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RADIOACTIVE WASTE MANAGEMENT
FOR NUCLEAR ENERGY CENTER

by

W. K. Winegardner and J. D. Kaser

January 1974

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CONTENTS

RADIOACTIVE WASTE MANAGEMENT FOR NUCLEAR ENERGY CENTER	1
A. Introduction	1
B. Summary.	1
C. High-Level Waste.	3
1. High-Level Waste Facility	4
D. Low-Level Waste	8
1. Low-Level Wastes Generation Rates.	8
2. Criteria and General Description for Retrievable Low-Level Radioactive Storage System	9
3. Description of Retrievable Surface Storage Facility for Low-Level Radioactive Wastes	11
4. Unit Operations for Storage of Low-Level Radioactive Waste	15
5. Accountability and Monitoring	18
6. Costs for Low-Level Radioactive Waste Disposal Site.	19
7. Capital Costs	19
E. Environmental Safeguards at the Repository Site for Radioactive Wastes	20
F. Benefits and Problems	20
G. Additional Studies	21
REFERENCES.	22

RADIOACTIVE WASTE MANAGEMENT
FOR NUCLEAR ENERGY CENTER

W. K. Winegardner and J. D. Kaser

A. INTRODUCTION

This report presents information developed during a brief study concerning the management of radioactive wastes within a Nuclear Energy Center (NEC). In addition to nuclear reactors for generating electrical power, the center includes an enrichment plant, fuel reprocessing plant, and fuel fabrication plant which also serve reactors outside the center. Facilities for treating and storing both high and low waste are described. Waste inventories are projected and estimated costs of the waste management facilities are presented. Benefits and problems are also briefly discussed. The information is generally applicable to NEC's at a variety of locations. Because of time limitations and the nature of the study, information was developed from preliminary data. There is no intent to imply that waste management schemes are optimum in relation to the center.

B. SUMMARY

Radioactive waste that cannot be released to the air or water will be managed within the center in the Waste Treatment and Storage Facility (WTSF), a Federal repository. Waste generation rates are based on an installed electrical generating capacity that increases from 10,000 to 15,000 MWe in 1985 to 40,000 MWe in the year 2000 and a total accumulated fuel processing load (to the year 2000) of 30,000 metric tons (tonnes). The processing load, which is assumed to be 72, 20 and 8% associated with LWR, LMFBR, and HTGR plants, respectively, reflects a market area about half of which is outside of the center.

It was assumed that the high-level solid waste arising from the chemical reprocessing of "spent" or irradiated fuel will be stored in canisters in modular concrete-walled water-filled basins; the water provides both shielding and cooling. Alternative concepts could also be

used, such as air-cooled shielded vaults, or individual waste canisters in their own shielded sealed cask stored out-of-doors. The high-level portion of the WTSF will also be sized to store compacted cladding hulls. Each storage module is capable of storing about 500 canisters or about 6000 ft³ of compacted hulls. Eight storage modules, requiring about 15,000 ft² of floor area would be provided by about 1990 along with a receiving and handling facility of similar size. Using 1974 dollars, a preliminary estimate of the total capital cost associated with this first stage of construction is \$40 million. Additional storage capacity for 3000 canisters and 12,000 ft³ of cladding hulls would then be constructed every 5 yr at an estimated cost of \$12 million. Costs for operation of the facility, estimated for 1990, are \$3 million/yr. Waste management schemes based on air cooling are potential alternatives to the water basin concept. Any facility should be designed for the retrievable, long term (100-yr) storage of high-level waste. After long term storage, offsite shipment may be required in conjunction with yet to be defined disposal concepts. The need for shipment would, of course, be negated if it is determined that the center is suitable for disposal.

Total low-level waste arising from operations within the center by the year 2000 is estimated to be 3.8 million ft³ of compacted, incinerated, and packaged solid, plus 1000 canisters of compressed noble gas. This volume of waste is estimated to contain 13 million Ci. The maximum throughput is estimated at 1200 ft³/day.

The treatment of solid low-level waste consists of sorting, compaction, incineration and packaging. It was assumed that low-level liquid and gaseous wastes are treated at the point of origin. Liquids are evaporated to a solid residue and gases are compressed and stored in cylinders. The packaged waste will be stored in modular shielded and unshielded warehouses until a permanent disposal method becomes available. Disposal may be onsite or the waste may be shipped to an offsite repository. In order to contain the low-level waste that will accumulate by the year 2000, 1.7 million ft² of storage space will be required. The

estimated cost of a low-level waste treatment facility designed for an output rate of 1200 ft³/day is \$60 million, while the cost of the 1.7 million ft² waste storage facility is about \$100 million.

The primary benefit derived from siting the WTSF within the center is that transportation of waste through non-Federal land is not required, at least for 100 yr. A potential problem is that siting considerations for waste management facilities and power reactors are not always compatible, e.g., a river can be viewed not only as a heat sink, but also as a potential driving force for dispersion of stored radionuclides. A potentially serious problem is that acts of war and sabotage and natural catastrophies can be related to a stored source of nuclides, now concentrated in one location.

C. HIGH-LEVEL WASTE

In the production of electrical power from nuclear energy, the nuclear processes that take place in the reactors result in the formation of radioactive fission products and heavy isotope build-up within the nuclear fuel. The irradiated or "spent" fuel will be discharged from the reactors of the NEC and then chemically processed at the fuel reprocessing plant to recover the significant amount of valuable "unspent" fissile and fertile materials for recycle. As an example, irradiated enriched uranium LWR fuels will typically contain about 30% of the original fissionable uranium and the fissionable plutonium produced by reactor irradiation. Chemical reprocessing will be used to separate and recover these useful products from the fission products and the higher waste actinides. Existing or planned reprocessing flowsheets are based on a solvent extraction process. Aqueous acidic "feed" solutions, arising from the dissolution of irradiated fuels in nitric acid, will be fed to the initial (first-cycle) solvent extraction contact. Here, most of the nuclear fuel products will be retained in an organic phase, while the fission products, along with a small quantity of uranium, plutonium or thorium (product loss) and generally all other actinide elements will be discarded as aqueous acidic high-level waste.

For this study it was assumed that this aqueous acidic high-level waste stream will be solidified, at the reprocessing plant, almost immediately after generation of the waste. The resulting solid waste will be transferred to the WTSF after about 5 yr of interim storage at the reprocessing plant. The transfer will take place in sealed metallic canisters, typically 12 in. inside diameter by 10 ft long, each containing 6.3 ft³ of solid waste, probably in the form of borosilicate glass. The interim storage period prior to transfer will result in individual canister heat generation rates of 5 kW or less.

About 7000 canisters of waste will be stored at the WTSF by the year 2000. The number of canisters that will accumulate was determined by assuming a fuel reprocessing plant load that increases almost linearly, from 1 tonne/day of fuel (300 tonnes/yr) in 1982 to 10 tonnes/day (3000 tonnes/yr) in 2000 (it is estimated that about half of the load arises from reactor plants not associated with the center). Furthermore, it was assumed that 72, 20, and 8% of the load is associated with LWR, LMFBFR, and HTGR plants, respectively, and that final volumes of solidified high-level waste from the three reactor types are 2, 3, and 6 ft³/tonnes, respectively.⁽¹⁾

The WTSF high-level waste facility will also be sized to store waste cladding hulls from spent LWR and LMFBFR fuels. Estimated volume of this material accumulated to the year 2000, based on a compacted product of 2 ft³/tonne, is 60,000 ft³. It was assumed that the compacted hulls are in the form of coated "bales" and that compaction facilities are available at the WTSF. Storage space for cladding hulls at the reprocessing plant will be minimal.

1. High-Level Waste Facility^(a)

a. Characteristics

Review of the concepts for high-level radioactive waste management indicates that the system should have the following characteristics:

(a) Characteristics, description and estimated costs for the facility were developed from information prepared for EPA and by BNW staff (Contract No. 68-01-0762) and presented in Program for the Management of Hazardous Wastes, Final Report, July 1973.

- Capability to accept sealed metallic canisters of previously solidified high-level radioactive wastes to a form which is chemically, thermally, and radiolytically stable.
- Capability to compact and store packages of waste cladding hulls.
- Assurance of the health and safety of the public and the protection of the environment.
- Safety of operation, including the ability to remove heat and maintain canister integrity and retrievability following extended periods of time.
- Controllability of effluent emissions to those in proposed Appendix I to 10 CFR 50 for nuclear reactors, which are generally 1.0 to 0.001% of those now in 10 CFR 20.
- Retrievability under all conditions.
- Ability to withstand all credible natural forces.
- Reasonable capital investment consistent with the objectives of safe waste storage for 100 yr or more, and safe recovery from unplanned events.
- Modular construction to provide waste storage space on a schedule consistent with future commercial reprocessing waste deliveries.
- Contamination-free operations.

Until a concept for ultimate disposal of high-level radioactive waste becomes available, it is planned that the WTSF will be used to store radioactive waste. The primary requirement is to provide safe storage for encapsulated solidified high-level waste for at least 100 yr and to make it possible to retrieve failed or weak canisters from storage areas and repackage the contained waste for continued storage or for shipment.

b. Description of Facility⁽²⁾

In the preliminary concept of the WTSF described here, the high-level waste will be stored in water basins built in modules. New modules will be constructed as required to handle the increasing waste inventory.

The water in the basins provides shielding and cooling for the canisters and shielding for the waste cladding hulls. Surveillance will be necessary to assure that the canisters remain in satisfactory condition. Extensive monitoring will be used to detect any evidence of canister overheating, leakage or deterioration so that necessary corrective action can be taken if the need arises.

Before proceeding it should be noted that there are alternative management systems that conceivably could be used instead of the water basin concept. Both air-cooled vaults and a system where canisters of solids are stored out-of-doors in heavy-walled steel casks are being evaluated in conjunction with the conceptual design of the Retrievable Surface Storage Facility (RSSF).⁽³⁾

Storage buildings will be designed for a service lifetime of at least 100 years and built to withstand all natural forces which might be expected at the facility such as severe storms, earthquakes, and floods, as well as all credible adverse accident conditions. It is expected that even with nominal maintenance the structures can be maintained in serviceable condition well beyond the design lifetime. The facility will be designed in accordance with nationally accepted codes and standards. A quality assurance program will be applied to the design, fabrication, construction, and testing of structures, systems and components of the facility, to assure that each component of the facility will perform its required function.

In addition to the storage basin, the WTSF also will have facilities to receive, inspect, and decontaminate high-level waste canisters and their transfer casks. The WTSF will be sized to receive up to 10 canisters per day. Facilities will also be provided to repackage failed canisters. Transfer casks containing canisters will be brought into the receiving area within the building and immersed in a stainless steel-lined receiving basin filled with water. The canisters will then be removed from the cask and inspected under water before they are moved into the storage basin.

Facilities will be provided to compact the cladding hulls at a maximum rate of 4 tons/day. It is estimated that the receiving and handling facility will require about 15,000 ft² of building floor area.

The initial storage area will consist of eight concrete-walled water basin storage modules requiring about 15,000 ft² of floor area. Each storage module is capable of storing about 500 high-level waste canisters or about 6000 ft³ of compacted hulls. The modules are lined with stainless steel and filled with water before any waste is emplaced. The height of water above the top of the canisters is sufficient to protect operating personnel from radiation. Above the modules is an enclosed working area from which an overhead crane is used to handle canisters and the optional cover blocks for each module. Storage modules will be connected to a water-filled transfer canal.

One central water treatment loop consisting of a filter, cooler, ion-exchanger, and auxiliary equipment will process the storage basin water in all modules. The temperature of the water in each module will be maintained at about 120°F by circulation through the tube side of a heat exchanger. Cooling water on the shell side will be pumped through externally located evaporative coolers. Maximum heat generation per module is 2.5 MW (500 5-kW canisters).

c. Estimated Costs

Preliminary cost estimates have been made for the WTSF waste repository to provide an initial economic appraisal of the conceptual design. The facility would be constructed in stages to handle the high-level waste canisters resulting from the continually increasing fuel reprocessing load. By 1990, the first stage of construction would be completed and the facility would be in operation. This first stage includes the cladding hull compaction, and receiving and handling facility as well as storage modules for storing a total of 3000 waste canisters and about 12,000 ft³ of compacted hulls. Using 1974 dollars a preliminary estimate of the total capital cost for this first stage of construction is about \$40 million. Direct and

indirect costs associated with the buildings, equipment, and auxiliaries for the receiving and storage facilities amount to \$23 million. An allowance of 75% of the direct and indirect costs, amounting to \$17 million, was estimated for the design of the facility, engineering, quality assurance, and contingencies.

Additional storage capacity for 3000 waste canisters and 12,000 ft³ of cladding hulls would be constructed approximately every five years to meet projected storage requirements. Estimated capital cost for these additions is about \$12 million of 1974 dollars.

Costs (in 1974 dollars) for operation of the facility, estimated for 1990, are about \$3 million/yr and result primarily from operating manpower, utilities, materials consumption, and equipment replacement.

D. LOW-LEVEL WASTE

1. Low-Level Wastes Generation Rates

Low-level waste generation rates for the various processing steps in the nuclear fuel cycle which are assumed to take place within the NEC were estimated from a previous study carried out for the Office of Environmental Affairs (USAEC).⁽⁴⁾

Gross waste generation rates were estimated from these data using the following assumptions in addition to the assumptions listed in the foregoing section:

- The total maximum full throughput rate for all types of fuels will be 10 tonnes/day.
- The solid low-level waste volume is reduced 50% by compaction and incineration.
- PuO₂-UO₂ fuels make up 5% of total fuel throughput.
- For the want of published information, the low-level solid waste generation rate for the U₃O₈ to UF₆ conversion process was assumed to be 10 ft³/MTU.

- Low-level aqueous wastes are decontaminated to releasable levels at the originating process facilities. The concentrated residues are handled as solid wastes.
- Low-level wastes are defined here as wastes with heat generation rates less than 0.1 W/ft^3 from radioactive decay.

The estimated low-level waste generated by operations of the NEC is shown in Table 1. The volumes shown in the table represent waste volumes after incineration, compaction and packaging.

2. Criteria and General Description for Retrievable Low-Level Radioactive Storage System

The overall criteria used for the conceptual design of the treatment and storage of low-level radioactive wastes in this report are derived from those previously cited for high-level wastes. The basic premise is that the system should not permit the release of biologically significant amounts of radioactivity into the environment.

The system for storage of low-level radioactive wastes was designed to meet the following requirements:

- It should accept sealed canisters of chemically, thermally, and radio-lytically stable, solid low-level radioactive wastes.
- The facility will provide for sorting, volume reduction and incineration of combustible solid wastes, and encapsulation of wastes which require treatment.
- It should provide instantaneous processing capacity at the rate of $1200 \text{ ft}^3/\text{day}$ output.
- The health and safety of the public and the protection of the environment should be assured.
- Storage capacity for all treated and packaged low-level radioactive wastes accumulated between 1982 and 2000 should be provided.

TABLE 1. Output Low-Level Waste from Low-Level Waste Processing Facility

Waste Source	Maximum Daily Rate ft ³ /day(a)	Cumulative Amount by Year 2000, ft ³ (a)	Cumulative Activity by Year 2000, Ci
Yellowcake Conversion and Enrichment	50	150,000	25,000
U-Th Fuel Fab for HGTR	2.5	7,000	7,400
PuO ₂ -UO ₂ Fuel Fab for LMFBR and LWR	45	136,000	3,900,000
UO ₂ Fuels	50	76,000	<0.1
Total Fuels Fabrication (Rounded)	<u>100</u>	<u>220,000</u>	<u>3,900,000</u>
Power Reactor Operations	100	360,000	4,000,000
LMFBR Fuels Reprocessing	60	130,000	2,000,000
LWR Fuels Reprocessing	860	2,600,000	3,100,000
HGTR Fuels Reprocessing	85	250,000	160,000
Total Reprocessing Low-Level Waste (Rounded)	<u>1,000</u>	<u>3,000,000</u>	<u>9,300,000</u>
Total Low-Level Waste (Rounded)	<u>1,200</u>	<u>3,800,000</u>	<u>13,000,000</u>

(a) Volumes are those after incineration, compaction, and processing

- Operation should be safe and should include the ability to maintain canister integrity and retrievability after extended periods of time.
- Effluent emissions should be controlled at least to those in proposed Appendix 1 to 10 CFR 50 for nuclear reactors, which are generally 1.0 to 0.001% of those now in CFR 20.
- The stored wastes should be retrievable under all conditions.
- The facility should be able to withstand all credible natural forces.
- Reasonable capital investment should be made consistent with the objectives of safe waste storage with retrievability for 100 yr or more and safe recovery from planned events.
- Construction should be modular to provide space on a schedule consistent with the objectives of safe waste storage with retrievability for 100 yr or more and safe recovery from planned events.
- Contamination-free operation should be provided.

Until a concept for permanent disposal of low-level radioactive wastes becomes available, a retrievable surface storage facility should be used to store low-level radioactive wastes. Other design considerations, such as surveillance, design lifetime, and integrity should be similar to those for high-level wastes.

The use of man-made retrievable surface storage facilities assures that there is a safe solution to the low-level waste problem for many tens of years and possibly several centuries. During this period development of an integrated waste management program should be completed to provide for optimal ultimate disposal.

3. Description of Retrievable Surface Storage Facility for Low-Level Radioactive Wastes

The scheme selected for disposal of low-level radioactive waste consists of a processing facility for volume reduction plus a facility for storage of the packaged residue for up to 100 yr. A flow diagram for the operations in the facility is shown in Figure 1.

FIGURE 1. Low-Level Radioactive Waste Processing and Storage Facility

The head-end materials-handling portion of the facility will provide systems for receiving and storing liquid and solid wastes, segregation of solid wastes into combustible and noncombustible fractions, and decontamination facilities for transportation, materials handling, and process equipment. Material will flow from the head-end materials handling facility to the processing systems or to storage. The receiving section will have access to the decontamination facility so that transportation equipment can be decontaminated as required. The receiving facility will be housed in the processing building to assure that all radioactive materials are contained during transfer operations.

Sufficient storage will be provided for one week's production capacity of both liquid and solid wastes prior to processing or final placement for storage. Several storage tanks will be provided so that the liquids can be segregated, neutralized, mixed with other wastes, and prepared as feed for the evaporation or incineration processes. Multiple glove boxes equipped with sorting equipment will allow segregation of the solid waste into noncombustible fractions for transfer to storage or to the packing area for final packaging prior to storage. Feed preparation of combustibles for incineration will also be performed in glove boxes. The decontamination facility to be located in the head-end materials handling and processing facility will be designed to handle the transportation equipment as well as equipment used in the processing facility.

Both combustible liquids and solids will be fed into a remotely controlled incinerator in a shielded area or into an alternative processing scheme for oxidation and volume reduction. Use of controlled air incineration to minimize the generation of fly ash and to provide complete oxidation of the offgases is anticipated. The offgases will be routed through a gas cleaning system to assure that the releases are within standards. The same offgas cleaning equipment will be used to process noncondensable gas from the evaporation and condenser system. The gas cleaning system will consist of wet and dry mist eliminating systems, a wet scrubber, and a final stage of High Efficiency Particulate (HEPA) filters. Solids from the incinerator and the gas cleaning systems will be transferred to the solids processing system for final packaging.

Noncombustible liquids will be processed through a remotely operated evaporator located in a shielded area. Special modifications of evaporation equipment may have to be designed to handle these radioactive liquids. Solids from the evaporation step will be transferred to the solids processing system for final treatment and packaging. Overheads from the evaporation system will be condensed to remove condensables while noncondensables will be routed through the gas cleaning system for particulate removal before discharge to the atmosphere. Condensate and all other process water will be routed to a retention basin for chemical and radioactive analysis before final discharge. Wastewaters that do not meet effluent standards will be recycled through the evaporation system.

The processing systems will be housed in a building with two or three ventilation zones to assure that air is always flowing from the zones of lower-level contamination to the zones of higher-level contamination. Building ventilation will be a major design consideration for this facility since personnel and the environment must be protected from the escape of contamination. All processing and operations must be done in enclosed hood-type facilities having detailed design which must be carried out with extreme care to assure confinement of radioactive contamination. All waste products (solid and liquid) generated within the facility, primarily from decontamination operations, are processed internally and handled as waste received from outside sources.

The receiving, handling and processing facility will be connected to two central corridors, which in turn, connect with the several warehouse structures. For the year 2000 a total of 34 warehouses, each 100 ft wide by 500 ft. long, will be arranged side by side and will connect at right angles to the central corridors. Each warehouse can accommodate 4000 waste containers in layers three high. Future expansion of the storage facility will be achieved by building additional warehouses and extending the central corridors; the overall layout is shown in Figure 2.

Two types of warehouses are used, one of which will be for wastes requiring shielding (up to about 3 ft of ordinary concrete). Waste canisters, which require shielding, are transferred by remotely operated crane down through the access corridor to the entrance of the appropriate warehouse. There the waste canister is transferred to the remotely-operated warehouse crane for transfer through the air lock and into its storage position. Wastes which do not require shielding, are transported by forklift. Gaseous wastes are stored in cylinders; these cylinders are kept in a separate shielded warehouse equipped with special adsorbent ventilation systems.

Each warehouse is provided with its independent supply of treated and prefiltered ventilation air. The compartmented ventilation exhaust from each warehouse is separately filtered and monitored prior to joining the exhaust air from the remaining warehouses. This compartmentation facilitates identification of canisters which have developed leaks during storage. All exhaust air from each warehouse is combined and passed through a bank of high efficiency filters and is monitored before being exhausted through the central facility stack.

4. Unit Operations for Storage of Low-Level Radioactive Waste

Unit operations at the disposal site for low-level radioactive wastes will involve 1) receiving, sorting, and handling; 2) decontamination of transportation devices, work areas, and equipment; 3) concentration, conversion to solid, and canning (e.g., incineration of solid wastes and evaporation of liquid wastes); and 4) storage for an extended period.

Safety Provisions

Provision will be made for possible spills and accidents in the receiving area. Unloading will be done within an enclosed area with controlled ventilation to prevent direct release of contamination to the environment which might result from surface contamination of containers or rupture of containers during handling. Spills will be isolated and cleaned up using established radioactive decontamination procedures. High radiation levels in wastes will be contained by special shielding. All other material with low radiation doses will be treated in hoods or glove boxes in the same way

FIGURE 2. Overall Layout of Low-Level Radioactive Waste Storage Facility

plutonium is handled in nuclear fuel plants. Direct monitoring of personnel for radioactive contamination and indirect monitoring of radiation doses with badges, pencils, and rings will be conducted. Because of the definition of low-level wastes, no significant heat generation problem is anticipated.

Evaporator operation results in the entrainment of some radioactive aerosols, which are controlled with close-coupled offgas equipment, and is by far the process step with the most potential for contamination spread by incidents such as temperature and pressure excursions. Combustion of organic liquids and cellulose in materials could result in temperature excursions and possible explosions if operating conditions become abnormal. Design for automatic pressure relief (to another enclosed vent system) and equipment shutdown would be an integral part of equipment design, particularly in view of the potential hazard of the radioactivity in the processed material. Release of radioactivity outside of the processing facility would be avoided by backup ventilation decontamination (filter) systems in case the primary offgas treatments fail. Spills resulting from the canning operation would be handled with routine isolation and cleanup procedures. Sampling of the retention pond should prevent aqueous releases. Environmental surveillance should include the placement of nearby wells for sampling purposes.

Safety problems associated with the storage facility are 1) container rupture followed by contamination spread, 2) criticality, 3) overheating, and 4) natural disasters. Canister rupture will be detected by ventilation gas sampling and criticality detection equipment will be located in the storage array. Similarly, temperature recording will detect unusual radioactive or chemical heating which will be supplemented with automatic fire alarms and automatic fire fighting equipment. Fire should be unlikely in the storage areas because combustible wastes will have been previously incinerated. The facility will be constructed to survive tornadoes and earthquakes, and located to avoid floods and ground subsidence.

Procedures to prevent sabotage or theft are not yet well developed beyond the usual military-type guard system; a factor which must be considered in detail during the final design phase. In any event, a high,

unclimbable fence will surround the total property of the disposal site, and another fence should probably be installed around the processing and warehouse area. The total site should have appropriate audio/visual surveillance.

5. Accountability and Monitoring

A major problem in handling low-level radioactive wastes is the determination of the amount of radioactivity in the incoming wastes. Waste producers will be required to inventory radioactivity in the wastes they send in terms of curies or grams of fissile materials and curies or grams of other radioactive materials. The incoming wastes must be monitored for total radiation level, external contamination and the total fissile content (to determine the potential for achieving criticality). It should not be necessary to reopen cans already adequately treated and packaged for storage. The initial monitoring will result in segregation on the basis of radiation level, the need for container decontamination, and the need for treatment. Normal radiation monitoring and isolation techniques should be used in the sorting area with the assumption that all materials contain plutonium.

All effluents of the volume reduction processes will be monitored (stack gases, retention pond effluent) before release. Because of the possibility of accidental releases during processing, environmental monitoring of air, water, land, biota and people around the site should be conducted routinely.

The solid waste materials should be monitored before packaging to provide an estimate of the content of specific nuclides; this will require some sampling. It is hoped that the technology for low-level continuous inventorying of solids will be developed to perform this task, but such technology is not available at this time. A more feasible alternative would be to do "whole body" monitoring of the can after sealing. Improvements in current technology would also be needed for this operation. A check for consistency would then be made between an accumulation of measured can contents and the estimates at the source with a best estimate being assigned forever to the can contents. Inventory controls would be imposed to decrease the likelihood of creating a critical mass during

storage and to segregate temporarily high radiation field materials until decay. A continuous program of air sampling and can monitoring is needed to check for failed cans.

Once the wastes are safely packaged and stored in warehouses, accountability of radioactive materials is largely a matter of restricting unauthorized access to the facility, keeping adequate records of inventories placed in storage, properly labeling each can for identification, and periodically estimating current and projected inventories of radionuclides that build up and decay as time progresses. This last item seriously complicates the inventory record problem, but it is desirable to help define the current and future hazard of the waste and to provide information for decisions that might be necessary regarding future disposition of the waste.

6. Costs for Low-Level Radioactive Waste Disposal Site

The capital and operating costs for facilities with incineration capacities of up to 500 lb/hr have been estimated, but no data on actual operating or capital costs for facilities of the size required to meet the total production rate of 1200 ft³/hr were available. Therefore, a capital and operating cost estimate was made for a facility that could compact, incinerate, and package 3,500 gal of liquid radioactive waste and incinerate an average of 1200 ft³ of solid radioactive waste per hour. The capital and operating costs of remote radioactive processing facilities are highly dependent on the design criteria and operational procedures established for the facility.

7. Capital Costs

The estimated capital cost for the low-level waste processing facility is rounded to \$60 million. Alternatively, an initial facility suitable for the period 1980 to 1990 could be built for about \$40 million, to be augmented by 1990 by additional processing capacity for an additional \$40 million. The approximate capital cost for the storage facility through the year 2000 is \$100 million.

Costs were established on the basis of buildings able to withstand tornadoes and earthquakes, with use of the present state-of-the-art practice for contamination control, shielding, and remote handling. Capital is also dependent on the height to which the canisters are stacked. The standard 4- x 6- x 6-ft high canisters can be stored from one to five high and satisfy technical requirements for storage. If containers are stacked three high, the capital cost for a storage facility is \$8/ft³ of material stored.

E. ENVIRONMENTAL SAFEGUARDS AT THE REPOSITORY SITE FOR RADIOACTIVE WASTES

A detailed survey of the geology of the site with regard to groundwater flow and aquifer characterization, structural and long-term stability characteristics of the underlying strata, and tectonic stability and frequency of earthquakes will be required before the plant is located. Prevailing meteorological conditions (wind velocity and direction versus time, air "dilution" factors, precipitation) and background radioactivity should be monitored and well established before site selection and during site operation.

Because of the long storage time anticipated, population trends should be anticipated and the existence of the storage facility should be considered in long-range local and regional plans. Arid regions of low population density with deep water tables are generally preferred but are not essential. It is assumed that an exclusion distance of at least one mile around the activities within the site, or especially from the ventilation stack location, would allow for good atmospheric dilution.

F. BENEFITS AND PROBLEMS

The primary benefit derived from siting the WTSF within the center is that transportation of high-level solids through non-Federal land is not required, at least for 100 years. A potential problem is that siting considerations for waste management facilities and power reactors are not always compatible, e.g., a river can be viewed not only as a heat sink, but also as a potential driving force for dispersion of stored radionuclides. Another potentially serious problem is that acts of war and sabotage and natural catastrophies can be related to a stored source of nuclides, now concentrated in only a few locations.

G. ADDITIONAL STUDIES

Because of time limitations and the nature of the study, the foregoing information was developed from preliminary data. There is no intent to imply that the waste management schemes are optimum or that water basin storage is the only candidate for potentially meeting the criteria presented earlier for high-level waste. As indicated earlier, in addition to water basin concepts for the management of high-level solid wastes, systems based on air cooling are under consideration in work associated with the conceptual design of a Retrievable Surface Storage Facility (RSSF).⁽³⁾ More specifically, both air-cooled vaults and a system where canisters of solids are stored out-of-doors in individual heavy-walled steel casks are being evaluated. Alternatives to simple compaction of cladding hulls (followed by containerization or coating) include melting or conversion to oxides (glasses) and even storage of uncompacted hulls in underground, shielded vaults.

Additional studies to optimize the WTSF in relation to other facilities of the center are needed. As an alternative, high-level solid waste storage could be essentially integral with the reprocessing plant. Solid geometries other than the typical 12-in. diam x 10-ft long canister may be warranted to facilitate heat removal. Additionally, the center may be sited to permit ultimate disposal in local geologic formations. Finally, additional work is needed to firm the system concepts and the very preliminary cost estimates that are presented.

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