at the site in the future. Acid sulphate soils are a particular issue area as it is difficult to identify where they will occur. These are clay and silt soils that form under anaerobic conditions within the past Littorina Sea stage of the Baltic and have the potential to acidify downstream water bodies.

Study of the overall range of soil properties and conditions both on Olkiluoto Island and the wider reference area sets the framework for experimental work to derive assessment parameters (e.g. sorption experiments) and ensures the use of appropriate literature data.

Mires will also develop over time and are not well represented at the site at present. Mire areas are represented by plant coverage of 75% or more and contain mire-specific plant species. The areas are also represented by a high groundwater table that is close to the surface of mineral soils. Over the assessment timeframe there will be a succession of mire development stages that need to be considered. There are various stages ranging from brackish marshes through minerotrophic treed and treeless mires to ombrotrophic bogs that can ultimately be overgrown by terrestrial plants. At this final stage of development there are no connections to ground or surface waters so the only source of water is from precipitation.

Groundwater fluctuation in mires impacts upon vegetation; when close to the surface the plant composition is very different compared to that associated with mires located in low groundwater table areas. Different processes and element fluxes are also notable. As with lakes, mires are not well represented on Olkiluoto Island as most have been drained. Reference mires have therefore been identified to allow processes and element fluxes to be studied and to represent the type of mires that could develop over the next 10,000 years. The reference mires have therefore been selected on the basis that they are as similar as possible to the type that would be expected to develop over time. Initially 30 candidate mires were identified, with 3 ultimately being selected for further study. These include a young mire, an old large mire and an old small mire. There are very different properties between the different mires.

The young mire (Lastensuo) is a concentric bog of an area of 4.4 km^2 within an overall catchment area of 11 km^2. The mire has dark hummocks around the centre with a base of decomposed bottom peat with weaker decomposition at the surface. At the thickest point the peat is 6 m and is subject to a very slow growth rate. The mire has a very low tree stand volume. The old large mire (Häädetkeidas) in contrast has a much greater tree stand volume.

A simple model for the mass balance of organic matter and key elements has been constructed with one model being used to represent all mire types. It is intended that information on mire development will be included in the model, but obtaining sufficient data for key elements is difficult without extensive and time-consuming field work.

In terms of lakes, these are classed as enclosed bodies of inland surface water that are surrounded by land. The surface area is larger than 1 ha and the water level is not affected by sea level. The salinity is zero. Different lakes are delineated according to productivity (oligotrophic to hypereutrophic). In order to develop, a basin is required within the topography of the sea bed, with land uplift then being the driving force behind formation. Lake development is therefore a continuing process and is affected by the catchment area; lakes are not therefore in a steady state. Initially in the development process, forming lakes will be semi-enclosed bays that will then become fully enclosed as land uplift continues. In order to be sustainable, water inflow must be at least equal to the outflow.

A biotope-based approach has been applied in modelling the surface system whereby each is divided into distinct biotopes with site data on each biotope being applied. For example, in terms of aquatic systems, there are four ecosystem types (open sea, coastal sea, lake and river). Open sea is treated as a single large biotope whereas coastal sea and lake ecosystems are each delineated into five biotopes (aphotic soft bottom, photic soft bottom, aphotic hard bottom, photic hard bottom and reed bed). Site data on each biotope have been derived from a characterisation programme that has been undertaken since 2010. The field sampling has aimed to investigate biomass and element cycling within each biotope and results of analyses are in agreement with available literature data. Conceptual models have been constructed from site data to represent biomass although some data gaps remain to be addressed. Biomass is then used to derive element fluxes and, since gaps are evident in terms of fluxes, some gaps in element fluxes are also present. More sampling work will be undertaken in the forward programme to address these gaps.

Overall, the approach to representing ecosystem development has therefore been to identify present-day analogues for the possible future evolution of the site. The use of these reference biotopes allows the lines of development to be investigated and assessment parameters to be analysed.

2.10 HARMONISATION OF CHEMICAL AND RADIOLOGICAL RISK ASSESSMENT AND RISK MANAGEMENT

Stuart Walker presented.

The US EPA addresses site clean-up under a number of different laws, however the focus of the presentation was on CERCLA (Superfund) sites and how they are remediated in line with National Contingency Plan (NCP) regulations. Superfund sites can be contaminated by both radionuclides and non-radioactive hazardous materials and the intention is to address these in a similar way where possible. The CERCLA programme deals with emergency response actions, but also non-time critical actions (i.e. remediation), the latter being the focus of the presentation.

There are currently in excess of 1,300 NPL (national priority list) sites for which only 66 are radioactively contaminated and, of these, 65 also have significant chemical contamination. Most of these sites have progressed well in terms of clean-up with 1,100 sites progressing to construction complete; however only 360 sites, of which 9 were radiation sites, have been deleted from the NPL since groundwater issues often persist after remediation activities have been undertaken and so remain on the list. Additional sites have been proposed for inclusion in the NPL.

With only 66 sites being radioactively contaminated, much of the focus of the CERCLA programme has been on chemical hazards. The decision was made to address radioactivity in a similar way to chemicals, thereby presenting information to the public using the same terminology. In many ways radiation fits well within the remediation framework for addressing non-radioactive hazards. For example, the primary effect of concern is cancer and people ingest the same amount of contaminated food whether it is chemically or radioactively contaminated. Similarly, dust resuspension and inhalation rates will be the same irrespective of whether contamination is from radionuclides or other hazardous substances. Migration through the subsurface can occur, whether radioactive or not.

Technical guides and tools are available to guide decision making with 9 criteria being in place for selection of remedies, two of which are threshold criteria that must be met. These relate to protection of people and the environment and to compliance with other federal and state laws (Applicable or Relevant and Appropriate Requirements (ARARs)), including the protection of current or future sources of drinking water. The ARARs often determine required clean up levels, but where these are not available or protective, the EPA sets site-specific clean up levels that, for carcinogens are based upon increased cancer risks, and for non-carcinogens are based on adverse human health effects in terms of a hazard index and/or address ecological concerns. Analysis always begins at the more protective end of the range, with movement away as the analysis progresses to show that this is justifiable.

The risk management framework applied is not the same as that applied internationally, but a similar scientific basis is used where appropriate. Clean up levels are expressed as risk levels rather than dose. A range of guidance documents are available from the US EPA and models and training are also made available on the internet. For example, soil screening guidance (SSG) was published in 1996 for chemical contaminants. The guidance is focussed on residential land use and includes survey and analysis procedures plus groundwater models. A radiation version has been developed, consistent with the 1996 chemical SSG, with models considering both ingestion and external exposure pathways. A chemical RSL calculator has also been developed that allows screening levels to be establishes in the absence of ARARs. The calculator can be run according to selected risk levels and 8 different scenarios/land uses can be evaluated. A radiation version of the calculator is again available. This is largely consistent with the chemical version in terms of scenarios, but includes agriculture. A recreation scenario is currently under development. The intention in developing the different calculators has been to make them look similar and to be consistent in terms of exposure assumptions and in the way inorganic substances are treated (for example in terms of resuspension rates). Steady state models are applied. Live training sessions are available on the internet.

Following the 9/11 attacks on the world trade centre, a risk assessment was undertaken to establish $1x10^{-4}$ risk based clean-up levels for the reuse of chemically contaminated buildings (largely due to concerns over asbestos). The output of the assessment is available from http://www.epa.gov/wtc/reports/contaminants_of_concern_benchmark_study.pdf. The building calculator has also been used to evaluate building clean up levels for scenarios such as dirty bombs. Inhalation of radioactivity was assessed the same as for chemicals within the world trade centre assessment, but consideration was also given to external exposure. Settled dust and ambient air are considered, but not resuspension of dust since this will vary widely depending upon the indoor environment. Fixed contamination is also included to account for any contamination within walls etc. The building calculator has two scenarios – residential and outdoor worker. For the latter, contaminated outdoor hard surfaces such as pavements are included in the tool. The calculators themselves are strictly for risk assessment and are different from survey procedures.

A risk based calculator for ecological effects caused by radiation is currently under development. The calculator is aimed at establishing risk-based Biota Concentration Guides (BCGs), or ecological benchmarks, for radioactively contaminated sites and fits within the Superfund framework for developing ecological benchmarks. The tool will include 12 animal or plant benchmark scenarios, consistent with the Department of Energy graded approach for biota assessments.

Further on-going work includes the development of a policy document for inorganics (metals and radionuclides) that will be underpinned by three published technical background documents on the monitored natural attenuation of inorganic contaminants in groundwater:

- Volume 1 - Technical Basis for Assessment, 2007;
- Volume 2 - Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate, and Selenium, 2007; and
- Volume 3 - Assessment for Radionuclides Including Americium, Cesium, Iodine, Plutonium, Radium, Radon, Strontium, Technecium, Thorium, Tritium, Uranium, 2010.

Work is also on-going to develop a calculator for field survey scenarios for ground-based scanning of surface and volumetric contamination. This is intended to facilitate real-time monitoring, but will not replace sampling and analysis.

All guidance documents are available from the EPA website.

The EPA holds regular meetings to discuss lessons learned and to identify where new guidance and tools are required. There are also numerous outreach tools to ensure community involvement and many publications are specifically written for a public audience, including a common radionuclides booklet (due to be updated in 2013). The booklet will include superfund and radiation risk assessment fact sheets and will provide information on the dose calculators. A video on the superfund risk assessment process and how the public can become involved is also provided online.

Throughout, information from various international programmes such as EMRAS are used as appropriate and international experts are often consulted.

A database is maintained on all superfund sites that tracks progress with each site. The database also allows review of site classifications in light of changes to risk levels to determine whether further remediation activities may be required.

2.11 CENTRAL ASIA LEGACY SITES: USE OF RADIONUCLIDE AND METAL ASSESSMENTS TO IDENTIFY CHALLENGES AND KNOWLEDGE GAPS

Deborah Oughton presented.

CERAD (Centre for Environmental Radioactivity) is a 10 year research programme that began in 2013 (www.cerad.umb.no). It is a large international collaboration with the University of Life Sciences, Oslo (UMB) being the main initiator, working in close partnership with the Norwegian Radiation Protection Authority (NRPA). There is an annual budget of around 5 million Euros, which includes support for project partners outside Norway. The objective is designed to provide new scientific knowledge and tools for better protection of people and environment from harmful effects of radiation (manmade and natural) and to significantly reduce the overall uncertainties in impact and risk assessments associated with radiation and radiation combined with other stressors through hypothesis directed research. It is planned to use an ecosystem based scientific approach that will be developed through a programme of targeted focused long-term research on:

- Source terms and release scenarios,
- Ecosystem transfer,
- Biological responses, and
- Impact and risk assessments.

Radioecology is not the only focus: research into UV, a potential stressor that can produce free radicals, is a recent addition to the scope of the project, including its combined effects with ionising radiation. This is currently a transient research area, but it is intended that it will be merged with the other research areas detailed above. In time, it is intended that a permanent institute for environmental radiation research will be established in Norway.

An example application of this kind of research is a project funded by NATO on a uranium mining and tailings sites in central Asia, once part of the former Soviet Union. The project is a collaboration between UMB and NRPA, plus support from local agencies, with UMB undertaking basic research and NRPA dealing with regulatory aspects. Field work was carried out between 2006 and 2009. The focus was on human health issues with field work being designed to establish supporting assessment data. However, the data has also been looked at in terms of biota assessments to identify challenges in terms of application of data within biota dose assessments using the ERICA assessment tool. Default assessment parameters (Kd and CR) were applied with available site activity concentration data for soils, sediments and water. Whilst the initial site research was not intended to support biosphere assessment, some plants and fish were collected and analysed, allowing comparison between predicted and measured activity concentrations. The work has been published in a special issue of the Journal of Environmental Radioactivity 123 (2013) 1–2.

In terms of the terrestrial environment, soil activity concentrations were high (maximum around 7 kBq uranium) although there was variability between sampling locations and the degree to which sampling locations were representative of the whole area is uncertain. External dose rates were measured at some sampling sites and were in good agreement (within a factor of 2) of external dose rates calculated using the ERICA tool. Internal dose rates were dominated by the contribution from Ra-226. The maximum internal dose rate was between 60 and 70 µGy/h and, as such, some impacts could occur to animals living in the area: the area represents an extreme environment and any animals present may either have adapted to the environment or are likely to be at the extreme limit of their tolerance. The purpose of the biota assessment was to consider whether there is reason for concern and to consider whether more surveys, focussed on plants and animals, should be undertaken to further investigate impact and which plants and animals should be the focus of any further survey work. Lichens and bryophytes were the organisms calculated to receive the greatest dose rates. For vegetation samples, calculated and measured activity concentrations were in good agreement and it was therefore concluded that the default CR data within ERICA were similar to actual ratios at the site.

CR data for uranium-series radionuclides in worms (a radiosensitive group of organisms) are lacking in ERICA; there is only 1 data point for uranium and no data are available for Ra-226. Internal dose to worms could therefore be 2 to 4 orders of magnitude greater than calculated. Research is therefore being undertaken to address this issue through gut exposure experiments.

An assessment has also been done on metal contamination measured at the study sites; however it has been difficult to identify metal screening levels that are agreed upon and that can form the basis for a risk analysis. Lowest effect levels from the Dutch environmental protection agency were used and compared against measured site data (see table below). Results indicate that metals pose a potential multi-stressor issue at the sites.

Metal	Site metal soil concentrations (mg/kg)			LEL* (mg/kg)
	Kurday	Issyk-Kul	Digmai (n=2)	
Cu	21 – 91	26 – 46	53 - 79	3.4 - 50
Cr	11 – 66	nd	51 - 59	0.4 – 81
Ni	20 – 54	16 – 34	10 – 13	13 – 100
As	9 – 53	9 – 33	50 - 58	5.7 – 60
Mo	0.64 – 102	n/a	n/a	3 - 190
Cd	0.29 – 0.94	0.35 – 1.2	n/a	0.8 – 20

For the aquatic environment, the assessment was more simple in terms of available models and site data. Some fish had been sampled from enclosed lakes and concentrations of polonium and radium were issues at some sites, but did not always dominate due to complex chemistry in aquatic systems. Issues with uranium concentration ratios in aquatic plants was confirmed by the study with the site data indicating that dose rates could be 100 times lower than those calculated using default ERICA CRs. Measured dose rates for fish were around 10 times lower than those calculated using default CR data for uranium.

For metals in water, assessment criteria were again lacking, but some drinking water standards were available. Arsenic and molybdenum were found at high concentrations and could again lead to multi-stressor effects.

Multi-stressor laboratory experiments have been used to follow up the results from the field surveys. Fish experiments with gamma radiation and copper exposure have been undertaken to look at additive and antagonistic effects through biomarker studies. However the largest sources of uncertainty are associated with internal doses from alpha radionuclides, relevant spatial scales of assessment and CR data for the major dose contributing radionuclides in the site organisms.

In terms of other project opportunities within CERAD, there is an irradiation facility available that will allow co-stressors (radiation (alpha and low-dose gamma) and non-radioactive materials (metals, pesticides etc.)) to be studied. The facility is licensed for work on both vertebrates and invertebrates (26 test species) and experiments are currently underway to look at multi-stressor effects in salmon and the nematode *C. elegans*. Experiments looking at relative biological effectiveness are also underway with zebra fish with reproductive endpoints being the focus.

Ecological field studies are planned in 2013 and will look at community and population level effects, including genetic diversity, of terrestrial organisms at a legacy radium production site (activities ceased in 1950s), subject to low human influence. The focus will be on the terrestrial system since plants and soil invertebrates typically have smaller spatial ranges than other animals. Mapping of both radionuclides and non-radionuclides will be undertaken and the type and diversity of plant and soil invertebrate species will be investigated using DNA barcoding methods. Resistance of populations is also an area of interest: in chronically exposed environments it is possible for populations to look similar to undisturbed environments, but additional stressors can lead to very different responses.

For both the radium and the Central Asia site there will be high background activity concentrations, since this was the reason for mining activities in the first place. Besides reference sites, background sites are not being specifically investigated however, although some work has been done at the Central Asia site in order to look at disequilibrium between U-238 and U-234 and the influence of mining activities. See discussion in several articles in the JER special issue mentioned above. It was noted however that for some uranium mining sites, there can be detailed documents available on the geology of sites and their geochemistry since such data was required prior to mining activities. Background data can therefore be obtained from such original mining literature.

Whilst some research programmes are underway, additional suggestions and feedback are invited, particularly with regard to multi-stressor effects since the facilities available are a real resource that can be reached out to.

2.12 NDA-RWMD POSITION ON THE ASSESSMENT OF CHEMOTOXIC SPECIES FOR DEEP GEOLOGICAL DISPOSAL

Helen Clark presented.

The NDA (Nuclear Decommissioning Authority) was established by the UK Government in 2005 with the remit to clean up civil public nuclear wastes and an advisory committee (CoRWM) was set up to look at long term waste solutions: CoRWM recommended geological disposal preceded by safe and secure interim storage as the preferred option. A White Paper was published in 2008 that details the framework. The depth of disposal will be between 200 m and 1 km underground. Both natural and man-made barriers will be used together to prevent radionuclide migration. The operational period will be around 100 years, after which time the facility will not be controlled. The concept is consistent with the internationally preferred method for disposal.

The site identification process is based around volunteerism with communities being invited to participate in the process and the NDA working in partnership with these volunteer communities. The BGS (British Geological Survey) would then undertake an initial screening of the geology to rule out sites with natural resources that could be exploited. By stage 4, desk based studies would be undertaken followed by surface site surveys at stage 5. Stage 6 would then involve underground investigations.

Three expressions of interest were initially received from Cumbria. These were from Cumbria County Council and 2 smaller boroughs in Cumbria. Shepway District Council in Kent also indicated interest and took a public vote on whether to enter the process by submitting an expression of interest, with the public voting against this. The siting process therefore was at this time, focussed around Cumbria. However, in 2013, the three areas in Cumbria took a vote on whether to move into stage 4 (desk-based studies) of the process. Although both of the smaller boroughs in Cumbria voted to proceed in the process Cumbria County Council voted against further involvement in the process due to concerns over the suitability of the geology and the ability to exit the process at a later stage. The current site selection process has therefore come to a halt and the Government is now reviewing the site selection process in light of these events with a call for feedback on the process being been made[a].

Decommissioning of nuclear sites will produce a wide variety of wastes, not all of which are radioactive and the hazardous properties of all wastes must be considered, whether they pertain to radioactivity or not. For example, lead is present in shielding and uranium is both radiological and chemically toxic. Consideration must be given as to how the different hazardous materials should be made safe within the disposal facility. In 2007, the NDA produced an inventory which was based on the annual UK Radiaoctive Waste Inventory. This took into account packaging materials, in addition to the waste itself. The inventory includes information on chemotoxic materials; however waste producers are not required to report on this aspect of their wastes. Nonetheless, no major discrepancies are envisaged (see table below).

Material	**2007 Inventory (tonnes)**	**Best estimate (tonnes)**	**Upper uncertainty (tonnes)**	**Lower uncertainty (tonnes)**
Aluminium	1,216	1,197	1,248	1,008
Lead	1,221	1,179	1,282	819
Zinc	51	69	119	41
Copper	349	335	352	302
Magnox	7,834	7,820	7,836	7,815
Zircaloy	1,479	1,476	1,480	1,474
Stainless Steel	27, 190	26,905	28,128	19,300
Other ferrous metals	45,350	45,637	46,607	44,261

In terms of regulatory requirements, the Environment Agency has produced guidance documents (Guidance on Requirements for Authorisation, GRA) for deep and near-surface disposal facilities. The GRA are aimed at the developers of facilities and detail regulatory requirements that must be met. High level requirement R10 stipulates that a developer must demonstrate that the system provides adequate protection against non-radioactive hazards and the Environmental Safety Case should provide a suitable level of protection against non-radiological hazards. However, unlike radiation for which ICRP guidelines are available, there is currently no internationally agreed procedure for evaluating the impacts of chemotoxics either individually or in combination with radiation. A hierarchical approach has

[a] At the time that this workshop was held in May 2013.

therefore been employed that makes maximum use of UK regulatory guidelines with International/EU guidelines (e.g. WHO drinking water guidelines) then being used by preference over other national guidelines (e.g. US EPA) to address data gaps.

Prior to the formation of the NDA, work relating to the disposal of radioactive waste was undertaken by UK Nirex Ltd and continued by the NDA-RWMD. Within their work programme, several research studies were done relating to chemotoxics in post closure period including preliminary assessments for human health in 2001 and then, in 2006, a 3-step screening assessment was undertaken. This assessment stated that some elements required further assessment and these were addressed in 2007 through a more detailed risk assessment for a generic facility that focussed on specific elements of concern (beryllium, cadmium, chromium, lead and uranium). The likelihood of additive and synergistic effects occurring for radiological and chemical toxins was then addressed in an assessment in 2009.

In December 2010 a suite of documents was published by NDA-RWMD known as the generic DSSC (Generic Disposal System Safety Case). Publication was intended to demonstrate the approach to meeting regulatory requirements, to help develop the assessment method and provide information to stakeholders. The generic DSSC also provides a technical benchmark in moving forward. The structure of the documents was based on the regulators who would review each document. For example, the Environmental Safety Case and its underpinning documents were aimed at meeting the GRA as set by the Environment Agency. The generic DSSC includes a generic transport safety case, a generic operational safety case and the environmental safety case. Supporting documents for each of these were also included. The approach detailed in the generic DSSC would be applied to suitable sites at an early stage of the site selection process in order to demonstrate ability to make a safety case at each site and to help screen the sites. Actual site data would be incorporated as the programme moves forward.

In terms of chemotoxic species in the generic DSSC, the approach is developing based on regulatory requirements. The Biosphere status report supports the post-closure safety assessment and the environmental safety case and identifies the specific toxic species that require analysis. The approach is based around a typical human health risk assessment with the initial starting point of the waste itself and consideration of potential for migration through to human receptors and consideration of the different exposure pathways. The focus is on individual impacts rather than cumulative effects from multiple contaminants; although it is acknowledged that multi-stressor effects can occur. It is therefore intended that target organs will be specifically considered in terms of mode of effect of different chemotoxics to allow potential additive, antagonistic and synergistic effects to be evaluated.

From the 2011 assessment inhalation rates were lower than ingestion rates for chemotoxics with chromium being the predominant concern and synergies between chromium and ionising radiation have been considered.

The current position with regard to chemotoxics is that previous work is being reviewed to identify future requirements and an MPhil is being sponsored (due to complete by the end of August). A number of IPT's have also been established, one of which is focussed on uranium and includes a task to look at radiological and chemotoxic risks. The focus of efforts to date with regard to chemotoxics has been on human health.

For human risk assessments, the same model has been used for contaminant transport in the biosphere as used for radionuclide transport such that foodchain and drinking water pathways are consistent. The assessment goes further than simply comparing environmental media concentrations against criteria (i.e. by focussing on the human receptor) to bring the assessment of chemotoxics in line with the assessment approach for radionuclides. This also enables synergistic effects (e.g. lung cancer risk from chromium and radionuclides) to be evaluated.

New groundwater regulations (specifically the European Groundwater Daughter Directive) have meant that the current methodology is being reviewed and is likely to be updated to reflect these regulatory changes.

2.13 ASSESSMENT FRAMEWORKS AND APPROACHES FOR HAZARDOUS AND RADIOACTIVE WASTE DISPOSAL: LEARNING, REGULATORY AGENCY ISSUES AND CHALLENGES FROM THE LLWR ASSESSMENT

Paul Robinson presented.

The purpose of the presentation was to describe some of the conflicts and challenges associated with the interaction of radiological and non-radiological performance assessment and regulatory compliance. The LLWR (Low Level Waste Repository) near Drigg in Cumbria was used as an illustrative example in the presentation. It was intended to provide the basis for presenting a regulatory perspective on the interaction between radiation and chemical assessments.

The Environment Agency is responsible for permitting for the disposal of solid, liquid and gaseous radioactive waste in England. The Environment Agency has recently permitted landfill disposal for VLLW and lower activity LLW, requiring investigation of the interaction between non-radiological impacts from existing disposals and the radiation and non-radiation impacts from radioactive wastes. With regard to LLW permitting, the Environment Agency is in the process of assessing LLW Repository Ltd's 2011 Environmental Safety Case (ESC) that will underpin the permit variation application for the conversion of the status of existing received wastes from stored to disposed and the extension of the disposal facility, effectively doubling the disposal capacity of the site.

The ESC takes account of known failures of capping systems for surface facilities and considers processes such as water ingress and flow of leachate into shallow and deep groundwater giving rise to radiological and chemical impacts. A particular challenge for LLW Repository Ltd relates to coastal erosion; this is a known issue, but the timescales are uncertain, ranging from several hundred to several thousand years in the future. Different scenarios are therefore considered and radiological and non-radiological impacts evaluated. Coastal erosion is not a problem faced only by the LLWR; Clifton March in Lancashire and CLESA at Sellafield are also likely to erode over a similar timescale. Kings Cliffe in Northamptonshire is not at risk from coastal erosion, but it is a domed structure and may therefore be subject to surface erosion, which is also an issue for the LLWR. In the UK, many landfills were historically built on saltmarsh locations and were regulated according to criteria in place at the time. The LLWR is constructed on the site of a former ordnance factory that was taken over by, and used for LLW storage and disposal. Whilst coastal erosion is a known issue, the regulatory approach in the UK requires that, if a site can demonstrate compliance with regulatory requirements then a permit can be granted: the Environment Agency cannot refuse a continued permit if an adequate ESC can be made and all other relevant regulatory requirements are met (e.g. related to habitat protection).

A similar level of protection is required for radioactive and non-radioactive materials. However, sometimes there are conflicting regulatory commitments, including compliance points and assessment criteria. For example, landfill assessments do not consider extended post-closure timescales due to the assumption that there is a declining source term and hence hazard will reduce to a point where regulatory compliance can be met and the permit surrendered. Whereas for radionuclides timescales are more important issue due to the persistence of certain radionuclides. There is also a lack of hazard criteria for some substances (e.g. radioactively contaminated asbestos). For hazardous assessments, groundwater is the receptor of primary interest and assessment criteria are derived from the EU

Groundwater Directive: it is assumed that leachate is present throughout the duration of the authorisation period. Following surrender of the site permit there is a need to demonstrate that there will be no hazard remaining, but the requirements differ between non-radioactive and radioactive disposal sites. A further issue relates to the fact that hazardous materials will comprise homogenous and discrete items and currently there is no framework to assess discrete items: the approach taken for landfill sites is largely to consider in terms of homogenous mixed soils.

A non-radiological hydrogeological risk assessment has been completed by LLW Repository Ltd which identified that hazardous and non-hazardous metals would be released at low levels to groundwater after a period of at least 500 years. This results in a number of exceedances in groundwater quality criteria over an extended period. The significance of the non-compliance was therefore investigated. Because of the long timescales involved, the need to optimise for radiological impacts and the scale of the non-compliance we are able to adopt a proportional approach. The assessment also identified hazards associated with asbestos and other materials as a result of coastal erosion, making waste and associated materials accessible to people. Because the Environment Agency does not expect landfill operators to undertake assessments for the exposure to asbestos as a result of long term erosion, it was not considered proportional to require LLW Repository Ltd to undertake an assessment of asbestos exposure.

The assessment performed by LLW Repository Ltd represents the first time that non-radioactive materials have been explicitly included in an ESC and, as such, areas of uncertainty and regulatory challenges were identified. For example, there is limited inventory information for non-radioactive materials since historically there has been limited interest in the chemotoxic hazards associated with radioactive waste: whilst it is known that mercury, beryllium and other chemotoxic materials have been disposed of, there are limited records.

In terms of protection targets, surface waters and groundwater are considered as are amenities. Human intrusion scenarios have been taken into account and the production of landfill gas is considered even though quantities of biodegradable materials are low. There are a number of protected habitats in the vicinity of the LLWR hence non-human biota assessments have also been considered as part of a Habitats Regulation Assessment and as part of the environment safety case.

The GRA (Guidance on Requirements for Authorisation) affords a similar level of protection from radioactive and non-radioactive hazards and aims to marry the legislative requirements together, ensuring that protection from non-radioactive hazards is no less stringent than the protection afforded at non-radioactive disposal sites and that all hazards are considered and assessed. There is however an established concept of optimisation for radioactive waste disposal that is not applied to non-radioactive waste disposal. There are a number of regulatory drivers behind the GRA approach, including the Water Framework Directive that requires a whole catchment approach to assessment and the Groundwater Directive which places strict controls on discharges to groundwaters and, for non-radioactive material disposal, there is a compliance point which is the site boundary.

LLW Repository Ltd has attempted to apply Landfill Directive requirements to the site, but a number of challenges have been identified. For example, requirements around the need to characterise a leachate and actively manage landfill gases may not be compliant with radiation protection objectives: no leachate is present to use as a source term as the disposal site is kept dry[a]. The site has therefore worked through the process in collaboration with the Environment Agency, allowing policy development to address areas of uncertainty. The inventory for non-radioactive materials has been investigated and is dominated by contamination derived from packaging and waste containers and the production of metals, but information is lacking on the non-radiological composition of the waste itself. This will improve in future as information is gathered from a requirement in the waste acceptance criteria and the site continues to operate: whilst the site assessment evaluates impacts from historical disposals, the emphasis is on future disposals.

An asbestos risk assessment has been performed by LLW Repository Ltd due to the perceived need to control hazards, which identified lack of guidance as an issue. This has promoted discussion within the Environment Agency between radioactive and non-radioactive material regulators. The assessment was deemed to be fit for purpose, but the need to consider coastal erosion due to the heterogeneity of waste was identified, as was the need to consider exposure to hazardous non-radioactive materials as a result of human intrusion.

Potential improvement areas identified include addressing issues with the non-radioactive hazardous waste inventory through characterisation work and the ongoing implementation of a non-radiological capacity framework. Failure scenarios for shallow disposal facilities tend to take an on/off approach, such as the assumption of sudden and total cap failure, however it may be more appropriate to consider more realistic gradual decline in performance as the cap degrades. There is also a need to clarify Groundwater Directive compliance procedures, which is not a sole national issue, but rather is required internationally.

A reasonableness approach has been applied in terms of the LLWR ESC. Our guidance requires that radiation hazards are optimised, but not non-radioactive hazards. Optimisation is carried out using an iterative approach to optimisation and assessment. Continued monitoring at the site will improve knowledge in terms of both radiological and non-radiological hazards that will in turn lead to more comprehensive assessments in the future.

The LLW Repository Ltd assessment (available online from www.llwrsite.com) demonstrates how assessments for a radioactive site can be developed and applied to non-radioactive materials. It serves to highlight the need to take account of the characteristics of both radioactive and non-radioactive hazards and to demonstrate compliance with European directives. Chemotoxic hazards might, in some cases, be greater than radiological hazards and they therefore should be afforded equivalent consideration. A combined and coherent approach to assessment also leads to a more rounded assessment of impacts that has benefits in terms of interacting with stakeholders. An internationally recognised consistent approach to authorisation could be of substantial benefit.

Whilst coastal erosion is a particular issue for the LLWR, all near-surface disposal facilities will be at risk from erosional processes. The effect of erosion on local amenities is potentially important: waste visibility (due to labelling and perceived value etc.) has the potential to impact upon use of local amenities. The action of people can, however, also lead to increased exposure to hazardous materials through collection of waste materials etc. and these various factors could form a useful part of site assessments.

[a] Any leachate in trenches and surface run-off is collected in holding tanks and monitored (for both radioactivity and non-radioactive materials) prior to discharge to off shore. Recovery of leachate will continue for at least 100 years following final disposals at the site.

2.14 METHODOLOGY FOR ENVIRONMENTAL REMEDIATION OF LEGACY SITES

Koen Mannaerts presented.

Mr Mannaerts set the scene by noting that Belgium is a small country with an average population density of around 350 inhabitants per km^2. Sites which are contaminated due to past industrial and other practices and events, and which remain as legacies that still require regulatory consideration, include areas contaminated with chemicals, but also some sites which have a radioactive component. Some of the latter include sites contaminated with naturally occurring radioactive material (NORM).

Nuclear matters are dealt with by the federal government and regulated by the Federal Agency for Nuclear Control (FANC), but for environmental chemicals there are 3 separately administered regions with separate rules and regulations, which can introduce complications to regulatory supervision over the possible need for intervention and remediation. Intervention does not have to include remediation, but it does involve consideration of risk management and related assessments. People are identified, so far as possible, as responsible for the contamination, and are responsible for funding assessments and remediation. The public are always engaged as stakeholders. The main stakeholders concerned with intervention and remediation are indicated in Figure 2.8.

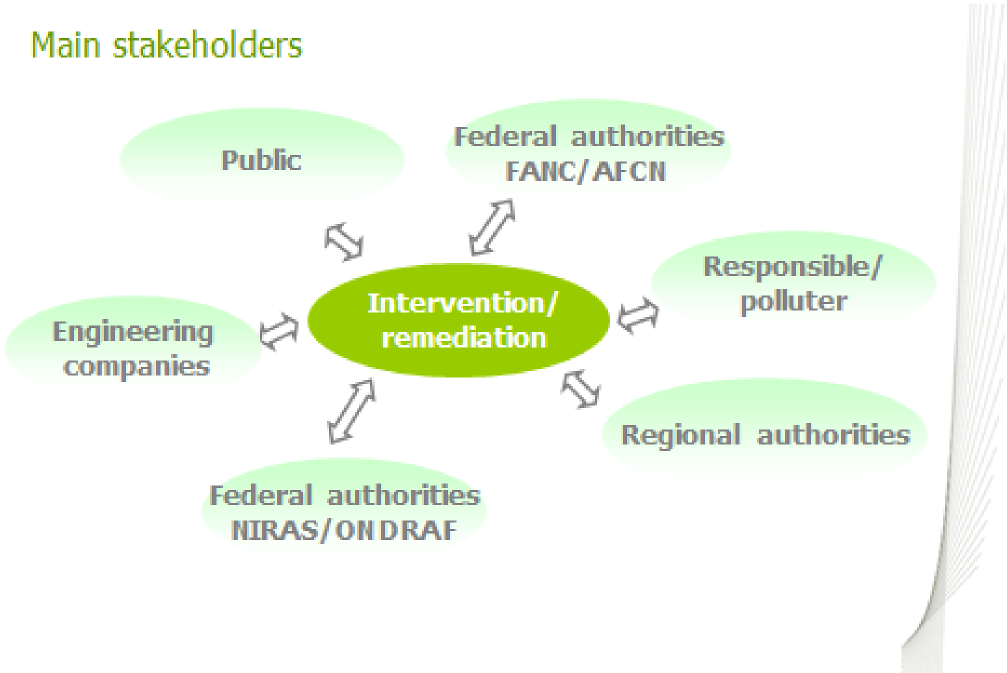


Figure 2-8. Main Stakeholders Concerned with Intervention and Remediation of Legacy Sites.

The features of assessments used to support risk management and decisions on remediation include:

- using a graded approach,
- inclusion of a waste management strategy,
- treating assessment as an iterative process,
- based on a generic framework without a rigid technical procedure,
- applied on a case-by-case basis

Typically, assessment is a multi-disciplinary process, as indicated in Figure 2-9.

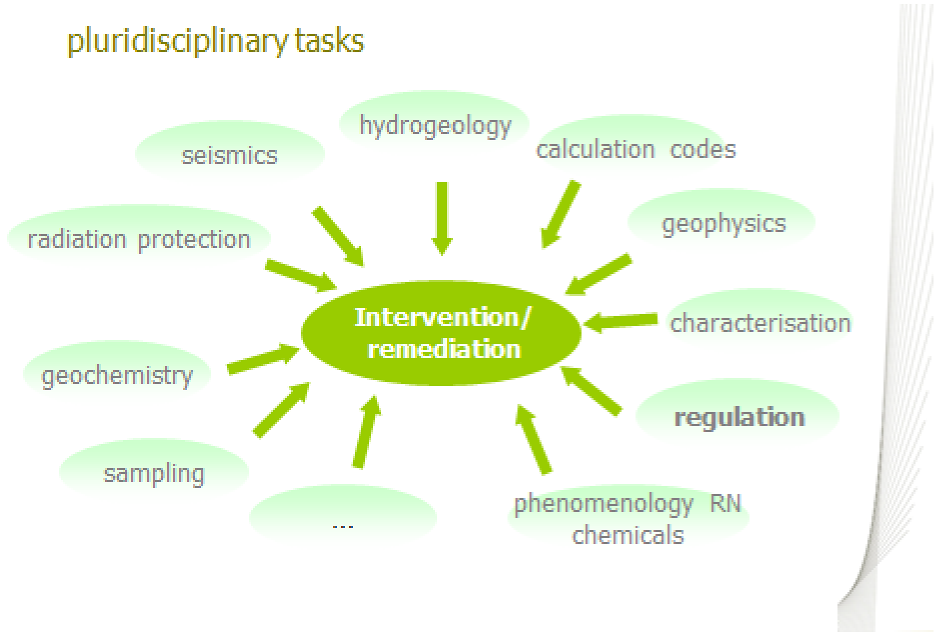


Figure 2-9. Assessment Methodology Tasks.

The management strategy for radioactive and other contaminated sites is broadly similar, involving risk evaluation, consideration of possible future land use and implementation. For radioactive contaminated sites, a specific options assessment is required. An overview is presented in Figure 2-10.

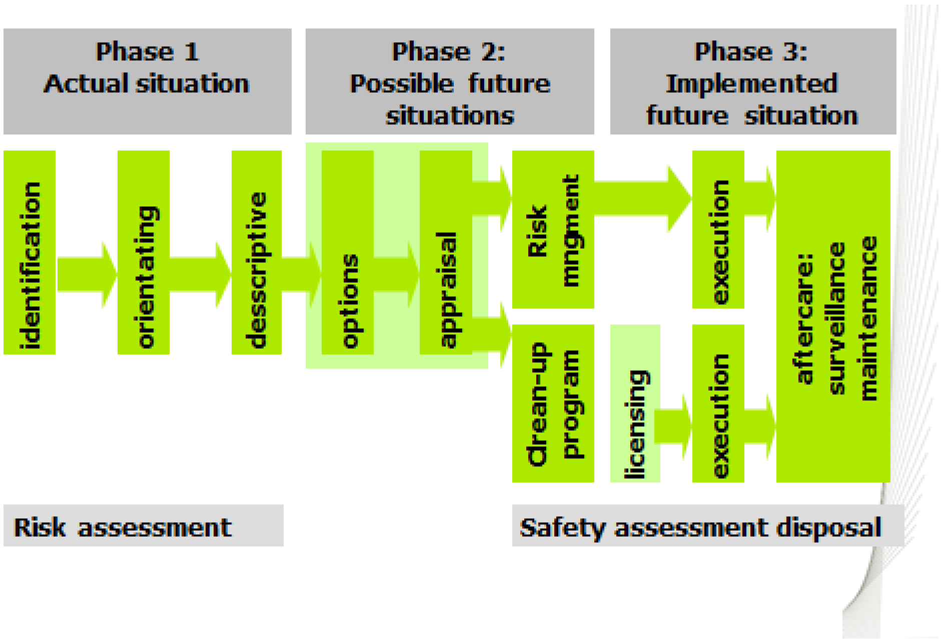


Figure 2-10. Overview of Process.

FANC has developed guidance on the intervention levels for radioactively contaminated sites as follows:

- dose < 0.3 mSv: no intervention;
- 0.3 < dose < 1 mSv: intervention rarely justified;
- 1 < dose < 3 mSv: intervention generally justified; and
- dose > 3 mSv: intervention always justified.

Assessments have to account for a defined sampling strategy and the dose assessment is based on at least three exposure scenarios; assuming current use, a "worst-case", and the likely evolution of the site. Regional authorities are responsible for non-radioactive contamination criteria.

The process was illustrated by reference to two examples, one involving a radium processing facility at Olen and the other a phosphate processing site, both of which present radioactive and chemical contamination. Both sites include areas where large volumes of waste have been deposited in near-surface dumps.

The presentation was concluded with the following key points:

- An approach for dealing with radioactively or mixed contaminated sites is available, comparable to the approach for chemically polluted sites;
- The assessment methodology exists as decision aiding tool;
- Decision making will always be influenced by a set of non-technical issues; and
- All aspects have to be considered a long time in advance before implementing a feasible, consistent, long-lasting and sustainable solution.

2.15 TRAFFIC LIGHT MODELS (TLM) FOR ASSESSING AND MANAGING RISKS ASSOCIATED WITH CONTAMINATED SITES

Maryline Moutier presented.

Ram-Ses is a Belgian risk assessment company, based in Wallonia, with a focus on soil expert advice and associated services such as ecological, human health and groundwater / surface water risk assessments. The organisation has developed a traffic light model for assessing and managing risks associated with contaminated sites. The model provides the technical tools required to evaluate the need for contaminated soil remediation and to select between remediation solutions.

Contaminated land policy has evolved considerably over recent years, particularly in response to incidents that highlighted land contamination as a human health issue. For example, the Love Canal disaster in the US involved a former dumping site that, 25 years later resulted in contamination, including carcinogens, leaching from the site into the backyard of a school built on the banks of the canal and into the basements of local residential properties. The Lekkerkerk disaster in the Netherlands also resulted from a former dumping site, but in this instance residential properties were built on the former dump site with families having to be relocated following the discovery of contaminated groundwater. Around 250 families had to be relocated at a cost of around $80 million.

Those examples led to a gradual evolution of contaminated land policies since the 80's. Ten years after these incidents, a more systematic approach to land contamination issues began with the development of national and regional inventories of polluted sites and with sites being prioritised according to soil contamination levels and the need for decontamination to allow for multi-function uses.

In the 1990's, the land policies evolved towards a risk assessment approach that distinguished between historical and new contamination. Tailor made assessment and remediation approaches became acceptable and it was no longer required for remediation activities to be undertaken that would allow multi-function use. The perspective of "land-use" is put forward in assessment and decision making. Subsequently, in 2000, a risk-based land management (RBLM) concept was established by CLARINET (Contaminated LAnd RemedIation Network for Environmental Technologies). The objective was to support decisions on risk acceptability and to determine actions to be taken, moving toward sustainable management of sites. The focus was not just on soil contamination, but also water management and ecological risk assessment.

Risk based land management concept is built on three key dimensions ("pillars") that have to be considered simultaneously to get a sustainable solution. The first "pillar" is fitness for use; a solution compatible with intended use of the site, taking into account human occupational scenarios that prevail for it. The second "pillar" is protection of the environment (and not only human health); risk assessment should be undertaken, including consideration of groundwater contamination to further evaluate if additional resources – soil or water – could be compromised by further transport and dispersion of contaminants. The third "pillar" is then long-term care; any solution should be acceptable in the long-term and take account of land planning. Together these should lead to two key decisions in terms of choice of solution and timeframe for implementation of those solutions.

Initially technical assessment tools were quite rigid, but have since developed to be more flexible, allowing a stepwise procedure to be followed. Within the first step, soil quality standards are applied to screen sites with further, more detailed assessment (step 2) being undertaken for sites where standards are exceeded.

The risk assessment procedure has evolved from decision support systems and started with a human focus, developing to a more integrated framework that also considers environmental impacts. Deterministic and probabilistic models can be applied; however, regulators tend not to like probabilistic approaches as it can be difficult to make decisions on the basis of probabilities. The process has evolved from a Boolean (white/black or yes/no) system to one where three risk zones are considered (Traffic Light Model, TLM). Within the lower zone (green zone), risks are considered to be acceptable whereas in the upper zone (red zone) risks are not acceptable. In the intermediate zone (orange zone), efforts should be made to reduce risks. The use of risk zones forms the basis for the traffic light system. Review of approaches applied in different countries has indicated that a 3-tier decision approach is often adopted with screening values being set according to national or regional background levels and applied as target values (long-term objectives generally associated to negligible risks) and others that represent cut-off values associated with (potentially) unacceptable risk and the need of remediation. Some countries also apply an intermediate value linked to the issue of warnings and triggering further action.

Whilst the overall approach between countries is largely consistent, there is large variability in the assessment criteria applied. Screening and trigger values can be as much as 2 orders of magnitude different and can vary in the actions they induce. Values representing unacceptable risks can also vary considerably. There are various reasons for the differences, including scientific, regulatory, geographical and socio-cultural reasons. The level of acceptable risk is largely due to national regulatory requirements whereas scientific reasons for differences can include whether the focus is on human health and/or the environment or whether certain processes (e.g. volatilisation) are considered (or not). In terms of geographical drivers, these can relate to soil properties and how they affect chemical behaviour. Socio-cultural differences can relate to factors such as food consumption habits (e.g. the amount of soil that is assumed to be consumed). There is a need to compromise between the different drivers, such as science and policy when deriving soil screening values and it should be born in mind that what is considered acceptable at one time may not be so at another: acceptability is therefore largely a political decision and caution and realism should be balanced.

There are different ways of working in developing precautionary soil standards (inducing also a reduction of errors of type II). Deriving values for different land uses can help to reduce variation, as well as the adjustment of values in relation to local conditions such as soil properties or bioavailability aspects. Another way of working is to reduce the incidence of those values. For instance, the use of a warning value based on conservative assumptions with the role to initiate a stepwise risk assessment procedure or to trigger actions if exceeded can also be beneficial, the timing of which can be variable. Keeping a second (risk-based) value derived with lesser conservative assumptions and/or based on higher risk limits might be interesting too. The value might be associated to a guideline role on the decisions, might have a "cut-off" character but the incidence if exceeded could be modulated (remediation is required but not urgent like in the Netherlands).

The framework for the risk based regulation of contaminated land can be schematised by three axes:

- the <u>screening risk assessment axis</u>, providing screening values according to various risk levels (negligible; intermediate and potentially unacceptable);
- the <u>site-specific risk assessment axis</u>, providing site-specific threshold values according to various risk levels (in general only the unacceptable risk level), equal to that considered in the screening assessment, but based on a more realistic derivation;
- the <u>risk management axis</u>, along which policy makers decide how to implement the values provided by the former two axes.

Along the risk management axis, the use of screening and site-specific threshold values is prescribed. Where intermediate risk values are exceeded, one approach can be to undertake further risk assessment or, alternatively, site-specific screening values can be derived. Where risks are considered unacceptable, remediation activities to achieve long-term objectives may be undertaken. This is the basic approach explaining how the traffic light system implemented in the development of numerical soil standards throughout Europe.

In Wallonia (Belgium), three numerical standards are used: a reference value based on natural and normal background concentrations; a risk based trigger value, which is the lowest of the trigger values protecting human health and the environment (including ecosystems and groundwater resources). The exceedance of the trigger value induces:

- further (detailed) investigation of the site including a (site-specific) risk assessment in order to determine if there is a "serious threat" or not for sites where pollution occurred <u>before 30/04/2007;</u>
- remediation for recently polluted sites <u>(pollution after 30/04/2007)</u>.

A third, called "intervention value", is also applied. Where this is exceeded, actions are triggered. Actions could comprise monitoring, introduction of security measures or remediation. If remediation activities are required, the (theoretical) remediation goal (or long-term objective) for historical sites is to attain the local background concentration but the core objective is to demonstrate that there is no "serious threat".

If pollutants are present with additive effects then remediation activities must at least achieve the trigger values for each of them. If there are no additive effects then it is possible for post-remediation concentrations to be above trigger values, but no “serious threat” must be demonstrated.

To have a coherent decision-system for contaminated sites in Wallonia, the “traffic light thinking” has also been adopted and implemented within the risk assessment procedure. The final result of that collaborative work comprising VITO (Flanders), the CEAEQ (Quebec), the BRGM (France) and a Walloon study bureau (Geolys) has been published in the Reference Guide for Risk Assessment method (GRER). The strategic options underlying the methodology and pointed out were discussed within four working groups with stakeholder involvement from the outset. There is one working group for each type of risk (human, groundwater and ecological) plus one for the general methodology.

The Walloon risk assessment procedure consists of a tiered approach. The first tier is a simplified risk assessment aimed at evaluating whether there is enough evidence (or not) to maintain a “serious threat” (as defined in the GRER) as hypothesis based on soil concentrations being compared against limit values for each type of risk and land use. Tier 2 is then a site-specific risk assessment that again focusses on the existence (or not) of “serious threats” with the RISC Human© code being applied to calculate risks for people and TerraSys™ applied for ecosystem risks. Simple equations are applied for leaching and spreading of pollutants.

In terms of human risk assessment there are 5 steps:

- Step 1: consolidation of the conceptual site model and selection of required parameters to calculate exposure dose;
- Step 2: identification of the dose-response relationship;
- Step 3: calculation of the exposure dose using RISC Human© (version 3.3) and representative air, soil and/or water concentrations;
- Step 4: risk characterisation through the calculation of a risk index; and
- Step 5: interpretation, conclusion and recommendations.

The risk assessment considers different routes of exposure to adult, child and infant.

The calculated risk indices (RI) are interpreted according to the TLM (and no longer according to a black (RI > 1) / white (RI < 1) approach). If the calculated RI associated to a given pollutant concentration is lower than 1, risk is considered to be acceptable (corresponding to the green zone of the TLM). The red zone of the TLM indicates unacceptable risk based on the exceedance of an “intervention risk index” (RI-I) and, in the intermediate zone (orange zone), additional criteria are taken into account such as additive interactions and assessment uncertainties. If following reduction of assessment uncertainties the output is still within the orange zone, it may be considered acceptable and monitoring activities may be continued. The RI-I are not fixed values and depend upon the type of pollutant. For pollutants without threshold effects (carcinogenic pollutants), the RI-I equals 10, corresponding to an excess lifetime cancer risk of 10^{-4}. For pollutants with threshold effects, the IR-I equals 2, 5 or 10 depending on the uncertainty factor associated to selected toxicological value (published in the GRER) and on the route of exposure.

Remediation activities relate to current land use and certificates are issued that state the intended land use, noting that for any other land use, additional remediation activities may be required.

A key benefit to the traffic light approach is that it allows additive effects to be considered, which has not been possible with prior approaches.

2.16 CONFIDENCE IN LONG-TERM IMPACT ASSESSMENT

Branko Kontic presented.

Mr Kontic presented a number of observations and challenges associated with building confidence in long-term assessments associated with radioactive waste disposal. These included:

- Changes in scientific opinion and regulatory requirements that have occurred within the history of the development of such assessments from the 1980s to the present day and the possibility for future changes.
- The problem of separating value judgments from scientifically supported assessment assumptions.
- The complex link between the setting of protection objectives and the justification of assumptions in assessments.
- The problem of balancing different protection objectives such as environmental protection and human health protection.
- The role of needs assessment related to industrial activity/sector, which produces waste, in the context of siting (voluntarism, economic interests, etc.) and impact assessment.
- The lack of connection between typical long-term safety assessments for planned waste repositories and the more typical set of considerations used in strategic assessments for major facilities and land use planning; consideration of site alternatives, optimisation of siting decisions
- Safety assessments cannot take account of the unpredictable in a clearly objective way, so assessment assumptions which involve, for example, human behaviour over the long-term, are bound to involve value judgments. This in turn can lead to lack of confidence in the results since different value judgments can be adopted. In conclusion, the need to distinguish between a site licensing process and land use planning (LUP) was highlighted, for example, as may be elucidated through strategic environmental assessment. LUP generally precedes land use licensing. It is important to stress that LUP is aimed at reaching agreement (consensus) among stakeholders about future land-use (including waste disposal), while licensing covers regulatory/administration approval of both technology and site after land-use plan has already specified the site. Protection objectives and assessment endpoints should also reflect stakeholders' needs in terms of land-use.

2.17 SAFETY CASE FOR SLOVENIAN L/ILW REPOSITORY

Sandi Virsek presented.

A potential site for the disposal of L/ILW waste has been selected in Slovenia at Vrbina Krsko and has been the basis for the development of an operational and post-closure safety case. The site is located on the bank of a river that is characterised by variable flow rates; the disposal location is 700m from the river. There are two cities in close proximity to the site with each having a population in the range of 20,000 to 30,000 people. A nuclear power plant and a hydropower plant are also in the locality and deep boreholes are present as a result of a local spa; hence the site is already quite well characterised.

The area where the repository would be located contains a gravel layer with an aquifer. Silty layers are also present within the bedrock. The land is also subject to periodic flooding; it is therefore being planned for the facility to be constructed in an area above the maximum flood level. The area has more than 32 owners and approval is required from all to be able to undertake further characterisation work (such as drilling additional boreholes), which has caused difficulty in terms of gaining permission on a short timescale for site characterisation activities. Characterisation works have therefore initially focused on the areas bordering the site with shallow boreholes being constructed to allow for geophysical analyses to be performed. These studies have indicated that gravel layers are over-consolidated: in excess of 100 m of gravel was identified in one of the lower boreholes. Data from the characterisation activities is reported in the safety case.

ARAO is small agency with just 21 people employed. A number of sub-contractors have therefore been required to support on the development of the safety case. The project has two parts – preparation of the safety assessment and associated calculations and development of waste acceptance criteria. The initial phase of work began in April 2011 and completed in December with more than 30 reports being prepared during that time. Independent review of the reports has been organised by ARAO with more than 800 comments being received. Final versions of the reports were issued in 2012.

The nuclear power plant is shared with Croatia such that only half of the plant and thus waste are the responsibility of Slovenia.

Institutional control is planned to last 300 years. Dose calculations were carried out into the future until after the peak dose occurs.

The approach to the safety assessment began with the screening of a FEP database and the development of (five) assessment scenarios for the post-closure phase. Other scenarios are considered for the operational phase (e.g. a drop scenario and a plane crash scenario).

The current disposal design assumes near surface silos extending to a depth of around 55m. The silos will be excavated from the surface with measures taken to prevent water inflow and will be constructed with a 2 m base slab and 1 m thick walls. It is currently planned that waste will be disposed in large dimension packages (2.5 m x 2.5 m x 3 m). The dimensions of the waste packages have been determined by interim storage requirements at the nuclear power plant. The design has been developed around current package requirements. However, the facility will continue to be optimised and alternative plans for packaging may be considered.

The initial conceptual design was developed in 2009 and initially it was planned that all empty space around containers would be filled with drainage material with a drainage system located below the silo. However, during optimisation a decision against the drainage system was taken and, instead, the use of less permeable materials is now preferred. Once emplacement has been completed, the top will be sealed with concrete and overlaid with a 5 m clay layer. Anchors will be used to counteract buoyancy forces during the operational phase. Once emplacement is complete, the weight of the silo will be at least as great as that associated with the excavated silt.

Borehole data from site characterisation activities have indicated that there are high groundwater pressures at certain times of the year in the region below where the silo will be constructed leading to an upward gradient. These upward gradients have been conservatively assumed to persist at all times in the assessment modelling that has been undertaken. Since it is not easy to model unsaturated conditions, consideration has had to be given to the time required for full saturation of the facility to be achieved. In the dose assessment, to be conservative, it has been assumed that the silo is re-saturated immediately after closure. Whether this is an appropriate assumption will be considered during the optimisation phase. The assessment model has been constructed in Ecolego and has been developed to be conservative. A more realistic model will be applied in the next phase that takes into account both upward and downward water gradients.

Concerning protection of the environment, dose rates to plants and animals were evaluated using the ERICA assessment tool and calculated dose rates compared against ICRP derived consideration reference levels (DCRL). The assessed dose rates were below the relevant DCRL's.

Results of doses to humans for the nominal scenario, which assumes a well is located in the middle of a plume of groundwater from the silo, indicate two peaks in dose that were slightly above the dose constraint. The first is associated with Ca-41 and the second is due to Ra-226 and U-238. Assessed doses above the dose constraint were only obtained for the well scenario; doses from activity in the groundwater discharging to a river were very much below the constraint. The peak in Ca-41 is likely to reduce during the next assessment phase as conservatisms are addressed. The volume of U-238/Ra-226 bearing wastes is very small and a more realistic assessment scenario would again likely reduce the peak dose calculated. Alternatively, disposal of such long-lived radioactive wastes could be postponed until a disposal solution is available for HLW although it may be difficult to separate already packaged wastes.

Fluvial erosion rates have been considered in terms of consequences of a change in river direction and the assessed risks are acceptable: the top of the silo will be located at 15 m below the surface, although this may reduce to 10 m in the final design. The site is not in an area at risk from glaciation and therefore deep glacial erosion is not envisaged.

The assessment models will also be applied to investigate how much waste can safely be disposed at the site. Consideration will be given to whether this current Slovenian waste plus Croatian wastes could be disposed and/or whether future waste generation could also be disposed of at the site. One silo will be required to contain the waste arising from the nuclear power plant. There is a plan to construct a second nuclear power plant, but there is no mandate to consider the wastes that would arise from a second plant at this time. The current mandate requires that ARAO consider wastes generated up until the end of operation of the current nuclear plant in 2020. There is nonetheless sufficient area at the site for additional silos should these be required.

Consideration has also been given to how mixed wastes (radioactive and non-radioactive hazardous waste) should be dealt with. It was concluded that there are currently no good regulations dealing with mixed wastes and, as such, Slovenian drinking water regulations were used to screen wastes and identify whether substances of concern were present. The different waste streams were then evaluated in terms of quantities of toxic contaminants, the scope for their leaching, and results compared against drinking water standards. Assessed concentrations of chemical contaminants were well below those standards.

The next phase of the programme will be to finalise the repository design and to prepare the construction license application. Safe disposal in Silo's at the proposed Vrbina Krsko site is considered achievable. Now that the disposal concept has been accepted and is considered to be of national importance, the possibility of buying the land from current owners can be considered. If all owners cannot be located then the Government will decide on a representative and money would be paid into a fund under a compulsory purchase scheme. Whilst there are a number of land owners, the majority of the area (~90%) is already owned by the Government.

2.18 ISSUES AND APPROACHES TO EVALUATING RADIATION EFFECTS ON NON-HUMAN BIOTA

Kathryn Higley & Liz Ruedig presented.

The presentation focussed on current work activities of the Oregon state university (OSU) research group relating to non-human biota dose assessment. Effects of radiation exposure on living organisms have been studied for many years and more recently, there has been increased interest in understanding how radionuclides transfer through the environment and the resultant doses delivered to non-human biota (NHB). In the US, the philosophy is that more detailed assessment approaches and work to address data gaps are not required in relation to NHB since there is no apparent impact. Nonetheless work is on-going to improve approaches where possible and address data and knowledge gaps.

There are a number of issues associated with current assessment approaches for NHB. For example, approaches for addressing spatial heterogeneity have not yet been developed and a number of data gaps are evident in terms of radiation effects and transfer between abiotic and biotic components of the environment. There is also confusion on what the focus of protection is, e.g. whether the focus is on individuals or populations. Concern is also growing around scientific literature being published by Møller and Mousseau that challenges long-held beliefs around the risks associated with radioactivity in the environment. Much of this work relates to studies being performed in the Chernobyl exclusion zone, with effects being reported at dose rates below natural background for some areas in organisms previously considered to be relatively radioresistant.

In terms of assessment data, IAEA TecDocs show a wide range of variation in concentration ratios, often over several orders of magnitude and site-specific data are often therefore preferred. As such, research has been undertaken on forests and at the Hanford site and a range of concentration ratios for a range of stable elements and biota have been developed using neutron activation. These data are being incorporated into the ERICA transfer database.

In terms of data on effects, there is less data available than might be thought and, where data are available, these are often not directly relevant to responses in nature. Much of the field data that is available has been derived from large sources placed in forests. Other data come from large animal studies in laboratories. Data on population-relevant endpoints and chronic exposures are largely lacking, as illustrated in Figure 2-11 (from Hinton & Garnier-Laplace [2009]).

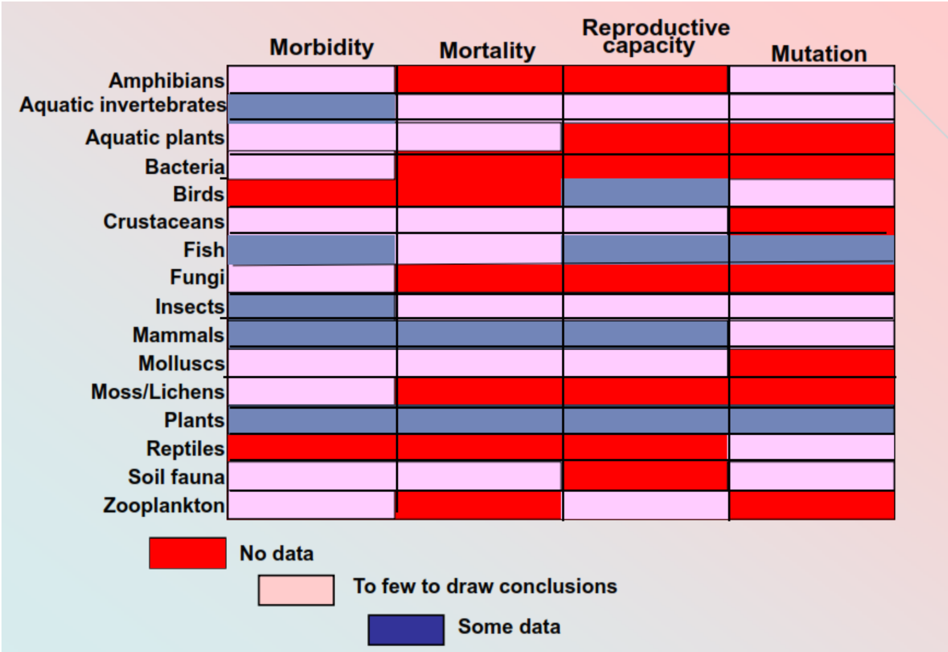


Figure 2-11. Availability of chronic effects data for non-human species exposed to gamma radiation (from Hinton & Garnier-Laplace, 2009).

The focus of protection for NHB is still debated. For people, individual lifetime risk, for which there is an established relationship, is the focus of assessment. However, for NHB the focus is more on deterministic effects (e.g. mortality and fecundity), but these are species-dependent and dose responses to chronic exposures are not well known. There is also a scarcity of long-term generation effect studies. Of those that are available, Ryabokon & Goncharova [2006] indicated that the mortality of embryos can increase over time in multi-generational studies.

There are also issues around assessment benchmarks. Various screening criteria and assessment benchmarks are being used internationally and these vary considerably, as illustrated below (Figure 2-12).

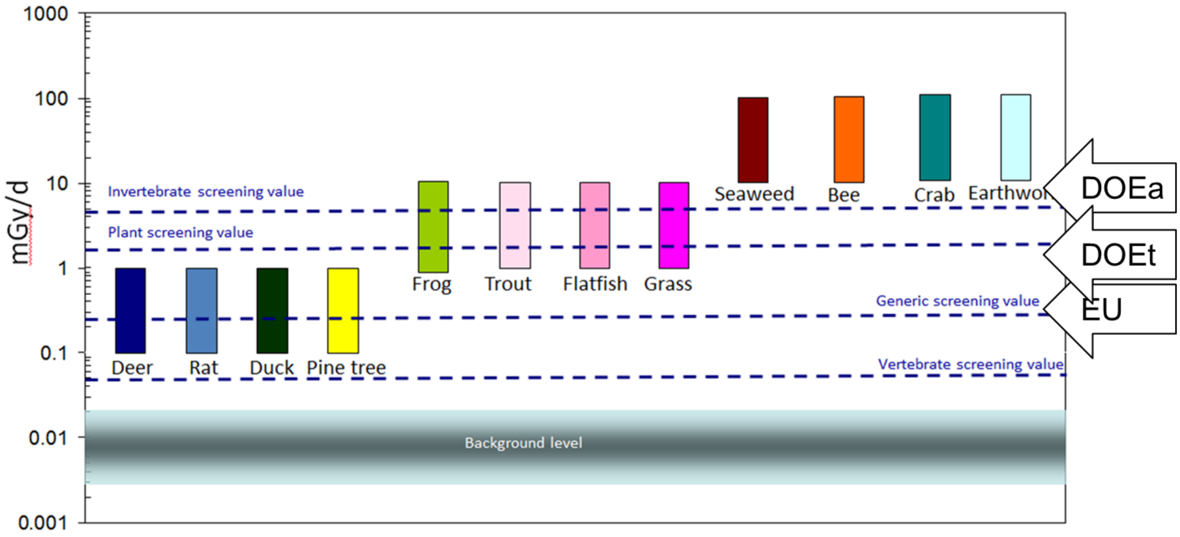


Figure 2-12. ICRP DCRL's in the context of US DoE benchmarks and the EU ERICA/PROTECT screening value.

A number of research programmes are therefore underway at OSU to address some of the many uncertainties and data gaps associated with NHB assessments.

The conventional approach to calculate dose to plants and animals is to use a simple ellipsoid configuration with homogenous distribution of radioactivity. However, in order to bring NHB dosimetry in line with that for people, voxel phantoms are being investigated and work is underway to develop voxel phantoms for the ICRP reference animals and plants (RAPs) that enable dose conversion factors to be computed.

The voxel phantoms are developed from 3-D CT images obtained post-mortem from which organs and tissues are identified and contoured, allowing a 3-D representation to be created. It is a time-consuming operation. However, once created, the phantoms can be used to derive absorbed fractions and organ doses. The absorbed fractions can then be used to derive dose conversion factors.

Absorbed dose fractions for crab, rat, flatfish and trout voxel phantoms have been compared against those from relevant homogenous ellipsoid models to evaluate whether or not the homogenous ellipsoid approach is fit for purpose or whether there are substantial over/underestimations of dose. Absorbed dose fractions are very different, particularly for those radionuclides such as Sr-90 that do not follow a homogenous distribution pattern, but rather accumulate in tissues and organs. By assuming homogenous distribution, dose rates are reduced with voxel models producing dose rates that differ from the homogenous ellipsoid model by up to 8 orders of magnitude for internally deposited radionuclides. Differences are also observed between the models for external radiation, with models having greater agreement for larger organisms. Further work is planned to derive voxel phantom models for remaining ICRP RAPs, including pine tree.

Ecological protection is concerned with whole-population impacts that typically involve loss of function. These are deterministic effects and are most likely to arise when an organ experiences a high dose rate. The use of voxel phantoms would allow organ doses to be evaluated and could provide the means by which organ dose criteria could be established. However, work is required to investigate the partitioning of radionuclides and to evaluate the biological relevance. Stable element analysis could be used in this regard to determine partitioning.

In terms of temporal and spatial variation, different ways of approaching the issue have been considered. Research programmes involving dosimeters with GPS are planned (e.g. wolf populations in the Chernobyl exclusion zone (see BIOPROTA 2013 annual workshop report for details)) that allow integrated dose responses to be evaluated. Currently the sensitivity of small dosimeters is not great and this is an area to be improved upon. Consideration of both internal and external exposure in relation to spatial heterogeneity is required. Research around Fukushima may help to address the issue of spatial scales of assessment by considering discrete measurements and how dose can be calculated across these. Consideration can also be given to the integration of dose across biota lifespans to address temporal scaling issues. Overall, studying animals and plants at contaminated sites is considered key to improving assessment approaches: organisms in the field can be 8 to 10 times more sensitive than those under laboratory conditions due to differences in energy management requirements and additional stressors. The OSU research group aims to continue research at Duke Swamp, continuing from work undertaken by Liz Ruedig on snails in 2012. The site allows dose rates to be measured and population effects to be researched in response to different dose rates.

3. DISCUSSION AND RECOMMENDATIONS

3.1 OVERVIEW OF KEY AREAS OF COMMONALITY, SYNERGIES AND LESSONS LEARNED

There are a number of synergies and areas of commonality, particularly in terms of assessment issues, between hazardous and radioactive waste disposal assessments. For both hazardous and radioactive wastes, assessments can be of value at all stages of waste management including the determination of compliance with protection objectives and derivation of waste acceptance criteria for disposal facilities. However, protection objectives and, hence, assessment endpoints and criteria for different types of wastes are sometimes unclear and inconsistent internationally and nationally. For example, the timeframe for assessment of the impact of radioactive waste disposal is typically a lot longer than for hazardous waste disposal.

With the lack of harmonisation in protection objectives and assessment criteria, different parties can adopt different assessment methods and points for comparison. A more integrated approach could promote proportionate radioactive and hazardous waste management, supported by common assessment methods. This could be especially relevant to wastes which present both types of hazard. In terms of points of comparison, there can be differences in terms of scientific endpoints (e.g. what level constitutes an impact on an ecosystem) and regulatory compliance endpoints. In addition, there can be differences in the types of people who are intended to be protected, and the period for which protection is both intended and needed. Harmonisation is seen as a good thing in terms of the use of best science and techniques, but it may be inappropriate to harmonise in terms of criteria since there are varied views internationally and nationally on the appropriate protection objectives. Furthermore, final decisions on waste disposal are not only dependent on the assessment of long-term impacts, but need to take into account many other factors including operational safety, transport and future land-use planning.

There are concerns regarding understanding of synergistic effects and how they should be prioritised and addressed within assessments. The combination of some contaminants may result in impacts which would not be apparent if present separately. Combinations of materials may also increase the risk; organic contaminants can, for example, mobilise radionuclides in some circumstances.

There is a noted potential difference in the approaches taken toward hazardous waste and solid radioactive waste safety assessments. For radioactive wastes, containment is a key priority to allow for natural decay and, hence, risk reduction over time while the contaminants are isolated from the environment. For hazardous wastes, in some circumstances, controlled dilution is adopted since dilution mitigates risks to individuals. Bringing the different assessment communities together could help support a proportionate approach to assessments and hence to waste management in general.

Engagement and cooperation between operators and regulators and other stakeholders can be mutually beneficial. Gaining the trust of stakeholders is important so that stakeholders will have confidence in technical judgements. Nonetheless, stakeholders often want to hear about technical issues and effective communication of these issues is therefore very important. Effective communication is not only useful in itself, it adds to credibility. Transparency of the value judgement aspects of an assessment is important and stakeholder input to such decisions may be helpful.

There may be benefit in harmonising the application of assessment techniques and tools, although it is acknowledged that, even with the same tools, different results can arise. Harmonisation can be resource efficient by avoiding unnecessary ‘reinventing the wheel’, but there is the potential for over-simplification in terms of application, for example, if important factors of a site-specific problem are overlooked. At least some degree of local site investigation is important in this regard, in ensuring an appropriate balance between site-specificity and application of harmonised assessment tools.

In summary, the following key messages arose from presentations and discussion:

- Ideally radionuclides and hazardous materials should be assessed on a common risk management basis. Some differences may be necessary, but there should at a minimum be an understanding of the basis of the approaches to allow differences to be understood and communicated.
- It would be beneficial for a common set of protection objectives and, hence, assessment endpoints and time frames to be developed for the different waste types, to support coherent risk management and allow alternative options to be compared on a comparable basis. Similarly, development of a common language to addressing issues would be very beneficial to avoid use of different terms that can be confusing and lead to errors and mistrust.
- Waste disposal assessments should be considered holistically rather than hazardous materials being something of an afterthought to radioactivity, or vice versa. This should not be taken to mean that there should not be any differences in how the assessments are made, but that the differences should be transparent, and the reasons for them should be explained. A holistic approach should support the proportionate application of resources to the different hazards presented by a waste.

3.2 RECOMMENDATIONS FOR FUTURE ACTIVITIES

In order to address the points and issues identified previously, the following activities were suggested.

- Further development of the interfaces between assessment communities concerned with hazardous waste disposal, NORM management and disposal, and post-disposal safety for radioactive waste is seen as beneficial. This could be implemented by further technical forums such as that described here. At a minimum, continued interaction should help to establish clearer links between assessment endpoints and to improve communication both between scientific assessment communities and those with an interest in the results of assessments. One possible subject area for a further technical forum would be to consider how the EU Groundwater Directive is applied in different countries and its implications for radioactive and hazardous waste disposal assessments.
- Analysis of the differences in protection objectives and assessment endpoints for radioactive and other hazardous disposal. Understanding of the rationale for differences could be used to promote closer harmonisation where that appears appropriate and provide and support the need for differences, again, where that is appropriate.
- Assessing different hazards independently does not allow multi-stressor effects to be considered, although it is acknowledged that this is a challenging issue. Synergistic issues could however be evaluated in terms of long-term assessments and conflicts in approaches could be identified.
- Optimisation techniques for radioactive and hazardous waste assessments could be evaluated and compared in terms of how assessments help to select between options. It may not be possible to fully combine approaches due to distinctions between hazardous substance characteristics, but the possibility of harmonisation could be evaluated: where distinctions are arbitrary there would be scope to bring assessments onto a common ground.

- Communication between different disciplines relevant to assessments was also suggested, e.g. geosphere and biosphere specialists, to encourage greater cooperation.

Appendix A. List of Participants

Participant	Affiliation
Koen Mannaerts	Federal Agency for Nuclear Control (FANC), Belgium
Maryline Moutier	Ram-Ses sprl, Belgium
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