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ENTOMBMENT: A VIABLE DECOMMISSIONING STRATEGY FOR RESEARCH REACTORS?

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Abstract
Entombment is not a novel decommissioning strategy in the history of the nuclear industry. Several projects based on this strategy have been implemented. Despite a significant potential for dose, radioactive waste and cost reduction, entombment has often been disregarded as a viable decommissioning strategy, generally as the result of environmental and other public concerns, and international positions discouraging its use. The objective of this paper is to establish an awareness of technical factors that may or may not favour the adoption of entombment as a decommissioning strategy. To support these considerations, the paper presents an overview of relevant national experiences. The expected end result is to show that, in lack of dismantling options, and subject to safety and environmental protection assessment, entombment can be a viable decommissioning option for research reactors and should be taken into consideration in decision making.

Keywords
decommissioning, disposal, entombment, site, strategy, surveillance

1. Introduction

For the purposes of this report entombment is 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. Therefore this approach is viewed as a permanent decommissioning strategy: after entombment, no more activities on the facility are foreseen. A period of site monitoring and surveillance should be maintained until institutional control can be lifted based on radioactive concentrations having decayed to "below regulatory concern" (clearance) levels. The reader should be warned however that in principle the decommissioning strategy can be reverted and entombed structures can be dismantled at a future time, if at a higher costs than had the dismantling be implemented without an interim entombment strategy. Alternative terms for entombment include "on-site disposal", "in-situ decommissioning" and others.

The fact that radioactive material will remain on site means that the facility will eventually become designated as a near surface waste disposal site and criteria for such a facility will need to be met. The permanent entombment of a facility where it stands may involve various engineering and regulatory approaches. In some cases a building may be collapsed, its remaining spaces filled with grout, and then capped with an earthen or concrete cover. In others, the building may be completely covered to create a large mound. In most entombment projects high activity waste (e.g. spent fuel and activated reactor internals) are removed prior to entombment to make sure that radioactive decay of the remaining active parts will reach release criteria within a not unreasonably long institutional control period. Radioactive contaminants are entombed to mitigate release and migration as demonstrated by risk-based performance analysis. The potential for accessing and spreading contaminants is essentially eliminated, ensuring long-term effectiveness.

2. Pros and cons of entombment

The IAEA report [1] lists a number of factors that are important when deciding on whether to choose the entombment option for a nuclear facility. Consideration of these factors allows comparison of advantages and disadvantages:

- Costs: Entombment is generally credited lower costs than other decommissioning strategies, as the effort for decontamination and dismantling is minimised. Components and structures need no or almost no segmentation and need not be removed. However, an entombed facility will need surveillance and monitoring, causing additional costs. Additional costs will also arise if long-lived radionuclides are present in non-negligible proportions, requiring additional effort for their removal or at least long-term assessment. A comprensive, internationally agreed overview of the decommissioning cost structure is given in ref [2].
- Occupational radiation dose: If the extent of decontamination and dismantling activities to reach the entombment status can be minimized, it is to be expected that the doses to the personnel will be lowest in the case of the entombment strategy. In addition, the amount of generated radioactive waste will be lowest in this case, leading also to significant dose reduction. If, however, only a small part of the facility, e.g. the reactor block of a research reactor, will be entombed, then the expected savings in dose commitment will be less.
- Independence from cost and availability constraints of off-site disposal facilities: If only a minimum decontamination and dismantling activities are carried out, there will also be only a minimum of radioactive waste that has to be shipped to interim storage or to a repository, making the decommissioning project virtually independent from off-site disposal facilities. This is a point where significant savings are possible. Furthermore, the availability of such a disposal facility in a particular country plays no role in this case.
- Environmental impact of establishing a disposal site: The fact that the entombed facility creates a disposal site is a major disadvantage of the in-situ dismantling strategy. This requires additional environmental impact assessments for the activity remaining in the entombed facility, taking into account all pathways by which it could possibly enter the environment and reach the biosphere. Stakeholders may stress this point during the licensing procedure, giving rise to a number of time-consuming assessments of the site, its properties and its surroundings etc. A precondition for a site to become eligible for entombment is that it has natural confinement factors rendering the site suitable for long term confinement of radioactive waste. In addition, the time scale over which the site has to be kept under surveillance may also be a concern for the population.
- Creation of additional disposal sites within a country as compared with centralized disposal facilities: The plans of turning a nuclear facility into a disposal site may also interfere with a country's strategy for radioactive waste management. There needs to be consensus among the rulemakers and the competent authorities that entombment should be a viable option in a particular country.
- Safety and environmental aspects of on-site disposal: Evaluation of the safety and environmental consequences of using the entombment strategy may be the most critical factor in gaining regulatory approval and public acceptance. Evidence has to be furnished that free release of the site will be possible at a later date and that in the meantime there will be no effect to the environment above trivial levels. The period of time over which this evidence has to be provided may easily exceed several decades, depending on the type of the facility and the properties of the dominant radionuclides. In general, the assessment will have to rely on conservative assumptions with respect to release rates and corrosion of natural and engineered barriers in order to be convincing.

3. International positions and national programmes

The newly published IAEA Safety Requirements [3] reads: "*Entombment, in which all or part of the facility is encased in a structurally long lived material, is not considered a decommissioning strategy and is not an option in the case of planned permanent shutdown. It may be considered a solution only under exceptional circumstances (e.g. following a severe accident*)". This paper intends to shed light on "exceptional circumstances" additional to accidents (the Chernobyl case). By using selected examples, this paper will strive to prove that research reactors may safely adopt entombment as a decommissioning strategy.

In certain technical environments, it is felt that the stigma against entombment should be lifted [4]. The key issues influencing entombment reconsideration are as follows. Decommissioning worker exposure and safety, transportation, cost, and lack of waste disposal capacity are shared drivers for developing the entombment option. As said above, the pursuing of an entombment strategy may mitigate the overall decommissioning concerns. However, since entombment relies on retarding the release of radionuclides for a very long period (the expected range may be 100 – 300 years i.e. comparable with the institutional control foreseen for low level waste disposal sites), evaluation of numerous factors prior to selection and implementation of entombment is necessary. These factors include:

- Size, complexity and type of nuclear facility.
- Residual radioactive inventory and associated radioactivity decay profile.
- Inclusion of conditioned operational waste.
- Location: geographic, topographical, demographic and local site conditions.
- Retention of radioactive constituents within the entombed structure.
- Integrity and durability of engineered barriers and appropriate shielding.
- Geology and hydrogeology of the site.
- Continued and future site use.
- Retrievability and repairability of the entombed structure.

Entombment has often been proposed for underground facilities –these facilities may have intrinsic advantages irrespective of their decommissioning strategies [5] The subject of entombment for underground pipes, tanks, vaults and tunnels is specifically addressed by a IAEA report [6]. Currently the US Department of Energy has an extensive programme underway on entombment (called InSitu Decommissioning, ISD) [7]. Some specific R&D aspects of the programme are given in [8, 9].

The DOE national laboratories and the US National Institute for Standards and Technology (NIST) have extensively worked on concrete mixtures that make them suitable for entombment projects [10, 11, 12]. Optimization of concrete properties addresses the following main aspects:

- Constructability.
- Infill and backfill rheological properties.
- Leaching; and
- Research Needs.

Entombment is more likely to be the preferred final decommissioning solution on multi facility sites and on sites where research facilities are located. As these sites are often situated in remote areas, the entombment can be viewed as the best solution. Occasionally the entombed structure can also house radioactive waste resulting from the decommissioning of parts of the same facility or other nearby facilities.

The cleaning out of buildings is essential for the operation of the entombed structure. All loose radioactive material must be removed to avoid a possible release from the structure. As the structure will have cracks, smaller portions of radioactive material might leak from the structure. In order to preserve the surroundings from contamination, sometimes special layers of clay or gravel are positioned around the structure. On top of that a special sealed waterproof coating by an organic compound is sometimes applied.

Although documentation about the structure and its location must be stored in the archives of the responsible organization (with a copy to the regulatory body), there is always a chance this information might get lost in future. Therefore markers must be placed to the structure itself and in the vicinity of the structure. These markers must have sufficient information on what the structure once was and its potential dangers to public health. They must lead future generations to where more detailed information can be found. The use of symbols is recommended.

Special attention must be given to leaching of radioactive material into groundwater surrounding the monolith. To avoid this leaching, the structure can be covered with a coating (this is difficult for the outside of the basements). Especially in cracks, isotopes like H^3 and Cs^{137} have the tendency to move fast. The groundwater surrounding the monolith should be monitored for the needed period after creation of the monolith. The timeframe for running this programme can be defined by using the radioactive inventory of the monolith. As the amount of easily leachable isotopes is higher, more sampling should be performed during the early years of the lifetime of the monolith. The structures that have become radioactive by neutron activation and do contain isotopes like C^{14}, Ni^{59} and Ni^{63}, are less prone to leaching as these structures act as an intrinsic barrier for the isotopes.

4. Operating experience with entombment

A comprehensive description of a number of entombment projects, studies or plans was given a few years ago by the IAEA in [2]. The following expands on entombment projects initiated a few years ago, either completed or close to completion. The focus is on research reactors.

4.1 Heavy Water Components Test Reactor (HWCTR)

HWCTR was an experimental nuclear reactor at the Savannah River Site, USA It was commonly called "Hector". The reactor was constructed starting in 1958. It had a cylindrical structure with a hemispherical dome. Its diameter was 70 ft (21.3 m) with a height of 125 ft (38.1 m). About 60 ft (18.3 m) was located underground, which eventually proved conducive to the entombment strategy.

Figure 1. Removal of HWCTR Steam Generator.

The concept of a heavy water moderated and cooled reactor for civilian power was tested from late 1962 to December 1964. The reactor never restarted. In 1965, fuel assemblies were removed, systems that contained heavy water were drained, fluid piping systems were drained, de-energized and disconnected and the spent fuel basin was drained and dried. The doors of the reactor were shut and it was not until more than 30 years later that decommissioning plans were considered and ultimately postponed due to budget constraints.. All auxiliary buildings were removed. Eventually decommissioning plans were resumed in early 2000s. The final decommissioned end state included in-situ decommissioning (entombment) with reactor vessel and 2 steam generators removed and disposed in trenches on site. Major work activities included the following:

- Remove and dispose the metal dome.
- Remove and dispose the reactor vessel.
- Remove and dispose the two steam generators (fig 1).
- Grout the spent fuel pool.
- Grout the below-grade areas of the building, including remaining piping and equipment.
- Install a concrete cover over the remaining grouted structure.

Projects were completed ahead of schedule in July 2011 and below cost (8.77 MUSD instead of foreseen 10.7 MUSD) [13].

4.2 Lucens reactor, Switzerland

The decommissioning strategy for the Lucens prototype reactor in Switzerland may have been selected partly because of the underground construction of the facility. Thirty years after the accident that put an end to Lucens operation the decision was made to fill and seal the caverns housing the reactor facility, and to release and terminate its nuclear licence. The site was released from regulatory oversight in 2003 in a condition that allows public access for observation of the conditions at the site. On the completion of this work the decision was made by the Swiss regulatory authorities to permanently terminate research activities here. Actions at the site are considered to be complete.

A total of 235 t of metallic scrap contaminated above the release values was packed into containers and drums before cementation and placement in several of the cavities of the system of underground caverns. These containers were inserted into these cavities such as the (emptied) fuel pool, condenser pits, upper and lower reactor pits and D_2O reservoir. They were then carefully filled with a flowing concrete mixture to form a homogeneous mass. The radioactive inventory of these buried materials in situ is 3.7 GBq. The non-activated and non-contaminated components of the CO_2 circuits could not be resold. These were left in place, and together with the piping of auxiliary systems were completely entombed.

After the operator of the Lucens facility, Energie Òuest Suisse (EOS), was discharged from its responsibility the underground area reverted to its former owner, Nationale Genossenschaft zur Förderung der Kernenergie (NGA), which in turn contracted the operator of the Swiss nuclear power plant at Mühleberg to survey what was left of the Lucens facility. The monitoring system comprised measurement of temperatures of the concrete during the curing period, as well as measurement of the amount of drained water, together with its physical and chemical properties. The installed drainage system is inspected periodically.

Figure 2. The Lucens site was converted to a museum store. See entrance.

The former machine hall cavern and the access tunnel were transformed into a storage area for cultural and historic exhibits (such as medieval period skeletons), thus creating a virtually unlimited non-nuclear reuse of parts of the site. Details and pictures of the redeveloped Lucens site are given in [14]. See fig 2.

4.3 Boiling Water Reactor Experiment-1 Landfill, INEEL, USA

The BORAX-1 reactor was a small experimental reactor used in the summer months of 1953 and 1954 for testing boiling water reactor technology. In 1954, the design mission of BORAX-1 was completed. In 1954, one final test was conducted that resulted in the intentional destruction of the reactor (fig 3).

The destruction of the reactor contaminated approximately 7 800 m^2 of the surrounding terrain. Immediately following the final test of the BORAX-1 reactor, much of the radioactive debris, including some fuel residue, was collected and buried onsite in the reactor shield tank. At BORAX-1, the contaminated area was covered with approximately 0.15 m (0.5 ft) of gravel to reduce radiation levels at the ground surface. Buried materials at the site consist of uncovered uranium fuel residue, irradiated metal scrap, and contaminated soil and debris. The burial ground is contained within the foundation of the BORAX-1 installation. The dimensions of the foundation are 5.5 × 9.8 × 3.4 m (18 × 32 × 11 ft). A mounded gravel and dirt cover approximately 1.5 m (5 ft) high and 9 m (30 ft) in diameter is centered over the buried shield tank. In the summer of 1997, an engineered long-term barrier was installed over the BORAX-1 landfill. The barrier was designed to provide shielding from penetrating radiation, a barrier to inadvertent human intrusion, and longevity through the use of predominantly naturally occurring materials. Percolation of water into these landfills does not pose an unacceptable risk to the environment, so these surface barriers were not designed to preclude percolation.

Figure 3. The photo shows the final BORAX-I experiment.

The design life of the barrier was based on reducing the total excess cancer risk for all contaminants to less than 1 in 10 000. The design life for the BORAX-1 barrier is 320 years. The barriers were designed to endure the erosive effects of wind and water, allowing them to maintain an acceptable depth of barrier over the course of the design life.

The BORAX-1 barrier was constructed with an under-layer consisting of the top 12 in. (6 in. of topsoil + 6 in. of gravel emplaced for shielding) (30 cm) of the surrounding contaminated 7800 -m^2 area. This soil was consolidated to a roughly 37 × 37 m (120 × 120 ft) area and compacted on top of where the reactor is buried. A riprap layer was placed over the consolidated soil to form the top layer of the barrier to minimize erosion. The surface barriers were designed to experience minimal erosion over the design life based on the soil types and the addition of the riprap layer. Erosion of the barrier would reduce the amount of radioactive shielding it provides. Areas adjacent to both barriers were graded to encourage drainage around and away from the capped landfill sites. The purpose of drainage control is to diminish erosion of the surface soils and barrier materials, not to avoid water infiltration. The surrounding area was also planted in native grass species to slow surface water flow velocities and provide additional erosion protection.

Although the surface barrier is operating as expected, additional rodent activity has been noted during the annual landfill inspections: Likely, the rabbits were using the boulder field as shelter. The annual inspection also noted that the new spring growth grass was well established [15].

4.4 Entombment of Super Kukla Facility, Nevada Test Site (NTS), USA

Lawrence Livermore National Laboratory's Super Kukla prompt-burst reactor was installed at the Nevada Test Site in 1964. The reactor was used to evaluate the damage that radiation might cause to materials in the vicinity of a nuclear blast. (Fig 4)

Figure 4. Super Kukla reactor during installation

The Super Kukla Facility consisted of four structures: : Building 5400, Building 5400A, Building 5410, and the Wooden Building known as the "Brock House." Building 5400 (Reactor Building) consisted of a basement pit foundation and reactor containment room. The Reactor Building extended underground under the footprint of the High Bay. The access tunnel is covered with at least 4 feet (1.3 m) of earth fill. Building 5400 housed the Super Kukla Reactor, which was used to test the effects of "prompt bursts," or intense pulses of radiation over a brief period of time, on a variety of samples. In 1979, operation and testing of the reactor ceased. The reactor core and components were disassembled and removed. The reactor fuel was sent for storage at the Y-12 Plant in Oak Ridge, Tennessee. The objectives of closure activities were designed for Closure in Place with use restrictions.

Radiological contaminants of concern (COCs) included Co^{60}, C^{14}, Cl^{36}, Cs^{137}, Eu^{152}, Eu^{154}, Eu^{155}, Fe^{55}, Am^{241}, tritium, Ni^{63}, isotopic plutonium, Sr^{90}, and isotopic uranium. The primary chemical COCs included PCBs, metals, and Freon. Aboveground structures were demolished and disposed. Radiologically impacted equipment (primarily activated metals) from Buildings 5400A, 5410, the Wooden Shed, and remaining in B-5400 were entombed in B-5400. The entombed debris and equipment did not increase the space requirements for grouting and entombment. The entombment of B-5400 renders the structure inaccessible, and there are no credible transport mechanisms for migration of contaminants.

Before placement of grout, radiologically impacted material and debris from Building 5400A, Building 5410 and the Wooden Shed were placed into Building 5400 for entombment. Additionally, the lead shielding wall located in the Reactor Room was left in place. The Closure Plan provides an analysis of the risks associated with the lead wall. The conclusion of this discussion is that the lead wall would be left in place because risk to workers removing it was determined greater than the risk associated to leave it in place. Additionally, due to the robustness of the existing concrete structure (i.e., floors, walls and ceiling), and the grouting of void spaces, the lead wall would be sufficiently encapsulated to prevent migration of hazardous material to groundwater.

Site setup for grouting activities began March 1, 2007. Grouting activities at Building 5400 took place from March 5 through March 21, 2007. A flowable grout was utilized to complete this task. The flowability of the grout was measured each day to ensure the material consistency and minimize void spaces within the structure. The overpressure well and heating, ventilation, and air conditioning (HVAC) piping were grouted separately before grouting the remainder of the building. The basement of the reactor room was filled utilizing a grout pump and pumping the grout into the basement at the top of the stairway.

The Reactor Room was filled utilizing an access hole in the B-5400A concrete slab located directly above the reactor stand. The steel doors at the entrance to the B-5400 tunnel were barricaded and an opening was cut through the door for grout placement into the tunnel area. An opening in the roof of the tunnel from a pre-filter unit was also utilized to fill the tunnel area [16].

4.5 Savannah River Site: The R- and P-Reactors

During the early 1950s, five production reactor facilities were built at the Savannah River Site (SRS). These facilities were built to produce materials to support the building of the nation's nuclear weapons stockpile in response to the Cold War. R-Reactor and P-Reactor were the first two facilities completed in 1953 and 1954. R-Reactor was removed from service in 1964 due to a combination of increased efficiency of reactor operations and a slowdown of the arms race. P-Reactor was taken off-line in 1988 to update the facility. Work to modernize the facility stopped in 1990 with the end of the Cold War. Both reactors have sat in a cold and dark state (US terminology for passive safe enclosure) since that time, and have been identified as the first two reactors at SRS for final closure.

Final closure for the reactor buildings involves In-Situ Decommissioning (ISD) [17]. It was estimated that this strategy would convey significant savings [18]. It involved filling all below grade levels of the buildings with grout. This will immobilize any residual contamination contained within the building and structurally stabilize the buildings. The reactor vessel itself was filled with grout to the maximum practical extent and capped with a reinforced concrete cap. Above grade sections of the buildings were demolished (fig 5). The Savannah River National Laboratory (SRNL) has assisted with building visualization through the development of 3D CAD models and scale physical models developed in the SRNL Rapid Additive Manufacturing (RAM) Laboratory [19].

Figure 5. Demolition of P reactor stack.

The suite of specialty grouts developed for this work at SRS includes:

- A low pH and chemical compatible grout to minimize the evolution of hydrogen gas when isolating aluminum and other reactive metal components in the SRS reactor vessels
- Specialty grouts to meet the needs for low viscosity (i.e., adequate lateral • flow over large areas), set times, phase separation and heat of hydration.

On June 28, 2011 top officials from DOE, Savannah River Site and other organizations sealed the access to the historic P and R Reactors as part of footprint reduction and legacy cleanup at the Savannah River Site [20].

4.6 Decommissioning of Industrial Uranium-Fuelled Graphite-Moderated Reactors at Krasnoyarsk Mining Chemical Plant, Russian Federation

The site of Krasnoyarsk Mining Chemical Plant is home to three industrial uranium-graphite reactors, namely AD, ADE-1 and ADE-2. Together with their auxiliaries and piping, they are placed inside openings mined in a mass of rock – reactor vaults lined with wholly-cast concrete.

The AD was a single-purpose flow reactor that used thermal neutrons. The reactor was operated from t 1958 to 1992. The ADE-1 was designed for power generation but in fact only used as a single-purpose flow reactor. Its operational lifetime lasted from 1961 to 2010.

At AD and ADE-1, most of the dismantling work systems and equipment has been completed, penetrations through the reactor vaults have been sealed, equipment and rooms decontaminated.

Until 2009, the decommissioning option envisaged for AD and ADE-1 reactors was long term safe enclosure within the reactor vaults for at least 100 years. This option was alternative to two other (entombment and dismantling), and envisaged sealing of the reactor equipment within the reactor space. The final decision on decommissioning strategy was to be made on expiry of the reactors enclosure period based on actual radiological condition at the time, integrity of the containment barriers, availability of technology and social and economic factors.

The dismantling option, which envisaged the removal of equipment, decontamination of rooms and shipment of all radioactive waste off site in order for the site to be cleaned up and made available for further use, was not considered as the main option due to the following reasons:

- Large scope of dismantling work to be performed in radiologically hazardous conditions;
- Largest amount of waste to be generated from dismantling (both radioactive and non-radioactive);
- Longest duration of the decommissioning project;
- Unavailability of disposal methods and programmes for management of radioactively contaminated graphite;
- Inadequacy of storage facilities for graphite. Available storage locations are normally designed for 50 years of storage, which is insufficient to the long term containment of graphite contaminants;
- Unavailability of regional radioactive waste repositories capable of accepting radwaste that contains long-lived radionuclides.

In 2009, it was demonstrated that it was feasible and economically justifiable to turn the reactor locations into repositories for final isolation of radioactive waste; therefore in-situ entombment came to be seen as the preferred decommissioning option for these reactors.

The shift from safe enclosure to in-situ entombment was caused primarily by the notable absence of any realistically viable approaches to disposal of the main radioactive reactor components, Instead, solutions were readily available that could be used for the entombment option. In 2010, an industry-wide concept of uranium-graphite reactor decommissioning was adopted, with in-situ entombment as its main option.

The key argument in favour of entombment of the Krasnoyarsk Mining Chemical Plant uranium-graphite reactors is the unique placement of these reactors inside excavations mined through solid rock. The rock mass provide a natural safety barrier – a natural external containment structure, which, in combination with already existing additional protection barriers will ensure compliance with radiation safety requirements. In addition, the rock mass acts as the key structural component of the entire underground structure, which is in this way capable of withstanding significant internal and external loads and impacts. Implementation of in-situ entombment will also provide a physical barrier to any unauthorized access to the radioactive waste containment zone. It should also be taken into account that the reactors site already accommodates near-surface and sub-surface radwaste stores and repositories. Regarding cost estimates, in-situ entombment requires less labour and less exposure than dismantling.

Safety assurance during in-situ entombment, of uranium-graphite reactors follows the same principles that are commonly used for safe management of radioactive waste.
Long term safety of long term radioactive waste in-situ entombment system shall be assured through implementation of the multi-barrier defence-in-depth principle. This approach envisages a combination of existing barriers (shroud, steel structures, concrete vault, rock surrounding the mine) and new barriers (clay backfill, concrete filling of sub-reactor space, sealing structure over the reactor vault) [21].

4.7.The IRT-M Reactor, Tblisi, Georgia

The nuclear research reactor IRT-M belonged to the Institute of Physics near Tblisi and operated during the 1960-1988 period. All nuclear fuel (both fresh and spent) was sent out of Georgia after final reactor shut down. The reactor decommission activity was conducted at different stages. As the first stage the reactor core together with some comparably high activity waste was grouted in concrete. A special underwater concreting technology was developed for this purpose (fig 6). Theoretical assessment of radioactive concentrations and radiation fields was conducted before the activity. The results were in good agreement with radiation monitoring data produced during the concreting activity. During the second and third stage of decommissioning reactor systems inside and outside of the reactor building were dismantled.

Figure 6. Georgia IRT Mockup for reactor grouting

The entombment strategy was based mainly on the following factors:

- Lack of state-of-the-art storage/disposal facilities in Georgia at the time the strategy was selected and presumably for a long time to come.
- Lack of financial and technological resources to fully dismantle the reactor.
- Relatively minor increment of radioactive waste in comparison with the reactor activated structure.
- The structure is radiation resistant and seismically safe.
- The above-ground entombed structure does not preclude future dismantling.
- There is a concept of locating in future a new low power nuclear facility on top of the concrete monolith.

All activities were conducted in the frame of the IAEA Technical Co-operation Project GEO/4/002 in the period in late 1990s and early 2000s. The IAEA-supported dismantling project goes on to dismantle more systems and buildings within the Tbilisi Centre [22].

5. Conclusions

Regardless of negative national and international positions, entombment remains a viable decommissioning strategy in several cases for example:

- To achieve a safer configuration of a shutdown reactor in a country or institution lacking basic infrastructure (e.g. dismantling expertise or funds, waste disposal prospects etc.).
- When adequate surveillance of the entombed facility can be ensured, typically when the facility is situated in a wider site bound to remain operational or under institutional control for a long time. A fundamental component of this approach is proper record-keeping.
- The use of entombment is limited to a small number in a given country, particularly to remote sites, in order to prevent the uncontrolled proliferation of waste disposal sites.
- To leave it open the option of dismantling entombed structures in a not-too-distant future.

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