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Report on a workshop on toxicants other than radionuclides in the context of geological disposal of radioactive wastes

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Abstract

This report provides a summary of presentations given at a one-day seminar on toxicants other than radionuclides in the context of the geological disposal of radioactive wastes, mainly concentrating on post-closure impacts. The initial presentations showed the potential inventory in low and intermediate level waste and the framework of legislation. This was followed by several presentations showing how other hazards than radiological are handled in France, Belgium and the UK. Thereafter, an introduction was given to a useful tool for modelling the behaviour of toxicants in the environment. Moreover, an example of a repository containing toxicants was given. Finally, a comparison between characteristics of repositories for chemically toxic and radiotoxic wastes was presented.

In addition, the report gives an account of the discussion arising from those presentations and the more general discussion that took place in the final session of the seminar.

Sammanfattning

Den här rapporten sammanfattar ett endagsseminarium om andra potentiella miljögifter i ett slutförvar för radioaktivt avfall. Huvudsakligen diskuteras eventuella effekter efter förslutning. Presentationerna började med tänkbara inventarier i låg och medelaktivt avfall samt det juridiska ramverket. Därefter gavs flera föredrag som visade hur avfallet hanteras i Frankrike, Belgien och Storbritannien. De följdes av en introduktion till ett verktyg som kan hantera toxiska ämnen. Ett exempel från Rönnskärsverken illustrerade hur ett förvar utan radioaktiva ämnen planerades. I en avslutande presentation jämfördes förvar för toxiskt avfall med förvar för radioaktiva ämnen.

Presentationerna följdes av en allmän diskussion som också sammanfattas i denna rapport.

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1 Introduction

This report provides a summary of presentations given at a one-day seminar on toxicants other than radionuclides in the context of the geological disposal of radioactive wastes, mainly concentrating on post-closure impacts. In addition, it gives an account of the discussion arising from those presentations and the more general discussion that took place in the final session of the seminar.

The seminar took place on 14 April 2016 and was attended by about 40 participants. The final programme for the seminar is given in Appendix 1 and the list of participants in Appendix 2.

Chapter 2 summarises the individual presentations and the brief discussions that followed each one. Chapter 3 then gives an account of the more general discussion that occurred during the final session of the day.

2 Summary of the presentations and associated discussion

2.1 Introduction (M Gontier)

Mikael Gontier introduced the seminar by commenting that SKB had been considering holding a meeting on this topic for some years and that this was a welcome opportunity to review the current position on this topic from a number of different perspectives. He noted that the individual presentations would be made available to participants as pdf files.

Mikael also drew attention to SKB documents relating to this issue (e.g P-10-13 relating to the spent fuel repository).

Finally, Mikael emphasised that a key objective of the seminar was to raise the right questions to be addressed in future studies.

2.2 Other toxicants in nuclear wastes (U Kautsky)

Ulrik Kautsky commented that a key issue to address is why non-radioactive toxic substances are handled differently from radionuclides in post-closure safety assessments. This question arises particularly in relation to the heavy metals, as these are indefinitely persistent in the environment, and their transport can readily be represented using the same types of models as are adopted for radionuclides. Furthermore, the modelling of their transport can be underpinned by reference to extensive elemental measurements allowing the pools and fluxes of these heavy metals to be adequately quantified.

Ulrik pointed out some reasons for differences in the handling of radionuclides and non-radioactive toxic substances. Radionuclides (and external and internal radiation exposures) are handled in a single integrated framework based on dosimetric quantities and allowing all exposures to be evaluated in terms of quantified risks to human health and the environment. In contrast, non-radioactive toxic substances generally have to be addressed on a case-by-case basis, with impacts on humans being controlled by setting substance-specific limits on intakes. Furthermore, toxicity data are not available or very extensive for some of the non-radioactive toxic substances of potential relevance. Ulrik also noted that with radionuclides protection of human health is the primary consideration, with protection of the environment a secondary issue. For non-radioactive toxic substances, the situation is often the reverse, with protection of the environment being seen as the primary consideration. Finally, Ulrik commented that exposure to ionising radiation is perceived as being hazardous at all levels of exposure and rigorous protection standards are set. In contrast, for some non-radioactive toxic substances, there is less perception of the hazard and existing standards may imply a potentially high level of impact.

Mike Thorne commented that the situation can be more complex than this. For example, the linear-no-threshold (LNT) model relating dose to effects in radiological protection is considered to be realistic and conservatisms are generally introduced in the modelling that is used to estimate the doses. In contrast, for non-radioactive toxic chemicals, the intakes may be estimated realistically, but large uncertainty factors (of up to about 1000) may then be used to take account of uncertainties in the relationship between intake and the induction of adverse effects.

Ulrik concluded by pointing to on-going studies and reports of relevance. These include:

- Bioprota Working Group: Issues Affecting the Assessment of Impacts of Disposal of Radioactive and Hazardous Waste, Workshop in Brussels in the week beginning 18 April 2016;
- NWMO TR-2015-03, Non-Radiological Interim Acceptance Criteria for the Protection of Persons and the Environment;
- Strålevern Rapport 2015:8, Comparison of Safety and Environmental Impact Assessments for Disposal of Radioactive Waste and Hazardous Waste: Report of an International Workshop.

2.3 Hazardous substances in low and intermediate level waste (B Herschend)

Björn Herschend introduced the concepts of the SFR repository for short-lived radioactive wastes and the proposed SFL repository for long-lived wastes. He commented that SFR will contain limited amounts of lead, asbestos and epoxy resins, but that other hazardous materials are not accepted. In the case of SFL, acceptance criteria have not yet been defined. Known toxic materials that may be disposed to SFL include cadmium in control rods and neutron reflectors, beryllium in neutron reflectors and lead (mainly as shielding of legacy scrap). Lead mats may also be disposed to SFR. There are also significant amounts of chromium present in ash from incineration. Sludges, ion-exchange resins, evaporator concentrates and filter aids will contain heavy metals (mainly derived from corrosion of stainless steels), decontamination chemicals, flocking agents and bitumen (which is not considered a toxic material and is used to immobilise some of the wastes). Operational waste with trash and scrap will also contain heavy metals, again largely from stainless steels, oils, solvents, paints, adhesives and coatings, and unknown amounts of asbestos. Legacy waste with trash and scrap to be disposed in SFL is estimated to contain 68 kg of cadmium and 2648 kg of lead. X-ray analysis of legacy trash and scrap has revealed fluids suspected to be mercury. A total estimated volume of five litres has been reported. This would result in 70 kg for disposal in SFL and 31 kg disposed of in SFR. Decommissioning waste mainly consists of concrete and steel. Hazardous organic substances may be present in limited amounts, but these will likely be cleared and treated as conventional material or sent to a controlled incineration facility. Some asphalt is to be disposed, but this is not generally considered to be a hazardous waste, unless it contains coal tar.

In discussion, it was noted that the lead shielding could be removed from the wastes to be disposed, if this was required. Mike Thorne raised the issue of uranium, as both a radiotoxic and chemically toxic material. Björn commented that about 15 tonnes of uranium is likely to be disposed in SFL. It was noted that Andra has identified significant amounts of antimony in its wastes. It is used as a fire protectant and concentrates in ashes.

2.4 The regulation of hazardous substances in radioactive waste – an overview of the legislative framework (M Lönnqvist)

Malin Lönnqvist addressed the regulation of hazardous substances in radioactive waste. She defined mixed waste as containing both radionuclides and other hazardous substances, and considered the questions:

- How is mixed waste primarily governed?
- Does general environmental law apply to the management of mixed waste?
- Do specific rules apply for some toxicants in mixed waste?

She particularly emphasised the hierarchical structure of the legal system with the order of precedence being constitution > laws > ordinances > regulations > guidelines, with EU treaties, regulations and directives primarily influencing national laws.

Malin noted that mixed waste is excluded from the scope of the Waste Framework Directive. However, even for mixed waste, an EU regulation on waste containing metallic mercury may be directly applicable as the regulation does not contain any explicit exclusion for mixed waste. Also, declassification of radioactive waste, i.e. declaring it non-radioactive, means that it becomes subject to rules regulating non-radioactive waste such as the Waste Ordinance (which is not – as a general rule – applicable to mixed waste, but may apply by analogy).

Overall, Malin commented that although there are general legal principles that have to be obeyed when managing mixed waste these are rather vague (the knowledge principle, the precautionary principle, conservation and reuse) and interpreted by the courts on a case-by-case-basis.

In the context of a discussion of Environmental Quality Standards (EQSs), it was emphasised that EQS values for surface waters could be either limit values (for chemical status) or target values / reference values (for ecological status). There are also EQS values for groundwaters as well as for air, but no EQS's for soils exist in Sweden (though there are some guidance values). Mike Thorne noted that the lack of EQS values for soils also applies in the UK. This had been partly overcome by calculating concentrations of pollutants in soil water and comparing them with EQS values for waters.

Malin concluded that (i) mixed waste is primarily governed by specific rules due to its radioactive content, (ii) general environmental law always applies to the management of mixed wastes and (iii) specific rules apply for some toxicants in mixed waste.

Matthew White asked how the EU Groundwater Quality Directive has been implemented in Sweden, particularly in the context of the requirement to 'prevent' the entry of hazardous substances into groundwater. Malin replied that the implementation has not given rise to any big discussions in Sweden.

2.5 Limits for hazardous wastes/toxic non-radioactive waste constituents in the waste acceptance criteria: Packages with "mixed" wastes (Y Segura)

Yannick Segura addressed the approach that has been adopted by Andra. Three steps are required:

- Definition of the list of toxic substances.
- Determination of the mass inventory of each of those substances.
- Choice of reference toxicological values for each substance.

The key substances were identified as Pb, B, Ni, Cr {including Cr(VI)}, As, Sb, Se, Cd, Hg, Be, CN, U, asbestos. Based on resource considerations, it was determined that no more than 15 substances should be studied (note that there are 13 in the above list). The selection was based on requirements in French and European legislation together with information on arisings from specific operations at nuclear facilities. In the future, polycyclic aromatic hydrocarbons (PAHs) are likely to be added, and specific consideration will be given to carcinogenic, mutagenic and reprotoxic agents. Yannick noted that careful consideration has to be given to organic compounds as these can decompose to yield products either more or less toxic than their predecessor. Also, refractory fibres may give rise to problems.

Yannick then described the use of risk indicators in limiting potential exposures to these substances. For non-carcinogenic substances, the hazard index must be < 1. For carcinogens, the excess lifetime risk must be $< 10^{-5}$.

Yannick outlined the impact assessment process as proceeding through the following steps:

- Identification of the protection objectives.
- Identification of the potential inventory.
- Application of the same exposure scenarios (water and air transfers) as for radionuclides.
- Consideration of the specific physico-chemical behavior of each toxic element.
- Estimation of concentration of released material (in water and air).
- Calculation of the Risk Factor and Excess of Individual Risk with reference toxicological values (using an Andra database from national and international bibliographic data that have been reviewed by a knowledgeable French organisation).
- Monitoring.
- Evaluation of non-cancer effects by calculation of "Hazard Factor" = level of absorption (inhalation or ingestion)/reference toxicological value and comparison with the protection objective.
- Evaluation of cancer effects by calculation of Excess Individual Risk = level of absorption (inhalation or ingestion) × reference toxicological value (also called Unit Excess Risk) and comparison with the protection objective.

Summations of Hazard Factors and Excess Individual Risks, both over substances and over ingestion and inhalation, are required in demonstrating compliance with the protection objectives.

Relevant toxicological databases were identified as including those of US EPA, WHO and ATSDR. It was noted that data for sub-chronic and acute exposure situations are often limited compared with data for chronic exposure situations. Andra has asked INERIS (L'Institut National de l'Environnement Industriel et des Risques) to provide relevant toxicological values.

Yannick commented that it may be that, in France, Andra is doing more than other countries in this area. Other countries often make much simpler comparisons with normal intakes of these substances. Currently, Andra does not have any problems in this area, but some substances could be becoming problematic. It was queried whether Andra or the authorities had taken the initiative in encouraging this detailed approach. Yannick responded that the issue had originally been raised by EDF in respect of lead in shielding. The waste producers then decided that account must be taken in general of toxic materials in wastes. The principal Andra initiative has been in determining the reference toxicological values to be used.

Finally, a brief reference was made to ensuring protection against toxic chemicals during the operational phase considering both fires and dropped package accidents.

In questioning, Yannick clarified that assessment timescales for non-radioactive toxic substances can be greater than 1000 years. There was also a more general discussion of how substances such as lead and arsenic should be treated where it is not clear whether or not there is a threshold for adverse effects. It was also noted that there may be some issues with VLLW disposal. Here, it is not mandatory to calculate an impact, but consideration may need to be given to the adverse impacts of disposed uranium and asbestos. In this context, uranium raises interesting issues, as it brings together the IAEA and WHO roles in setting standards for radioactive and chemically toxic materials, respectively.

2.6 Chemotoxics in a Belgian context (E D Lopez)

Emma Dorado Lopez emphasised the specific issues that arise with radioactive and chemically toxic waste disposal in Belgium taking into account the regional divisions in the country associated with high and variable population densities. LLW waste is to be disposed in a surface facility at Dessel. Both ILW and HLW are intended for disposal in a deep geological facility, but no Decision in Principle (DiP) has yet been taken. Possible disposal strata are the Boom Clay and the Ypressian Clay.

ONDRAF recognises the importance of public participation in the siting process and has a strategy plan to achieve a DiP (completed 2010) aiming for a DiP at around 2020. The impact of toxic chemicals is included in the environmental impact component of the safety assessment and currently two persons within ONDRAF are addressing this component.

Currently, evaluations of the impact of toxic chemicals are based on computing concentrations in the aquifer above the Boom Clay formation and making comparisons based on drinking water standards. A comment was made that the drinking water pathway is not always the most important for radionuclides and that this may also be the case for toxic chemicals.

A major problem is that the composition of the waste in drums is not well known. Therefore, inverse calculations are used to calculate potentially acceptable amounts, with a view to emphasising to waste producers that this information is required. Currently, acceptance criteria are being reviewed, but none have yet been adopted.

It was noted that beryllium is not a critical substance in either France or Belgium. This contrasts with the situation in the UK (see below).

A comment was made that the application of inappropriate acceptance criteria could result in the rerouting of toxic chemicals to alternative, less satisfactory disposal options.

2.7 Evaluating the chemical toxicity of key substances released from a repository: The UK approach and some experience from the US (M Thorne)

Mike Thorne summarised a series of studies undertaken for UK Nirex Limited and RWM on the impacts of toxic chemicals that could potentially be released from a geological disposal facility for ILW. The earliest screening study (Atkinson et al. 2001) addressed almost all the elements in the periodic table, composites (such as asbestiform minerals and glass fibres), inorganic anions, organic compounds and gases. Standards for evaluation comprised:

- Carcinogens identified by the International Agency for Research on Cancer.
- WHO Drinking Water Standards.
- UK and US Drinking Water Standards.
- Normal Daily Dietary Intakes.
- Acute Toxicity Data (used for organic materials for which Drinking Water Standards were unavailable).

Based on near-field pore water concentrations, materials that either exceeded current estimates of safe levels or whose impacts could not be quantified comprised:

- Beryllium
- Phenol
- Benzene
- Nitrite
- Organo-metallics

A subsequent study (Hunter et al. 2006) was based on the 2004 UK National Waste Inventory, included contributions from waste packaging and grouts, as well as the wastes themselves, and addressed the groundwater, human intrusion and gaseous release pathways. A three tier screening approach was taken. The three tiers were:

- Tier 1: Dissolution in repository pore water and mixing with near-surface waters (chemistry not taken into account), with account also taken of longitudinal dispersion in the geosphere.
- Tier 2: Dissolution in repository pore water, effects of near-field chemistry (solubility limits and sorption coefficients) and mixing with near-surface waters (excludes sorption in the geosphere).
- Tier 3: As Tier 2, but including degradation of toxic materials in the geosphere.

For the groundwater pathway, Be, Al, Cr, Mn, Fe, Pb and U exceeded their screening levels for at least one of the cases considered. For human intrusion, only Cr and phenol exceeded the screening level, but Cr is mainly relatively unavailable in stainless steel and would likely be released in a form less toxic than Cr(VI), which is assumed for screening. Also, phenol will degrade rapidly in an aerobic environment and this was not taken into account in the screening calculations. In respect of the gas pathway, only for benzene did the concentration in a building constructed over the release area exceed its screening level, but inclusion of partitioning between the solution and gas phases reduced the concentration to below the screening level.

Subsequently, an updated assessment was made (Davis et al. 2007). This was mainly notable for the inclusion of probabilistic assessment calculations. It resulted in Be being the only material that exceeded 10% of its drinking water limit. Therefore, a subsequent more detailed study of the behaviour of Be in the biosphere was undertaken (Thorne 2007). This used the transport model normally applied to radionuclides. For inhalation, the study found that:

- The assessed air concentration was about three orders of magnitude below the Lowest Observable Adverse Effect Level (LOAEL).
- The assessed concentration in soil of repository derived Be is less than the average concentration of the element in soils of the USA.

- The assessed concentration in air is within the range typically observed in the USA.
- The EPA geometric mean risk factor for cancer induction from inhaled Be implies a lifetime risk of 1 10^{-7} for the assessed concentration.

For ingestion, the study found that:

- The upper-bound estimate on intake of repository derived Be is 7.9 μg d^{-1}.
- Total intake rates of Be in foods are 5 to 100 μg d^{-1}.
- The ATSDR MRL for Be is 2 μg kg^{-1} d^{-1} or 140 μg d^{-1} for a 70 kg adult.

These various lines of argument indicated that repository derived Be would not have an adverse impact on human health.

The possibility of synergistic effects between various toxic chemicals that could be released from a geological disposal facility and the ionising radiation from radionuclide releases was studied by Wilson et al. (2011). They studied three cases of decreasing conservatism in respect of release and transport, and addressed Be, Cd, Cr, Pb and U.

In addressing possible combined effects between the various substances and also with exposure to ionising radiations, three topics were identified that warranted consideration:

- Combined effects on the kidneys from ingestion of cadmium, uranium and lead.
- Combined effects between ingested lead and exposure to ionising radiation with respect to induction of various types of cancer.
- Combined effects between all five key substances and exposure to ionising radiation with respect to lung cancer induction.

Most recently, a study has been undertaken to investigate the circumstances in which either the radiotoxicity or chemical toxicity of uranium is of predominant importance (Wilson and Thorne 2015, see also Thorne and Wilson 2015). This study shows that whether chemical or radiological considerations dominate depends on the chemical form of the uranium, the route of entry into the body, the degree of depletion or enrichment, and the presence or absence of radioactive progeny. This study is also of interest because it addresses the chemical toxicity of uranium for acute exposures of different duration, as might arise in occupational contexts.

The Supplemental Environmental Impact Assessment (SEIS) for Yucca Mountain addresses the potential for groundwater contamination by toxic chemicals released from a proposed repository for spent fuel and HLW. Here the emphasis is on preserving groundwater resources, so an emphasis is placed on the total burden of Mo, Ni and V added to the aquifer, as well as the concentrations of those elements at the point of abstraction. Results from the assessment undertaken by the US NRC showed that:

- The highest calculated total uranium concentration in the groundwater at Amargosa Farms corresponds to less than 1 μ/L; for comparison, the EPA MCL for U in drinking water is 30 μ/L.
- While no MCLs have been established for the metals Mo and V, the calculated groundwater concentrations for these potential contaminants are all much lower than one part per million, which is comparable to the levels occurring naturally at present.
- The calculated peak concentration of Ni in groundwater at Amargosa Farms is 0.02 mg/L, and is estimated to occur at 74 000 years for the cooler/wetter climate. This concentration is much lower than the EPA National Recommended Water Quality Criterion for Ni of 0.61 mg/L.

Finally, Mike commented on some issues arising in the UK when distinguishing hazardous pollutants (that are to be prevented from entering groundwater) from other pollutants (whose entry is to be limited). A hazardous substance is defined as one that is toxic, persistent and liable to bioaccumulate, under the following definitions:

- Toxic:
  - No Observed Effect Concentration (NOEC) < 0.01 mg/L for freshwater or marine organisms.
  - Carcinogenic, germ cell mutagenic or toxic for reproduction.
  - Other evidence of chronic toxicity.

- Persistent:
  - Degradation half life > 60 d (marine water), > 40 d (fresh or estuarine water), > 180 d (marine sediments), > 120 d (freshwater or estuarine sediments), > 120 d (soil).
- Bioaccumulating:
  - Bioconcentration factor for aquatic species > 2000 on a fresh weight basis.

A hazardous substance is also one that gives rise to an equivalent level of concern to substances defined as hazardous under the above criteria.

It is not clear that this distinction between hazardous and other substances is useful in protecting human health and the environment, and it is not consistent with how the entry of radionuclides into groundwaters is controlled.

2.8 The MERLIN-expo tool: General introduction (P Cifroy)

Philippe Cifroy outlined the purpose and scope of the Merlin-Expo Tool that has been developed since 2007 in a series of EU-funded projects. The initial project developed a prototype that has subsequently been developed for marketing. This Tool integrates within an overall software framework models for contaminant transport, accumulation in environmental media, and behaviour affecting exposure, as well as physiologically based pharmacokinetic plus biological response models. A library of such models is available and these can be used in various combinations. The system also incorporates advanced functionality for uncertainty and sensitivity analyses. In terms of a tiered approach to assessing the impacts of releases of toxic chemicals to the environment, the Merlin-Expo Tool is envisaged as being applied at the highest tier of detailed, site-specific assessments. Simpler tools will generally be more appropriate in more generic assessments. Merlin-Expo has been benchmarked against EUSES (the European Union System for the Evaluation of Substances).

A particular challenge is how to communicate a complex model (or rather a suite of complex models that can be utilised in different combinations). The action plan includes on-line training (see the Merlin-Expo website, http://merlin-expo.eu/) with tutorials on both the models and the software, development of documentation, and provision of training courses. It has been determined that the model documentation must be:

- Comprehensive, i.e. containing all the information needed by end-users.
- Transparent, i.e. sources of information (e.g. scientific background, parameter values) must be accessible to end-users.
- Unambiguous, i.e. 'variability' in interpretation among different end-users must be minimized.
- Structured, i.e. to avoid a 'mixture' of general considerations, lengthy verbal descriptions, lengthy justifications, complex mathematics, etc.
- Adapted for a targeted end-user, some of whom will want to read the entire model description in detail, whereas others will only want to have a general idea of the purpose of the model, its structure and/or the processes represented.

This documentation is being developed in collaboration with CEN (the European Centre for Standards) together with contributions from various national safety assessment organisations. It comprises five levels: 1. Basic knowledge; 2. Process knowledge; 3. Input data; 4. Mathematics; 5. Model evaluation.

Model scenarios that have been simulated include internal exposures to PAHs following atmospheric dispersion, distribution of benzo(α)pyrene in a freshwater system and resulting internal exposures via drinking water, and assessments of impacts on biota of persistent organic pollutants (PCBs). Reverse modelling has also been undertaken for the reconstruction of past exposures, e.g. reconstruction of exposures of Italian women to PCBs through measurements of concentrations in breast milk.

The extension of the modelling framework to estimating impacts on non-human biota is a recent development. In the study of the impact of PCBs in the Venice lagoon, a classic food-web approach was used and good agreement between measured and predicted concentrations was obtained. Other recent work has used the modelling system to investigate specific processes.

In discussion, it was noted that the chemical models included address only the fate of chemicals in the environment and not their toxicological impacts on biota. Also, Philippe expressed a preference for starting with a model that is more complex than necessary and then demonstrating how it can be simplified in a specific context. Asked whether the user can add his/her own models to the system, Philippe responded that this can be done, but only by formal submission through the development team. If accepted, it is then entered into the model library with its own documentation.

2.9 Rönnskär non-radiological waste (R Christiansson)

The Rönnskärverken-Boliden processing plant has operated since 1930. It is based on a gold mine, and copper and lead concentrates are smelted and refined. Operations are very variable in time and are strongly dependent upon the strength of the world markets for various metals.

More specifically, Rönnskär is one of the world’s most efficient copper smelters and a world-leader in the recycling of copper and precious metals from electronic scrap. At Rönnskär, copper and lead concentrates from Boliden´s own mines and external mines are smelted and refined. The smelter is an integrated metallurgical complex, which extracts high-purity metals, with the main products being copper, zinc clinker, lead and precious metals. Its by-products include sulphuric acid. Hazardous wastes arise and are stored in concrete silos. Waste production has varied over the period that the plant has been operating, and the waste types have altered as processes have changed, with some of the historic waste forms being difficult to reprocess. Currently about 8000 tonnes per year of hazardous wastes are produced.

During the 1990s, several suggestions were made concerning the disposal of mercury contaminated wastes from the plant and in 2003 the Parliament determined that mercury contaminated wastes should be disposed in an underground environment. In 2005, the management of the Rönnskär plant decided on a new strategy for waste management and in Boliden started to investigate the possibility to use one of their old mines for final disposal of hazardous waste from the Rönnskär plant. In January 2007, an expert review panel was established for review of the technical documentation for the application. This comprised Mark Elert (Kemakta), Margareta Svensson (SAKAB) and Rolf Christiansson (SKB). The alternatives that were studied are an existing mine at Äkulla, which is located 57 km from Rönnskär, and new caverns under the Rönnskär plant. The latter was included mainly because there is a legal requirement to compare alternatives within a Swedish Environmental Impact Assessment. At Äkulla, existing ore-extraction space would be used for disposal, but additional, specially excavated, space might also be required. This would depend upon the extent of future mining, which would depend, in turn, on the world price of gold. The logistics of disposal would be challenging with one route used both for extraction and waste emplacement. Also, a small biosphere receptor would seem to need to be associated with potential releases of toxic chemicals. On the basis of various considerations such as these, it was eventually decided that new caverns under the Rönnskär plant was the preferred option.

The Expert Review Panel followed the project up to July 2010 with a focus on the siting of the repository under the Rönnskär plant. Some key issues were identified. In particular, it was considered that the repository ought to be established in two steps: 1 – detailed design of the access ramp and a risk assessment of the possibility of draining contaminated water to the tunnel; 2 – investigations for an optimized layout of the repository with respect to geological conditions, types of wastes and volumes after chemical stabilization.

It was also identified that there is a need for more work on how the most critical wastes shall be stabilized, and the long-term leaching of such wastes to be expected in the actual geochemical environment at depth.

Hearings on the proposed approach were held between 2010 and 2013. These led to some changes in design, notably the use of wide-turn tunnels for the ramp access to explore a larger volume of rock and the allocation of separate caverns for each waste type. An expanded expert review group was established in Spring 2013 and construction of the new facility was scheduled to begin in May 2015.

2.10 Hazardous and radioactive waste – differences in perspectives and strategy (M Elert)

Mark Elert addressed differences and similarities in assessments for disposal of conventional and radioactive wastes. For conventional wastes, there is common legislation across the EU that distinguishes hazardous, non-hazardous and inert wastes. Classification is based on the inherent properties of the wastes and some types of waste are always classified as hazardous on account of their origin. Fifteen types of dangerous properties are identified that could make a waste hazardous (e.g. flammable, explosive, carcinogenic), but the content of hazardous substances is also taken into account, with classification based on the rules for classification and labelling of chemical products (the CLP Directive).

Disposal is typically to landfills, with an emphasis on a geological barrier below and a suitable top cover above. However, underground disposal also occurs, e.g. disused rock caverns for oil storage and the use of deep mines. Deep geological storage is required for wastes containing more than 0.1% mercury.

Testing and characterising of the wastes is done against limit values for leaching of metals, salts and organic matter, pH and for organic content. Some wastes (organic, liquid and explosive) cannot be disposed unless a special exception is granted.

Risk assessments for conventional wastes typically focus on leaching and contamination of groundwater and surface water resources, rather than fully studying all potential exposure pathways. The timescale of assessment is often much shorter than for radiological assessments (typically the ‘thousand-year perspective’) and scenario analyses are not usually performed. Risk assessments for conventional wastes tend to be generic rather than site specific, and have more of a focus on the environment than on human health. A further consideration in such assessments is the considerable uncertainties that exist in relation to the risks associated with many chemicals.

Mark identified a number of types of mixed wastes that exhibit both radiological and chemical hazards. These include:

- Pyrite (arsenic, heavy metals, radium, uranium).
- Bioash from areas affected by Chernobyl (metals, Cs-137).
- Peat ash (heavy metals, uranium, thorium, K-40).
- Water filters (arsenic, heavy metals, uranium).
- Cleared radioactive waste.
- Decommissioning waste.

Special challenges with the wastes relate to the applicability of different laws and regulations, the existence of different regulators, and the existence of different cultures for their handling.

For Rönnskär, key issues are the substantial amount of hazardous wastes (currently about 280 000 tonnes), the variety of forms (e.g. sludge, pellets, dust), the high content of heavy metals (with Cd being a bigger problem than Hg) and the large variation in pH (2 to 12). Mark emphasised that there is no intention to make Rönnskär a national waste disposal site.

The Environmental Courts have imposed the following conditions.

- An approved investigation before disposal of waste can begin.
- A system design consisting of: a suitable host rock; sufficient barriers; waste with suitable properties (leaching, permeability), if necessary stabilised.
- Maximum releases: 10 g of mercury per year and 10 kg of cadmium per year, with investigation of the possibility to limit releases to 1 g of mercury per year and 1 kg of cadmium per year.
- A goal of a water flow less than 1 L/m^2 per year in the domain of repository.

In terms of waste handling, there is a requirement for stabilizing waste to reduce leaching and improve mechanical stability, for reprocessing of some waste types, and for separating different waste types in the repository.

A preliminary risk assessment will be based on leaching tests, with no credit taken for sorption in the bedrock, with long time-scales considered and with an analysis of scenarios (e.g. accounting for rising sea level and earthquakes).

Overall, Mark concluded that both sides have much to learn from comparing approaches to the handling of conventional and radioactive wastes. The radioactive waste community is good at modelling impacts, but the conventional waste community has more practical knowledge.

In discussion, Matthew White commented that, in the UK, there is now a requirement to assess the impacts of hazardous waste landfills out to the time of peak concentration and not solely in a ‘thousand-year perspective’.

3 General discussion

Mike Thorne structured the general discussion under a series of broad questions.

- What are the sources of toxic chemicals in the repository and what is their potential for release from wastes, packaging and other materials, including a consideration of which are the priority chemicals?
- How should transport through and release from the engineered system be represented, including considerations of chemical and biological transformations to more or less toxic forms, and likely chemical speciation on release?
- How should transport through the geosphere be represented, including considerations of chemical and biological transformations that would affect both toxicity and transport properties?
- How should distribution and transport in the biosphere be represented?
- What are the important routes of potential exposure of humans and what are the adverse effects of individual toxic chemicals on humans?
- What are the important routes of potential exposure of non-human biota and what are the adverse effects of individual toxic chemicals on non-human biota?
- What, if any, are the potential synergistic effects between toxic chemicals and between toxic chemicals and radiation exposure?
- What is the status of existing and proposed regulatory regimes, including protection of human health, the environment and resources such as groundwater?
- What approaches may be adopted to demonstrating compliance?

Not all of these matters were addressed in the general discussion, but some had already been addressed by the speakers and in the discussions on the individual presentations. Therefore, this section combines comments from the general discussion with those made earlier in the seminar.

3.1 Sources of toxic chemicals

Andra (Section 2.5) has addressed the toxic chemicals present in a wide range of VLLW, LLW and ILW. Key substances were identified as Pb, B, Ni, Cr, As, Sb, Se, Cd, Hg, Be, CN, U and asbestos. PAHs may also be added in future. In Belgium (Section 2.6), waste compositions are not well defined and inverse calculations are being performed to encourage waste producers to generate the relevant information. Although Be is listed by Andra as a key substance, it was subsequently stated in discussion that Be is not a critical substance in either France or Belgium. In the UK (Section 2.7) a structured sequence of screening studies for ILW first identified Be, phenol, benzene, nitrite and organo-metallics as being of potential concern. However, in a subsequent study, using updated inventory information, the key substances for the groundwater pathway were identified as Be, Al, Cr, Mn, Fe, Pb and U. Realistic analyses of the human intrusion and gas pathways eliminated phenol and benzene from consideration and this meant that no substances additional to those identified for the groundwater pathway required consideration. More recent work has focused on Be, Cd, Cr, Pb and U, with specific consideration being given to potential synergistic effects, and the potential for uranium to constitute both a chemotoxic and a radiotoxic hazard. For spent fuel and HLW at Yucca Mountain (Section 2.7) the key substances are Mo, Ni and V, arising from corrosion of the packages in which the wastes are proposed to be emplaced. At Rönnskär (Section 2.9), where the wastes are conventional in nature, Cd and Hg are of greatest concern.

Thus, in general, the key substances are mainly metals and semi-metals rather than organics. In terms of a combination of mass and toxicity Pb, Cd, Cr and U may be of particular relevance, with Be also of potential importance for some waste types.

3.2 Release from the engineered system and transport in the geosphere

In general, simple models in which the inventory is assumed to be dissolved in repository pore water or an overlying aquifer (Sections 2.6 and 2.7) have been used for screening, with sorption and longitudinal dispersion in the geosphere taken into account in some cases (Section 2.7). Overall, this aspect of assessment studies was not covered in depth in the seminar, but, in general, there seems no reason to use release and transport models for metals and semi-metals that differ from those used for radionuclides (Sections 2.2 and 2.7).

3.3 Transport in the biosphere

Some organisations focus on calculating concentrations in groundwaters or surface waters and then make comparisons with drinking water standards (Section 2.6). Other organisations employ the same models as are used for representing radionuclide transport in the biosphere (Section 2.7), but it may be useful for detailed, site-specific assessments to employ a more comprehensive modelling framework such as the MERLIN-Expo Tool (Section 2.8). This has been demonstrated to be applicable to assessing impacts on humans and non-human biota for a wide range of organic and inorganic pollutants, and to be applicable to both direct and inverse modelling problems. It is also able to address uncertainty and sensitivity analyses, and is also fully documented. However, it is probably unduly complex to apply in screening studies and generic assessments.

3.4 Exposures of humans

A key consideration that was brought out in the general discussion is that the types of effects arising from various chemicals differ and that they are not readily commensurate in terms of impacts on health. This is obscured by the use of LOAELs and NOAELs in standards setting without consideration of the severity, or even the clinical significance, of the effects under consideration. Also, the implications of exposures depend very much upon the route of exposure and the chemical form. This was mentioned several times in the context of Cr(VI) relative to Cr(III), while the significance of inhalation exposures relative to ingestion exposures has been studied specifically for Be (Section 2.7).

3.5 Exposures of non-human biota

Exposures of non-human biota were addressed only relatively briefly in the seminar. In general assessments seem to be based on comparisons with Environmental Quality Standards (EQSs), which have been set by a variety of approaches. Even the MERLIN-Expo Tool currently only extends to evaluating the fate of chemicals in the environment and not toxicological impacts on non-human biota (Section 2.8). Given that a short-list of key substances can be identified (Section 3.1), there might be merit in a detailed review and evaluation of the environmental toxicological data available for these substances, as is being done by INERIS on behalf of Andra in respect of human toxicology (Section 2.5).

3.6 Synergistic effects

In general, synergistic effects have not been addressed, except in so far as the use of Hazard Factors and Excess Individual Risks (Section 2.5) implies that impacts from individual substances can be summed (including both summing over substances and summing over pathways of exposure). Only RWM (Section 2.7) seems to have explicitly addressed potential synergistic interactions between various key substances, and between those substances and radiation exposures. Even in that case, the consideration was limited to human health impacts and did not address impacts on non-human biota.

3.7 Regulatory regimes

The regulatory regimes for radioactive and hazardous chemical wastes lie within the same hierarchical structure (Section 2.4), but they are handled substantially differently. Mixed wastes may be regulated under one or other of the regimes and some aspects, e.g. mercury and cadmium contaminated radioactive wastes may be subject to both (Section 2.10). Challenges in harmonising the approaches adopted for radioactive and hazardous chemical wastes relate not only to the different laws and regulations, but also to the existence of different regulators and the existence of different cultures for waste handling and regulation (Section 2.10).

3.8 Demonstrating compliance

The various assessments that have been undertaken (e.g. Sections 2.5 and 2.7) have not resulted in the identification of major concerns over the chemical toxicity of radioactive wastes. However, the non-radiological impacts of mixed wastes are not so low that this aspect can be disregarded in future (Section 2.5) and waste producers need to be encouraged to provide details on toxic chemicals present in their wastes (Section 2.6), nor should toxic materials present in waste packaging and grouts/backfills be neglected, as these can sometimes be the most significant factor in determining impacts, as in the proposed spent fuel and HLW repository at Yucca Mountain (Section 2.7).

References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.se/publications.

Atkinson R, Chambers A V, Crookshanks C E, Gould L J, Heath T G, Linklater C M, Thorne M C, Williams S J, 2001. A preliminary chemical toxicity assessment for the Nirex Repository Concept. AEAT/R/ENV/0474, UK Nirex Limited.

Davis K, Poole M, Williams S J, 2007. Development of a groundwater toxicity assessment for key stable elements in the Nirex PGRC. Serco Assurance Report SA/ENV-0943 to UK Nirex Limited.

Hunter F M I, Jackson C P, Kelly M, Williams S J, 2006. A post-closure toxicity screening assessment for the Nirex Phased Geological Repository Concept. Serco Assurance Report SA/ENV-0854 to UK Nirex Limited.

Jones C, Svensson H, Wiborgh M,Yesilova H, 2010. Kemisk toxicitet hos ämnen som deponeras i slutförvaret för använt kärnbränsle. SKB P-10-13, Svensk Kärnbränslehantering AB. (In Swedish.)

Thorne M C, 2007. An evaluation of the potential toxicological significance of releases of beryllium from a deep geological repository, Mike Thorne and Associates Limited Report MTA/P0017/2007-1: Issue 2 to UK Nirex Limited.

Thorne M C, Wilson J, 2015. Generally applicable limits on intakes of uranium based on its chemical toxicity and the radiological significance of intakes at those limits. Journal of Radiological Protection 35, 743–762.

Wilson J, Thorne M C, 2015. An assessment and comparison of the chemotoxic and radiotoxic properties of uranium compounds. ASSIST report to RWM 1207-ASS-6-1, Version 1.2.

Wilson J C, Thorne M C, Towler G, Norris S, 2011. Illustrative assessment of human health issues arising from the potential release of chemotoxic substances from a generic geological disposal facility for radioactive waste. Journal of Radiological Protection 31, 411–430.

Appendix 1

Final programme for the seminar

The seminar took place on 14 April 2016 at the offices of Lundqvist and Lindqvist in Stockholm. The final agenda is listed below.

Item	Activity	Speaker	Start Time	End Time
1	Introduction	Mikael Gontier	09:00:00	09:10:00
2	Introduction of participants	All	09:10:00	09:20:00
3	Other toxicants in nuclear waste	Ulrik Kautsky	09:20:00	09:25:00
4	Hazardous substances in low and intermediate level radioactive waste	Björn Herschend	09:25:00	09:40:00
5	The regulation of hazardous substances in radioactive waste – an overview of the legislative framework	Malin Lönnqvist	09:40:00	09:55:00
6	Coffee break		09:55:00	10:15:00
7	Limits for hazardous wastes/toxic non-radioactive waste constituents in the Waste Acceptance Criteria: Packages with “mixed” wastes	Yannick Segura	10:15:00	11:15:00
8	Chemotoxics in a Belgian context	Emma Dorado Lopez	11:15:00	11:30:00
9	Lunch		11:30:00	12:30:00
10	Evaluating the chemical toxicity of key substances released from a repository: The UK approach and some experience from the US	Mike Thorne	12:30:00	13:15:00
11	The MERLIN-Expo tool: General introduction	Philippe Cifroy	13:15:00	14:15:00
12	Rönnskär non-radiological waste	Rolf Christiansson	14:15:00	14:35:00
13	Hazardous and radioactive waste – differences in perspectives and strategy	Mark Elert	14:35:00	14:55:00
15	Coffee break		14:55:00	15:15:00
16	General discussion	Led by Mike Thorne	15:15:00	16:45:00

Appendix 2

List of participants

Participant	Organisation
Yannick Segura	ANDRA
Anders Löfgren	Ecoanalytica/SKB
Philippe Ciffroy	EDF
Rodolfo Avila	Facilia AB
Mark Elert	Kemakta AB
Sara Grolander	Kemakta AB
Celia Jones	Kemakta AB
Malin Lönnqvist	Mannheimer Swartling
Mats Tröjbom	Mats Tröjbom Konsult AB
Mike Thorne	Mike Thorne and Associates Limited
Matthew White	NDA
Emma Dorado Lopez	Ondraf
Kirsi Riekki	Posiva Oy
Mikael Gontier	SKB
Ulrik Kautsky	SKB
Jenny Brandefelt	SKB
Eva Andersson	SKB
Olle Hjerne	SKB
Björn Gylling	SKB
Björn Söderbäck	SKB
Raymond Munier	SKB
Sara Nordén	SKB
Ella Ekeroth	SKB
Claes Johansson	SKB
Klas Källström	SKB
Mattias Elving	SKB
Börje Torstenfelt	SKB
Allan Hedin	SKB
Ingrid Wigstrand	SKB
Rolf Christiansson	SKB
Björn Herschend	SKB
Theresa Millqvist	SKB
Anna Pettersson	SKB
Lisa Almkvist	SKB
Katrin Ahlford	SKB
Peter Larsson	SKB
Kristina Skagius	SKB
Anna Rosell	SKB
Teresita Morales	SKB
Ulla Bergström	SKB

Arkitektkopia AB, Bromma, 2016

SKB is tasked with managing Swedish nuclear and radioactive waste in a safe way.

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