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ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

PROGRESS TOWARD DISPOSAL OF LLRW IN CANADA

PROGRESSION VERS L'ÉVACUATION (STOCKAGE PERMANENT) DES DÉCHETS DE FAIBLE RADIOACTIVITÉ AU CANADA

D.H. CHARLESWORTH

Paper to be presented at: 1989 Joint International Waste Management Conference, Kyoto, Japan, 1989 October 22-28, sponsored by American Society of Mechanical Engineers, Atomic Energy Society of Japan, and Japan Society of Mechanical Engineers

Chalk River Nuclear Laboratories Laboratoires nucléaires de Chalk River

Chalk River, Ontario K0J 1J0

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RÉSUMÉ

Les déchets de faible radioactivité sont gérés actuellement, au Canada, par des techniques de stockage provisoire appliquées par les principaux producteurs des déchets en question. Les avantages possibles de l'évacuation (stockage permanent) ont conduit Énergie atomique du Canada limitée à entreprendre un programme de mise au point et démonstration pour passer du stockage provisoire à l'évacuation (stockage permanent) en ses Laboratoires de recherches de Chalk River. Les premières phases de la démonstration sont basées sur une version améliorée de l'enfouissement (décharge) contrôlé à faible profondeur des déchets les moins dangereux ainsi que sur une conception unique d'enceinte souterraine en béton.

Le programme comporte la mise au point et les essais de l'appareillage auxiliaire et des procédés et techniques nécessaires pour soutenir le système d'évacuation (stockage permanent) ainsi que les techniques d'évaluation de la sûreté et les renseignements nécessaires pour assurer sa sûreté.

Technologie de la gestion des déchets
Énergie atomique du Canada limitée
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ABSTRACT

Low-level radioactive wastes are managed in Canada currently by interim storage methods operated by the major generators of the wastes. The potential benefits of permanent disposal have led Atomic Energy of Canada Limited to undertake a development and demonstration program to make the transition from storage to disposal at its Chalk River Nuclear Laboratories. The first stages of the demonstration are based on an enhanced version of shallow land burial for the least hazardous wastes, and a unique design of a belowground concrete vault.

The program includes the development and testing of the auxiliary equipment, processes and procedures necessary to support the disposal system, as well as the performance assessment methods and information needed to assure its safety.

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INTRODUCTION

Most of the low-level radioactive wastes (LLRW) in Canada are managed by three organizations, Atomic Energy of Canada Limited (AECL), Ontario Hydro, and Cameco. All currently use storage rather than disposal methods. However, the potential benefits of permanent disposal, which include less handling, less worker dose, and less responsibility on future generations, and a stated preference by the regulatory agency for permanent disposal (AECB, 1987) have led AECL to undertake a development and demonstration program (Dixon, 1985) to make the transition from storage to disposal. This paper describes the progress made in that program.

The Canadian nuclear industry and radioisotope users produce roughly 13 000 cubic metres (as-generated volume) of LLRW a year. The major producers of LLRW, and their approximate generation rates, are the three nuclear-electric utilities (8000 m^3/a) and the two nuclear research centres (3000 m^3/a) of Atomic Energy of Canada Limited (AECL). Minor producers, such as radioisotope processors and users, generate an additional 2000 m^3/a that are sent to AECL's storage facilities at the Chalk River Nuclear Laboratories (CRNL). Cameco (formerly Eldorado Nuclear) stores the wastes from its uranium refining and conversion operations at its own sites.

In addition to the LLRW that are continuing to be generated from the above-mentioned sources, there is a large existing inventory (about 1 200 000 m^3) (Cameron et al., 1986) stored at several locations. A majority of this waste arose from uranium refinery operations and its permanent disposal is currently the focus of a separate program begun under the direction of a federal task force (Siting, 1987). A discussion of those activities is outside the scope of this paper.

OUTLINE OF AECL'S LLRW DISPOSAL PROGRAM

In the 1970's, AECL undertook to develop improved methods of managing LLRW, including permanent disposal. Because the first application of these methods was to use near-surface facilities at the CRNL site, compatibility with its overburden conditions was a requirement. The CRNL conditions are typical of the Canadian Shield (Killey and Devgun, 1986). Much of the site is bedrock, exposed or covered by less than about 1.5 m of unconsolidated sediments. The sediments are primarily bouldery, sandy glacial till and aeolian and fluvial sands, with no significant deposits of low-permeability material. The most attractive locations for disposal facilities (as well as current storage facilities) were several sand ridges in which the water table was as much as 15 m below the surface. Because of the permeability of the sand and the temperate humid climate, effective containment of the disposed waste requires the use of engineered barriers to supplement the retention characteristics of the site.

Since much of the containment role is to be based on engineered barriers, one possible strategy was to categorize the wastes and tailor the barriers to the needs of each category. To this end, categories were defined according to the duration of the potential hazard of the wastes, that is, their hazardous lifetime. Three categories were chosen corresponding to hazardous lifetimes of less than 150 years, less than 500 years, and greater than 500 years. Disposal concepts were chosen (Dixon, 1985) with containment characteristics expected to match or exceed the necessary period of safe performance.

The number of waste categories was set at three to correspond with observed distributions in the radiological decay properties of the wastes. Many of the wastes from radioisotope users and reactor operation contain significant concentrations of only radionuclides of relatively short half-lives, for example, radiopharmaceuticals containing iodine-125 and reactor wastes contaminated with activated corrosion products such as zinc-65 and cobalt-60, and with tritium. If these wastes contain no more than minor concentrations of longer-lived nuclides such as cesium-137 or the actinides, the residual hazard of the buried wastes is small after 150 years of radiological decay.

Wastes that are contaminated from sources of fission products such as defected irradiated fuel, isotope-production targets, or destructive examination of developmental nuclear fuel, may remain hazardous for several hundred years. Isolation of this category of wastes for up to 500 years is considered desirable.

The third category of LLRW is primarily material containing sufficiently high concentrations of long-lived radionuclides, such as the uranium and thorium series, or carbon-14, that the potential hazard may persist for periods that are long in comparison to the expected durability of man-made materials. For the permanent disposal of these wastes, natural isolating barriers are appropriate.

The AECL LLRW program undertook to develop and demonstrate disposal concepts matched to each of the waste categories along with auxiliary technologies such as waste characterization and treatment, and safety-assessment methodology, needed to establish an integrated system to manage all LLRW.

CONCEPTS AND PROTOTYPES

To be satisfactory under Canadian regulations (AECB, 1987), a LLRW disposal system must ensure that the serious health risk to individuals is less than one in a million per year as a result of migration of nuclides from the waste through pathways in the environment, or by inadvertent intrusion of the waste. Thus, the disposal concepts to be used at CRNL for each of the categories of waste must prevent exposure through either of the scenarios, nuclide migration or human intrusion, for at least a time period equal to the hazardous lifetime of the waste.

For the more than forty years that CRNL has been in operation, mildly radioactive wastes have been buried in dry sand above the water table, with monitoring of the groundwater downgradient of the waste to measure the degree to which any nuclides migrated (Killey and Devgun, 1986). Although this procedure has been considered a method of storage, thus requiring continuing care and maintenance, experience has shown that migration of most radionuclides was greatly retarded. The prime exceptions were tritium and ruthenium which, once they had been carried downward by infiltrating water of precipitation, travelled at the groundwater velocity, and, to a lesser extent, strontium-90 and complexed cobalt-60 that moved at a small fraction of the velocity. An 8000 m^2 test section of the burial area was covered by a polyethylene membrane in 1983 to minimize water infiltration. Subsequent monitoring (Killey and Munch, 1986) revealed that the concentration of tritium in the groundwater leaving the covered portion of burial area had decreased markedly.

Based on the encouraging storage experience of 40 years, a disposal concept based on burial is being developed to accept the lowest category of LLRW, that with a hazardous lifetime of less than 150 years. The concept, known as the Improved Sand Trench (IST), and shown in Fig. 1, incorporates a cap made of a water-shedding membrane supported on a panel structure of lean-concrete. The infiltrating water intercepted by the cap drains laterally to drainage channels at the boundaries of each panel. The protective mechanisms of the concept are:

- an infiltration barrier, to restrict downward transport of nuclides from the waste;
- a consolidated cap, to support the membrane and reduce uneven subsidence;
- a relatively dry waste environment, supported on a sand bed, which slows bacterial degradation of the waste;
- a free-flowing unconfined aquifer in a sand layer well below the waste, which dilutes any escaping nonreactive radionuclides, but provides a reasonable retardation for most other nuclides.

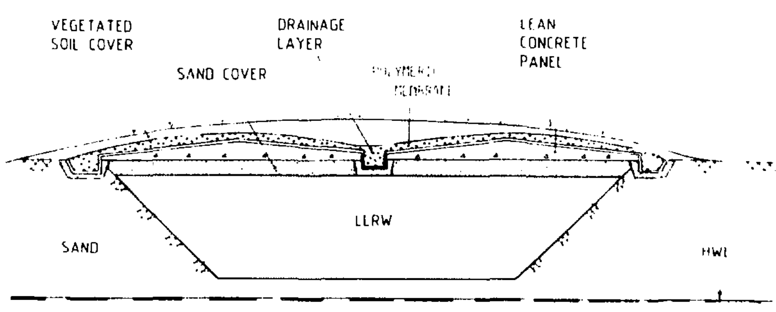

FIGURE 1 SECTION THROUGH IMPROVED SAND TRENCH

FIGURE 1: SECTION THROUGH IMPROVED SAND TRENCH

Although the concrete cap provides some protection against potential inadvertent intrusion, a period of active institutional care followed by an additional period of passive access and land-use controls is expected to avoid an intrusion risk for most, if not all, of the hazardous lifetime.

A site at CRNL has been selected for a prototype IST unit to demonstrate the construction and operational aspects. The unit is planned to be available in 1992.

The IST disposal concept would not be expected to provide assured protection for the full hazardous lifetime of wastes containing significant concentrations of radionuclides such as strontium-90 and cesium-137, a period which might extend for several centuries. Development of a concept suitable for the disposal of this category of LLRW was the first to be undertaken in the AECL program. A unique design of belowground concrete vault has been adopted to fulfill this role.

The concept, named IRUS (for Intrusion Resistant Underground Structure), is based on modular concrete vaults, approximately 30 m long, 20 m wide, and 10 m deep, designed to provide isolation of the contained waste for at least 500 years. Isolation for this period involves long-term protection of the waste from contact with water and inadvertent intruders.

Since the modules will be located in free-draining soil above the water table, the major threat from water is the infiltrating water from rain and snowmelt. The closed structure, as illustrated in Fig. 2, is enclosed by the curved walls of the vault, capped by a massive concrete cap which will support the load of the covering soil mound, plus other loads which might be unintentionally imposed during possible uncontrolled future use of the site. The combination of the cap and the water-shedding features of the soil cover are expected to maintain a largely dry environment in the vault for hundreds of years. Under these conditions, migration of the radionuclides will be dominated by diffusional processes.

Although the vault structure is expected to protect the waste from infiltrating water, engineering knowledge is not currently adequate to ensure leak-free performance for 500 years. The possibility of some water penetrating the vault is mitigated by engineering the floor of the vault to be both permeable and radionuclide retardant. The floor will consist of permeable layers of sand, clay, and clinoptilolite, a natural zeolite, which will avoid the retention of water that infiltrates the vault from prolonged contact with the waste, yet have adsorption properties to greatly retard soluble radionuclides released from the waste.

The one-metre-thick reinforced concrete cap provides a durable barrier to infiltrating water and a substantial deterrent to inadvertent intrusion by people, animals, or plants. Also, although institutional control of the site is not expected to provide assured limitations of its use, the CRNL property is situated in an area sufficiently remote that urban development is unlikely for many years.

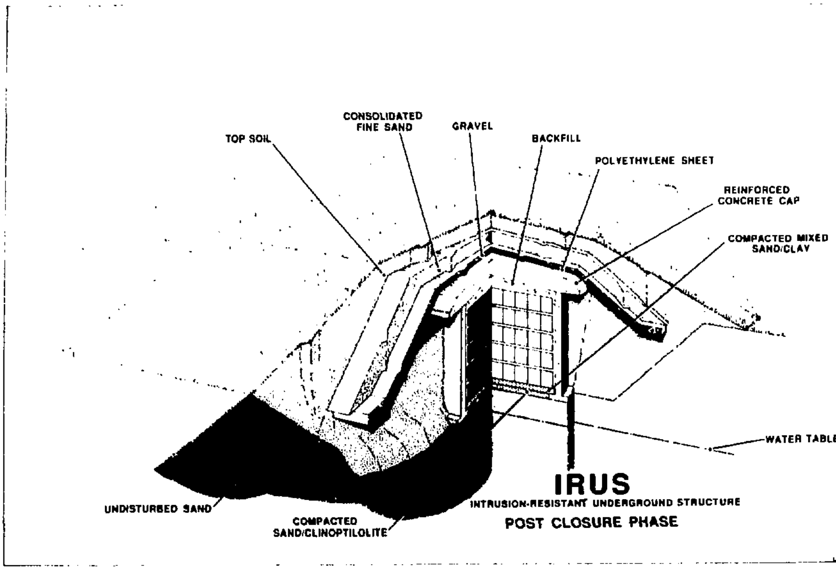

FIGURE 2: IRUS AFTER CLOSURE

The first stage of licensing of three demonstration IRUS modules has been completed. The concept and the site have been approved. The next stage of licensing, to gain approval for start of construction, is now underway.

The small quantity of LLRW from the nuclear industry that contains sufficient concentrations of long-lived radionuclides, to make its prolonged isolation by the IRUS concept difficult to substantiate, will continue to be managed by interim storage in the immediate future. In the overall plans, disposal of this category of waste in a rock cavity is preferred. However, cost factors make it desirable to postpone development of such a repository until an economic scale of operation is needed.

WASTE CATEGORIZATION

The matching of categories of waste to a range of disposal concepts requires good characterization of the radiological and physical properties. The AECL program has therefore included the development of methods of effectively estimating the radionuclide content of individual waste packages. A microcomputer-based system is being commissioned for incorporation in the routine handling of LLRW at CRNL (Burns et al., 1989).

The detector system uses a combination of sodium-iodide and gadolinium crystals, the former to measure the gross gamma-ray activity of the package, and the latter to obtain an energy spectrum if the former measurement indicates sufficient radioactivity is present to warrant detailed analysis.

Since only gamma rays are measured, additional information must be input if an estimate is to be obtained of the radionuclides which emit only alpha or beta radiation. This is based on the source of the waste stream and previous destructive analyses of waste samples believed to be typical of such wastes. The full analyses (Csullog and Hardy, 1988) provide scaling factors relating the quantities of gamma-detectable nuclides to the amounts of nondetectable nuclides also in wastes.

An important function of the method is to retain the pertinent information in a conveniently usable form in a database in the site's mainframe computer. This information, which includes the location in the storage or disposal unit where the package was emplaced, will enable confirmation that the radioactive inventory is within the licensed capacity of the repository.

The permissible level of uncertainty in this estimate will be set by the closeness to which the matching of the overall hazardous lifetime of the waste, and the isolation capability of the disposal concept, is attempted. It is possible that, if the overall waste production rate is low enough that there is no economic advantage in concurrent operation of disposal units of both the IST and IRUS types, all except the very long-lived wastes would be emplaced in IRUS modules. In this event, the attention paid to characterization of the lowest category of waste might be considerably relaxed.

WASTE TREATMENT

Because waste treatment to reduce the volume of waste and convert it to a more stable form can be beneficial to storage as well as disposal operations, development of processing methods began early in the program. At CRNL, treatment facilities for both solid and liquid wastes have been integrated into a Waste Treatment Centre (Buckley et al., 1988a).

Compaction and incineration are used for processing those solid wastes that have appropriate characteristics. Since its first operation in 1981, a controlled-air batch-fed incinerator has been volume reducing up to 1000 m^3/a of wastes to produce about 7 m^3/a of ash. Bituminization of the ash further reduces its volume. The off-gas system consists of an air-to-air heat exchanger, and a baghouse filter backed up by roughing and high-efficiency filters. Because no wet scrubber is installed, the content of chlorinated polymers in the feed is limited by the acid-gas emission limits. The operation of the incinerator has been generally satisfactory, including an increase in batch size by precompaction to 1600 kg from the design value of 1000 kg. The heat exchanger has required regular maintenance for cleaning of solidified scale deposits and for replacement of corroded tubes. Filter performance has been excellent. Recent modifications have permitted the injection of nonhalogenated organic waste liquids directly into the afterburner. Scintillation fluids, still in their plastic and glass vials, are charged as part of the solid waste stream.

Bagged solid wastes not suitable for incineration are compacted into bales. A volume-reduction factor averaging greater than 6 is achieved. Tests with a slow-speed, high-torque shredder have demonstrated that volume reduction by compaction can be increased by a further 50% by shredding the waste before charging it to the baler. Shredding of feed to the incinerator has shown no particular advantages. Perhaps the most useful application of shredding is for solid wastes such as decommissioning debris, the size of which is not suitable for feeding to the incinerator or baler in its original form.

Past practice at CRNL for the management of 20 000 m^3/a of low-level aqueous wastes has included discharge to seepage pits. Although monitoring has shown that migration of the contained radionuclides has been controlled by adsorption on the soil, the method relies on long-term care of the area. To eliminate future discharges, a combination of membrane processes, evaporation, and bituminization have been installed in the Waste Treatment Centre. Continual equipment difficulties with several makes of membrane equipment (ultrafiltration, microfiltration, and reverse osmosis) have frustrated routine operation of the plant. Modifications and trouble-shooting are continuing to improve system performance.

SAFETY ASSESSMENT

Unlike storage, the effective performance of which is established by continued monitoring, assured performance of disposal methods beyond a reasonable period of monitoring must usually be done in advance by predictions based on computerized models describing the important physical and chemical processes anticipated to occur under the long-term conditions to which the waste will be exposed. To assess the performance of such disposal methods as IRUS and IST, AECL has developed the COSMOS S/D code, and undertaken experimental studies to define and confirm the characteristics of the processes to be modelled.

The COSMOS S/D code (Jarvis et al., 1986) is the result of modelling the various migration processes by which radionuclides might move from the LLRW contained in a vault or trench to the surrounding environment, and thus result in radiation doses to nearby residents. The code tracks the release of nuclides through leaching or solution from the waste once the container has failed, and their transport via diffusion and advection through the backfill and buffer layers, out of the disposal unit. The conditions (Torok and Buckley, 1988) under which the transport occurs can be either relatively dry as in a leaktight vault, or somewhat wet as a result of infiltrating water trickling through a cracked vault roof. The water-shedding performance of the roof is an important factor influencing not only the waterborne migration of nuclides but also the corrosion of the metal and the biological degradation of the organic portions of the waste. The corrosion and degradation processes will affect nuclide release via gaseous as well as waterborne pathways.

If escape of some nuclides from the engineered parts of the disposal system is predicted, the COSMOS code calculates their movement in groundwater through the overburden to a nearby well and surface stream, or by atmospheric dispersion above ground. The eventual potential risk to individuals is assessed by considering the various exposure pathways from ingestion, inhalation, and external radiation. The code can be applied in either a stochastic or deterministic mode (hence the S/D identification of COSMOS S/D).

Assessments using the COSMOS code have shown that vault systems should effectively contain the predominant radionuclides, such as H-3, Co-60, Cs-137, and Sr-90 in LLRW, until decay has reduced their concentration to insignificant levels. The most likely sources of risk are the long-lived mobile nuclides such as carbon-14, iodine-129, and technetium-99, if they are present in significant amounts. Calculations also show that other very long-lived nuclides, such as Cs-135, which are much less mobile in the environment, could eventually present some small risk if stable conditions led to little dispersion.

Because such disposal methods as the IRUS and IST seek to immobilize LLRW in relatively dry environments for long periods, modelling required information on the behaviour of nuclides and materials under these conditions, which was not available in the literature. AECL has undertaken an experimental program of laboratory and field tests to remove some of the most important uncertainties in the existing knowledge (Torok and Buckley, 1988).

One of the major concerns is the prediction of near-field conditions and the long-term degradation of materials. Since the durability of concrete is important to maintaining a water barrier around the waste, studies are being made of degradation processes (Buckley et al., 1988b) that might cause vault failure and the suitable concrete formulations that will resist these processes. The important factors may be present on the outside of the vault as contaminants such as chlorides, and inside the vault such as carbon dioxide from the biodegradation of the waste.

The chemical conditions within the vault (Torok and Buckley, 1988) are not expected to be uniform in time or space. Oxygen present at time of closure will be quickly consumed by container corrosion and biodegradation, leading to a reducing environment. The pH will tend to be raised by the presence of the concrete and lowered by the fatty acids from the degradation of cellulose. Migration of the nuclides will be enhanced by any increase in moisture content from water infiltration, particularly in any zones of liquid flow under leakage paths in the vault roof.

Experiments in laboratory lysimeters (Torok et al., 1989) have been used to study factors affecting nuclide migration in the backfill that will surround the wastes and the adsorptive buffer layer through which an infiltrated water will leave the vault. Both solution and particle transport can be important. Other experiments (Buckley et al., 1988b) have measured the rate of nuclide diffusion in buffer and backfill as a function of moisture content. Recently, field lysimeter studies have begun to measure these processes on a larger scale.

The primary results coming from these studies are a better understanding of the processes occurring in the disposal systems and the parametric values defining them. These results then support the further development of the predictive models, and aid, through sensitivity analysis, refinement of the disposal system design.

CONCLUSION

Over the more than forty years of nuclear activities in Canada, interim storage has served as a suitable method of managing low-level radioactive wastes. However, continued use of storage builds a growing legacy of a need for future actions to maintain, monitor, and eventually replace the facilities containing the wastes. Recognition of these future responsibilities has led AECL to develop permanent disposal concepts, the auxiliary procedures, and the performance assessment methods needed to implement them.

Studies, development and design have now progressed to the point of licensing a site at the Chalk River Nuclear Laboratories on which the first disposal modules will be ready for loading in the early 1990's. The disposal system will rely primarily on engineered barriers to isolate the waste from water and delay the release of radionuclides from their containment. The properties of the site will provide supplementary containment and ensure that risks to individuals in the surrounding area do not exceed the regulatory limit of 10^{-6} per year.

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