Best Practice Form

Best Practice Title:	SRS P and R Reactor Disassembly Basin *In Situ* Decommissioning		
DOE Site:	Savannah River Site	**Facility Name:**	P and R Reactors
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Interviewed by:	Information provided by papers WM2010- 10499 and ICEM2010- 40273	**Transcribed by:**	Heidi Henderson

Brief Description of Best Practice: (Provide a short, "abstract-like" description of the best practice)

The U.S. Department of Energy (DOE) is conducting "*In Situ* Decommissioning" (ISD) closures (i.e., entombment) at a number of facilities throughout the complex. Among the largest such actions to date are the closures of the P and R Reactors at the Savannah River Site (SRS), near Aiken, South Carolina. ISD is the permanent entombment of a facility. It has been adopted by the DOE for a certain class of facilities where this strategy presents a safer and more cost-effective closure methodology than complete removal and transport to a disposal facility. The U.S. DOE concept for facility ISD is to physically stabilize and isolate intact, structurally sound facilities that are no longer needed and are scheduled for disposal. The 105-R Reactor Building was the first SRS reactor facility to undergo the ISD process followed by the 105-P Reactor Building.

The best practice followed at SRS guided the identification and selection of appropriate ISD fill materials to successfully overcome the wide variety of challenges that the large size and structural complexity of these facilities presented. Considerations for grout formulations had to account for flowability, long-term stability, set times, heat generation and interactions with materials within the structure. The large size and configuration of the facilities necessitated that grout be pumped from the exterior to the spaces to be filled. This in turn required that the material retain a high degree of flowability to move through piping without plugging while also meeting the required leveling properties at the pour site. Set times and curing properties were controlled to meet operational schedules, while not generating sufficient heat (known as heat of hydration) to compromise the properties of the fill material. In addition, the properties of residual materials in the facility necessitate additional requirements for the grout formulations. For example, where significant quantities of aluminum were present in the facility, common formulations of highly alkaline grouts were not appropriate because of the potential for hydrogen generation with the resultant risks. SRS developed specialized inorganic grout formulations to address this issue (see references in the Additional Information section of this Best Practice).

Summary:

The P Reactor (operated 1954-1988) and R Reactor (operated 1953-1964) produced special nuclear materials for the U.S. nuclear weapons program. The DOE closure program was established to accelerate the reduction of risk and cost associated with excess nuclear facilities. Under this program a strategy was developed for SRS with the appropriate state and federal agencies to close facilities with Early Action Records of Decision as a key component of the closure strategies addressing these specific facilities within their respective Operable Units at the SRS.

The SRS P Reactor (105-P) is shown in Figure 1. It is very similar to the R Reactor (105-R). The ISD concepts for both reactors are illustrated in schematic cross-sections in Figure 2. The complexity of the spaces which were to be filled and limitations on floor loading necessitated that grout delivery occur outside of the structure. The placement strategy developed for the SRS R Reactor Disassembly Basin was also applicable to decommissioning the P Reactor Disassembly Basin and the below grade portions of both the 105-P and 105-R facilities. The ISD process consisted of placing cementitious grout materials below grade up to ground surface in the disassembly basin areas. The above grade structure over the disassembly basin areas was demolished and removed. A concrete cap covers the grouted area of the disassembly basin and this will be the final configuration. Other below grade areas in the two reactor buildings were filled as indicated in Figure 3, with the remaining above grade structures being sealed to prevent human and/or animal access. The ISD process for the entire 105-P and 105-R facilities required approximately 250,000 cubic yards (191,140 cubic meters) of grout and 2,400 cubic yards (1,835 cubic meters) of structural concrete which were poured on an accelerated schedule.

Figure 1. Photograph of the 105-P reactor building (similar to the 105-R building)

Figure 2. Cross-Section through 105-P (105-R) Reactor Building before ISD

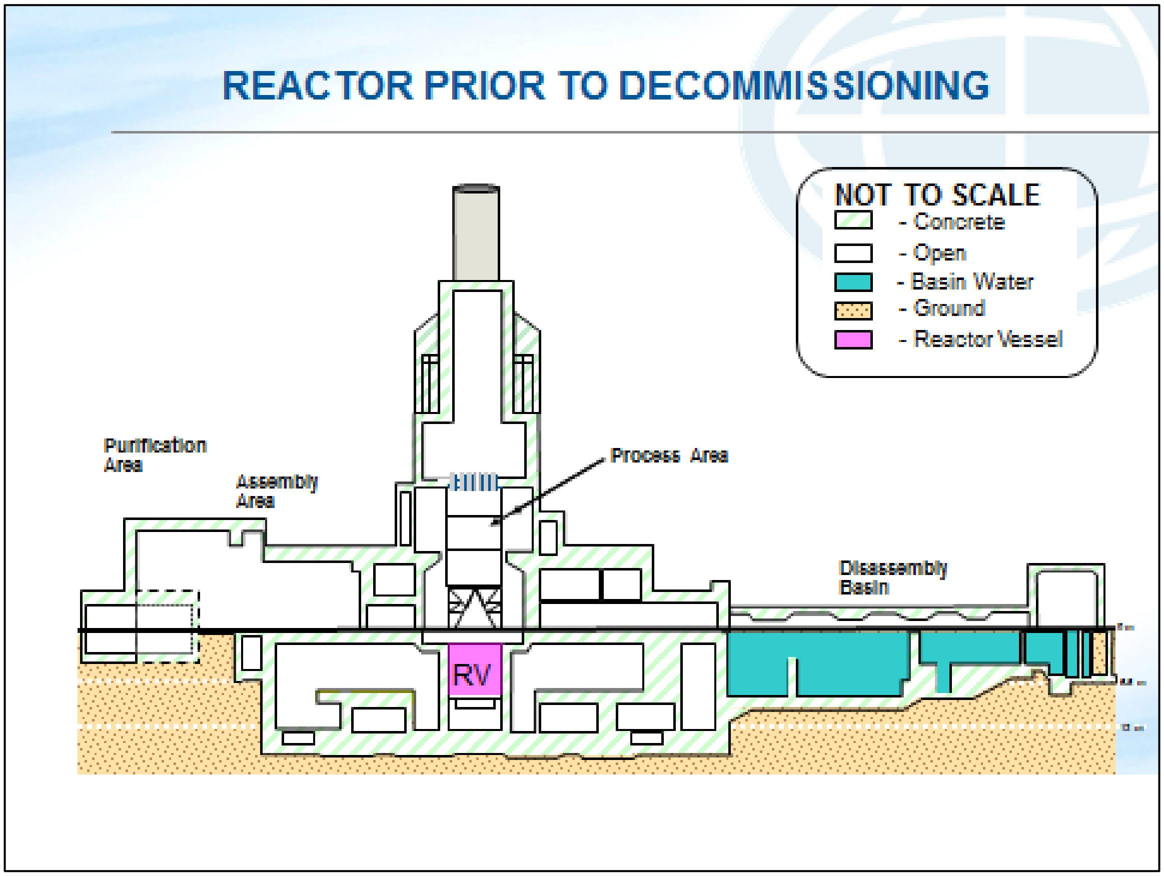
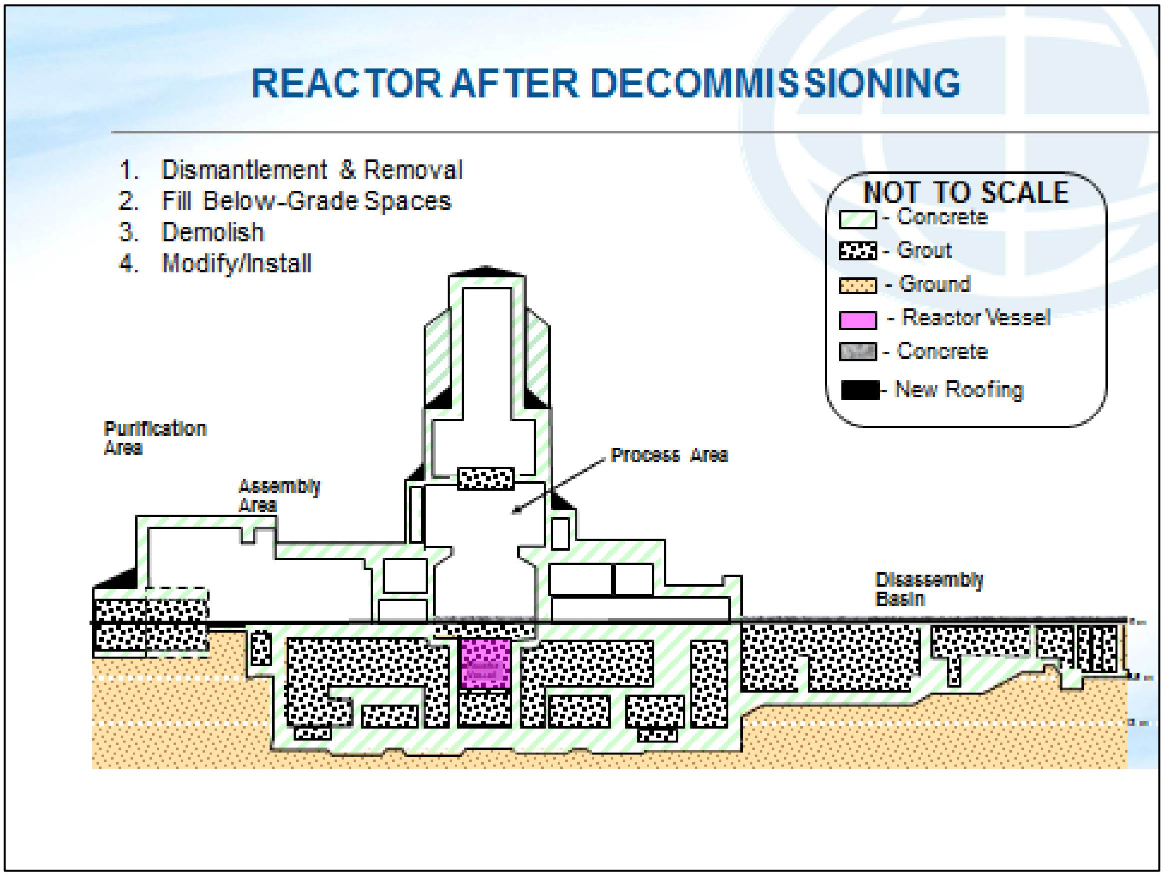


Figure 3. Cross-Section Through 105-P (105-R) Reactor Building After ISD



Closure of SRS's P and R Reactors using the ISD strategy presented unique challenges relative to the development and delivery of grout formulations to meet project specific needs. The primary requirement was to develop grout formulations that could be pumped in large volumes, over long distances, to remote areas. To achieve this objective, conventional concrete mixing and delivery techniques were modified. These modifications are project-specific and the general areas that must be considered are outlined below. Specific use of *in situ* techniques must be scoped and are designed for the specific project.

Additionally, because of the very large grout volumes involved, it was essential that commercial vendors be able to obtain, mix, and deliver grout mixes that satisfied these technical criteria. Key issues addressed by the grout formulation and placement plans included:

- adequate flowability to allow pumping to remote placement locations;
- self-leveling properties;
- incorporation of additives to balance the need for set times required for project execution while managing the heat of hydration to minimize cracking in the pour;
- pumping pressures to prevent separation of grout components;
- compatibility between grout formulations and the materials to be encapsulated and isolated; and
- radiological influence on fresh and cured grout properties.

A complete understanding of the physical configuration of the facility was critical to the successful completion of the projects. Where the ISD strategy involved placing large volumes of grout into complex facilities, the entire sequence, transit route, delivery mechanisms, and ultimate final condition of grout inside the facility had to be well characterized. Safe and successful project execution demanded that the team be able to manage the many diverse elements of ISD implementation; it was essential that the individual ISD strategy elements be identified and the project team assembled at the outset of ISD implementation.

An example of this approach for developing the grout placement strategy for the P and R Reactor Disassembly Basins included the following actions:

- assemble a team of on-site personnel with the appropriate skill mix;
- develop a CAD model and rapid prototype model of the basin to facilitate visualization of the facility and Proposed work activities;
- group areas within the disassembly basin according to relevant conditions and stabilization needs;
- identify stabilization material requirements for various areas in the respective reactor building;
- develop cementitious fill formulations that meet both the ISD requirements and construction needs;
- test the cementitious materials to confirm material requirements are met;
- identify construction verification activities to confirm material placement; and
- support procurement of fill materials for the disassembly basin and for the reactor ISD.

Why the best practice was used: (Briefly describe the issue/improvement opportunity the best practice was developed to address)

Due to the large size and structural complexity of these facilities, standard demolition would have incurred additional risk of exposure to the workers, the public, and the environment, as well as having generated a large quantity of waste and resultant additional cost. The ISD strategy to decommission the retired nuclear facilities provided a much safer and more cost-effective closure methodology.

The grout formulations used during the ISD had to meet multiple and diverse requirements, as described in the previous section. Following the best practice allowed the project team to identify the various requirements and develop specific grout formulations to best meet the ISD requirements and construction needs.

What problems/issues were associated with the best practice: (Briefly describe the problems/issues experienced with the initial deployment of the best practice that, if avoided, would make the deployment of this best practice easier the" next time".)

The radiological contamination, heights, extensive basements, and thick concrete walls of the buildings made the effort complex and difficult. Extensive planning and hazard analysis ensured the ISD was completed safely.

The following is but one example (material compatibility) of a problem/issue that the ISD process addressed during project evolution.

Reactor vessel stabilization is a critical element of the ISD strategy. The compatibility of grout materials and internal reactor components was evaluated to identify and eliminate possible adverse conditions during filling operations. The potential for hydrogen generation during grout placement was evaluated in several areas of the P and R Reactors because of the use of aluminum components in the reactor vessel. The focus was on the rate at which aluminum alloys react with corrosive high pH Portland cement based grout (pH > 12-12.5) to produce hydrogen gas, thereby creating a potential hazardous deflagration/explosion condition.

One circum-neutral chemical grout formulation identified for initial consideration did not possess the proper chemical characteristics, having exceptionally short set times and high heat of hydration. Research efforts were directed toward developing grout formulations that would meet operational requirements for chemical compatibility and have extended set times and reduced heat of hydration.

The evaluation results for the R Disassembly Basin concluded that: *"The risk of accumulation of a flammable mixture of hydrogen above the surface of the water during placement of grout-CLSM [controlled low strength material] into the R Basin VTS [vertical tube storage] disassembly area is very low. Conservative calculations estimate that there is insufficient aluminum present in the basin VTS area to result in significant hydrogen evolution."*

Comparable results were derived for the P Reactor Disassembly Basin and the R Reactor Vessel. Nevertheless, the following recommendations were provided to further minimize the potential for hydrogen evolution.

- Minimize the initial temperature of the water and grout-CLSM as much as practical. Lower temperatures mean lower hydrogen generation rates.
- Ventilate the building above the basin rim as much as practical (e.g., leave doors open) to further disperse hydrogen.
- Minimize interruptions to the grout-CLSM placement process as much as possible. Interruptions will result in higher water temperatures and hence higher hydrogen evolution rates.

The analysis reached a different conclusion for the P Reactor vessel where aluminum alloy Universal Sleeve Housings remain in place and significantly increase the surface area of aluminum exposed to corrosion relative to R Reactor. Conservative calculations indicated that there was potential for explosive levels of hydrogen to accumulate such that the condition would be difficult to mitigate using the recommendations noted above. The rate of hydrogen generation has been demonstrated to increase as both temperature and grout pH increase.

Developing a grouting strategy for the P Reactor vessel was further complicated by the limited access to the interior of the vessel and the enclosed positioning of the vessel which limits air flow and heat dissipation. Efforts were focused on developing a strategy that included a grout formulation that is compatible with the exposed facility materials and ensured that the grout could be delivered to the vessel in a manner that minimized the potential for delivery system maintenance which would result in additional worker exposure.

The search for a grout formulation with a lower pH (<10.5) began with Ceramicrete, a magnesium potassium phosphate grout formulation developed by Argonne National Laboratory (ANL). Initial testing of the original formulations revealed that the formulation had good placement properties and compressive strengths, but the reaction rates for the cementitious components were slow and the temperatures rose to a point approaching the upper limit for the reactor vessel application. Alternative formulations of the circum-neutral pH magnesium phosphate and a calcium aluminate grout formulation were tested for application to the reactor vessel stabilization. Scale-up testing of the formulations focused on addressing the following issues:

- extending the grout working time;
- material flowability between and around obstacles;
- reduced chemical reaction temperature rise; and
- grout delivery configurations that support engineering, operations and safety requirements.

How the success of the Best Practice was measured: (What data/operating experience is available to document how successful the best practice has been?)

In August 2011, the U.S. DOE completed the successful ISD of the two large reactor complexes at SRS, avoiding the potential hazards and cost associated with generating and disposing of an estimated 137,000 tons (5,400,000 cubic feet) of contaminated debris per reactor. The potential hazards that were avoided by using ISD compared to classic decommissioning/demolition were industrial worker exposure to radioactive or hazardous contamination, the potential for accidents to occur on-site during demolition, and cross contamination due to immobilization of contamination.

The two reactor ISD projects met contractual and regulatory objectives/ standards for residual contamination and physical/ chemical hazards. The two projects also fully supported an overall effort to remediate the P and R Areas at the SRS.

Actual, fully-burdened costs for each of the reactor *in situ* decommissioning projects was about $73M, 29% of the estimated cost of about $250M for full demolition of the above-grade structures along with reactor vessel removal and below-grade decontamination of *each* reactor complex; thereby realizing a 71% cost avoidance as compared to the cost of full scale D&D

What are the benefits of the best practice: (Briefly describe the benefits derived from implementing the best practice.)

Advantages of using the ISD strategy are:

- Entombment of the facilities limit worker exposure by drastically reducing the handling and movement of radioactive or contaminated substances;
- Encapsulation in grout prevents migration of contaminants and radiation emission, thereby ensuring the safety of on-site personnel and the public; and
- ISD costs a fraction of the cost of demolition and hence has great cost savings.
- Greenhouse gas reduction as a result of decreased use of heavy equipment in size reduction and dismantlement, rubble removal and transportation to disposal site.

In addition, the U.S. DOE development and deployment of the ISD approach has established a roadmap for ISD of other large nuclear facilities in the United States and around the globe.

Alternative solutions considered: (Other solutions to the issue/improvement opportunity considered prior to implementing the best practice?)

The alternative solution to ISD is demolition. Demolition is defined as the dismantlement of a facility followed by removal of the debris from the site and transportation to permitted burial facilities for disposal. With respect to nuclear facilities it also entails filling the space below-grade with grout or leaving the foundation intact.

Demolition is typically considered for non-hardened structures and structures with little residual contamination. However, demolition is not recommended for: hardened, concrete structures; structures that have significant residual contamination and/or radioactivity; sufficiently large structures where entombment has clear advantages over removal; and structures located at sites where institutional controls will be maintained.

While demolition is sometimes appropriate, the disadvantages of demolishing nuclear facilities are that it incurs risk of exposure to workers, the public, and the environment; generates waste; and is costly.

Additional Information:	
References:	Serrato, M.G., Langton, C.A., Gladden, J.B., Long, J.T., Blankenship, J.K., Hannah, G.R., Stubblefield, R.B., Szilagyi, A.P., "Considerations for Grout Formulations for Facility Closures Using *In Situ* Strategies," International Conference on Environmental Remediation and Radioactive Waste Management (ICM2010-40273), October 2010. Langton, C.A., Serrato, M.G., Blankenship, J.K., Griffin, W.B., "Savannah River Site R-Reactor Disassembly Basin *In Situ* Decommissioning," Waste Management 2010 Symposium (10499), March 2010. U.S. Department of Energy, "United States Department of Energy In-Situ Decommissioning of Large Nuclear Facilities: Pioneering Strategy for Global Application," Trifold brochure, August 2012. Negin, C., Szilagyi, A., Collazo, Y., Lee, P., Gladden, J., Seitz, R. and Wilson, M., 2010, "*In Situ* Decommissioning Moves Ahead," Paper 10345, Waste Management 2010 Symposium, Phoenix, AZ. DOE 2009, "DOE EM Strategy and Experience for *In Situ* Decommissioning", U.S. Department of Energy, Office of Environmental Management, Office of Engineering and Technology. Available at: http://www.em.doe.gov/EM20Pages/PDFs/ISD_Strategy_Sept_4_2009.pdf Bobbitt, J., 2010, "SRS R Reactor ISD Visualization and Planning Through Rapid Prototyping," Poster Session 68, WM Symposia 2010, Phoenix AZ. Wiersma, B., 2010. Assessment of the Potential for Hydrogen Generation During Grouting Operations in the R and P Reactor Vessels, SRNL-STI-2009-00639, Rev 2, May 2010, Savannah River Nuclear Solutions, LLC, Savannah River Site, Aiken, SC 29808. Stefanko, D., Langton, C. and Singh, D., "Magnesium Potassium Phosphate Grout for P Reactor Vessel *In Situ* Decommissioning (U)," SRNL-STI-2010-00333 (Draft), May 15, 2010 Savannah River Nuclear Solutions, LLC, Savannah River Site, Aiken, SC 29808.
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