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Abstract— *Cementitious materials have physical and chemical properties that are well suited for the requirements of radioactive waste management. Namely, the materials have low permeability and durability that is consistent with the time frame required for short-lived radionuclides to decay. Furthermore, cementitious materials can provide a long-term chemical environment that substantially reduces the mobility of some long-lived radionuclides of concern for decommissioning (e.g., C-14, Ni-63, Ni-59). Because of these properties, cementitious materials are common in low-level radioactive waste disposal facilities throughout the world[1] and are an attractive option for entombment of nuclear facilities[2]. This paper describes design considerations for cementitious barriers in the context of performance over time frames of a few hundreds of years (directed towards short-lived radionuclides) and time frames of thousands of years (directed towards longer-lived radionuclides). The emphasis is on providing an overview of concepts for entombment that take advantage of the properties of cementitious materials and experience from the design of low-level radioactive waste disposal facilities. A few examples of the previous use of cementitious materials for entombment of decommissioned nuclear facilities and proposals for the use in future decommissioning of nuclear reactors in a few countries are also included to provide global perspective.*

I. INTRODUCTION

Cementitious materials have properties that are well suited for the requirements of radioactive waste management. Namely, the materials have low permeability and durability that is consistent with the time frame required for short-lived radionuclides to decay. Furthermore, cementitious materials can provide a long-term chemical environment that substantially reduces the mobility of some long-lived radionuclides of concern for decommissioning (e.g., C-14, Ni-63, Ni-59). Because of these properties, cementitious materials are common in low-level waste disposal facilities throughout the world[1] and are an attractive option for entombment of nuclear facilities[2]. This paper includes a discussion of design considerations for the use of cementitious materials and examples of the existing and potential use of cementitious materials as barriers for entombment of nuclear reactors.

II. DESIGN CONSIDERATIONS

When considering the use of cementitious materials as part of an entombment concept, physical and chemical aspects of the materials should be designed in the context of both short- and long-term performance. As a physical barrier, the cementitious materials provide low permeability, structural stability, and intrusion protection for a few hundred years. A few hundred years of relatively complete isolation provides enough time for short-lived radionuclides to decay to negligible levels.

Well-designed cementitious barriers can limit water flow for a short time prior to the formation of cracks. However, behavior after cracks have formed is also an important consideration[3]. It has been shown that including a layer of low permeability material, such as clay, over the top of a concrete barrier effectively controls the flow rate into cracks that will form[4]. Adding a high permeability layer, such as gravel, above the clay further enhances the performance by providing a flow pathway around the barrier. Figure 1 shows an example of the use of a combination of concrete, clay and gravel to form a relatively impermeable barrier[4] after the concrete cracks.

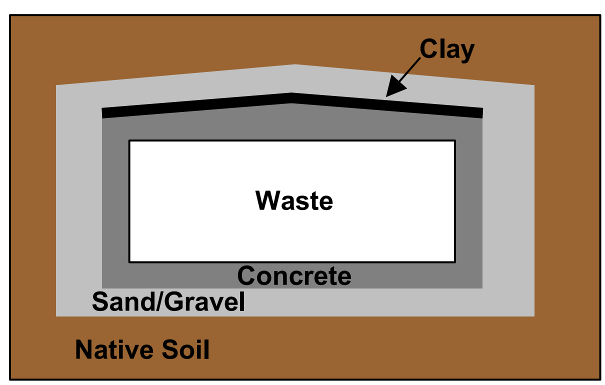

Figure 1. Example configuration to limit leakage through cracks that form in concrete[4].

Over longer time frames, as cementitious materials degrade and cease to function as a barrier to water flow, chemical characteristics can be exploited to limit the release of longer-lived radionuclides which may be present in low concentrations. The chemical properties will persist well beyond the time of physical failure. Due to the chemical properties, cementitious materials limit the migration of carbon and nickel very well, which is beneficial because C-14, Ni-63, and Ni-59 are important radionuclides in the context of decommissioning. Furthermore, specialized mixes can be developed to create a chemical environment that is targeted to limit the release of specific radionuclides. For example, addition of blast furnace slag to a concrete mix can help produce reducing conditions, which substantially limits the release of an otherwise mobile radionuclide, Technetium-99[5].

The multiple barrier concept is an effective approach for the isolation of radioactive wastes and is useful to help convince the public of the measures that are taken to isolate radioactive wastes. This concept has been applied at a number of low-level radioactive waste disposal facilities. For example, at the El Cabril disposal facility in Spain[6], concrete vaults are combined with concrete containers and other materials to form multiple barriers to the release of radionuclides (see Figure 2). Additional barriers can include engineered covers designed to limit infiltration, environmental monitoring around the facility, as well as other institutional "barriers", such as public records, deed restrictions, and other legal means of limiting access to the area. In many cases, a combination of physical, chemical, and institutional barriers are used to implement the multiple barriers concept.

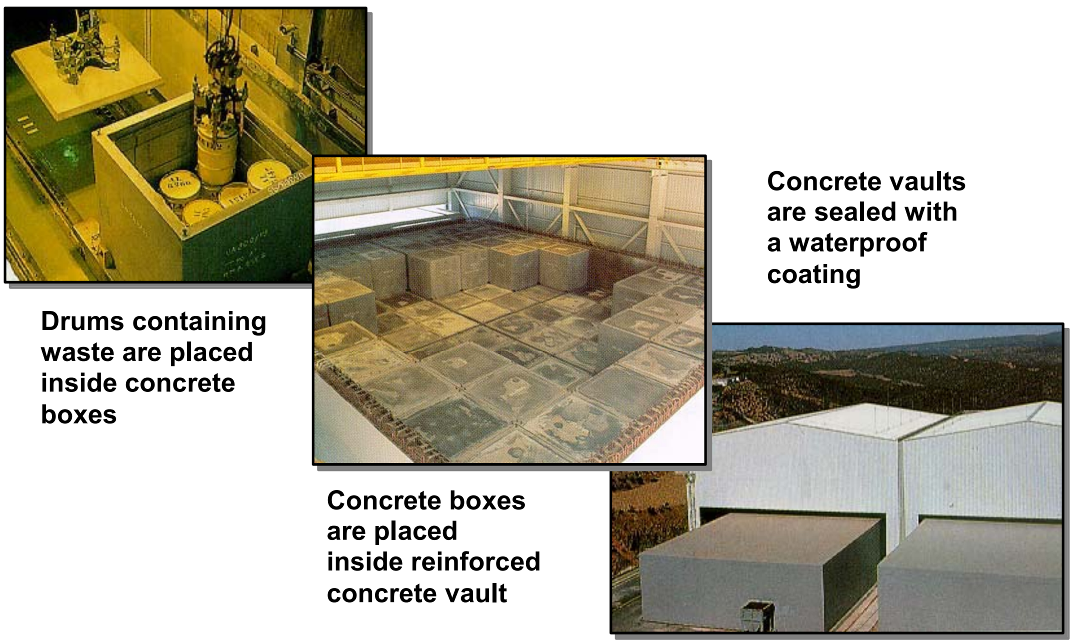

Figure 2. Multiple concrete barrier concept employed at the El Cabril radioactive waste disposal facility in Spain.

III. INTERNATIONAL EXPERIENCE WITH ENTOMBMENT

There are a number of international organizations that have activities addressing decommissioning of nuclear facilities, including the International Atomic Energy Agency (IAEA) (www.iaea.org), Nuclear Energy Agency (www.nea.fr), and the World Nuclear Association (www.world-nuclear.org). These organizations are an excellent source of information about global activities in the nuclear industry, including decommissioning. The information in this section is obtained from a TECDOC produced by the IAEA[2]. Some examples of on-site disposal of reactors and plans for on-site disposal of reactors are discussed in the following paragraphs.

To date, the use of entombment and on-site disposal has been limited to smaller demonstration or research reactors with the exception of the Chernobyl reactor, which is only an interim measure. Examples of entombment and on-site disposal of reactors in the United States and Switzerland are briefly described here. Proposed approaches being considered in Canada, Germany, and the United Kingdom (UK) are also briefly described to illustrate proposed concepts including the use of entombment for decommissioning of nuclear reactors.

II.A. United States Experience

Several smaller reactors have been disposed on-site in the United States and Puerto Rico. These include demonstration nuclear power plants operated in the 1960s and experimental/test reactors operated from the 1950s to 1970. Demonstration plants that were disposed on-site were located in Nebraska (Hallam nuclear power facility), Ohio (Piqua nuclear power facility), and Puerto Rico (Boiling Nuclear Superheater Power Station (BONUS)). Some test reactors have also been disposed on-site. For example, an Air Force test reactor that operated from 1967 to 1970 was disposed on-site in Ohio (Air Force Nuclear Engineering Center Reactor (AFNECR)) and five experimental reactors operated in the 1950s and 1960s were disposed on-site at the Idaho National Engineering and Environmental Laboratory (INEEL) (Boiling Water Reactor Experiment (BORAX-I, II, III, IV, and V)).

In general, non-structural radioactive components were removed prior to entombment. In some cases, some of the components were placed in the reactor compartment prior to entombment (e.g., the BONUS reactor). Somewhat different approaches to entombment were used for the reactors. The reactor compartments were typically filled with sand or concrete and steel plates and thick concrete barriers were placed on top of the reactor compartments after they were filled. In the case of the Hallam reactor, the steel plates and entire entombed reactor compartment were covered with a plastic film and tar to limit water contact with the facility.

II.B. Swiss Experience

The 10 MW experimental gas cooled reactor at Lucens experienced an accident in 1969 that precluded any further operations. The reactor complex was housed in underground caverns. After internals and support equipment were dismantled and decontaminated, entombment of the complex was completed using concrete as a fill material. Two caverns containing the reactor facility and the fuel ponds were filled with concrete and the lower part of the turbine hall and auxiliary rooms were also filled with concrete. An extensive drainage system was installed to provide the capability to monitor groundwater.

IV. PROPOSALS AND PLANS FOR THE USE OF ENTOMBMENT

A number of countries are considering the use of entombment and on-site disposal for nuclear reactors that have reached the end of their operating life. In most cases, entombment and on-site disposal is one of several options being considered, thus it is not the preferred option in some cases and has not yet been formally approved. When the entombment option is considered, cementitious materials are typically an integral part of these plans. In order to provide perspective of different options being considered, proposed on-site disposal approaches in Canada, Germany, and the UK are described in the following sections. Each of the concepts involves a multiple barrier approach to isolate the wastes from the environment, but the approach is implemented in different ways. The information below is summarized from an IAEA TECDOC[2].

III.A. Canadian Concept

"One-piece removal and on-site burial" is one of several options being considered for decommissioning of CANDU reactors. In this option, a mined shaft more than 50 m deep is created beneath the reactor building and the reactor components are lowered into the shaft. The final configuration includes grouting around the reactor components and other auxiliary wastes that are placed in the shaft as shown in Figure 3. A second similar concept involves constructing the shaft outside of the reactor building, which simplifies shaft construction and dismantling of the reactor, but requires robust transportation systems to move the components. A third concept being considered for the Bruce Nuclear Generating Site, as well as other multiple reactor sites, is to develop a centralized vault for all of the reactors and components. This option allows more flexibility in choosing an appropriate disposal location, but also requires a robust transportation system.

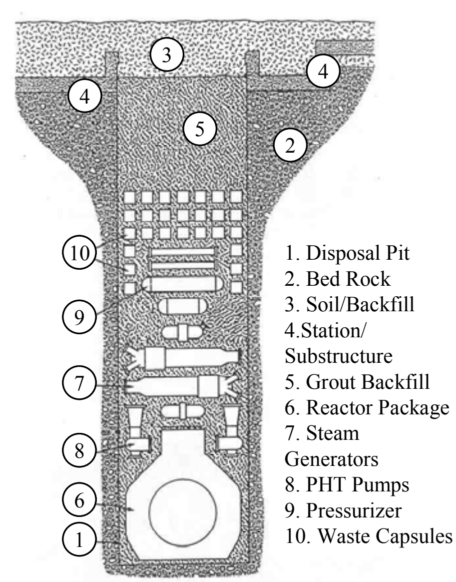

Figure 3. Entombment concept being considered in Canada.

III.B. German Concept

One concept for decommissioning being considered in Germany is on-site sinking of the reactor building in total or only sinking the reactor itself. This proposal was described as being in the technical feasibility stage. The concept includes multiple engineered barriers around the decommissioned facility. The proposal is that a caisson approach be used to sink the reactor building to a point where the base of the building is roughly 50 m below the surface. This technique involves the use of a concrete seal jacket around the structure to be lowered, which will also serve as a barrier after completion of the project. When the caisson is lowered to the proper depth, the reactor building would be filled with a specially designed grout or concrete mixture. The building would then be covered by a steel plate and bitumen sealing material, which would in turn be covered by another layer of concrete to provide multiple barriers.

III.C. United Kingdom Concept

On-site disposal as a decommissioning strategy in the UK is also in a conceptual stage. The UK concept differs from the other two concepts presented above in the fact that it is a mounded above ground entombment approach. This approach was selected because most of the UK reactors are located in coastal areas. The entombment approach included filling the reactor building with grout to provide additional barriers to radionuclide release and to improve long-term stability (see Figure 4). As shown in the figure, a concrete cap is included above the reactor building to add an additional barrier to water flow. A mound is then constructed around and over the structure using sand dredged from the sea. A vegetative layer is added to the top of the mound to encourage evapotranspiration and reduce infiltration through the mound.

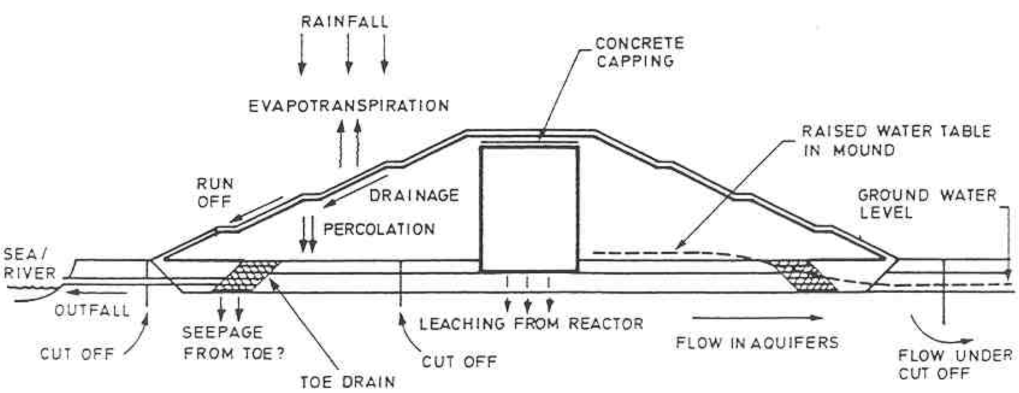

Figure 4. Entombment concept being considered in the United Kingdom.

V. CONCLUSIONS

Cementitious materials have beneficial properties in the context of providing barriers for use in an entombment concept for decommissioning of nuclear reactors. In the short-term, cementitious materials provide an effective physical barrier to water flow and intrusion. In the longer-term, after losing effectiveness as a physical barrier, cementitious materials provide an effective chemical barrier to the migration of some long-lived radionuclides that tend to be mobile in soils and are a concern for decommissioning (e.g., C-14, Ni-59, Ni-63). Furthermore, the chemical properties of a cementitious material can be engineered to react with selected radionuclides through the design of a customized mix.

These physical and chemical properties should both be considered when designing a multiple barrier system to use as part of an entombment concept. Because of these favorable characteristics, cementitious materials have played an important role in existing cases where entombment has been used for reactor decommissioning and also play an important role in entombment approaches that have been considered for use in many different countries.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

1. International Atomic Energy Agency, "Planning and Operation of Low-Level Waste Disposal Facilities," *Proceedings of a Symposium, Vienna, 17-21 June 1996*, STI/PUB/1002, International Atomic Energy Agency, Vienna (1997).

2. International Atomic Energy Agency, "On-site disposal as a decommissioning strategy," IAEA-TECDOC-1124, International Atomic Energy Agency, Vienna (1999).

3. J.C. Walton and R.R. Seitz, "Fluid Flow Through Fractures in Below Ground Concrete Vaults,", Waste Management, **12**, pp. 179-187 (1992).

4. R.R. Seitz and J.C. Walton, "Modeling Approaches for Concrete Barriers Used in Low-Level Waste Disposal," NUREG/CR-6070, Prepared by the Idaho National Engineering Laboratory for the U.S. Nuclear Regulatory Commission, Washington, DC (1993).

5. J.C. Walton, "Performance of Intact and Partially Degraded Concrete Barriers in Limiting Mass Transport," NUREG/CR-5445, Prepared by the Idaho National Engineering Laboratory for the U.S. Nuclear Regulatory Commission, Washington, DC (1992).

6. P. Zuloaga, A. Guerra-Librero, and A. Morales, "L/ILW Disposal Experience in Spain After the Startup of El Cabril Disposal Facility," *Proceedings of a Symposium on Planning and Operation of Low-Level Waste Disposal Facilities, Vienna, 17-21 June 1996*, STI/PUB/1002, International Atomic Energy Agency, Vienna (1997).