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Is Entombment an Acceptable Option for Decommissioning? An International Perspective – 13488

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ABSTRACT

Selection of a decommissioning strategy is one of the key steps in the preparation for decommissioning of nuclear facilities and other facilities using radioactive material. Approaches being implemented or considered by Member States include immediate dismantling, deferred dismantling and entombment. Other options or slight modifications of these strategies are also possible.

Entombment has been identified in the current International Atomic Energy Agency (IAEA) Safety Standards as one of the three basic decommissioning strategies and has been defined as a decommissioning strategy by which radioactive contaminants are encased in a structurally long lived material until radioactivity decays to a level permitting the unrestricted release of the facility, or release with restrictions imposed by the regulatory body.

Although all three strategies have been considered, in principle, applicable to all facilities, their application to some facilities may not be appropriate owing to political concerns, safety or environmental requirements, technical considerations, local conditions or financial considerations.

The IAEA is currently revising the decommissioning Safety Standards and one of the issues widely discussed has been the applicability of entombment in the context of decommissioning and its general objective to enable removal of regulatory control from the decommissioned facility. The IAEA recently established a consultancy to collect and discuss experience and lessons learned from entombment projects, to identify regulatory requirements and expectations for applying entombment as a decommissioning option strategy, in compliance with the internationally agreed standards.

INTRODUCTION: IAEA SAFETY FRAMEWORK

To understand why the question of the applicability and or appropriateness of entombment is being asked, it is first important to understand the context within which the question is being raised.

The IAEA was set up as the world´s "Atoms for Peace" organization in 1957 within the United Nations. The Agency works with its Member States and multiple partners worldwide to promote safe, secure and peaceful nuclear technologies. The IAEA Secretariat is headquartered at the Vienna International Centre in Vienna, Austria. Operational liaison and regional offices are located in Geneva, Switzerland; New York, USA; Toronto, Canada; and Tokyo, Japan. The IAEA runs or supports research centers and scientific laboratories in Vienna and Seibersdorf, Austria; Monaco; and Trieste, Italy. The IAEA's mission is guided by the interests and needs of Member States, strategic plans and the vision embodied in the IAEA Statute. Three main pillars - or areas of work - underpin the IAEA's mission: Safety and Security; Science and Technology; and Safeguards and Verification.

The IAEA safety standards have a status derived from the IAEA's Statute [1], which authorizes the IAEA "To establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property ... and to provide for the application of these standards" [Article III, Functions, Statute of the IAEA]. Although not mandatory, the IAEA safety standards provide a framework of fundamental principles, requirements and guidance to ensure safety for use by its member states. They are developed through an open and transparent process for gathering, integrating and sharing the knowledge and experience gained from the actual use of technologies and from the application of the safety standards, including emerging trends and issues of regulatory importance.

These safety standards are organized in a hierarchy as illustrated in Table I [2] and described below:

- Safety Fundamentals: As the primary publication in the Safety Standards Series, Fundamental Safety Principles establishes the fundamental safety objective and principles of protection and safety.

- Safety Requirements: An integrated and consistent set of stable Safety Requirements publications establish the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objectives and principles of the Safety Fundamentals. If they are not met, measures must be taken to reach or restore the required level of safety. Their format and style facilitate their use by Member States for the establishment, in a harmonized manner, of their national regulatory framework.

Safety Guides: Safety Guides provide recommendations and guidance on how to comply with the requirements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. Table I illustrates the full hierarchy and lists the titles of the general and specific requirements.

Table I: Hierarchy of IAEA Safety Standards	
Level 1: Safety Fundamentals Fundamental Safety Principles	
Level 2: General Safety Requirements	Level 3: Safety Requirements
Part 1. Government, Legal, and Regulatory Framework for Safety	1. Site Evaluation for Nuclear Installations
Part 2. Leadership and Management for Safety	2. Safety of Nuclear Power Plants 2.1 Design and Construction 2.2 Commissioning and Operation
Part 3. Radiation Protection and the Safety of Radiation Sources	
Part 4. Safety Assessment for Facilities and Activities	3. Safety of Research Reactors
Part 5. Predisposal Management of Radioactive Waste	4. Safety of Nuclear Fuel Cycle Facilities
Part 6. Decommissioning and Termination of Activities	5. Safety of Radioactive Waste Disposal Facilities
Part 7. Emergency Preparedness and Response	6. Safe Transport of Radioactive Material
Level 3: Collection of Safety Guides	

IAEA, DOE, AND NRC DECOMMISSIONING ALTERNATIVES

According to the IAEA decommissioning safety standards [3] (herein after referred to as WS-R-5) 'decommissioning' refers to the administrative and technical actions taken to allow the removal of some or all of the regulatory requirements from a facility (except for a repository, for which the term 'closed' and not 'decommissioned' is used). A facility, as used in WS-R-5, means a building and its associated land and equipment in which radioactive material is produced, processed, used, handled or stored on such a scale that consideration of safety is required. The requirement goes on to acknowledge that a "a facility is considered decommissioned when an approved end state has been reached" and also recognizes that the "end state" cannot be globally defined but must rather be "tailored to address the safety and environmental needs in each situation."

Article 1.5 of the WS-R-5 also describes three strategies for decommissioning based on approaches being implemented or considered by Member States. These are:

Immediate dismantling: the strategy by which the equipment, structures and parts of a facility containing radioactive contaminants are removed or decontaminated to a level that permits the facility to be released for unrestricted use, or with restrictions imposed by the regulatory body. In this case decommissioning implementation activities begin shortly after the permanent cessation of operations. This strategy implies prompt completion of the decommissioning project and involves the removal of all radioactive material from the facility to another new or existing licensed facility and its processing for either long term storage or disposal.

Deferred dismantling (sometimes called safe storage, safe store or safe enclosure): the strategy in which parts of a facility containing radioactive contaminants are either processed or placed in such a condition that they can be safely stored and maintained until they can subsequently be

decontaminated and/or dismantled to levels that permit the facility to be released for unrestricted use or with restrictions imposed by the regulatory body.

Entombment: the strategy by which radioactive contaminants are encased in a structurally long lived material until radioactivity decays to a level permitting the unrestricted release of the facility, or release with restrictions imposed by the regulatory body."

Article 1.5 of the WS-R-5 goes on to state that "these strategies are, in principle, applicable to all facilities; however, their application to some facilities may not be appropriate owing to political concerns, safety or environmental requirements, technical considerations, local conditions or financial considerations." And further, that "the preferred decommissioning strategy shall be immediate dismantling."

The IAEA approach of allowing local conditions, needs, and expectations for future uses define the end state is consistent with requirements applied in the decommissioning of former US defense nuclear facilities. For these facilities, decommissioning takes place after deactivation and includes surveillance and maintenance, decontamination, and/or dismantlement. These actions are taken at the end of the life of a facility to retire it from service with adequate regard for the health and safety of workers and the public and protection of the environment. The ultimate goal of decommissioning is unrestricted release or restricted use of the site [4]. Although DOE does not specifically recommend a decommissioning strategy for its facilities, it has issued a strategy document [5] that endorses the application of entombment and describes a series of steps that could be applied to select candidates for entombment.

According to a 1995 policy [6], decommissioning of DOE defense nuclear facilities is conducted by the US DOE Office of Environmental Management and driven by the requirements of CERCLA [7], which establishes a risk-based end state in consideration of future use, such as residential, industrial, or recreational. This policy is the result of a joint effort by EPA and DOE to develop an approach to decommissioning that ensures protection of worker and public health and the environment that is consistent with CERCLA, that provides for stakeholder involvement, and that achieves risk reduction without unnecessary delay.

For its licensed nuclear power plants, Title 10 of the Code of Federal Regulations, Section 50.2 defines decommissioning as the safe removal of a facility from service and reduction of residual radioactivity to a level that permits termination of the NRC license. Three alternatives are considered: DECON, SAFSTOR, or ENTOMB. Table II provides the definition of each alternative.

Table II: NRC Decommissioning Alternatives [8]
DECON: This alternative represents immediate dismantlement. Under this alternative, equipment, structures, and portions of the facility containing radioactive contaminants are removed or decontaminated to a level that permits release of the property and termination of the license.
SAFSTOR: This alternative is also referred to as "delayed DECON." Under this alternative, a nuclear facility is maintained and monitored in a condition that allows the radioactivity to decay; afterwards it is dismantled.
ENTOMB: Under this alternative, radioactive contaminants are encased in a structurally sound material such as concrete and maintained and monitored until the radioactivity decays to a level allowing release of the property. The NRC has deferred rulemaking that would clarify the use of the ENTOMB option for reactors pending completion of research studies on entombment viability issues.

While these three organizations all recognize entombment, they also recognize that its application is very situational, and so within the IAEA framework, it may not be appropriate to maintain it as a prescribed strategy. To that end, the IAEA is working on a revision to WS-R-5, wherein entombment is no longer considered on the same "level" as immediate and deferred dismantlement, that is, not a "strategy" and not a solution for normal planned shutdown, but should only be considered a solution under exceptional circumstances (such as severe accidents) for existing facilities. This position is supported by an IAEA publication issued in 1999 concerning on site disposal as a decommissioning strategy [9].

APPLICATIONS OF ENTOMBMENT EXPERIENCES TO DATE

With very few decommissioning projects to date having used this strategy, limited practical experience is available and is concentrated in several Member States only. Table III summarizes experiences to date.

Table III: Entombment Experiences to Date			
Country	**Experience - Type of facility**	**Context**	**Framework**
USA	US DOE		
	• Savannah River Site o Production Reactor o Test Reactor o Underground Tanks	CERCLA Remedial Action for the Reactors; 3116 Waste Incidental to Reprocessing for the Tanks	CERCLA
	• Legacy Test Demonstration Reactors: o Bonus Reactor o Piqua Reactor o Hallam Reactor	Entombment	Atomic Energy Act (pre-dates CERCLA and other environmental requirements)
	• Idaho National Laboratory o Waste Calcination Facility o CPP-601/640 Fuel Reprocessing Complex	• Entombment, • Entombment w/demolition of above-grade structure	• Atomic Energy Act (facility shutdown in 1981; entombment decision in 1998) • RCRA/CERCLA
	• Argonne National Laboratory o Waste Vaults	Entombment	Atomic Energy Act
Republic of Georgia	Pool-type research reactor	Reactor core barrel entombed	None, National Laws and regulatory requirements in development
Switzerland	Research reactor, post-accident	Disposal of 235 tons of scrap metal having 3.7 GBq of activity	Not known if regulatory requirements were available
Italy	RB-1 Research Reactor (Montecuccolino)	Decommissioning debris added to reactor vessel and entombed to floor level to allow the space to be used for other purposes	Unknown

Due to the limited application of the entombment strategy, detailed guidance on the technical and safety aspects of entombment has never been developed within the IAEA framework.

In the recent years several Member States have renewed their interest in application of the entombment strategy in decommissioning. Further, the recent US experience with entombment of former production reactors, and the challenges facing Japan in the recovery from the accident at the Fukushima-Daiichi, has brought this option to the forefront. Discussions at several international meetings showed that entombment cannot be ignored as an option and that an effort to consolidate international experience with entombment is needed. Regulatory expectations on evaluation and demonstration of long term safety of entombed facilities needs to be identified and explained in order to provide operators with a basis for consideration of this option in the strategy selection process.

In August 2012, the IAEA hosted its first consultancy meeting on this topic. Five representatives from four member states (Belgium, France, Russia, and the United States) came together to share experiences and perspectives on the applicability, challenges, and considerations associated with the use of entombment.

THE FUTURE OF ENTOMBMENT – FITTING A SQUARE PEG IN A ROUND HOLE?

After a discussion of experiences with entombment, the members of the consultancy team began a discussion of how the entombment option fits, or doesn't fit, within the IAEA framework of safety standards. The team considered entombment from three perspectives: (1) decommissioning, (2) radioactive waste management, and (3) remediation. These three perspectives cross the following IAEA safety standards:

- Decommissioning of Facilities Using Radioactive Waste Safety [3]
- Predisposal Management of Radioactive Waste [10]
- Disposal of Radioactive Waste [11]
- Remediation of Areas Contaminated by Past Activities and Accidents [12]

While each of these touch on an element that is relevant to entombment, none of them were written primarily for entombment. This has led the team to highlight and focus on the key questions that must be answered in order to resolve and appropriately align the entombment option within the existing framework.

Decommissioning Requirements as a Framework for Entombment

The fundamental objective of the requirements of the IAEA decommissioning framework [3] is to ensure that the end-state of the facilities and/or Sites at the completion of the decommissioning project can allow the release of the facilities and/or Sites from regulatory controls (with or without restrictions depending on the radiological objectives met and the related radiological impact). This approach implies formally the termination of the license or the authorization given. In principle, it means that the facility is no longer considered a nuclear facility and the surrounding areas and site can be reused for industrial or public purposes. Depending upon the source term remaining in an

entombed facility, it may be hundreds, or even thousands of years before a facility could be completely released from regulatory and institutional controls. This is a fundamental challenge to the use of the entombment approach within the decommissioning standard, and a key consideration in establishing appropriate regulatory expectations. If the goal is to release the facility from regulatory controls, what then is an acceptable "waiting" time? Once entombed, is it still a "facility"?

Waste Management Requirements as a Framework for Entombment

The waste management section of the framework may be applicable as some consider that once a facility is entombed, it becomes a de-facto near-surface disposal facility. With that perspective, the IAEA waste management standards are difficult to apply, as they stem from the assumption that a disposal facility begins with specific site characterization and site selection requirements, and specific design, construction, operation, and closure requirements. Fitting entombment into the waste management standards would mean bypassing the site selection through operation requirements and then attempting to meet only the closure requirements. It would not be feasible or reasonable to "back-fit" the other elements of the requirement. These standards also pose the question of whether or not the facility is in and of its self "waste". One must consider whether the contamination remaining in the facility, for example activated metal, is a waste if it is not intended to be removed from the facility during the decommissioning process. Application of [10] would infer preparation of the waste to meet the acceptance criteria of a disposal facility. In entombment, there is minimal, if any pretreatment or conditioning of the waste/material left in place.

Within the waste management framework the consultancy team is also considering whether entombment creates a "storage" or a "disposal" facility. According to [11], storage and disposal are described as follows:

The term 'disposal' refers to the emplacement of radioactive waste into a facility or a location with no intention of retrieving the waste. Disposal options are designed to contain the waste by means of passive engineered and natural features and to isolate it from the accessible biosphere to the extent necessitated by the associated hazard. The term disposal implies that retrieval is not intended; it does not mean that retrieval is not possible. [11 section 1.8] The challenge to the disposal context is whether the barriers typically used to entomb a facility (concrete, clay), and its near surface location can withstand long enough to ensure isolation of the inventory through decay.

By contrast, the term 'storage' refers to the retention of radioactive waste in a facility or a location with the intention of retrieving the waste. Both options, disposal and storage, are designed to contain waste and to isolate it from the accessible biosphere to the extent necessary. The important difference is that storage is a temporary measure following which some future action is planned. This may include further conditioning or packaging of the waste and, ultimately, its disposal. Consequently, the challenge to the storage context is that entombment is considered a final action, and no retrieval or similar actions are envisioned. [11, section 1.9)

If entombment is considered the final action, then disposal as defined by [11] may be appropriate. However, the focus may then need to shift to the level of dismantling required to ensure that the remaining inventory is compatible with the concept of Near Surface Disposal Facility. If, alternatively, the entombment is an interim action, then storage may be applicable.

In the recent application of entombment in the US these questions were carefully evaluated. Within the DOE, decommissioning is conducted as a remediation under the CERCLA. Radioactive waste disposal is governed by DOE Order 435.1, Radioactive Waste Management (November 1999). Lee et.al. [13] assessed the extent to which the performance assessment (PA) criteria of DOE Order 435.1 should be applied when DOE facilities are undergoing entombment. They concluded specific conditions would dictate the applicability of DOE Order 435.1 and describe those conditions as follows:

- Requires a crosswalk[1] to ensure compliance with substantive requirements under DOE Order 435.1 if the decommissioning action under CERCLA:
  - imports low level material and waste from outside the area of contamination (AOC) into an AOC.
  - utilizes an existing facility or structure to receive low-level waste (LLW) and material from CERCLA actions within and outside the AOC on a continuing basis, which would be similar to creation of a new disposal facility.
- Does not require a crosswalk to ensure compliance with substantive requirements under DOE Order 435.1 if the action under CERCLA:
  - leaves existing waste, material and equipment in the facility or structure to be dispositioned in-situ.
  - relocates or consolidates materials and waste from within the AOC to a facility within the AOC that will be in-situ decommissioned.
  - imports CERCLA waste from one AOC, on a case-by-case basis, into another CERCLA AOC undergoing remediation. (DOE guidance establishes that this does not need a crosswalk because you are not developing a new radioactive waste disposal facility.)

The decommissioning of P-Reactor, R-Reactor, and the Heavy Water Components Test Reactor was accomplished in a manner that did not require a crosswalk. However, this approach did introduce the concept and potential of using the remediation requirements as the framework for entombment.

Remediation Requirements as a Framework for Entombment

IAEA Safety Requirements WS-R-3, Remediation of Areas Contaminated by Past Activities and Accidents [11] specifies the safety requirements "relating to the remediation of areas affected by radioactive residues as a result of uncontrolled events, such as accidents, and certain types of past activities." [12] establishes that the remediation approach be justified through a decision making

[1] a crosswalk is a comparison of the entombment project approach to the requirements of the DOE Order, to demonstrate that the project plan effectively meets the requirements of the DOE Order

process that balances factors such as health effects, costs, including the costs of managing the waste generated from the action, and environmental impacts. Multiple options should be evaluated and considered. The remediation requirements also recognize that while the ultimate goal is to release the area from regulatory controls, this may not be possible. This requirement does not contain elements that specifically exclude entombment; however, [12] does specifically state "the scope of the publication excludes…decommissioning activities." The challenge to the remediation context is the expectation that remediation is applied to facilities that pre-date current standards and regulations. Further, within the IAEA context, remediation is applied to those situations where the contamination is pre-existing, and reserves decommissioning for actions taken as part of the life-cycle plans for a facility. Said another way, decommissioning is an activity that is planned for, while remediation is intended for addressing contamination that was not planned.

CONCLUSION

Entombment blurs the lines between decommissioning, disposal, and remediation. It has elements of each but does not fit cleanly into any. The IAEA and the Entombment Consultancy Team recognize that there is a need for the entombment option. The Consultancy will continue evaluating existing practical experiences and lessons learned from projects implemented based on the entombment approach and will identify regulatory requirements and expectations for applying entombment in compliance with the internationally agreed upon standards. The Consultancy is expected to complete its work in 2013.

REFERENCES

[1] The Statute of the International Atomic Energy Agency, approved 23 October 1956, and as amended. http://www.iaea.org/About/statute.html

[2] International Atomic Energy Agency Safety Standards, June 2009 http://www-ns.iaea.org/downloads/standards/iaea-safety-standards-brochure.pdf

[3] International Atomic Energy Agency, Decommissioning of Facilities Using Radioactive Material, IAEA Safety Requirements Series No. WS-R-5, IAEA, Vienna, 2006

[4] Decommissioning Handbook: Procedures and Practices for Decommissioning. DOE/EM-0383. January 2000.

[5] DOE EM Strategy and Experience for In Situ Decommissioning. U.S. Department of Energy Office of Environmental Management, Office of Engineering and Technology, EM-20. September 2009.

[6 Policy on Decommissioning DOE Facilities Under CERCLA. May 22, 1995. US DOE and US EPA.

[7] 42 USC Chapter 103 – Comprehensive Environmental Response, Compensation, and Liability Act, December 11, 1980, as amended.

[8] U.S. NRC Fact Sheet on Decommissioning Nuclear Power Plants, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/decommissioning.html

[9] On-Site Disposal as a Decommissioning Strategy. IAEA-TEC DOC-1124. November 1999.

[10] **International Atomic Energy Agency, Predisposal Management of Radioactive Waste, IAEA General Safety Requirements Part 5, IAEA, Vienna, 2009**

[11] **International Atomic Energy Agency, Disposal of Radioactive Waste, IAEA Specific Safety Requirements Series No. SSR-5, IAEA, Vienna, 2011**

[12] **International Atomic Energy Agency,** Remediation of Areas Contaminated by Past Activities and Accidents, **IAEA Safety Requirements Series No. Ws-R-3, IAEA, Vienna, 2003**

[13] Applicability of Performance Assessment Methodologies to In-Situ Decommissioning. Patricia L. Lee, Roger Seitz, Elmer Wilhite, Savannah River National Laboratory and Michele Wilson, Jesse Roach, Savannah River Nuclear Solutions. SRNL-RP-2009-00329, Rev. 0, March 30, 2009.