Recent Trends in Nuclear Waste Disposal

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HU ISSN 1418-7108: HEJ Manuscript no.: ENV-020507-A

Abstract

Environmental radioactivity has been an important area of research throughout the 20th century, because contamination of land and water by radioactive materials has caused many of the serious environmental problems. Significant aspects of environmental radioactivity contains final disposal of low-, intermediate-, and high-level radioactive wastes, the interim storage of and final disposal options for spent fuel, the hydrogeological investigation of repository sites. Furthermore, it includes the basic safety requirements related to the disposal of radioactive wastes in near surface repositories. It also comprises requirements for the protection of human health, for the assessment procedures needed to ensure that safety is achieved, and technical requirements for waste acceptance and for siting, design, construction, operation and closure of the repository as well as for the post-closure phase. The preferred option for eventual disposal of long-lived radioactive waste is emplacement in repositories deep underground in geologic media.

1 Introduction

Recent work of research of environmental radioactivity having been stimulated mainly: remarkable power of radionuclides as tracer of the rates and mechanisms of environmental processes, and the potential health implication of contaminant radionuclides 1 in the environment. Salient aspects of environmental radioactivity include consideration of tracer applications, sources and environmental impact of antropogenic radionuclides, radioactive waste disposal and future exploitation of nuclear energy [19]. In 1998, radioactive waste management around the world focused on management solution for: the final disposal of radioactive waste, the interim storage and final disposal option for spent fuel, the disposition of excess weapons plutonium, waste repositories, decontamination, decommissioning, remedial actions and treatment, environmental occurrence and transport of radionuclides [3].

The protection of environment and ethical issues that it raises is important topics in the debate on the long-term management of radioactive waste. Pescatore, [26] describes an overview of the general ethical principles developed in wider context of the debate on the environment, and then addresses the specific

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Table 1: The relative radiotoxicity of some significant radionuclides.

RADIOTOXICITY	RADIONUCLIDES
very high	$^{90}Sr, ^{210}Pb, ^{211}At, ^{226}Ra, ^{227}Ac, ^{239}Pu, ^{241}Am, ^{242}Cm\ldots$
High	$^{45}Ca, ^{59}Fe, ^{89}Sr, ^{131}I, ^{140}Ba, ^{234}Th, ^{238}U\ldots$
Medium	$^{22}Na, ^{24}Na, ^{32}P, ^{35}S, ^{36}Cl, ^{42}K, ^{60}Co, ^{132}I, ^{137}Cs\ldots$
Slight	$^{3}H, ^{7}Be, ^{14}C, ^{18}F$

Table 2: Classification and characterisation of radioactive waste.

Classification of radioactive waste	Characterisation
I. HIGH ACTIVITY, LONG LIFE	high intensity of β- or γ- radiation, large α- activity high radiotoxicity, large making of heat
II. MEDIUM ACTIVITY, LONG LIFE	medium intensity of β- or γ- radiation, large α- activity medium radiotoxicity, medium making of heat
III. LOW ACTIVITY, LONG LIFE	low intensity of β- or γ- radiation, large α- activity low or medium radiotoxicity, negligible making of heat
IV. MEDIUM ACTIVITY, SHORT LIFE	medium intensity of β- or γ- radiation, negligible α- activity medium radiotoxicity, medium making of heat
V. LOW ACTIVITY, SHORT LIFE	low intensity of β- or γ- radiation, negligible α- activity low radiotoxicity, negligible making of heat

case the management of long-lived radioactive waste. In 31 August - 4 September 1998 held international conference in Vienna. This objective of the conference was to foster the exchange of information on topical issues in nuclear, radiation and radioactive waste safety, with aim of consolidation an international consensus on the current state of these issues, priorities for future work, and the need for strengthening international co-operation. Contents include: safety management, occupation radiation protection, modernisation of nuclear power plants, radiological protection principles for situation of chronic exposure to residual radioactive materials, decommissioning and reclamation of land, disposal of long-lived waste and regulatory strategie.

2 Radioactive waste disposal

Computational tools and techniques developed in the late 1950s and early 1960s to analyse the reliability of nuclear weapon delivery system were adopted in the early 1970s for probabilistic risk assessment of nuclear power reactors, a technology for which behaviour was unknown. In turn, these analyses become important foundation for performance assessment of nuclear waste disposal in the late 1970s [14]; [29]. Vincenti, [38] interprets, in your article, briefly highlight the development of radiation science, technology and applications that generate commercial low-level radioactive waste. It will focus on the past 18 years since the passage of the Low-Level Radioactive Waste Policy Act of 1980 and summarise the current status of national low-level radioactive waste facility development. Radioactive waste is categorised for five basic group: high, medium, low activity (long life) and medium, low activity (short life) 2. Safe disposal of radioactive waste, especially spent fuel 3, ex-military fissile materials and other forms of this waste, is one the major challenges facing contemporary science.

Currently, internationally preferred solution is for geological disposal by interment in a mined and engineered, multi-barrier repository [1]; [9]; [10]; [11]. Recent advances in the knowledge of continental crustal rock and fluids at depths of several kilometres suggest that much deeper disposal might offer a safer and environmentally more acceptable solution to the high-level waste problem [12]. Member countries within the OECD prefer geological disposal of long-lived radioactive waste also, because is it a practical solution to protect humans and their environment for the foreseeable future [35]. For example, in Germany has been planed the utilisation and removal of waste material into opencast and underground mines as well as the final storage of radioactive waste in excavated voids of mines [16].

Table 3: The presence of most significant radionuclides in the fuel cells of a typical energetic nuclear reactorat a typical time.

NUCLIDE	HALF-LIFE	SPECIFIC ACTIVITY OF THE FUEL [MBq.g-1]
^{134}I	52 m	44 400
^{133}I	20,3 h	40 700
^{135}I	6,7 h	37 000
^{132}I	2,3 d	29 600
^{131}I	8,1 d	20 350
^{137}Cs	30 y	2 331
$^{90}Sr -^{90}Y$	27,7 y - 64 h	1544
^{85}Kr	10,7 y	222
^{60}Co	5,3 y	111
^{239}Pu	24 390 y	7,777
^{14}C	5730 y	0,11
^{129}I	$1,7.10^7$ y	0,0011

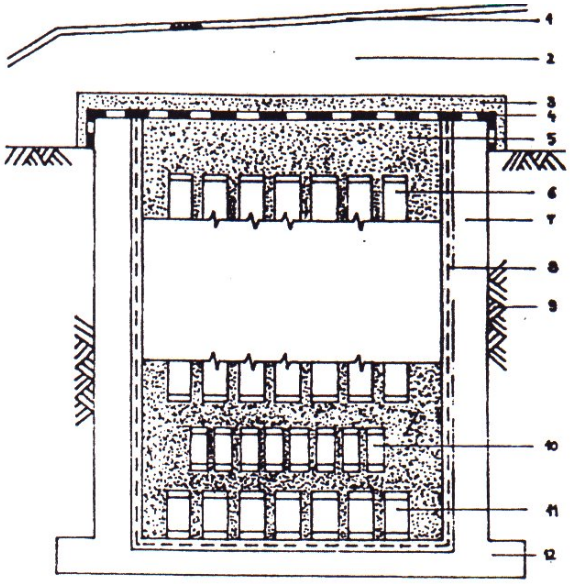
m - minute, h - hour, d - day, y - year

Engineered disposal system has generally been constructed at or near the surface for wastes with low-level radioactivity and wastes with short-lived radioactivity. It is being built or is planned to built deep underground in geological formation for high-level and long-lived wastes. A safety assessment of this type of nuclear waste repository 1 requires the ability to build credible models for radionuclides migration [20]. The Thermochemical Data Base project (OECD) aims to make widely available basic thermochemical data of type needed for safety assessment of nuclear storage facilities [23]. The component of the programs on deep geological disposal of radioactive waste is hydrogeological investigation too, based on experience gained in member states on those rock types considered as having potential to host a repository [5], [15], [43]. The French Institute of Protection and Nuclear Safety is developing in situ studies concerning the confining properties of this kind of geological barrier at the Turnemire tunnel site (Averyron, French). The past research programme covered physical and physico-chemical properties of the consolidated argillaceous medium, diffusive and convective transport, rock and water chemistry and long-term behaviour of the host rock. Investigation concludes that fluid circulation in the unperturbed matrix is very slow. However, past tectonic events have induced fractures, which might accelerate these circulations. The hydraulic role of fractures in this type rock is poorly known. A detailed study of the role these fractures is presently by [4], who summarises the results obtained so far at Tournemire, and the current research orientation.

1- grassy soil, 2- poured soil, 3- concrete for isolation, 4- watertight isolation layer, 5- concrete, 6- the upper row of barrels, 7- wall of the repository, 8- watertight isolation layer, 9- soil, 10- 200-l-barrels, 11- 400-l-barrels, 12- the bottom plate.

The UK nuclear industry uses seawater for both operational purpose and waste discharge. Atmospheric and direct radiation discharges also affect the surrounding coastal environment. The regulation of these discharges has underground great changes in the last decade. The quantification of the composition of the discharges introduces the current legislative controls over radioactive discharges, concentrating on the Radioactive Substances Act 1993 and analyses the authorisation framework implemented by Environmental Agency [21]. Calculation of radiological risk are required to assess the safety of any potential future UK deep underground repository for intermediate-level and certain low-level solid radioactive wastes. In support of such calculations, contaminant movement and dilution in the terrestrial biosphere is investigated using the physically based modelling system. Two case studies are presented involving modelling of contaminants representing long-lived poorly sorbed radionuclides in the near-surface aquifers and surface waters of hypothetical catchments. The catchments are characterised in terms of detailed spatial data for topography, the river network, soils and vegetation. Simulations are run for temperate and boreal climates representing possible future conditions at a repository site. Results are presented in terms of the concentration of contamination in the aquifer, a soils and in surface waters, these ear used to support the simpler models used in risk calculations [25]. A simple methodology has been devel-

Figure 1: Repository of nuclear waste.



oped for evaluating the technical capabilities of potential sites for disposal of mixed low-level radioactive waste. The results of the evaluation are expressed as "permissible radionuclides concentration in disposed waste". The methodology includes an analysis of three separate pathways:

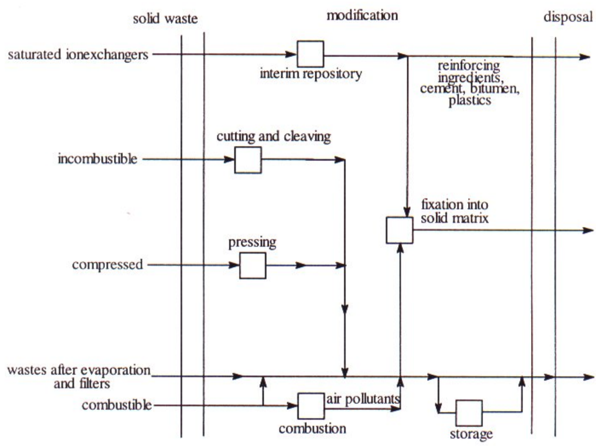
1. Releases of radionuclides to groundwater.
2. Releases of potential volatile radionuclides to the atmosphere.
3. The consequences of inadvertent intrusion into a disposal facility.

For each radionuclides, its limiting permissible concentrations in disposed waste is the lowest of the permissible concentration determined from each of the three pathways [39]. Ten sites were evaluated as potential locations for disposal of mixed low-level radioactive waste. The results were summarised by the 58 evaluated radionuclides according to their half-lives and environmental mobility and by their limiting pathway (i.e., the pathway providing the lowest permissible radionuclides concentration in disposed waste of the tree evaluated pathways) and they indicate that all evaluated sites have the technical capability for disposal of same radionuclides in the waste [40]. Carter [7] has been proposed a new approach to creating and verifying bottom barriers under existing waste dumps. This approach can help create safer long-term contaminant for long-buried radioactive materials without the hazards of digging it up. Be using the new jet grouting technology, radioactive waste is encapsulated without returning spoils to the surface. This technique uses a hematite analogue grout with rheological properties that allow relatively small volumes of the grout to disrupt and thoroughly mix with soil and debris, reducing the amount of grout required and spoils produced.

3 Radionuclides transport models for radioactive waste repositories

Increasingly the burial of nuclear waste in deep underground repositories is being regarded as safe long-term solution for disposal. However, to support this safety assessment models of the associated risks are required [24], [22]. An important component of these models is the upward migration of radionuclides from a contaminated water table into arable and pasture crops. The results show the importance of correctly characterising the soil hydrology and indicate that model conceptualisation derived from surface contamination studies may not adequately capture the various processes which influence the upward

Figure 2: Possibility of processing of radioactive solid waste.



movement of radionuclides in vadose zone [6]; [7], [?]. A method to simulation the long-term migration of radionuclides in near surface of river catchment, following their release from a deep underground repository for radioactive waste involves constructing a lumped model in which catchment is represented by number of conceptual water storage compartments. The flow rates to and from these compartments are prescribed by function that summarise the results from physically based distributed models run for a range of characteristic flow regimes [32]. Control of runoff (reducing infiltration) and erosion at shallow land burials is necessary in order to assure environmentally safe disposal of low-level radioactive waste. [2] is studied evaluated the runoff and erosion response of two perennial grass species on simulated waste burial covers at Idaho National Engineering and Environmental laboratory (INEEL). Distribution coefficients (k_d) are widely used as a first approach to the understanding and determination of the eventual fates of metals and radionuclides released into aquatic environments. The theoretical description of their dependence on particle size allow us to identify and separate in environmental samples of supercritical bottom sediments the contributions of both naturally occurring particles and contaminated ones coming from radioactive emulsion waste released into aquatic ecosystem. Laissaoui et al. [17]is presented, in yours paper, the theoretical basis the technique as well as its application to environmental samples from the Odiel River, in Southeast Spain. The application of this technique provides both direct informations about the extent of the radiological impact and a suitable data set for environmental modelling purposes. Jerzemba et al. [13] is described an analytically based method for modelling the time-depended radionuclides areal densities of contaminated soil surface layers when the soil experiences simultaneous leaching, surface erosion and chain radioactive decay. The model is used predict time-dependent radionuclides areal densities in a volcanic ash blanket contaminated with spent nuclear fuel particles for the purpose of assessing the risk of radiation exposure from an extrusive volcanic event near a proposed high-level waste repository at Yucca Mountain. Although the analysis presented herein is for modelling contaminated volcanic ash blankets, the model would work equally well for modelling time-depended radionuclides contamination of land surfaces in, for example, site decommissioning. It is suggested the general solution for serial decay can also be used to model the release of radionuclides from the waste packages under anticipated repository conditions. Mathematical models of radionuclides distribution and transport in the environment have been developed to assess the impact on the people of routine and accidental releases of radioactivity from a variety of nuclear activities, including: weapons development, production, and testing, power production and waste disposal [31], [37], [41], [42]. The model is used estimate human exposures and doses in situations where measurements have not been made or would be impossible or impractical to make. The results shows the various applications and types of models currently used to represent the distribution and transport of radionuclides in the terrestrial and aquatic environments, as well as integrated global models for selected radionuclides and special issues in the fields of solid radioactive waste disposal and dose reconstruction [36].

4 Microbial studies in the repository of the nuclear waste

Many countries considering radioactive waste disposal have, or are considering programs to study and quantify microbial effects in terms of their particular disposal concept. Quantitative research should cover topics such as the kinetics of microbial activity in geological media, microbial effects on radionuclide migration in host rock (including effects of biofilms), tolerance to extreme conditions of radiation, heat and desiccation, microbially- influenced corrosion of waste containers and microbial gas production. The research should be performed in relevant disposal environments with ultimate objective to quantify those effects that need to be include in models for predictive and safety assessment purposes. An example is the viability of microbes in clay-based sealing materials. Laboratory studies have shown that the clay content of these barriers strongly affects microbial activity and movement. This is supported by natural environment and analogue observations that show clay deposits to contain very old tree segments and dense clay lenses in sediments to contain much smaller, less diverse and less active microbial population than more porous sediments [33]. A full-scale nuclear waste disposal container experiment was carried out 240 m below ground in an underground granitic rock research laboratory in Canada. During the experiment, the heat caused a mass transport of water and moisture content gradients developed in the buffer ranging from 13% closes to the heater to 23% at the rock wall of the deposition hole. Upon decommissioning after 2,5 years, microorganisms could be cultured from all samples having a moisture content above 15% but not from samples with moisture content below 15%. Heterotrophic aerobic and anaerobic bacteria were found in numbers ranging from 10^1 to 10^6 cells/g dry weight buffer. Approximately 10^2, or less, sulphate-reducing bacteria and methanogenes per gram of dry weight buffer were also found. A total of 79 isolates from five buffer layers were identified as representing the beta, gamma and delta groups of Proteobacteria and Gram-positive bacteria. Sixty-seven 16S rRNA clones that were obtained from three buffer layers were classified into 21 clone groups representing alpha and gamma groups of Proteobacteria, Gram-positive bacteria, and a yeast. Approximately 20% of the population comprised Gram-positive bacteria. Members of the genera *Amycolatopsis, Bacillus*, and *Nocardia* predominated. Among Gram-negative bacteria, the genera *Acinetobacer* and *Pseudomonas* predominated. The results suggest that a nuclear fuel waste buffer will be populated by active microorganisms only if the moisture content is above a value where free water is available for active life [34]. Microbiological studies of spent nuclear fuel storage basins at Savannah River Site (SRS) were performed as a preliminary step to elucidate the potential for microbial-influenced corrosion in these facilities. Total direct counts and culturable counts performed during a 2- year period indicated microbial densities of 10^4 to 10^7 cells/mL in water samples and on submerged metal coupons collected from these basins. The presence of several biocorrosion- relevant microbial groups was detected with commercially available test kits. Scanning electron microscopy and X-ray spectra analysis of osmium tetraoxide-stained coupons demonstrated the development of microbial biofilm communities on some metal coupons submerged for 3 weeks in storage basins. The results suggest that, despite the oligotrophic and radiological environment of the SRS storage basins and the active water deionization treatment commonly applied to prevent electrochemical corrosion in these facilities, these conditions do not prevent microbial colonisation and survival. Basin chemistry control and corrosion surveillance programs instituted several years ago have substantially abated all corrosion mechanisms [30]. Pitonzo et al. [28] presents the results that have significant implications for underground storage of nuclear waste as they indicate that indigenous microorganisms are capable of surviving gamma irradiation in a viable but nonculturable (VBNC). A time-course experiment was conducted to evaluate the effects of gamma radiation on the indigenous microbiota present in rock obtained from Yucca Mountain. The microbial communities were characterised after receiving cumulative doses of 0, 0.098, 0.58, 2.33, 4.67, 7.01 and 9.34 kGy. Radiation-resistant microorganisms in the pulverised rocks become VBNC after a cumulative dose of 2.33 kGy. VBNC microorganisms lose the ability to grow on the media on which they have routinely been cultured in response to the environmental stress imposed (i. E. radiation) but can be detected throughout the time course using direct fluorescence microscopy techniques. Libert et al. [18] is demonstred concerns the effect of organic acids produced by microorganisms in a deep repository. In a first step, they are studded the conditions leading to cellulose degradation and organic acids production by cellulotytic microorganism: fermentative conditions lead to an increase of the organic acids production. Secondly, the complexation properties of uranium by these acids are shown. The effect of the organic acids on the degradation of cement, used as an engineered barrier or as an embedding matrix for nuclear waste is shown. The leaching of calcium is correlated to the pH of the solution and to organic acid production. Biodegradation of cement is expressed in terms of equivalent leach layer thickness in calcium.

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