IMPACT OF PAST EXPERIENCES ON ENGINEERING A SHALLOW LAND BURIAL FACILITY

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ABSTRACT

Past experiences with in-ground storage and disposal of low-level radioactive wastes at Chalk River Nuclear Laboratories (CRNL) and elsewhere have provided valuable lessons relevant to the design of future disposal systems. This paper reviews the related past experiences and discusses their impact on engineering disposal systems in general, as well as the impact on the conceptual design of CRNL's planned shallow land burial facility.

INTRODUCTION

Disposal of solid low-level radioactive wastes (LLW) by shallow ground burial has been practiced in many countries from the very beginning of the nuclear era. Over the years, these techniques have continued to be used sometimes with little change. In some cases, the disposal practice was no different from the sanitary landfill operations. However, with the increased understanding of long-term hazards of such wastes, and increased public concern and social pressure, the shallow ground burial facility designs have lately begun to evolve significantly.

Because the LLW are produced routinely and in large bulk, shallow ground disposal in an engineered form is still needed as a safe and cost-effective method for managing these wastes.

Various types of LLW have been managed in unlined trenches at the Chalk River Nuclear Laboratories (CRNL) since 1946. This technique was later supplemented by interim storage in a variety of concrete structures. In 1982, when a program was set up to convert the storage operations to permanent disposal, it was decided that appropriate disposal systems should be developed, matched to broad categories of waste based on the duration of the hazard (1,2). For the bulk of the LLW, including some of higher activity, the concept selected was that of shallow land burial enhanced be engineered barriers (SLB). Other concepts identified as being suitable at CRNL for wastes of shorter or longer hazard include: improved sand trench for the very low activity LLW, and shallow rock cavity for the intermediate-level wastes.

Our own experiences with in-ground storage and disposal, as well as those at several sites elsewhere, had a sigificant impact on shaping the conceptual design of our planned SLB.

This paper discusses how these past experiences have influenced our approach to waste disposal as the engineering of CRNL's first prototype SLB.

EXPERIENCES WITH WASTE MANAGEMENT AT CRNL

CRNL hosts a large inventory of radioactive wastes (consolidated volume of about 50 000 m^3), the bulk of which (approximately 80%) are LLW. This inventory is increasing at a rate of about 3 000 m^3/a. Besides the wastes generated on site (about 50%), CRNL receives wastes from a variety of sources across Canada ranging from hospitals, universities, and research institutions, to the industrial radioisotope users, fuel fabricators, and a closeby small power reactor at Rolphton, Ontario.

Most of the LLW have been managed by burial in unlined trenches dug into sand with trench bottoms well above the water table. Intermediate-level wastes, as well as a small inventory (less than 5% of the total) of high level solid radioactive wastes (HLW), have been stored in concrete bunkers and concrete tile holes respectively.

Higher activity liquid wastes are stored in storage tanks on the site. Low-level liquid wastes have been routinely discharged to some seepage pits on the site, a practice which is now being phased out.

Our previous waste management practices have used the isolate and contain, or dilute and disperse, principles separately based on the hazard of the wastes. In the past dozen years, a systems engineering approach has evolved to consider all aspects of the waste management. This includes waste characterization and segregation, processing to achieve volume reduction, stabilization, and disposal in engineered facilities. For disposal, our philosophy is to use the two above-mentioned principles in tandem. Our experience with one of our earlier trenches, where a non-reinforced concrete cap collapsed and led to the flooding of a concrete trench, has illustrated the need for a trench design with a reinforced concrete cap as well as a permeable floor. Since it is not possible to guarantee the integrity of a waste disposal facility over many hundreds of years, if the containment does fail, it is better to have slow dispersion and dilution of the radionuclides in geologic or ecosystems than high concentration slug injections into the environment.

Since 1982, the Waste Treatment Centre (WTC) at CRNL has processed a large portion of the solid waste being generated on site through incineration. This starved-air incinerator has routinely achieved volume reduction factors of about 150:1 and the resulting ash is being stored in 210 L drums. A baler unit is used for the nonincinerable solid wastes and provides a volume reduction of about 8:1. A plant for the processing of liquid wastes is also located at the WTC. This plant is currently in the commissioning stages. It uses ultrafiltration and reverse osmosis to concentrate liquid wastes. The concentrates will be bituminized and disposed along with other solid wastes. Equipment for bituminizing the ash as well as the liquid concentrates is in place and some commissioning tests have been made.

Through a disposal project initiated in 1982, the disposal strategy at CRNL has evolved to a stage where construction of the first prototype SLB (designated SLB-P1) for LLW is scheduled to begin in 1989. A suitable site for SLB-P1 has been selected and characterized (3-5).

The bulk of the LLW at CRNL has a hazardous lifetime (defined as the period of time over which the waste presents a potential radiation hazard to humans under conditions of disposal) of less than 500 years. Thus, the facility containment should provide protection for 500 years. In the facility design, it is anticipated that the design lifetime of over 500 years is achievable cost-effectively with high quality durable concrete applied underground in a generally benign environment.

Our past experience has also given us valuable information on the radionuclide retention capability of our sediments. This has provided feedback to the design of SLB-P1's engineered barriers.

Since no special infiltration control measures were applied to the sand trenches where LLW were buried, radioactive plumes, primarily H-3 and in some cases Co-60 and Sr-90, have originated at some of these areas.

Contaminant plumes have also migrated from the seepage pits on the CRNL property where liquid low-level wastes were discharged.

In most cases, except tritium (and mobile Co-60 in complexed form), the radionuclides have migrated only limited distances due to sorption on the sediments. Near the site selected for SLB-P1, two radioactive plumes (4,5) from previous waste management operations have provided a large in-situ geoscientific data base over the past three decades of monitoring.

One of the plumes is a Sr-90 plume that originated from a seepage pit associated with a dismantled Nitrate Plant (NP) which was used in the early 1950's to decompose some ammonium nitrate solutions containing mixed fission products. The front of the plume (average activity on sand $<10\ \mathrm{Bq \cdot g^{-1}}$) has migrated about 300 m; however, the bulk of Sr-90 in the plume (average activity $>300\ \mathrm{Bq \cdot g^{-1}}$) has migrated less than about 70 m. In general, Sr-90 is being transported at <3% of groundwater velocities which in this area range from $0.07\ \mathrm{m \cdot d^{-1}}$ to $0.73\ \mathrm{m \cdot d^{-1}}$. The sands have been quite successful in attenuating the radionuclide migration through mechanisms involving ion exchange as well as kinetically slow chemisorption on ironoxyhydroxide coatings of sand grains. Even though an appreciable amount of Cs-137 was also present in NP source, it has been almost completely immobile and only very small amounts of Cs-137 have been detected 25 m from the NP pit.

The second contaminant plume that has been relevant to the SLB-P1 design development originates from a nearby Area "C", where very low-level solid wastes are buried in unlined sand trenches. Tritium (as tritiated water), being a nonreactive species, has moved at groundwater velocities, and significant concentrations have been monitored in a swamp receiving the groundwater discharge downstream of Area "C". Low levels of Co-60 have also been measured in the plume, and it has been ascertained that some Co-60 in a complexed form (with the abundant organics in the Area "C" waste) has been migrating at velocities close to that of the groundwater with little retention on the sediments.

Three dimensional modelling of the hydrogeology of this general area (by SWIFT finite difference code), including the SLB-P1 site, has shown good agreement of predicted hydraulic heads and groundwater flowlines with observations (6). Another three-dimensional modelling, incorporating both water and contaminant transport in this area, has been recently completed (7) in a joint study by CRNL and Battelle Pacific Northwest Laboratories using the finite element code CFEST. Relative simplicity of the hydrogeologic system has facilitated the modellability of the site and reliable predictions can be made into the future.

The discharge of the contaminants into high flow and relatively rapid groundwater aquifers has ensured dilution of the nonreactive contaminants. Significant flows of local surface water systems, and the eventual large dilution by the high flow Ottawa River, provide added insurance against large individual doses.

The primary cause of the tritium plume, as well as the other plumes, has been precipitation infiltrating the waste area from the top, leaching the radionuclides and percolating to the groundwater aquifer from where the contaminants were transported by the groundwater flow. In 1983 as a part of an experiment to assess the value of an effective cover, a cover consisting of a polyethylene membrane and about 1 m of soil was installed on a portion of the Area "C" trench; on the rest of the trench, the cover consists of only 1 m of the backfill sand. Monitoring of tritium in the groundwater samples from boreholes downstream of Area "C" has shown, over the past four years, that the cover has been effective in reducing the tritium releases from the covered area.

Plastic membranes have limited life, perhaps thirty years or so, and thus cannot be expected to maintain integrity over the long term that is necessary for disposal. Nevertheless, CRNL's experience with waste management underlines the importance of restricting infiltration of water into a waste trench.

RELEVANT INTERNATIONAL EXPERIENCES

Drigg Site, U.K.

The Drigg site in Cumbria is currently the major LLW disposal site in the United Kingdom (8).

Trenches, that are approximately 8 m deep, are dug into glacial sand that overlies stratified deposits of gravel and clay. The solid rock of St. Bees sandstone underlies the site. The clay, lying between the trenches and the sandstone formation, acts as a seal to keep the infiltration out of the sandstone aquifer.

After filling, the trenches are covered with soil which is essentially ineffective in restricting the infiltration of water into the trenches (average precipitation in this area amounts to about 1200 mm annually). The floors of the trenches are sloped and the water draining from the trenches runs over the clay into Drigg Stream which, in turn, runs into River Irt. The water from the Drigg site is thus eventually diluted in the Irish Sea.

Because of a lack of good knowledge of the radiological constituents in the waste, and the lack of adequate controls that would ensure that only LLW are disposed here, Drigg's major reliance on the dilute and disperse principle has been the target of criticism.

The Environmental Committee of the House of Commons (U.K.), in a report issued recently (8), has recommended that while, with some modifications, the Drigg site can continue operation, it is an unacceptable model for any future disposal site. Recommendations of the Committee for continued operation include subjecting the operation to several modifications. These include proper sorting of wastes; disposal only of short-lived non-alpha, low-activity wastes; prohibition on certain radionuclides; volume reduction of the waste through compaction or incineration; proper packaging of the wastes in appropriately labeled containers; and an adherence to a waste acceptance criteria.

Because the Drigg site is likely to be full by the turn of the century, the U.K. plans to develop another LLW repository around 1991 (and a repository for intermediate-level wastes around year 2000) (9). The U.K. NIREX (Nuclear Industry Radioactive Waste Executive) Ltd., which is responsible for the development of these facilities, currently favours the multi-barrier concept, and clay and marl outcrops for hosting the LLW repository (9).

Centre de la Manche, France

Centre de la Manche, which started operation in 1969, has used a multi-barrier approach (10,11). The intermediate-level wastes are disposed of in concrete monoliths located below the ground surface, and the low-level wastes in earth-covered tumuli which are built on top of the monoliths.

The multi-barrier approach to shallow land burial is appropriate in the humid French climate (annual precipitation about 1000 mm) and the La Hague peninsula where water tables are relatively shallow (6 to 15 m depth). The approach is adaptable so that a site with very particular characteristics is not necessary.

Special collection and monitoring points underneath the trenches are used to check very small amounts of run-off or drainage water entering during operation, or that might permeate the covers after the operating period.

The wastes are generally neutralized and immobilized by the producers and then put into approved packages consisting of steel drums, steel boxes and concrete cylinders. Waste acceptance regulations are strictly followed. Water, air, and soil are regularly monitored.

The barriers are expected to maintain integrity over at least 300 years and it is expected that some form of supervision during this time will continue.

The experience at Centre de la Manche with engineered containment has been satisfactory so far. French experience has also shown that highly engineered systems are not unreasonably expensive.

Eastern Region Sites, U.S.A.

Three commercial LLW disposal sites in the humid eastern region of the United States have experienced a number of problems. Out of the four such sites in this region, only Barnwell, South Carolina, is still operational (it opened in 1971). The other sites, located at West Valley, New York, Maxey Flats, Kentucky, and Sheffield, Illinois, have been closed since 1975, 1977, and 1978 respectively (these sites opened in 1963, 1963 and 1967 respectively). Contaminant migrations have occurred at these sites resulting from a number of factors. Important among those reported (12-14) are the loss of surface water control, erosion, infiltration of precipitation through degraded trench caps, and the "bathtub effect" (due to low-permeability of the sediments, water infiltrated the trenches through the earthen covers faster than it was able to drain out of the bottom, thus filling the trenches, accelerating the leaching of the wastes and eventually overflowing). A host of other factors related to inadequate site characterization, inadequate waste characterization, limited site capacity, lack of adequate financing, etc. have also been mentioned.

Even though the health and safety of the public have never been endangered at any of these sites, the performance of the sites has been less than satisfactory.

ENGINEERING A SHALLOW LAND BURIAL FACILITY

The primary objective of any radioactive waste disposal is to isolate the wastes from the human environment for the length of time over which they remain hazardous to humans, and to keep the possibility of any releases or radiation hazards during this time to as low as reasonably achievable (ALARA).

Of all the possible scenarios and pathways for radionuclides to reach man, or cause a radiation hazard, two types of possibilities may be considered most probable:

(1) transportation of radionuclides by the groundwater flow to surface water systems or through the use of groundwater aquifers by man (such as drinking wells, etc.); and

(2) direct human intrusion into the facility.

Groundwater transport of radionuclides is perhaps the single most important pathway for these to reach man. The principle scenario is the infiltration of precipitation from above into the waste or groundwater intrusion into the trench from below; the leaching of the wastes through waste/water contact; and subsequent transportation of the radionuclides by groundwater flow to surface water bodies.

A waste disposal design should try to minimize the chances of occurrence of such a scenario, and should mitigate adverse consequences if such a failure of the system does occur.

Direct human intrusion into a waste facility is also an important scenario. Barriers to inadvertent intrusion should be provided but, since the prevention of all deliberate intrusion is not possible, it is reasonable that onus of a deliberate action be placed on the intruder himself. Any barriers designed to discourage inadvertent human intrusion will, in all likelihood, be effective against other bio-intrusion as well (such as the plants and animals).

For engineering LLW disposal facilities based in shallow ground, two types of defences need to be considered:

(1) defence in the near-field which is mainly directed at engineered containment and intrusion resistance; and

(2) defence in the far-field which relies primarily on the site's favourable characteristics.

Containment can be achieved through a combination of: minimization of water fluxes in contact with the waste; leach-resistant waste forms; and adsorptive retardation of radionuclides in buffer materials. Since containment is primarily determined by the facility design, it lends itself to be fully engineered.

The defence in the far-field depends on the site-specific as well as regional characteristics such as geology, hydrogeology and geochemistry.

In an ideal case, both types of defences are adequate and can provide redundancy. In practice, neither can be completely proved to be fully adequate by itself over the long term and the two cannot be regarded as mutually independent. The best strategy is to use these defences to complement each other. The degree of shared reliance will vary from case to case.

To achieve the containment objectives, and as illustrated by past experience, the following considerations are important in engineering a shallow land burial facility.

1. The structure should provide the main barrier to infiltration of water into the facility. Primarily, the infiltration is from the top; however, account should also be taken of lateral water flows.

2. The potential rise of the water table should be taken into account and the base of the facility positioned a safe distance above the water table. The facility should be designed in such a way so as to minimize the waste/water contact. The "bathtub effect" experienced at some of the closed sites shows that it is necessary to provide a way out for any water that may get into the facility.

   In some cases, the use of engineered solutions such as water table suppression can be investigated.

3. Engineered barriers to radionuclides, such as leach-resistant waste forms, packaging, and the use of high sorption capacity buffers, should also be implemented.

4. Site engineering should be implemented to facilitate runoff away from the facility, for example, through recontouring of the site topography. Local topography should be stabilized to avoid surface erosion problems.

5. During the operational phase of the facility, attempts should be made to keep the trenches dry either through a rigid-frame structure covering the trench or some temporary measures such as tarpaulins. Especially in areas where a significant part of the annual precipitation occurs as snow, a rigid-frame structure can facilitate a dry year-round operation.

6. The structure (especially the cap) should provide the main barrier to inadvertent human intrusion into the facility in future after the site has been closed and returned to natural environment.

7. The structure should maintain integrity until the radioactivity in the waste has decayed to innocuous levels and the waste no longer presents a hazard to humans.

The points presented above illustrate that the most crucial part of a waste disposal structure is its cap, since it forms the primary barrier to infiltration of surface precipitation. In humid climates, the past experiences of failure of the disposal sites have demonstrated the inadequacy of simple backfill earth covers. The permeability of various soils determines their effectiveness as cover materials. As Table 1 shows, the effectiveness of clays, for example, can exceed that of sands by several orders of magnitude. It should be noted here, however, that the swelling (when wet) and shrinking (on drying) behaviour of many clays can lead to fracturing, which essentially negates their effectiveness as an infiltration barrier. Sandy clay may offer the best compromise. Nevertheless, earthen covers may not maintain integrity over the hazardous lifetime of the waste. The use of synthetic water-shedding membranes, such as Hypalon, to increase the effectiveness of the soil cover, also has limitations related to the life of the membranes.

Subsidence is a factor in the continued effectiveness of earthen covers as they are not self-supporting. In past experiences at some sites, localized subsidence has aggravated the situation by funnelling the surface precipitation into the trench. In addition, earthen covers, unless very thick, provide limited defence against bio-intrusion. Covers, consisting of plastic membranes and soil, are most useful for storage facilities where continual supervision is in effect and where remedial actions can be taken when necessary.

Reinforced concrete caps, for example, in a concrete-shell structure, may be supported by concrete walls, such that the self-compaction of the waste over years will not lead to a collapse of the cap. They can be intrusion-resistant and long-lasting. Some ancient structures, for example, the Roman Colosseum in which pozzolanic cement was used, have demonstrated that a long service lifetime is attainable. With proper care as to the mix and the exposure conditions, concrete structures that can last several hundred years without significant degradation are practicable.

Concrete walls, besides supporting the cap, also eliminate lateral flows into the facility.

An engineered permeable bottom of the facility will ensure that, if water does permeate into the facility, it can quickly drain out. Buffer layers can be included in the facility floor to enhance retention of the radionuclides.

TABLE I: Theoretical volume of water that could enter a completed waste disposal trench through 1 m^2 of various cover materials in 1 day.

Cover Material	Vol. of water, m^3
Uniform coarse sand	406
Uniform medium sand	101
Clean, well-graded sand and gravel	101
Uniform fine sand	4
Well-graded silty sand and gravel	0.4
Silty sand	0.1
Sandy clay	4.9×10^{-3}
Clay	9.1×10^{-5}

(Adapted from Salvato et al (15).

NOTES:

(i) Q, the quantity of water discharged in unit time, is determined by using Darcy's Law: $Q = PIA$, where P is the coefficient of permeability of the material (available in Salvato et al.(15) as ft/day), I is the hydraulic gradient, and A is the cross-section area through which the water flows.

(ii) Assumptions are: cover material is uniform; cover material is saturated; there is no resistance to flow below the cover material; a thin covering of water is maintained over the top surface of the cover material; and Darcy's Law is applicable for this purpose.

(iii) The data listed in Table I are the theoretical values useful only for a qualitative comparative evaluation of the cover materials. In actual practice, the amount of water entering the trench will depend on precipitation rates, local hydrogeological conditions, characteristics of the cover material, slope of the cover, presence or absence of a vegetation cover, and the percolation of water through the waste.

The degree to which the reliance will need to be placed on the engineered defences affects the overall cost of disposal and depends on the far-field defence provided by the site. These site-related considerations are noted below:

1. Sufficient geoscientific/geotechnial information should be available about the site. In humid areas, the hydrology of the site is most important. The site should be capable of being characterized, modeled, analyzed and monitored.
2. The site should provide sufficient depth to water table so that groundwater intrusion, perennial or otherwise, into the waste, will not occur.
3. The surface drainage into the site from any upstream areas should be minimal.
4. As a complement to the engineered defences, the site should provide sufficient retention times for reactive radionuclides over the groundwater flowpath to surface. Since some of the radionuclides (e.g. H-3) are nonreactive and carried at groundwater velocities, dilution at the discharge should be large (large body of water or surface water flow into high flow streams or rivers). This ensures that the radionuclide concentrations in surface water, and hence the potential dose to an individual, will be low.
5. The site and the conceptual design of the facility should be compatible.

If the performance of the engineered system does not have sufficient reliability, then the geologic host medium at the site should provide large retardation capability for the reactive radionuclide species, and long groundwater residence times for nonreactive radionuclide species.

The key to a successful radioactive waste disposal is the satisfactory performance of the system as a whole, i.e. the facility as well as its near- and far-field environments. Since the ultimate regulatory requirements are expressed in terms of risk to an individual, or in terms of dose limits for an individual member of the public (16-18) it is imperative that a systems analysis approach be applied to the total disposal system.

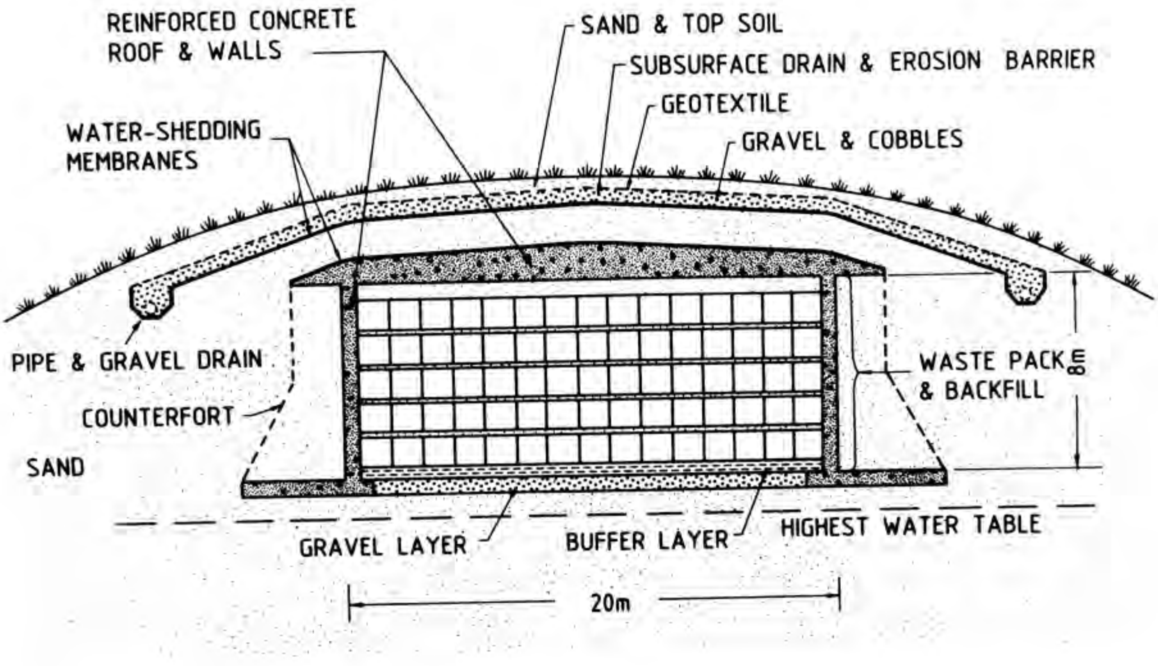

Fig. 1: SLB-P1 Cross-section

CRNL'S SLB-P1 DESIGN

In designing the SLB-P1, we have attempted to implement the philosophy described in the previous section which in turn has been strongly influenced by the past experiences with LLW disposal.

Figure 1 shows a schematic cross-section of the conceptual design of SLB-P1.

The facility of dimensions 100 m long x 20 m wide x 8 m deep will be built in three decoupled cells (separated by a gap of several centimetres), each about 33 m long. This will alleviate potential seismic and differential settlement concerns. The cap, nominally a metre thick, will be constructed of reinforced concrete to provide the main infiltration barrier as well as resistance to human intrusion. Other infiltration barriers may be added on top and a vegetation cover will be used to stabilize the topography. The walls supporting the cap will also be constructed of reinforced concrete and will provide a barrier to lateral intrusion of water. The engineering design and construction activities will conform with the appropriate codes, regulations and standards.

Some ports, with concrete plugs in the cap, may be used for instrumentation and to allow the possibility of grouting, if necessary, some ten years after closure of the facility. Gas production in the facility will be monitored even though attempts will be made to minimize it by treatment and conditioning of the waste. Eventually, the ports will be permanently sealed.

The sediments at the base of the facility will be compacted and the repository floor will be based a safe distance above the highest recorded water table. It will be kept permeable and appropriately engineered. The permeable bottom will ensure that any water that may permeate the facility will be drained out.

Buffer and backfill materials of high radionuclide sorption capacity will be used in the repository. The wastes emplaced in the facility will be treated and packaged. Since most of the LLW is being incinerated, the resulting ash will be bituminized and disposed as leach-resistant bitumen blocks. Waste acceptance controls will be applied to pathogenic and mixed wastes. Through the application of waste acceptance criteria, it will be ensured that only allowed types of waste (radionuclides, concentrations) are emplaced in the facility.

A rigid-frame, but removable, structure will be constructed over the facility to provide a dry environment during the operating phase of the facility. After the closure of the facility, it can be dismantled and used again over another vault.

Since it is a prototype, the facility will be intensively monitored for some ten years after closure. Appropriate instrumentation will be installed for the measurement of moisture content in the repository and any subsidence that may occur at the base. The physical and chemical performance of the buffer will also be monitored. Hydrogeologic monitoring of the site around the facility will be maintained and the sampling of the groundwaters for chemical analysis will continue. Vegetation at the site will also be sampled occasionally and compared to the baseline data.

The facility is being located at a site which has been fully characterized and which offers significant complementary features to the facility design.

It is proposed that some form of institutional control will be in effect on the facility and the site for a period of 100 years. Even though the facility may be monitored scientifically for only the first ten or so years, passive controls on the site will continue for the duration of the institutional control period. These controls may consist of land use control and a preservation of the knowledge of the facility and its location through site markers, maps, records, etc. The radioactivity from the waste is expected to decay significantly after the first hundred years and the site can be returned to its natural environment.

Since the SLB-Pl is a prototype for the other units to follow, its construction, operation, closure, and monitoring during the first ten or so years after closure should provide a confirmation of the adequacy of the technology applied and any further design improvements that may be necessary.

CONCLUSIONS

Past experiences with shallow ground disposal of LLW at CRNL and elsewhere have significantly influenced our disposal philosophy and the design of our first prototype disposal facility. We believe that the conceptual multi-barrier design that has evolved, combined with a systems engineering approach applied to the whole disposal system, should provide for a safe and cost-effective disposal.

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