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Chemical Risks from Nuclear Waste Repositories

Abstract

Studies concerning the chemical risks of nuclear waste are reviewed. The radiological toxicity of the material is of primary concern but the potential nonradiological toxicity should not be overlooked as the chemotoxic substances may reach the biosphere from a nuclear waste repository.

In the report is concluded that the possible chemotoxic effects of a repository for nuclear waste should be studied as a part of the formal risk assessment of the disposal concept.

Keywords (chosen by the author)

Keywords: Radioactive waste, genotoxic effects, risk assessment, nuclear waste, nuclear waste repository, chemical risks, chemotoxic effects.

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1. Introduction

Ionizing radiation and many chemical substances give rise to so-called genotoxic effects, so named because the initial event leading to the disease is a damage to the gene material, DNA. These effects which comprise cancer and hereditary diseases have certain characteristics which make them a special problem in the context of health protection: The effects appear already at very low doses, most probably without any threshold, the risk increasing proportionally to the dose. This property differs from toxic effects in a classical sense which do not appear until above a critical threshold dose or threshold concentration, and makes risks of these diseases a dominating problem at mostly low environmental doses. Since the frequency of diseases but not their severity is affected by dose, these effects are considered to be stochastic phenomena.

Apart from their potential radiotoxicity the elements introduced in waste repositories may thus exhibit a certain chemical toxicity. These radioactive or stable elements originate in reactor operations and in irradiated fuels or in reprocessing operations. Chemical wastes are also generated during the decommissioning of nuclear facilities. They are found in the container assembly and possibly in the engineered barriers of the repository. Certain canister materials and fuel assembly components are also possible toxic materials under many environmental conditions.

While, in the short term, the radiological toxicity of these materials is of primary concern, the potential nonradiological toxicity and potential synergistic effects of the container and waste materials should not be overlooked. In the longer time frame, as radioactive decay depletes the radionuclides, the non-radiological toxicity potential may become the dominant issue (Fig.1). The risk of any toxic material reaching the biosphere from the repository and the synergistic effects of chemicals and radionuclides should thus be factored into the safety analyses. Depending on various factors (e.g. solubility, volatility, particle size, decomposition rate), the relative chemical toxicity may either increase or decrease with time. Some of the chemicals will remain as they are, however, some of the organic material will decompose

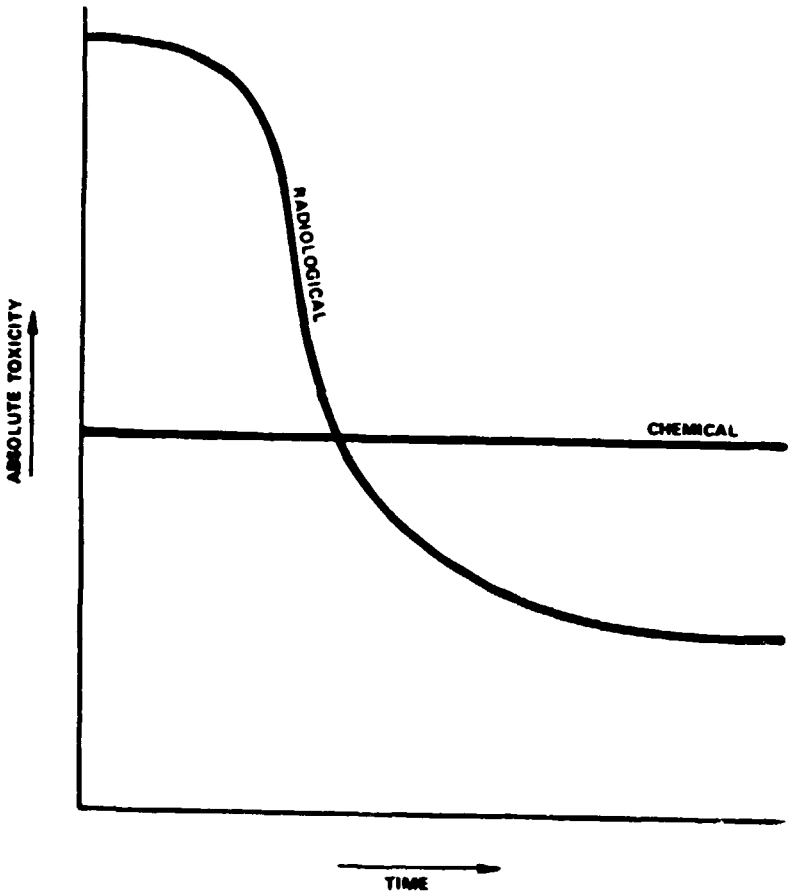

Figure 1. Generalized relationships of radiological and chemotoxic risks of nuclear waste.

Until recently far-field migration effects of chemotoxic substances and their resulting contamination impact on the ecosystem have not been much studied.

The methodical tools applied in nuclear waste disposal safety analysis for the radiological harm may also be suitable for chemotoxic waste.

In this report an attempt is made to summarize the suggestions and the work carried out on the chemical toxicity of the nuclear waste.

2. The CSSN-Report

The French High Council for Nuclear Safety (Conseil Superieur de la Surété Nucléaire - CSSN) appointed 1983 a Working Group on Research and Development in Radioactive Waste Management under the chairmanship of professor R. Castaing. In its report (ref. 1) submitted to the Council 1984 the chemical toxicity of nuclear waste was discussed. The Working Group recommended that research should be carried out to identify chemical elements significantly present in all types of nuclear waste and to evaluate the risks.

3. The SKBF/KBS-Study of SFR

In connection with the safety analysis of the Swedish SFR repository at Forsmark for low-level and intermediate level waste Scandia Consult AB presented a report (ref. 2) on chemical risks from the repository. In the report it was concluded that the small leakage from the repository should not give any chemical harm to man and environment. This conclusion was accepted by the Swedish environmental protection authorities.

4. The Nagra-Study

The Swiss National Cooperative for the Storage of Radioactive Waste (Nagra) has made a detailed survey of potential chemical risks of repositories in Switzerland, (ref. 3).

According to the protection objectives for Project Warranty (Gewähr), 1985, as formulated by the Swiss Federal authorities, a radioactive waste repository should exhibit no adverse effects on man and environment from a chemotoxic point of view. The report demonstrates that construction and operation of repositories as described in Project Warranty, 1985, allow this objective to be met.

The Swiss Federal Office for Environmental Protection made available a list of relevant ecotoxic materials and other substances which could present a problem due to their chemical and toxic properties. The drawing up of an inventory of ecotoxic and other potentially harmful substances in the type B (low and intermediate level waste) and type C (high-level waste) repositories has shown that these materials occur mainly in the type B repository and the heavy metals Ni, Cd, Cu, and Cr can be taken as representative.

In agreement with the Federal Office for Environmental Protection and due to possible implications for human health, cadmium was selected for further investigation by Nagra, mainly because of the interest attracted by this metal in ecological discussions. Under the assumption that the cadmium originally emplaced in metal form later oxidizes and migrates as a bivalent cation with groundwater from the repository zone into the biosphere the maximum expected cadmium concentration in the biosphere can be determined. The methods and parameters used for the transport calculation were similar to those for radioactive materials in Project Warranty.

No maximum allowable concentrations are laid down for Cd and other chemotoxic materials in the environment. However, in order to

assess the values calculated, reference can be made to the standard values for heavy metal content in agriculturally viable soils as well as to natural concentrations. For cadmium, the calculated content in the ground is around an order of magnitude lower than the corresponding standard value for agriculturally exploited ground, while the soluble proportion is around a factor of 30 lower than the relevant standard value.

Based on the conservative calculation of material transport in the geo- and biosphere and on the evaluation of the results outlined above, Nagra has concluded that the cadmium present in the repository causes no significant increase in environmental Cd concentrations. The ecotoxic risk potential of cadmium from the type B repository was therefore regarded as insignificant by the authors. This conclusion holds as well for a type C repository (high-level radioactive waste), because its content of Cd is low and the migration paths to the biosphere are large.

Simple comparative calculations in the report of Nagra show that the ecotoxic conditions for the other heavy metals (nickel, copper and chrome) are basically the same as those for cadmium.

The result of this Nagra-report has been accepted by the Swiss Federal Office for Environmental Protection as reported at a meeting with Nagra management and experts on January 11, 1988, in Baden, Switzerland.

5. The AECL-Study

The Atomic Energy of Canada (AECL) has in 1987 issued an assessment of the long-term impact of chemically toxic contaminants from the disposal of nuclear fuel waste. The Report (ref. 4) presents a study on the potential for impact on man of chemically toxic contaminants associated with the Canadian concept for the disposal of nuclear fuel waste. The elements of concern are determined through a series of screening criteria such as elemental abundances and solubilities. A systems variability analysis approach is then used to predict the possible concentrations of these elements that may arise in the biosphere. These concentrations were compared with environmental guidelines such as permissible levels in drinking water. Conclusions were finally made regarding the potential for the chemically toxic contaminants to have an impact on man.

According to the AECL-Study there are over 50 elements associated with nuclear fuel waste disposal that should be taken into

consideration for an assessment of chemical toxicity impact. For the purposes of the study, these elements were assumed to occur in one or more of the six representative waste forms, where "waste form" refers to any potential source of toxic elements. The six waste forms considered are: used fuel, sodium borosilicate glass, a hypothetical composite container, a lead-antimony infilling material, a zinc infilling material, and zircaloy.

A consideration of criteria such as solubility limits and natural abundances has resulted in the elimination of most elements from further detailed consideration. The 12 remaining elements that were carried through a more detailed assessment are boron, bromine, cadmium, chromium, cesium, molybdenum, nickel, lead, antimony, samarium, technetium and zinc.

This assessment was carried out using a modified version of the stochastic systems assessment code, SYVAC 2, originally developed to evaluate the radiological impacts of underground disposal of nuclear wastes. In SYVAC 2 a set of equations describes the transport of chemical elements from the repository through the bedrock to the biosphere. Some parameters in these equations cannot be measured precisely, but upper and lower limits can be given from them. This uncertainty about parameter values, and consequently about the results of the calculation, is handled by repeated calculations. In each calculation different parameter values are selected in a random way, but so that each parameter is within its uncertainty range.

In all 1000 calculations were made for each waste form. Each calculation gave the concentrations of each of the elements in respectively the soil, lake and well compartments of the biosphere. These concentrations differed from one calculation to another since the parameters had been changed, but the results from 1000 calculations gave a range of predicted concentrations for each element and the probability that the concentrations exceed acceptable levels in the biosphere. Maximum estimated concentrations were then compared with acceptable levels of concentration in the biosphere, and the results statistically interpreted.

In general, the results suggest that there exists a low probability that nuclear fuel waste disposal could give rise to chemically harmful impacts. For the soil compartment, only chromium, molybdenum and lead occasionally exceeded their acceptable levels, with a maximum occurrence of 17 out of 1000 simulations for molybdenum which owes to the composite container. For the lake

compartment, the same three elements were the only ones to exceed their acceptable levels, with a maximum occurrence of 8 out of 1000 simulations for chromium (from the composite container). For the well compartment, boron, bromine, chromium, molybdenum and technetium occasionally exceeded their acceptable levels, with a maximum occurrence of 83 out of 1000 simulations for boron (from sodium borosilicate glass).

As a measure of the potential risks, the authors have compared the ratios of the calculated mean concentrations with the corresponding acceptable levels. Using this criterion, only the well compartment has ratios exceeding unity for chromium (from the composite container), molybdenum (from the composite container and from the sodium borosilicate glass) and boron (from the sodium borosilicate glass), listed in order from the highest to lowest ratio.

There are four major factors that affect these results. The first three, the elemental inventories, release rates and toxicities, mostly affect the magnitudes of the estimated impacts. The fourth factor, the elemental mobility in the geosphere, mostly affects the frequencies with which estimated impacts occur. All four factors contribute to the potential hazards from chemical toxicity, although one or more factors may be dominant.

Based on these results, it was concluded by the authors that there is a low probability of realizing significant chemical impacts from the disposal of nuclear fuel wastes in Canada. If desired, these impacts can be readily reduced or even eliminated. For example the current disposal concept in Canada involves used fuel enclosed in a titanium container. Consequently, there would be no potential chemical toxicity effects from either the composite container or from the sodium borosilicate glass waste forms that were considered in this report, and no instances where an estimated mean concentration of an element exceeds its acceptable level.

It is emphasized that the results described in the AECL-Study are preliminary, in that they are based on computer models and data that are still in the process of review, development and research. Although it can be expected that further changes to the models and data will lead to some changes with details of the conclusions, in general the conclusions should not change in an overall qualitative sense. On the whole, most approximations and simplifications in

SYVAC2 are of a conservative nature, so that the estimated impacts are expected to be lower than those stated.

Nevertheless, the major recommendations of the AECL-report are that the assessment of potential chemical impacts should be part of the formal concept safety assessment, and that these studies should be repeated using the updated models and data. It is also suggested that, for future assessment studies, the evaluation of chemical toxicity effects be based on a better-quantified measure of impact and risk, possibly through detailed evaluations of the toxicologies of selected elements.

6. Discussion

A comparison of chemical and radiological hazards presents difficulties from the differences in the types of harm and the problems in qualifying the extent of harm. High acute doses of radiation or high acute intakes of chemical poisons can produce deleterious effects. For these cases a reasure of the risk for lethality can be used to compare chemical and radiological toxicities.

Such comparisons are of limited value in the study of nuclear waste repositories since large single intakes of contaminants are very unlikely. A much more likely situation is the intake of very small quantities of contaminants involving either radiological risk or chemical risk or both types of risks. These effects which comprise cancer and hereditary diseases have certain characteristics which make them a special problem in the context of health protection. The effects appear already at very low doses, most probably without any threshold. The risk increases thus proportionally to the dose. The effects of low level exposures to radiation have been more studied than those from low level exposures to chemicals. However, there exist now data making possible an evaluation of the long-term chemical health effects on man even if it must be admitted that uncertainties still exist. Studies of the cancer risks from chemicals are given in the evaluations of the International Agency for Research on Cancer (IARC) (ref. 5).

A fairly extensive list of papers concerning chemical risks is available in the SSI Report 88-14 (ref. 6). The assessments of risks from low-level exposures to radiation and chemicals have been discussed at several conferences most recently at the seminar "Applications, Perspectives and Limitations of Comparative Risk

Assessment and Risk Management" organized by the Commission of the European Communities held in Nice, France, September 26-30, 1988 and at the symposium: Management of Risk from Genotoxic Substances in the Environment in Stockholm, 3-6 October, 1988 (Proceedings from the symposium will be available from the National Institute of Radiation Protection, Stockholm).

7. Conclusions

The detailed studies carried out in Switzerland and Canada do not indicate that there is a significant chemical risk for man and environment due to a repository for nuclear waste according to the Swiss and Canadian concepts.

It is, however, recommended that an assessment of the potential chemical impact should be a part of the formal safety assesssment for nuclear waste repositories.

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Rapport-nummer	Titel (undertitel)	Författare
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