AECL-9787

ATOMIC ENERGY
OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE
DU CANADA LIMITÉE

AECL EXPERIENCE WITH LOW-LEVEL RADIOACTIVE WASTE TECHNOLOGIES

L'EXPÉRIENCE DE L'EACL AVEC LES TECHNIQUES DES DÉCHETS DE FAIBLE RADIOACTIVITÉ

L.P. BUCKLEY and D.H. CHARLESWORTH

Presented at AIChE 1988 Summer National Meeting August 21-24, Denver Colorado

Chalk River Nuclear Laboratories
Laboratoires nucléaires de Chalk River

Chalk River, Ontario

August 1988 août

ATOMIC ENERGY OF CANADA LIMITED

AECL Experience with Low-Level Radioactive Waste Technologies

by

L.P. Buckley, D.H. Charlesworth

presented at AIChE 1988 Summer National Meeting
August 21-24, Denver Colorado

Waste Management Technology Division
Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario KOJ 1J0
1988 August

AECL-9787

L'ÉNERGIE ATOMIQUE DU CANADA, LIMITÉE

L'expérience de l'EACL avec les techniques des déchets de faible radioactivité

par

L.P. Buckley, D.H. Charlesworth

RÉSUMÉ

L'Énergie Atomique du Canada, Limitée (EACL), en tant qu'organisme du gouvernement Canadien chargé de la recherche et du développement des applications pacifiques de l'énergie nucléaire, a de l'expérience dans la manutention d'une grande variété de déchets radioactifs depuis plus de 40 ans. Les déchets de faible radioactivité (DFR) sont produits au Canada par les fabricants de combustible nucléaire et les centrales électronucléaires et proviennent des applications médicales et industrielles des radioisotopes ainsi que des centres de recherche. Les techniques avec lesquelles l'EACL a une solide expérience se situent dans les secteurs du traitement, du stockage, de l'évacuation et de l'évaluation de la sûreté des DFR. Bien que le compactage et l'incinération soient les méthodes prédominantes pratiquées pour les déchets solides, on emploie les techniques de purification et de réduction de volume pour les déchets liquides. On continue de mettre au point les méthodes de traitement pour améliorer et augmenter le rendement d'exploitation et convenir au passage du stockage des déchets à leur évacuation. Les études et la planification de sites éventuels pour un dépôt d'évacuation de DFR devant remplacer les installations de stockage actuelles sont en bonne voie, l'entrée en service devant être en 1991. Les déchets seront évacués dans une construction souterraine résistante à l'intrusion conçue pour avoir une durée de service utile de plus 500 ans. Au-delà de cette période, la radioactivité des déchets aura diminué et atteint un niveau inoffensif. On évalue la sûreté de l'évacuation des DFR à l'aide d'une série de modèles mathématiques reliés entre eux, réalisés à Chalk River, en particulier pour prédire la migration des radionucléides à travers et à partir du dépôt après sa fermeture et les effets consécutifs sur la santé du public des radionucléides libérés. On examinera les diverses techniques permettant de s'occuper des déchets radioactifs de leur création à leur évacuation.

Technologie de la gestion des déchets
l'Énergie Atomique du Canada, Limitée
Laboratoires Nucléaires de Chalk River
Chalk River, Ontario KOJ 1JO
1988 août

AECL-9787

ATOMIC ENERGY OF CANADA LIMITED

AECL Experience with Low-Level Radioactive Waste Technologies

by

L.P. Buckley, D.H. Charlesworth

ABSTRACT

Atomic Energy of Canada Limited (AECL), as the Canadian government agency responsible for research and development of peaceful uses of nuclear energy, has had experience in handling a wide variety of radioactive wastes for over 40 years. Low-level radioactive waste (LLRW) is generated in Canada from nuclear fuel manufacturers and nuclear power facilities, from medical and industrial uses of radioisotopes and from research facilities. The technologies with which AECL has strength lie in the areas of processing, storage, disposal and safety assessment of LLRW. While compaction and incineration are the predominant methods practised for solid wastes, purification techniques and volume reduction methods are used for liquid wastes. The methods for processing continue to be developed to improve and increase the efficiency of operation and to accommodate the transition from storage of the waste to disposal. Site-specific studies and planning for a LLRW disposal repository to replace current storage facilities are well underway with in-service operation to begin in 1991. The waste will be disposed of in an intrusion-resistant underground structure designed to have a service life of over 500 years. Beyond this period of time the radioactivity in the waste will have decayed to innocuous levels. Safety assessments of LLRW disposal are performed with the aid of a series of interconnected mathematical models developed at Chalk River specifically to predict the movement of radionuclides through and away from the repository after its closure and the subsequent health effects of the released radionuclides on the public. The various technologies for dealing with radioactive wastes from their creation to disposal will be discussed.

Waste Management Technology Division
Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario KOJ 1J0
1988 August

AECL-9787

Introduction

The program for the management of low-level radioactive wastes in Canada is one of continued reliance on interim storage methods while policies, regulations and technologies are put in place to permit transition to disposal expected to begin early in the 1990s [1]. In Canada, low-level radioactive wastes are defined as all radioactive wastes other than used nuclear fuel and uranium mine tailings. The sources include nuclear power generation, uranium refining and nuclear fuel production, nuclear fuel research and development, and production and use of radioisotopes for medical research and industrial purposes. As well, there are various industrial processes such as fertilizer production in which the radioactivity is only incidental to the operation and there is an accumulated inventory of historic wastes arising from practices involving natural radionuclides, primarily radium, which must eventually be disposed of.

The Atomic Energy Control Board (AECB) is the Canadian regulatory authority administering the Atomic Energy Control Act, which covers the siting, design, manufacture, construction, commissioning, operation and decommissioning of nuclear facilities and the production, possession, use and disposal of prescribed substances. The AECB regulations are based on objective rather than prescriptive requirements for all licensees, and so licensees are responsible to apply to the AECB for licence approval and have to prove to the AECB that the safety and radiation protection systems proposed will meet the regulations and conform to the as-low-as-reasonably-achievable (ALARA) principle. The AECB has recently issued regulatory policy statements on guidelines for the disposal of radioactive wastes [2] and for the identification of a de minimis category of LLRW [3]. The documents are directed at minimizing the burden placed on future generations as well as protecting human health and the environment.

The characteristics of LLRW vary widely, depending upon their source and the degree of processing which they have undergone. There are two very broad categories [4]: uranium-contaminated, primarily a granular or soil-like material contaminated with natural long-lived radionuclides with a present inventory of 15 300 000 m^3, but now being produced at a much lower rate; the other is much smaller in quantity, being produced at the rate of 13 000 m^3/a by the nuclear industry and containing primarily man-made radionuclides having a large range of half-life. Estimates of the waste to accumulate over the period 1985-2025 are presented in Table 1. The nuclear industry estimates are based on current production by the three Canadian nuclear-electric utilities, Ontario Hydro, New Brunswick Power, and Hydro Quebec, the two national research laboratories at Chalk River, Ontario and Pinawa, Manitoba, and the uranium refining company, Eldorado Nuclear Limited.

The characteristics of the nuclear-industry wastes are presented in Table 2. The wide range of waste produced requires waste treatment practices which manage the quantities in a manner that assures protection of the public and the environment. The wastes are primarily housekeeping wastes composed of paper and plastic sheeting, mopheads, used protective clothing, rubber gloves, rags, and contaminated hardware. More contaminated wastes include spent ion exchange resins, filters, and wastes from isotope production [5]. The wastes are generally contaminated with short-lived radionuclides such as Co-60, and H-3, and longer-lived radionuclides such as Sr-90 and Cs-137, with some wastes (resins) containing C-14, a radionuclide with a half-life of 5730 years. Institutional wastes are handled by the national collection and storage service offered by Chalk River and the wastes tend to be composed of animal carcasses, scintillation vials, liquids, filters, syringes, wipes and gloves.

The contents of this paper will focus primarily on experiences gained in the operation of facilities at Chalk River, and the course of action taken to dispose of wastes generated on the site, and institutional wastes brought to the site.

Waste Processing and Conditioning

The practical experience in handling the wide variety of solid and liquid wastes goes back more than 40 years when the Chalk River site was first opened. Over the intervening years, waste has been stored, with the need for continual surveillance, maintenance and land-use control. To remove this responsibility and the associated cost from future generations, a program was undertaken to develop advanced waste-treatment processes to provide conditioned waste which could be transferred from storage to disposal [6]. The work culminated in the construction of a waste treatment centre to demonstrate volume reduction techniques on a commercial scale and to improve the management of Chalk River wastes. The choice of processes, equipment and materials for use in the facility was made after an extensive research and development program which included both laboratory and pilot plant tests.

The waste treatment centre integrates several processes with the specific aim of converting waste into a stable, leach-resistant form suitable for disposal. The basic flowsheet is presented in Figure 1. The facility is comprised of: a controlled air incinerator for combustible solid and liquid wastes; a baler for non-incinerable solid wastes; membrane filtration, reverse osmosis and evaporator systems for dilute aqueous wastes; and a ribbon blender and wiped-film bituminizer to immobilize the incinerator ash and liquid waste concentrates.

Solid Waste Processing

With the distribution of incinerable and non-incinerable wastes currently at 70% and 30% respectively, the incinerable category is burned in a batch-loaded, two-stage, starved-air incinerator. The system, shown in Figure 2, consists of a vertical stainless-steel primary chamber, a horizontal refractory-lined afterburner and a dry flue gas treatment system. The incinerator was designed to burn about 1000 kg (10 m^3) of solid waste every 24 hours. Details of the incinerator design have been published along with a number of operating highlights [7,8]. The incinerator has performed quite satisfactorily since 1982, when radioactive wastes were first processed. The waste charge has been gradually increased to where 1600 kg are processed in each burn cycle, providing improved throughput with no detrimental effects on performance.

The incinerator has consistently produced an inert ash product, free flowing and containing 1-3 wt% fixed carbon. An average volume reduction factor (initial waste volume/ash volume) of about 150:1 is consistently achieved.

Particulate release of radioactivity has remained negligible at less than 40 kBq of beta-gamma radioactivity per burn, demonstrating the effective removal of particles with the dry gas filtration system. The original HEPA (high efficient particulate aerosol) filters operated satisfactorily for six years until their replacement in 1988. The incinerator has been used to burn scintillation vials, and is equipped to burn liquid organics, mostly machine oils. The most critical component of the incinerator is the air-to-air heat exchanger which, while giving satisfactory performance, is susceptible to corrosion and deposition difficulties under high-temperature, cyclic operating conditions. Many of the tubes have failed and are progressively being replaced. The incinerator continues to serve as a test bed to evaluate corrosion resistant alloys.

The nonincinerable wastes are compacted in a 50 ton baler. The baler is equipped with a single chamber downstroke hydraulic ram to force the material into a bale of roughly 0.5 m^3 volume. The baler is equipped with a ventilation system to prevent airborne contamination during its operation and air is exhausted through HEPA filters into the main building exhaust system. The baling operation is quite simple, and has been virtually maintenance free. The baler produces waste packages having a volume reduction of greater than 6:1 over the uncompacted waste. Each bale weighs roughly 290 kg, and contact radiation fields vary widely from 20 µGy/h to 20 mGy/h.

Some wastes which now are not incinerated or compacted may still be processible if they are first shredded. A slow-speed, high-torque shredder is undergoing evaluation tests. The particular shredder was purchased because the slow speed (<100 rpm) generates little dust, and the high-torque allows most materials to be shredded. The limited operating data indicate that shredded waste can be compacted to a higher density than unshredded waste, providing as much as a 50% increase in the volume reduction factor. Shredding does not appear to improve the burning rate or ash quality of the incinerator, while it appears to require more waste handling, and thus a higher operating exposure to workers.

Liquid Waste Processing

During the last 35 years, approximately 20 000 m^3 of low-level aqueous wastes have been discharged annually into seepage pits at Chalk River. Extensive monitoring has shown that only a small fraction of the radionuclides has migrated away from the vicinity of the seepage pits. To eliminate future discharges, part of the waste treatment centre houses a facility to treat the annual volume of waste. The system is comprised of three interconnected, recirculating membrane separation systems and was installed to concentrate radionuclides and other impurities in a small volume with the bulk of the processed water discharged to the Ottawa River. It also provides an opportunity for evaluation of the relative merits of the various processing options. A schematic of the present design is shown in Figure 2.

The liquid waste is first fed to a microfiltration system which removes suspended solid particles. The waste still containing dissolved materials is then to be fed to a spiral-wound reverse osmosis system. The permeate from the spiral-wound membrane system will be low in radioactivity and will be stored, checked and then released to the Ottawa River. The retentate from both the spiral-wound and the microfiltration systems is directed to the final system, a tubular reverse-osmosis system. The system can handle a slurry and will provide additional concentration of the waste stream. The permeate from the tubular system must be recycled to the spiral-wound system because of the considerable activity present in the liquid. The initial feed will be reduced by a factor of 200-250 and will contain about 5 wt% dissolved and suspended solids. The concentrate leaving the system will be solidified in bitumen. The original system was an extremely complex, computer-controlled design which could not be effectively commissioned. Modifications have been made to the volume reduction facility and it is now being re-commissioned with an expected startup late this year.

A thin-film evaporator is available to handle special feeds which cannot be tolerated in the membrane separation system. These wastes are typically alkaline, with oxidizing substances which would damage the cellulose acetate membranes. Typically the wastes arise from the decontamination of loops used to test prototype fuels, or to test fuels in atypical reactor operations such as loss-of-coolant accidents. The wastes have to be shipped separately to the waste treatment centre and are to be handled on a special, rather than routine, basis.

Immobilization

The solidification systems for the incinerator ash and liquid waste use bitumen as the matrix material [9]. The incinerator ash is mixed with molten bitumen in a steam-heated, ribbon-blender mixer. The bulky ash is added in weighed increments to the blender and mixed with a precharged amount of bitumen. Typically two to three drums (210 L/drum) of ash are mixed with a half-drum of bitumen to produce a single drum of solidified waste. The mixture is discharged from the blender at a temperature of 150°C, and is allowed to cool for several hours before it is moved. With the high volume-reduction factor achieved from incineration, the blender operation is expected to be done on an irregular basis, producing two to three drums of solidified ash a month.

The thin-film evaporator used to immobilize the liquid waste is also steam heated, and uses a bitumen emulsion fed simultaneously with the liquid waste. The vertical evaporator has a set of internal blades which rotate at 1000-1200 rpm to create a turbulent film of bitumen emulsion on the heated cylindrical surface. The water is evaporated and the salts and suspended solids are homogeneously mixed with the bitumen to create a product having between 35 and 45 wt% solids. The evaporation rate is 100 kg/h, and at the low solids feed concentration, a drum of solidified waste is discharged from the system every sixteen hours. The overall volume reduction factor for the dilute feed entering the facility to a drum of bituminized waste exiting the treatment centre is 1600:1; 500 m^3 of liquid waste will become about 1.5 drums of product requiring storage and eventual disposal.

Waste Storage

The Chalk River facilities are located in elevated and well-drained deposits of sand. The radioactive waste is placed in the sand directly, or in concrete trenches above the water table to reduce the likelihood of contact with water. Storage, not disposal, is the only current means of handling radioactive wastes in Canada. Wastes have been stored at Chalk River since 1946. About 100 000 m^3 of solid radioactive wastes are in storage on the Chalk River property. The distribution of the waste is eighty percent low-level waste, fifteen percent intermediate-level and five percent fuel (high-level) waste [10].

The bulk of the LLRW waste has been buried in sand, well above the water table. Some measures have been applied to a portion of the trench area to minimize water infiltration. Polyethylene sheeting was laid down and covered with an additional metre of sand in 1982. The program was successful in reducing the rate of migration of highly mobile tritium from the site. Solid wastes with higher levels of radioactivity are stored in retrievable, reinforced concrete structures. Again, these facilities are above the water table. The structures range from 0.15 to 6 m in diameter and depths of up to 5 m. Each structure is fitted with a removable, weather-proof cover.

Waste Disposal

Waste storage is considered interim because some of the wastes will be radioactive beyond expected periods of surveillance. Disposal is a permanent method of management, without any intent to retrieve the waste, and will not rely on perpetual institutional controls and monitoring. The waste disposal program has been designed to take advantage of the more than 40 years of experience in the safe storage of LLRW. AECL has taken the lead in developing and demonstrating disposal of low-level radioactive wastes [1]. The strategy adopted for the disposal program involves characterizing the wastes according to their radionuclide content, grading the wastes into categories appropriate to their hazardous lifetimes and disposing of them in a repository suited to isolate and contain wastes so that their radiological hazards will not exceed the AECB's regulatory guidelines.

Three concepts that have been studied by AECL include:

1. Improved Sand Trench (IST) for wastes that need isolation for up to about 150 years;

2. Intrusion-Resistant Underground Structure (IRUS) for wastes that require isolation up to about 500 years;

3. Shallow Rock Cavity (SRC) for wastes that need isolation for more than 500 years.

From a knowledge of the radiological characteristics of the stored wastes and the wastes currently produced by AECL and shipped by medical, scientific and industrial users of radioisotopes, the bulk of the waste is likely to be disposed of in IRUS. The other concepts will complement, not replace, IRUS.

Concept

The disposal program was undertaken at Chalk River to minimize the impact of stored wastes on the environment, to minimize costs associated with long-term storage programs involving surveillance and monitoring, and to demonstrate that the disposal technique is viable, safe and suitable. The disposal facility will be located belowground in a stable sand ridge, but above the water table. Several engineered barriers will be used together as a system to prevent the ingress of water, to restrict the migration of radionuclides and to inhibit intrusion. The barriers include:

prepared waste forms;
backfill and buffer materials;
monolithic concrete walls and roof;
earthen cover.

The structure will have 60-cm-thick reinforced-concrete walls and a 100-cm-thick, self-supporting reinforced-concrete cover. Backfill will be placed around the waste forms and a thin layer will be placed between layers of waste packages to provide stability and a drainage path for any water which might enter the facility. The vault is designed with a floor prepared from permeable layers of sand, clay and clinoptilolite, a natural zeolite. The buffer layers will permit easy drainage of water, but will have large adsorption properties to retain soluble radionuclides released from the waste. The permeable bottom will be located about one metre above the highest recorded water table level. The concrete roof will be protected by over a metre of local materials which will serve to drain away infiltrating precipitation, and to keep the cap below the frost line. The various features of the repository concept are shown in Figure 3. Operation of IRUS is expected to commence about the fall of 1991. The site in which the facility will be located has been approved. It is fully characterized, and much is known about the hydrology.

From a rigorous examination of the various potential pathways for movement of radionuclides away from the repository, the most reasonable is through migration of radioactivity in water. The repository concept was developed to isolate the waste from the environment, but the most plausible failures involve ingress of water. The massive concrete cover will eventually degrade and allow water to infiltrate past the waste packages. A second possible route for radionuclide migration is through a rising water table which would allow ground water to come in contact with the waste, and then as the water table receded, radioactivity would be carried down through the buffer material and into the water table. The third conceivable failure lies in the inadvertent intrusion of the repository by humans, perhaps through the drilling of a well into or in close proximity to the repository.

To assess how radionuclides will move within the repository, a development program has been underway for some time [11]. As the program has developed, more information has been assessed and knowledge of water and radionuclide transport in saturated and unsaturated media has grown. The inadvertent intrusion of the repository is being addressed in performance assessments.

Development Program

The research and development programs are directed towards establishing confidence levels of performance for the engineered barriers so that even if there are potential failures of one or more of the barriers, the radiological consequences to the public of escaping radionuclides will be acceptable. The various programs involve studying the barriers on an individual basis and then together to determine the effects of their interactions. One of the major concerns is durability, since the repository is expected to isolate the waste from the public until the radioactivity becomes innocuous. The measurement of the rate of degradation depends on a knowledge of the chemistry in and around the repository. The environment within the disposal facility is expected to be reducing, but wide swings in pH values of the water within the repository can be expected depending on whether the water is in contact with the concrete, in which case the pH values will be about 11 to 12. At the other extreme, the degradation of cellulose waste could produce fatty acids and the pH values could range from 4 to 5. The extremes are used as the basis for durability experiments for both concrete and buffer/backfill materials.

The corrosion of containers, and the biological degradation of waste, will create an environment which is devoid of oxygen. The rate of degradation is dependent on the amount of water present. Another factor dependent on the quantity of water present is the release of radionuclides from the waste forms and their subsequent transport through the buffer and backfill materials. Experiments are underway to measure corrosion rates, biodegradation rates and the transport of radionuclides in saturated and unsaturated conditions.

Since concrete is the major barrier to water infiltration and intrusion, a significant program has been undertaken to be able to design a concrete which will provide the integrity needed for the 500-year isolation period. Durability is not only affected by the environment in which it is placed, but also by the ingredients and their proportions in the mix design and by the stresses absorbed by the service conditions [12]. To determine the longevity of the concrete, various degradation mechanisms have been considered. They include alkali-aggregate reactions, chemical deterioration by chloride and sulphate attack, carbonic acid corrosion, freeze-thaw scaling, leaching and dissolution of lime. The program is expected to provide information on the corrosion rates under extreme service conditions, to use the information to predict the useful engineering lifetime, and to enable concretes for other repository service conditions to be designed.

Combination experiments of waste form, buffer and backfill materials, and crushed concrete provide information on the rate of release of radionuclides and upon their movement in saturated and unsaturated conditions. The use of lysimeters, devices which are used to measure water percolation through soils, enable information to be collected and models developed to predict the release and transport of radionuclides. Field-scale lysimeters are being constructed to mimic the conditions within the repository both for the expected environment, and for failure modes, either from water infiltration or from flooding caused by a rising water table. The lysimeters will hold full-size waste forms and will be placed in backfill and buffer materials in a similar manner to which the waste will be expected to be placed in the actual repository.

Safety Assessment

The objective of the safety assessment is to analyze the expected performance of IRUS, i.e., the movement of radionuclides away from the facility or the intrusion of man, animals or plants into the facility and to compare the results with the accepted criteria for disposal laid down by the AECB. The assessment involves two parts: pre-closure and post-closure periods [13].

Risks from the operation of the facility during the pre-closure period fall mainly upon the workers who will be filling the repository. The risks to the workers during normal operation of IRUS will be quite similar to those for waste treatment and storage operations. Indeed, these risks have been shown to be quite small over several decades of experience at Chalk River. Radiation exposure to the workers will be maintained well below regulatory limits by adopting new techniques, mainly remote handling operations for the waste and backfill. Abnormal situations arising from the disposal operation might arise from flooding, earthquakes, fire and waste spillage.

The risk of flooding will be reduced by the use of the weathershield building and by the location of the facility above the water table in an elevated free-draining sand ridge. The seismic risks for the area were factored into the design. The risk of fire will be minimized by having the wastes properly packaged and identified to eliminate pyrophoric materials, and as an added safety precaution, each freshly laid layer of waste will be covered by a layer of backfill. The most likely risk will come from waste spillage. But spills can be minimized by proper training, by adhering to procedures and proper maintenance of waste handling equipment. There are proven procedures to cope with waste spills and to satisfactorily clean-up any radioactivity.

Risks from the post-closure operation of IRUS have to be examined in light of the impact on members of the general public, and in some cases the most affected individuals. The facility is built to provide isolation of the waste from the environment, to contain the waste contaminants and to control the release of radionuclides. The pathways likely for radionuclides to be released from the repository include gas, water and intrusion. The release of radioactive gases in quantities large enough to affect a critical group of the public is not likely to be a concern in the early stages of the post closure period. The water shedding capabilities of the different engineered barriers are unlikely to be destroyed to the extent that would allow a large ingress of water to promote vigorous biological degradation, the eventual source for any release of radioactive gases. Eventually the barriers will degrade, but by then the radionuclide of most concern for this pathway, tritium, will have decayed.

Plausible intrusion-risk scenarios are limited only by the imagination; they fall into two categories, deliberate or inadvertent. It is recognized that protection against deliberate intrusion is not possible. Efforts have focussed on how to cope with inadvertent intrusion. The inadvertent intrusion risks grow with time as less and less knowledge is retained about the whereabouts of the site. On the other hand, the waste source diminishes with time with the decay of the radionuclides to natural isotopes. Inadvertent intrusion is a hypothetical event which may or may not take place at some point in the future. The major barrier to inadvertent intrusion is the massive cover prepared from reinforced concrete, about one metre thick. The most plausible scenarios include the sinking of a well downstream of the repository and the use of water for drinking, washing and for agricultural purposes such as watering livestock and crops.

Predictive Modelling

To analyze the impact of radionuclide migration away from the repository, a complex mathematical code has been developed to model the leaching of radionuclides from the facility, their migration through the ground, their dispersion in surface waters and the atmosphere and their eventual irradiation of humans [14]. The COSMOS-S/D code complex was developed for the safety assessment analysis of IRUS, but it is suitable for a wide range of low-level radioactive waste disposal situations. The code structure is in modular form and several sections can be used independently; the code can be run with single input values for each of the different parameters to provide a deterministic output, or the code can be run in a stochastic mode, where each of the input parameters has a distribution of values given to it. A stochastic case would require several hundred passes through COSMOS versus one for a deterministic case.

COSMOS models the failure of containers and the consequent leaching of radioactivity from the waste forms; it incorporates a performance function for the massive concrete roof to allow the introduction of infiltrating water to the waste packages. It then determines the passage of the radioactivity through the surrounding backfill and buffer both for saturated and unsaturated regions; the subsequent transport through the consolidated deposits below the repository; movement into the water table; and transport to a receptor point, usually a well or surface water. The model can also account for some discharge of radioactivity through the gas pathway as a result of container corrosion and biological degradation. Finally, the code calculates the potential doses to an affected population from groundwater, surface waters and atmospheric releases from irrigation. The general structure of the code is given in Figure 4. Calculations of different scenarios indicate that with the assumptions made for the various barriers, the impact on critical members of the public will be well below the risk guidelines prepared by the regulatory body.

Summary

AECL has developed through its many operations, procedures to handle the diverse radioactive wastes generated as a by-product of research and development. For more than 40 years wastes have been routinely handled, processed and stored on company property. Processes have been developed to reduce the volumes of liquid and solid wastes and to prepare waste forms that can be easily handled for interim periods of time or are also suitable for direct disposal. A transition from storage to disposal is being spearheaded by AECL so that wastes can be handled more efficiently, and so that the regulators, other waste producers and the public will see the operation to be safe, practicable and affordable.

To ensure the long-term responsibilities for LLRW management, there has been a strong commitment to safety assessment of the disposal facility including a research and development program to understand the processes taking place and to obtain confidence in the performance of various engineered barriers. The assessment includes the preparation of predictive mathematical models to estimate the future risk to the general public from the eventual release of radioactivity from the repository. The program of waste identification, categorization, processing, handling and planned disposal will avoid unnecessary costs and risks to workers and minimize the impacts on future generations.

References

1. D.H. Charlesworth, J. Howieson, "An Overview of the Management of Low-Level Radioactive Waste in Canada", presented at the International Symposium on Management of Low- and Intermediate-Level Radioactive Wastes, held in Stockholm, Sweden, May 16-20, 1988.

2. Atomic Energy Control Board, "Regulatory Objectives, Requirements and Guidelines for the Disposal of Radioactive Wastes - Long-term Aspects", Regulatory document R-104, 1987.

3. Atomic Energy Control Board, "Prerequisites for the Exemption of Certain Radioactive Materials for Further Licensing upon Transferral for Disposal", Regulatory Document R-85, in publication.

4. D.J. Cameron, B.J. Franklin, R.W. Pollock, R.L. Zelmer, "An Analysis of the Need for Low-Level Radioactive Waste Disposal in Canada and the Alternatives for Establishing Disposal Facilities", Canadian Nuclear Society, Proceedings of the 2nd International Conference on Radioactive Waste Management, pp 354-360, Winnipeg, 1982.

5. T.J. Carter, P.K.M. Rao, "A Review of Low-Level Radioactive Waste Management Technology in the Canadian Nuclear Industry", Nuclear Journal of Canada, Vol. 1, No. 2, pp 166-172, 1987.

6. W.T. Bourns, L.P. Buckley, K.A. Burrill, "Development of Techniques for Radwaste Systems in CANDU Power Stations", Atomic Energy of Canada Limited Report AECL-6534, 1979.

7. L.P. Buckley, V.T.Le, N.V. Beamer, "Processing of LLRW Arising from AECL Nuclear Research Centres", Presented at the 9th Annual Canadian Nuclear Society Meeting, Winnipeg, Manitoba, June 12-15, 1988. Also Atomic Energy of Canada Limited Report AECL-9620, 1988.

8. V.T. Le, N.V. Beamer, L.P. Buckley, "Experience with Radioactive Waste Incineration at Chalk River Nuclear Laboratories", Presented at the 1988 International Conference on Incineration of Hazardous, Radioactive and Mixed Wastes, San Francisco, California, May 3-6, 1988. Also Atomic Energy of Canada Limited Report AECL-9722, 1988.

9. L.P. Buckley, W.H. Pettipas, "Bituminization of Reactor Wastes: Development, Design and Demonstration", Atomic Energy of Canada Limited Report AECL-7338, 1981.

10. R.J. Heystee, P.K.M. Rao, "Canadian Experiences in Characterization of Two Low-Level and Intermediate-Level Radioactive Waste Management Sites", IAEA Seminar on the Site Investigation Techniques and Assessment Methods for Underground Disposal of Radioactive Wastes, Sofia, Bulgaria, February 6-10, 1984.

11. L.P. Buckley, "Waste Packages and Engineered Barriers for the Chalk River Nuclear Laboratories' Disposal Program", Atomic Energy of Canada Limited Report AECL-8853, 1985.

12. K.E. Philipose, "500 Year Concrete for a Radioactive Waste Repository", Atomic Energy of Canada Limited Report AECL-9721, 1988.

13. D.G. Hardy, D.F. Dixon, "The Transition from Storage to Permanent Disposal of Low- and Intermediate-Level Wastes at the Chalk River Nuclear Laboratories", Atomic Energy of Canada Limited Report AECL-8728, 1985.

14. R.G. Jarvis, R.Y. Adam, C.I. Bretzlaff, J.M. Laurens, S.R. Wilkinson, "The COSMOS S/D Assessment Code Complex for a SLB Repository at CRNL", Atomic Energy of Canada Limited Report AECL-9350, 1986.

Table 1: Canada's Low-Level Waste Volume Projections (Based on Ref. 4)

	LLW projections (m^3) to year 2025
Category (a)	
Canadian nuclear industry	
Refining	65 000
Fuel fabrication	14 800
Utilities	156 500
Isotopes and research	61 200
Category (b)	
Other producers (Institutional/industrial)	
Licensed users	12 900
Industries using naturally radioactive feedstocks	57 100
Total	367 500

These exclude about 1.2 million m^3 of wastes, primarily contaminated soils at several 'historic' sites, CRNL site and waste management sites of Eldorado Resources Limited at Welcome and Port Granby, Ontario.

Some compaction of the wastes at the source is assumed, as is carried out by the producers normally.

Table 2: LOW-LEVEL RADIOACTIVE WASTE CHARACTERISTICS

SOURCES	TYPICAL WASTES	VOLUMES m^3/a	RADIONUCLIDE TYPE (main) and ACTIVITY RANGE TBq/a
Radio-isotope Users (research institutions and hospitals.)	Sealed sources of undisturbed equipment such as gauges, radiography cameras, static electricity eliminators. Contaminated materials such as animmal carcasses, scintillation vials, liquids, filters, syringes, wipes and gloves.	320	140 Co-60 15 Cs-137 7 Eu-154 11 Pm-147 + other mixed isotopes
Nuclear Fuel Fabricators Eldorado Resources Limited (ERL)	Uranium contaminated materials and residues (large historic waste volumes).	370 1625	1.5 Uranium
Nuclear Utilities, e.g. Ontario Hydro, Hydro-Quebec and New Brunswick Electric Power Commission	Reactor purification system waste such as filter vessels, ion exchange resins. Reactor maintenance waste such as paper, cloth, glass, plastic, sheet metal materials, piping and equipment components.	3910	150. H-3 1.6 Co-60 .4 Sr-90 .4 Ca-137
Incidental Wastes	Residues from abrasive manufacturing or specialty metal alloy production (phosphogypsum tailings, filters and tank liners are not included).	1430	.003 Ra-226 .003 Th-230 .05 Th-232 .05 U
Atomic Energy of Canada Ltd. (AECL), e.g., CRNL and WNRE	Contaminated material from laboratory and plant operation, reactor maintenance and purification wastes and wastes from isotope production.	1530	3.7 H-3 2.6 Co-60 0.5 Sr-90 0.5 Cs-137

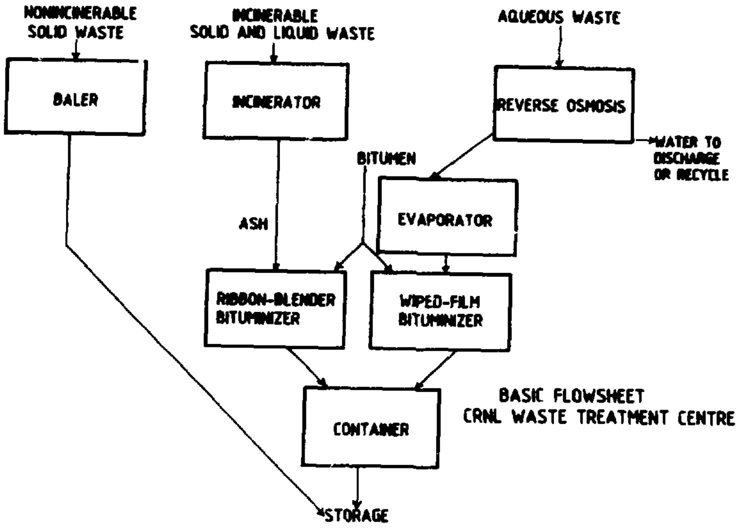

Figure 1: Flowsheet of CRNL Waste Treatment Centre (WTC)

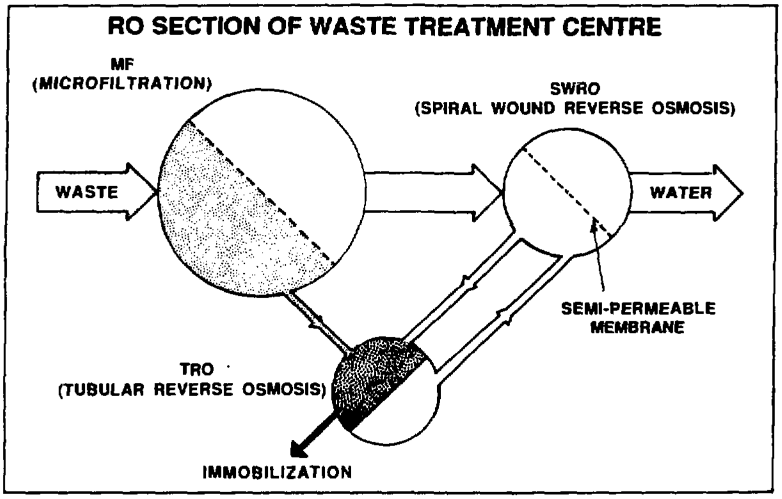

Figure 2: Flowsheet of the Liquid Waste Treatment Process of the WTC

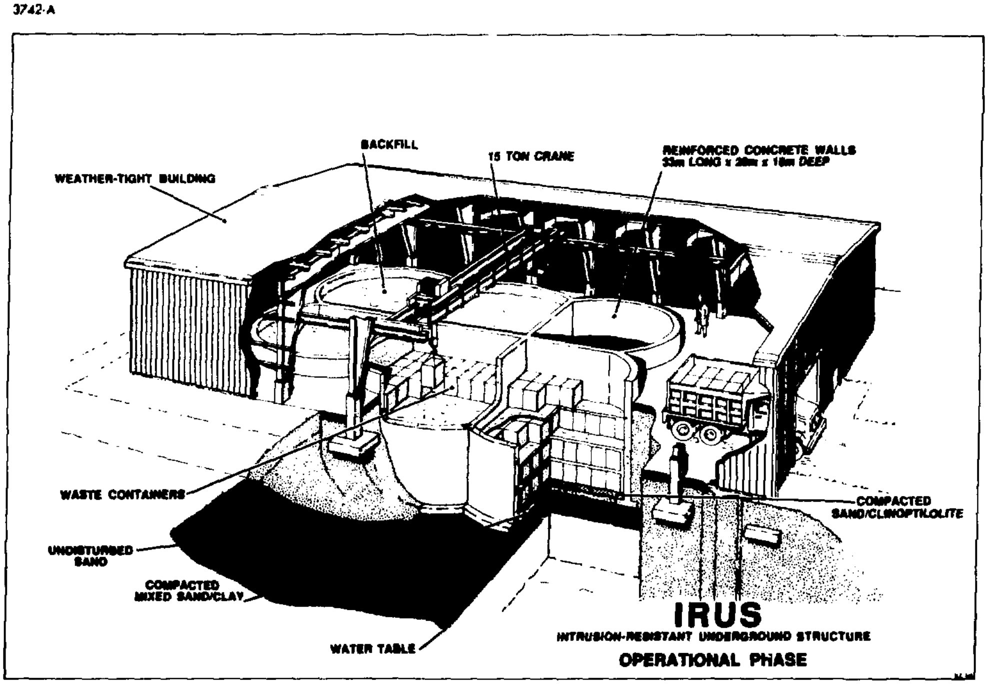

Figure 3: Proposed Facility for the Disposal of LLRW

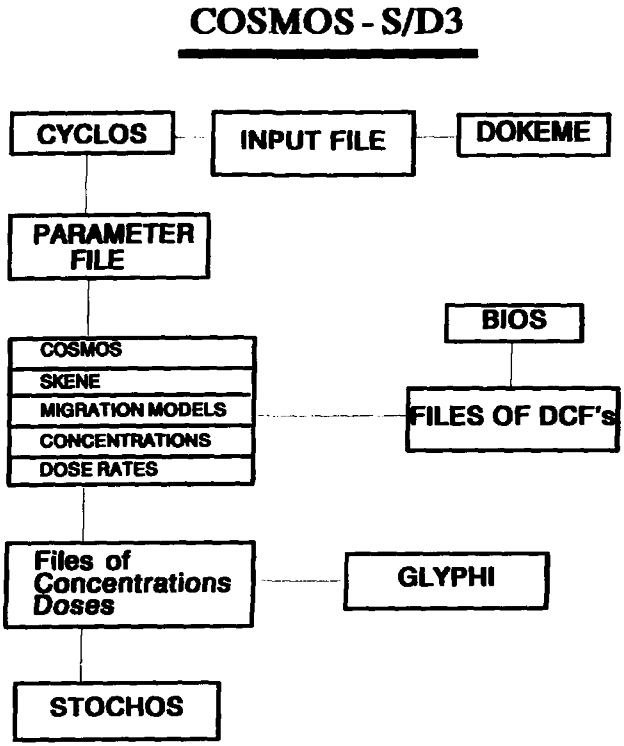

Figure 4: COSMOS-S/D Structure

ISSN 0067-0367

To identify individual documents in the series we have assigned an AECL- number to each.

Please refer to the AECL- number when requesting additional copies of this document

from

Scientific Document Distribution Office
Atomic Energy of Canada Limited
Chalk River, Ontario, Canada
K0J 1J0

Price: A

ISSN 0067-0367

Pour identifier les rapports individuels faisant partie de cette série nous avons assigné un numéro AECL- à chacun.

Veuillez faire mention du numéro AECL- si vous demandez d'autres exemplaires de ce rapport

au

Service de Distribution des Documents Officiels
L'Energie Atomique du Canada Limitée
Chalk River, Ontario, Canada
K0J 1J0

Prix: A