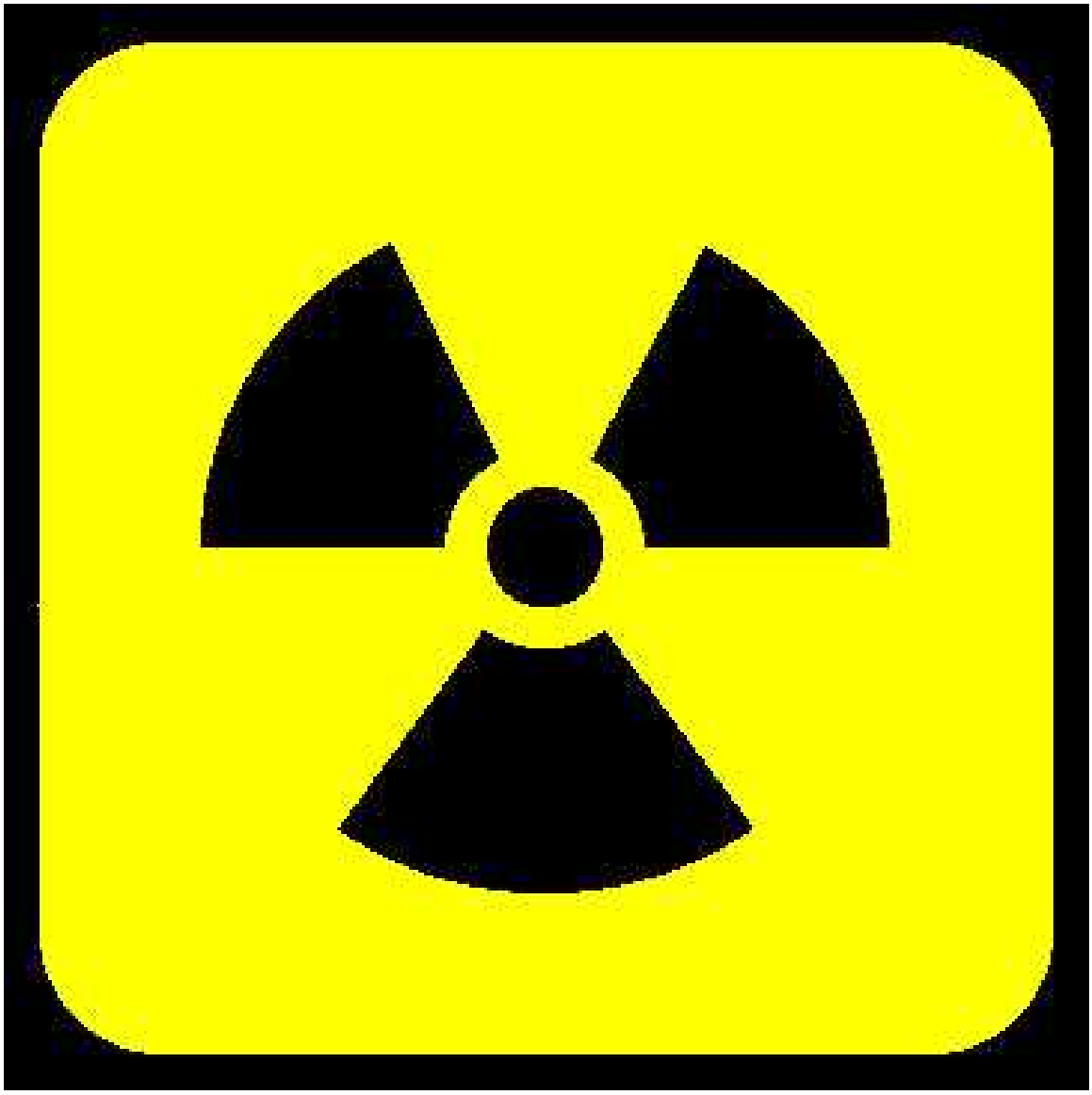
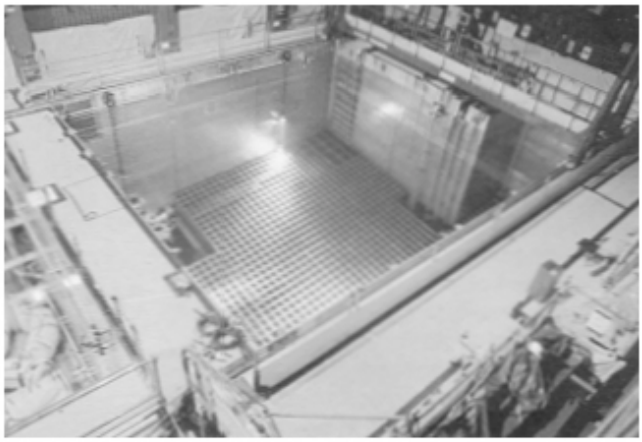
APPENDIX CC

NUCLEAR WASTE STORAGE



Yucca mountain, Nevada



Wet storage

Underground dry storage

APPENDIX CC

NUCLEAR WASTE STORAGE

MICHIEL P.H. BRONGERS[1]

SUMMARY

Nuclear wastes are generated from spent nuclear fuel, dismantled weapons, and products such as radio pharmaceuticals. The most important design item for the safe storage of nuclear waste is the effective shielding of radiation. Corrosion is a form of material degradation that may result when moisture or water comes into contact with the package materials. A corrosion failure may not result in a large release of nuclear waste and radiation; however, a leak would be considered potentially hazardous and would, therefore, not be acceptable.

In order to minimize the probability of nuclear exposure, special packages are designed to meet the protection standards for temporary dry or wet storage, or for permanent underground storage. Currently, nuclear waste is stored at temporary locations, including water basins in nuclear power plants and at dry locations aboveground. Deep underground storage in Yucca Mountain, Nevada has been proposed as a permanent storage solution for high-level nuclear waste from spent nuclear fuel.

The Office of Civilian Radioactive Waste Management of the U.S. Department Of Energy (DOE) estimated that over the next 100 years, a total of $20.6 billion (1998 dollars) will be spent on development and evaluation, licensing, pre-emplacement construction, emplacement operations, monitoring, and closure and decommissioning of the permanent waste disposal site. It is noted that the 100-year estimates are for the time of construction, filling, and closing only. These estimates do not reflect the long-term processes of canister degradation beyond 100 or 10,000 years of storage. The current sector description includes a description of the aforementioned DOE report, but does not include data on the annual cost of corrosion related to the storage of nuclear waste.

The proposed design for the permanent waste disposal is for steel canisters containing the spent fuel to be stored within other steel canisters and buried horizontally in chambers 300 m below the earth's surface. Scientists designed the canisters to last at least 1,000 years and will depend on the mountain itself to provide a natural barrier to survive the minimum 10,000 years required by the government. If it is assumed that only part of the cost of waste package fabrication is spent on corrosion design and features that mitigate or prevent corrosion, then the average direct total cost of corrosion is less than $42.2 million per year ($4,980 million per 118 years).

TABLE OF CONTENTS

SECTOR DESCRIPTION CC1
- Transition from Interim Storage to Permanent Storage CC2
- Cask Design for Permanent Storage CC3
- Effect of Location on Corrosion Nuclear Storage Containers CC3
- The Costs of Nuclear Waste Facility for Permanent Storage CC4

REFERENCES CC6

[1] CC Technologies Laboratories, Inc., Dublin, Ohio.

LIST OF TABLES

Table 1. Total repository costs for radioactive waste in Yucca Mountain by construction phase (1998 dollars) as reported by the U.S. Department of Energy(DOE) in 1998..... CC5

Table 2. Costs of nuclear waste package fabrication for permanent storage (1998 dollars), as reported by the U.S. Department of Energy..... CC5

LIST OF FIGURES

Figure 1. Volume of low-level waste received at U.S. disposal facilities between 1985 and 1994..... CC1

Figure 2. Example of shallow undergrond dry storage of low-level radioactive waste in Richland, Washington..... CC2

Figure 3. Example of wet storage (underwater) of high-level nuclear waste, at the Diablo Canyon plant in California CC2

Figure 4. View of the desert area surrounding Yucca Mountain, Nevada, which is the site of a proposed permanent high-level waste storage..... CC4

SECTOR DESCRIPTION

Nuclear wastes are generated from spent nuclear fuel from electric power plants, dismantled weapons, and products such as radio pharmaceuticals. The most important design item for the safe storage of nuclear waste is the effective shielding of radiation. In order to minimize the probability of nuclear exposure, special packages are designed to meet the protection standards for temporary dry or wet storage, or for permanent underground storage. The most common materials of construction include steel and concrete. The wall thickness of the packages is generally thick in comparison to the contained volume.

Corrosion is a form of material degradation that results when moisture or water comes into contact with the package materials. A corrosion failure may not result in a large release of nuclear waste and radiation; however, a leak would be considered potentially hazardous and would, therefore, not be acceptable. Currently, nuclear waste is stored at temporary locations, including water basins in nuclear power plants and at dry locations aboveground. Deep underground storage in Yucca Mountain, Nevada has been proposed as a permanent storage solution.

When considering the total costs of nuclear storage, it is nearly impossible to distinguish the specific corrosion costs. Some corrosion-related costs that can be determined include the costs for nuclear waste package design and package fabrication, and the costs for remediation of temporary sites that are being used for longer periods than they are designed for. This sector description highlights these topics.

The vast majority of nuclear shipments are very small in size (less than 1 lb per shipment) and total approximately 2.8 million shipments per year (average 7,656 shipments per day).[1] Spent fuel shipments (material only) typically weigh 0.5 to 1.0 ton for truck shipments and up to 10 tons for rail shipments. In addition, the protective lead shipping casks for containment of the spent fuel weigh many more additional tons. Corrosion is not an issue in the transportation of nuclear wastes because of the stringent package requirements and the short duration of the transport; however, corrosion is an important issue in the design of the casks used for permanent storage. Figure 1 shows the volume of low-level waste received at U.S. disposal facilities in the 10-year period between 1985 and 1994.[2]

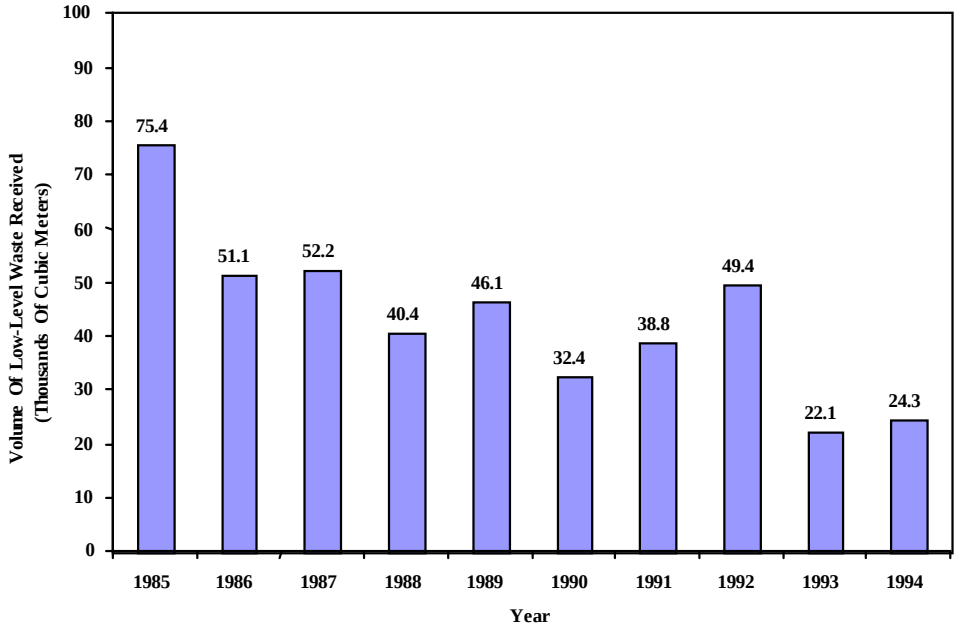


Figure 1. Volume of low-level waste received at U.S. disposal facilities between 1985 and 1994.[2]

Transition from Interim Storage to Permanent Storage

In the year 2000, interim storage facilities for nuclear waste were numerous. Interim nuclear storage is characterized by a number of older tanks that have a radioactive leak history and have a need for remedial action. Low-level waste (LLW) can be liquid or solid waste in containers. It is stored "dry", aboveground or relatively shallow underground (see figure 2). Currently, there are a total of 249.8 thousand m^3 buried LLW and 105.9 thousand m^3 stored aboveground LLW at the U.S. Department of Energy (DOE) facilities.[3] The cost of dry storage is reported to be $1.2 million per cask.

Figure 2. Example of shallow undergrond dry storage of low-level radioactive waste in Richland, Washington.[2]

High-level waste (HLW) from spent nuclear fuel from nuclear power plants is generally stored in water basins at the plants where it was used (see figure 3). Currently, a total of 29,948 tons of spent nuclear fuel is stored at commercial reactors.[3] Dry storage and wet basin storage are designed as temporary solutions. A long-term storage repository is currently under study and development; however, the research and the design of a site for permanent nuclear waste repository is not completed yet.

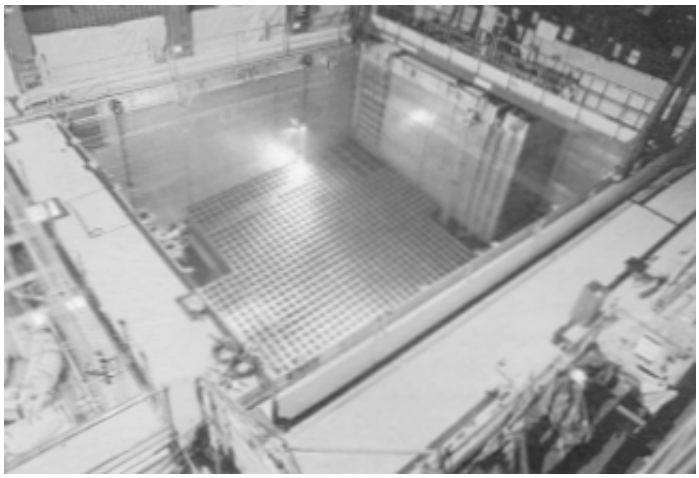


Figure 3. Example of wet storage (underwater) of high-level nuclear waste, at the Diablo Canyon plant in California.[2]

As an example, the K West and the K East basins in Hanford, Washington are two concrete basins that were built in 1951 to temporarily store nuclear fuel produced at DOE's Hanford site. Although the initial plan was to terminate the service within 20 years, the two basins continue to receive spent fuel from reactors. It has been reported that rods in open canisters have corroded in the basin, releasing isotopes into the basin water. Basin cleanup plans, waste removal, and ground water contamination were subsequently announced. The costs for this work will be considerable.

Cask Design for Permanent Storage

In addition to the unavoidable material aging due to exposure to radiation from the radioactive content, material aging due to corrosion is expected to be a concern in the long-term storage of nuclear waste. It has further been suggested that heat generation from radiation can drive the corrosion rate much higher. Several cask designs have been proposed, each with different materials of construction. The most common proposed materials include carbon steel, stainless steel, and concrete constructions.

Today, nearly all nuclear waste generated is solid waste. As a result, this waste is relatively non-corrosive, which minimizes the risk for internal corrosion damage to storage and transportation tanks. There is, however, a significant amount of old liquid nuclear waste in storage, which can corrode the containers internally. In addition, the presence of water in the solid waste could potentially cause corrosion problems. External corrosion may occur as well, because the older liquid waste is stored in buried tanks and the tanks are therefore exposed to ground water. The consequences of leaks are great from the perspective of remedial costs, damage to the environment, and a loss of public trust; therefore, long-term extrapolations must be made to assure the structural integrity of the storage containers in centuries to come.

The potential for corrosion of permanent storage canisters has been and continues to be under investigation. In 1999, a literature review and a summary of plutonium oxide and metal storage package failures was published by Eller et al.[(4)] Metal oxidation in non-airtight packages with gas pressurization were identified as the most common mechanisms of package failure. An example of a possible corrosion problem was further described in a study on hydrogen/oxygen recombination and generation of plutonium storage environments.[(5)] There are also publications available regarding the prediction of service life of steel in concrete used for the storage of low-level nuclear waste, for example, see the work by Andrade and Cruz.[(6)] The current sector description does not aim to be complete in describing all perceived corrosion issues. The above references are mentioned only as examples of past research.

In a September 2000 meeting on key technical issues regarding container life, the U.S. Nuclear Regulatory Commission (NRC) and representatives of the U.S. Department of Energy (DOE) discussed the ongoing research into the effects of corrosion processes on the lifetime of the containers.[(7)]

This meeting is mentioned here to illustrate the wide range of material issues that designers are facing. In nuclear waste containers, both corrosion from the inside and from the outside should be considered. The issues included, but were not limited to: general and localized corrosion of the waste package outer barrier, methods for corrosion rate measurements, documentation on materials such as Alloy 22 and titanium, the influence of silica deposition on the corrosion of metal surfaces, passive film stability including that on welded and aged material, electrochemical potentials, microbiologically influenced corrosion (MIC), stress distribution due to laser peening and induction annealing, stress corrosion cracking (SCC) and its influence on rock fall impact strength, and deadload stressing and the effects of the fabrication sequence and of welding. This long list surely requires extensive research at considerable cost.

Effect of Location on Corrosion Nuclear Storage Containers

The current plans for a permanent nuclear storage repository are to build it at a relatively dry site at a depth of several hundred meters below the surface. Scientists consider that the presence of water will eventually corrode the storage canisters. In the United States, the Yucca Mountain site (see figure 4) is reported to be a good location

due to its low water content. The proposed design for the waste disposal is for steel canisters containing the spent fuel to be stored within other steel canisters and buried horizontally in chambers 300 m below the earth's surface. Scientists designed the canisters to last at least 1,000 years and will depend on the mountain itself to provide a natural barrier to survive the minimum 10,000 years required by the government; however, there is no guarantee that canisters at Yucca Mountain will be free from water flow for 10,000 years.

Figure 4. View of the desert area surrounding Yucca Mountain, Nevada, which is the site of a proposed permanent high-level waste storage.

The Costs of Nuclear Waste Facility for Permanent Storage

In 1998, the Office of Civilian Radioactive Waste Management of the U.S. Department Of Energy (DOE) published an analysis of the total life cycle cost for the permanent disposal of radioactive waste in Yucca Mountain, Nevada.[8] This site is proposed for high-level waste repository. The analysis was based on the most current plans, strategies, and policies. Since the estimates span over 100 years, the concept should be viewed as representative of the waste management system that will ultimately be developed. It is noted that the 100-year estimates are for the time of construction, filling, and closing only. These estimates do not reflect the long-term processes of canister degradation beyond 100 or 10,000 years of storage. Table 1 shows the total estimated repository costs by construction phase and by the average cost per year. Table 2 is similar to table 1; however, table 2 only reports the fabrication costs of the waste packages. If it is assumed that only part of the cost of waste package fabrication is spent on corrosion design and features that mitigate or prevent corrosion, then the average direct total cost of corrosion is less than $42.2 million per year ($4,980 million per 118 years). This calculation excludes any costs of potential environmental clean-up if the permanent storage would leak radiation. It is also recognized that the majority of the costs are incurred in the period prior to the year 2041; therefore, the actual direct cost per year is higher for nuclear waste package fabrication for permanent storage.

Table 1. Total repository costs for radioactive waste in Yucca Mountain by construction phase (1998 dollars) as reported by the U.S. Department of Energy (DOE) in 1998.[8]

CONSTRUCTION PHASE		NUMBER OF YEARS	HISTORICAL (1983-2002) ($ x million)	FUTURE COST WITHOUT CONTINGENCY (1999-2116) ($ x million)	CONTINGENCY COST ($ x million)	TOTAL (1999-2116) ($ x million)	AVERAGE COST PER YEAR ($ x million)
Development and Evaluation	1983-2002	20	4,910	990	-	990	49.5
Licensing	2002-2005	4	-	670	90	760	190.0
Pre-Emplacement Construction	2005-2010	6	-	2,460	490	2,950	491.7
Emplacement Operations	2010-2041	32	-	13,580	2,310	15,890	496.6
Monitoring	2041-2110	70	-	2,590	630	3,220	46.0
Closure and Decommissioning	2110-2116	7	-	330	70	400	57.1
		TOTAL	**$4,910**	**$20,620**	**$3,590**	**$24,210**	

Table 2. Costs of nuclear waste package fabrication for permanent storage (1998 dollars), as reported by the U.S. Department of Energy.[8]

CONSTRUCTION PHASE		NUMBER OF YEARS	FUTURE COST WITHOUT CONTINGENCY (1999-2116) ($ x million)	CONTINGENCY COST ($ x million)	TOTAL (1999-2116) ($ x million)	AVERAGE COST PER YEAR ($ x million)
Development and Evaluation	1983-2002	20	-	-	-	-
Licensing	2002-2005	4	40	-	40	10.0
Pre-Emplacement Construction	2005-2010	6	50	-	50	8.3
Emplacement Operations	2010-2041	32	4,870	-	4,870	152.2
Monitoring	2041-2110	70	20	-	20	0.3
Closure and Decommissioning	2110-2116	7	-	-	-	-
		TOTAL	**$4,980**	**-**	**$4,980**	

REFERENCES

1 "Hazardous Materials Shipments", The Office of Hazardous Materials Safety Research and Special Programs Administration, U.S. Department of Transportation (DOT), Washington, DC, October 1998.

2 "Radioactive Waste: Production, Storage, Disposal", NRC Report Number: NUREG/BR-0216, Office of Public Affairs, U.S. Nuclear Regulatory Commission, Washington DC 20555-0001, July 1996.

3 M. Sei, G. Borchert, K. Chance, "An Examination Of U.S. Nuclear Waste Status", Chem. 480, April 6, 1998, http://www.utm.edu/departments/artsci/chemistry/NUWaste.htm.

4 P. G. Eller, R. W. Szempruch, and J. W. McClard, "Summary Of Plutonium Oxide And Metal Storage Package Failures", Los Alamos National Laboratory, LA-UR-99-2896, 1999.

5 J. A. Lloyd, P. G. Eller, L Hyder, "Literature Search Hydrogen/Oxygen Recombination and Generation of Plutonium Storage Environments", Los Alamos National Laboratory, LA-UR-98-4557.

6 C. Andrade, and M. Cruz Alonso, "Values Of Corrosion Rate Of Steel In Concrete To Predict Service Life Of Concrete Structures", Application Of Accelerated Corrosion Tests To Service Life Prediction Of Materials, ASTM STP 1194, G. Cragnolino and N. Sridhar, Eds., American Society for Testing and Materials, Philadelphia, 1994.

7. "Summary of Key Technical Issues (KTI) Meetings and Associated Files" – "Summary of the Resolution of the Key Technical Issue on Container Life and Source Term", Nuclear Regulatory Commission, September 12 – 13, 2000, http://www.nrc.gov/NMSS/DWM/092100agreement.htm, May 2001.

8 "Analysis Of The Total System Life Cycle Cost Of The Civilian Radioactive Waste Management Program", DOE/RW-510, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, DC-20586, December 1998.