DOE EM Project Experience & Lessons Learned
for
In Situ Decommissioning

Prepared By

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Contents

Acronyms vii
1. Introduction 1
1.1 Background 1
1.2 Purpose 2
1.3 Intended Audience 2
1.4 The Rationale for ISD 2
2. Executive Summary 4
2.1 Overview 4
2.2 Comparisons among ISD Projects 4
2.3 ISD Project Field Work Management 6
2.4 Variation from Initial Plans 6
2.5 Highlights of Lessons from within this Report 11
2.6 Appendices 15
3. Idaho National Laboratory CPP-601/640 Fuel Reprocessing Complex 17
3.1 Description and Conditions 17
3.2 Regulatory Approach and Compliance Summary 19
3.3 Project Description 20
3.4 Change from Original Planning 26
4. Hanford U Canyon 29
4.1 Background 29
4.2 Description and Conditions 29
4.3 ISD Project 33
4.3.1 Project Elements 33
4.3.2 Characterization 33
4.3.3 Reactivation 35
4.3.4 Equipment Placement 35
4.3.5 Removal of Tank D-10 36
4.3.6 Grout Campaign 38
4.3.7 Future Project Completion 40
5. Savannah River Site P and R Reactors 42
5.1 Description and Conditions 43
5.2 ISD Project 44
5.3 Changes from Original Planning 54
5.4 Future Considerations for Reactor Disassembly Basins at SRS 55
6. Small Reactor Projects 57
6.1 INL Small Reactor Project Descriptions 57
6.2 Heavy Water Component Test Reactor (HWCTR) Project Description 62
6.2.1 Description and Conditions 62
6.2.2 ISD Project 63
6.2.3 Secondary Waste Disposal 67
7. Management Insights 68
7.1 Health and Safety 68
7.2 Logistics 69
7.3 Project Planning Examples 70
7.4 Advance Preparation 71

8. Grout and Concrete Experience 74
8.1 Grout and Concrete Mix Experience and Specifications 74
8.2 Batch Plants 83
8.3 Preparation for Grouting 85
8.3.1 Management Center Tracking Tools 85
8.3.2 Closures and Seals 86
8.3.3 Fixtures, Devices, and Gadgetry 87
8.4 Core Drilling 88
8.5 Grout Delivery and Conveyance 90
9. Post-Closure Examples 94
9.1 U Canyon 94
9.2 Savannah River Site 95
10. References 98
Appendix A – Project Design Requirements 99
A.1 Purpose 99
A.2 Modification Traveler Elements 99
A.3 General Performance Requirements 100
A.4 Specific Performance Requirements 101
Appendix B – Reactivation at U Canyon 105
Appendix C – Engineering Planning at U Canyon for Equipment Placement 113
Appendix D – Example Checklists for Equipment and Grout Placement 117
D.1 Purpose 117
D.2 Example Checklist for Equipment Placement Prior to Grouting 117
D.3 Example Checklist for Grout Placement Readiness 119
D.4 Example Checklist for Grout Placement 120
Appendix E – Above Grade ISD Hazard Category Evaluation 121
E.1 Purpose 121
E. 2 Overview of Methodology 121
E. 3 Events Leading to a Release 122
E. 4 Results 122
Appendix F – Work Breakdown Structure 123
Appendix G – Project Risk Management Example 125
G.1 Purpose 125
G.2 Project Risks Considered 125
G.3 Contingency Calculation 127
G.4 Results of the Technical and Programmatic Risk Assessment 128
Appendix H – Use of Three-Dimensional Modeling 129
Appendix I – Canyon Grouting Status Display 131

Tables

Table 1 - Project Change Examples 7
Table 2 – P-Reactor and R-Reactor ISD Cementitious Materials 50
Table 3 – P-Reactor and R-Reactor Decommissioning Cost Summary ($millions) 54
Table 4 – INL Grout Mixes Used for Fill 75
Table 5 – P-Reactor and R-Reactor ISD Cementitious Materials 77
Table 6 – 105-P Reactor Vessel Low pH Grout Properties & Requirements 80
Table 7 – Calcium Aluminate Sulfate Grout Proportions 80
Table 8 – Modification Design Deliverables 100
Table 9 – Example of Canyon Equipment Tabulation 114
Table 10 – Example of the Recommendations for Canyon Cell Loading 116
Table 11 – P Reactor WBS to Level 8 123
Table 12 – P Reactor WBS below Level 8 123
Table 13 – P Reactor Residual Risk 125
Table 14 – P Reactor Contingency Results 128

Figures

Figure 1 – CPP-601/640 Prior to Decommissioning; CPP-627 in the Background 17
Figure 2 – Isometric View of CPP-601 18
Figure 3 – CPP-601 Operating Corridor Before & After Deactivation 21
Figure 4 – CPP-601 Process Makeup Deck after Tank Removal 22
Figure 5 – Sample Blisters in CPP-601 22
Figure 6 – Transite Panel Removal 23
Figure 7 – CPP-601 Grouting Operations 24
Figure 8 – CPP-640 Grouting Operations 25
Figure 9 – Structure Demolition 25
Figure 10 – CPP-601/640 ISD Interim End-State 26
Figure 11 – Sample Blisters in CPP-601 27
Figure 12 – Sample Blister Removal with Excavator 28
Figure 13 – U Canyon 30
Figure 14 – Canyon Cross Section 31
Figure 15 – Canyon Cell Arrangement 31
Figure 16 – Canyon Operating Deck 32
Figure 17 – Remote Technology for U Canyon Characterization 34
Figure 18 – Equipment on Canyon Deck 35
Figure 19 – Removal of Tank D-10 from U Canyon 37
Figure 20 – P-Reactor circa 2009 Prior to Decommissioning 42
Figure 21 – Graphic Representation of P-Reactor Building In Situ Decommissioning 45
Figure 22 – In Situ Decommissioning P-Reactor Area 46
Figure 23 – Stack Rubble Placed in Storage Tank Room 47
Figure 24 – P-Reactor Disassembly Basin Demolition 48
Figure 25 – Grouting of P-Reactor Disassembly Basin Water Evaporators 48
Figure 26 – Cutaway Model of the P Reactor Vessel 49
Figure 27 – Grouting of P-Reactor Vessel 49
Figure 28 - 105-R Reactor Disassembly Basin Areas 51
Figure 29 – Disassembly Basin Before and During Grouting 52
Figure 30 – Completed Grouting of the Disassembly Basin and Transfer Canal 52
Figure 31 – Forming the Reactor Vessel Cap and as Completed 53
Figure 32 – Typical Door Opening Sealing 53

Figure 33 – Construction of New Roofs 54
Figure 34 – Loss of Fluid Test Facility during Demolition 58
Figure 35 – Processing LOFT to 3 ft below Grade and the Lower Containment Vessel after Grouting 58
Figure 36 – Power Burst Facility before Demolition in 2008 59
Figure 37 – PBF End-State 60
Figure 38 – ETR Vessel installed in 1956, and during removal for disposal in 2007 61
Figure 39 – The Materials Test Reactor 62
Figure 40 – HWCTR circa 1960 and Prior to D&D 63
Figure 41 – HWCTR Schematic Cross Section 64
Figure 42 – HWCTR Containment Dome Lift and Demolition 65
Figure 43 – HWCTR Reactor Vessel Removal 65
Figure 44 – Transfer Coffin Grouting in the HWCTR Basement 66
Figure 45 – HWCTR Closure Cap 66
Figure 46 – Cross Section of the P Reactor Vessel 82
Figure 47 – Placement of U Canyon Grout Plant 84
Figure 48 – U Canyon Grout Plant 85
Figure 49 – Pumping Grout at U Canyon 90
Figure 50 – U Canyon Grout Addition Points 92
Figure 51 – U Canyon Engineered Barrier Components 94
Figure 52 – Zone Diagram for Project Design Requirements 102
Figure 53 – Existing Bridge Crane 107
Figure 54 – U Canyon Railroad Tunnel 111
Figure 55 – Equipment above Cells 8 and 32 114
Figure 56 – Cell 20 with Cover Block Lifted 115
Figure 57 – R Reactor 3-D Model 130
Figure 58 – U Canyon Cross Section 131
Figure 59 – Grouting Status Display Method at U Canyon 132
Figure 60 – Canyon Status Full Display 133

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Acronyms

Note: Acronyms and abbreviations for units of measure are assumed to be understood by the reader.

ACM	asbestos containing material
AOC	Area of Contamination
ALARA	As Low as Reasonably Achievable
ARRA	American Recovery and Reinvestment Act of 2009
ASTM	American Society of Testing and Materials
CAD	Computer-Aided-Design
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLSM	Controlled Low Strength Material
CMS/FS	Corrective Measures Study/Feasibility Studies
CPP	Chemical Processing Plant (facility prefix used at INL)
D&D	Deactivation & Decommissioning
D&E	Designation for the canal between the process and the disassembly areas at the P- and R-Reactors at SRS
DEQ	Department of Environmental Quality
DOE	Department of Energy
D&R	Deactivation and Remediation
DSA	Documented Safety Analysis
EM	Office of Environmental Management
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
ETR	Engineering Test Reactor
FHC	Facility Hazard Category
GFSI	Government Furnished Services and Information
GSF	gross square feet (building or facility size attribute)
HEPA	High-Efficiency Particulate Air (filter)
HM	Hot Makeup area
HWCTR	Heavy Water Components Test Reactor
HWMA	Hazardous Waste Management Act
ICDF	Idaho CERCLA Disposal Facility
ICW	Integral Crystalline Waterproofing
INL	Idaho National Laboratory

INTEC	Idaho Nuclear Technology and Engineering Center
ISD	In Situ Decommissioning
LFL	Lower Flammability Limit
LLW	low level waste
LOFT	Loss-of-Fluid Test Facility (also called the LOFT Reactor)
MAR	Material-at-Risk
MTR	Materials Test Reactor
NAMs	Negative Air Machines
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
NTCRA	Non-Time-Critical Removal Action
PBF	Power Burst Facility
PCB	polychlorinated biphenyls
PM	Process Makeup area
PPE	Personal Protective Equipment
PSOs	Program Secretarial Offices
RCT	Radiation Control Technician
RCRA	Resource Conservation and Recovery Act
RQs	Reportable Quantities
ROD	Record of Decision
S&M	Surveillance and Maintenance
SRNL	Savannah River National Laboratory
SRNS	Savannah River Nuclear Solutions
SRS	Savannah River Site
T&P	Technical and Programmatic
T&PRA	Technical and Programmatic Risk Assessment
TRU	Transuranic
WBS	Work Breakdown Structure
WIPP	Waste Isolation Pilot Plant

1. Introduction

1.1 Background

In situ decommissioning (ISD) is the permanent entombment[1] of a contaminated facility. Within this report "In Situ Decommissioning" and "ISD" are used for convenience in communicating the general concept of permanent entombment as the decommissioning end-state of a facility within the DOE Complex. ISD is not a revolutionary concept. Since the 1970s, the U.S. Nuclear Regulatory Commission (NRC) has recognized entombment as a decommissioning option.

A general description of an ISD project encompasses an entombed facility; in some cases limited to the below-grade portion of a facility. The envelope of the project may extend beyond the outer walls. The entombed portions of the facility are of robust construction, generally of reinforced concrete exterior that provides a migration barrier between internal contamination and the environment; with significant internal void spaces backfilled or grouted. The scope of entombment may include ancillary equipment and structures and may contain radioactive and hazardous materials and contamination within the facility and waste imported from outside the facility.

ISD is a permanent decommissioning end-state. The detailed physical completion conditions (the end-state) of the decommissioned facility is project-specific and in conformance with regulatory approval processes. The final condition is passive, meaning there are no requirements for ongoing operational systems or equipment within the decommissioned facility. Key to ISD is the "performance assessment" conducted with the use of pathway modeling to demonstrate the long term safety to the environment and to the public health. ISD projects are presumed to be under indefinite institutional control of the U.S. Government.

To institutionalize the ISD concept, the U.S. Department of Energy (DOE) published the report, *DOE EM Strategy and Experience for In Situ Decommissioning* [Ref: EM-2009]. That report formalized the definition of ISD for Departmental purposes, as: "In situ decommissioning is the permanent entombment of a facility that contains radiological contamination, with or without chemical contamination. Achievement of the entombed end-state is a result of established regulatory review and approval processes for decommissioning of DOE facilities."

Prior to the issuance of that report, DOE had completed its first major ISD project, the old Waste Calcine Facility (CPP-633) at Idaho National Laboratory (INL). At the time of the report, several smaller facilities at INL (i.e., Loss of Fluid Test Facility [LOFT]; Power Burst Facility [PBF]; Engineering Test Reactor [ETR], and Materials Test Reactor [MTR]) were in the process of undergoing ISD-like closure; their completions are described in this report. Other facilities at Hanford, INL, and the Savannah River Site (SRS) were in the latter stages of ISD planning and preparation for implementation.

The American Recovery and Reinvestment Act of 2009 (ARRA) provided the funding for the accelerated execution of the Hanford, INL, and SRS ISD projects; this was accomplished in 2010 and 2011. Among these successes, reported here, were the P-Area and R-Area reactors at SRS and the CPP-601/640 fuel processing facility at INL. The Heavy Water Components Test Reactor (HWCTR) at SRS for which the major radiological source term was removed (i.e., the reactor vessel and steam generators) also had remaining chemical hazards (primarily polychlorinated biphenyl, PCB) entombed by filling the below-

[1] In "entombment," facilities containing radioactive contaminants are permanently encased within in a structurally stable material, such as concrete, and appropriately maintained and monitored until the radioactivity decays to a level permitting restricted release of the property.

grade structure with grout. ARRA funding was also used to prepare U Canyon at Hanford for future ISD closure by clearing off the canyon operating deck and filling of the canyon cells with grout.

1.2 Purpose

The purpose of this report is to capture the considerable technical experience gained to date for implementation of ISD projects at DOE facilities. As current and projected budgets for the EM program indicate reduced and flat funding profiles for the foreseeable future, the potential exists for this institutional knowledge to be lost as the ramp-down of project staffing commences with the cessation of ARRA. EM's Office of Deactivation & Decommissioning and Facility Engineering tasked this summary report to record the experience while still readily accessible. The primary objective is to provide a reference for use by the DOE's federal project directors along with other federal and contractor managers and staff so they may effectively and efficiently plan and implement subsequent ISD projects.

This report does not address programmatic subjects, such as the variations among the three sites in the regulatory approach to select ISD as a preferred alternative; the interface with DOE's Waste Management Order, DOE O 435.1 [DOE-2007], and others. EM's strategy report [Ref: EM-2009] should be consulted for that information.

1.3 Intended Audience

This report in combination with the *DOE EM Strategy and Experience for In Situ Decommissioning* [Ref: EM-2009] is intended as a reference and resource for DOE Headquarters and Field management, project managers and engineers, regulators, stakeholders and others interested in ISD as a significant approach to solving the problem of decommissioning select contaminated facilities. Examples of use by various audiences include:

- EM Headquarters managers, field managers, and program secretarial offices up to the Office of the Under Secretary, as decision-makers for allocating limited cleanup funding, will find case studies of DOE's demonstrated experience and technical lessons learned in support of the ISD option for deactivation and decommissioning (D&D) projects.
- Project managers and project engineers, work planners and supervisors will have a technical manual of proven practices to identify opportunities and obstacles in their candidate ISD projects.
- Federal stakeholders such as Members of Congress, the Office of Management and Budget, the Defense Nuclear Facilities Safety Board, and State regulatory agencies can understand the benefits of an ISD option in terms of public and environmental safety and risk reduction and will understand the regulatory compliance and acceptance criteria afforded by ISD approaches.
- Agencies and organizations, such as the U.S. Environmental Protection Agency, U.S. Department of Transportation, U.S. Army Corps of Engineers, National Governors' Association, Energy Facility Contractors Group and Interstate Technology and Regulatory Council, among others, can gain an overall understanding of ISD as implemented by the DOE.
- The international nuclear community can learn about the details of the United States' ISD technical approaches for consideration at nuclear facilities abroad.

1.4 The Rationale for ISD

The EM program faces the challenge of decommissioning thousands of excess nuclear facilities, many of which are highly contaminated. Each project involves the complete deactivation, decommissioning, demolition and transport of the resultant debris of a sturdy, hardened facility and its enclosed contaminated equipment and process systems, including miles of pipelines and tons of contaminated structures. ISD offers, in many cases, the safest, timeliest, and most cost-effective decommissioning

solution. Consideration of ISD as an acceptable end-state to decommissioning is underscored by the following observations:

- Does it make sense (is it the optimal approach) to demolish some of DOE's sturdy, hardened facilities, only to transport the remains to a waste disposal site, which may be only a few miles away in some cases, and a few thousand miles away in others (for which the cost would be prohibitively high)? The environmental consequences of ISD are comparable or less than the alternative of complete removal.
- Is the ALARA (As Low As Reasonably Achievable) radiation exposure principle being practiced? Exposures to workers are typically lower for a less costly entombment option than for more expensive cleanout, demolition, and complete removal.
- Why not turn the liability of these facilities into an asset and use them for permanent placement of selected wastes? Long-term protection of the public and environment from the entombed radiation sources can be shown to be acceptable and meet regulatory requirements.
- Is costly complete demolition the best use of limited resources? From a purely budgetary perspective, resources saved by ISD can be used to achieve further risk reduction.

Of course not all facilities are amenable to ISD for a variety of reasons. These questions are addressed on a project-by-project basis through the regulatory approval process to determine the decommissioning end-state of a facility. The ISD option is feasible for a limited, but meaningful number of DOE contaminated facilities for which there is substantial incremental environmental, safety, and cost benefits versus alternate actions to demolish and excavate the entire facility and transport the rubble to a radioactive waste landfill.

The bases for selection of facilities as candidates for ISD are institutional, technical, and safety:

- Institutional feasibility relates to locations at DOE Federal sites where controls will be maintained for the foreseeable future, and ultimately by the Office of Legacy Management. Institutional feasibility will also tend to rule out urban and suburban locations, as well as other DOE sites where the government's ownership and management is clearly not indefinite.
- Technical feasibility relates to candidate facilities of robust construction, i.e., primarily some form of masonry, and sufficiently large so that there is a clear advantage to partially demolish and entomb in place compared with complete removal. Of note, ISD projects completed and planned to date have a significant fraction of their volume below grade, a factor that contributes significantly to technical feasibility.
- While all EM work is approached with procedures and controls to ensure the safety of workers and the public, ISD usually offers the safest decommissioning alternative. Entombment limits the radiation exposure to demolition teams because it drastically reduces the handling and movement of the material. Encapsulation in grout prevents migration of contaminants and radiation emission, thereby ensuring the safety of onsite personnel and the public.

The long-term risk to personnel and the environment associated with ISD must be shown to be within acceptance criteria applied to other permanent sources located at the same government site. Overall site composite risk analyses include low level waste (LLW) disposal facilities and entombed waste tanks.

2. Executive Summary

2.1 Overview

The American Recovery and Reinvestment Act of 2009 provided a rare opportunity to complete decommissioning projects of the magnitude and complexity described in this report within an aggressively specified time period. All projects were completed in two years. This accomplishment required extraordinary performance from contractor workers, engineers, support personnel and managers at the site, along with DOE managers at the field offices and headquarters. Environmental regulators played an important oversight role; public stakeholders supported the projects for the risk reductions achieved, jobs they created, and for reducing by an order of magnitude the amount the fiscal burden of the alternative demolition and waste management approach.

Many lessons have been gained through the ISD project completions by validating the technical and project management approaches as well as encountering many challenges, some of which were not anticipated. Much has been learned regarding logistical interfaces, materials sources and supplies, and practical technical requirements that can become unexpectedly problematic. These projects have quirks and nuances that could not be foreseen.

This executive summary compares projects and highlights some of the lessons learned. Detailed discussions and descriptions are provided in subsequent sections of this report. Managers, engineers, and planners of future projects will undoubtedly find points of interest to them throughout the report; some might be called lessons, but most will be insights of value to formulating and executing their projects.

In the overview, this report contains:

- Detailed description of three major and several minor ISD projects at Hanford, INL, and SRS.
- Topical sections that address management insights; experience with activities related to grout and concrete (those activities being a major aspects of all ISD projects), and post-closure configurations.
- Nine appendices that describe a variety of methods used at the ISD projects described in this report. These appendices provide examples of planning, engineering, and management tools that should be of use for future projects.

2.2 Comparisons among ISD Projects

ISD projects addressed in this report share similarities and have differences. In general, their scope has been for two types of facilities; namely, nuclear reactors and radioactive chemical processing facilities. The projects described here include:

- Two large reactors (P and R) and their ancillary facilities at SRS.
- Fuel processing facilities at INL (Buildings 601/640 and at Hanford (U Canyon).
- The below grade portion of several small reactors facilities at INL and one at SRS.

One observation drawn from these projects regards several small ISD projects. They are different from the large reactor ISD projects in that the reactor vessel and other components within the structures were removed and disposed of in the local CERCLA or low level waste disposal cell. At these projects the major sources of contamination was removed, leaving below grade small amounts of radioactivity with reasonably short half lives that will decay to inconsequential levels in hundreds of years. The technical difficulty, potential personnel exposure, and cost for these projects were sufficiently low such that

leaving the more significant source (the reactor vessel) was not warranted. Another driver for removing the significant sources of contamination is that these smaller facilities were all relatively isolated by distance from a much large closure area where the government can focus its management of ongoing institutional control.

Among the larger projects, there are significant differences at the three sites for the degree of structure that remains above ground. The differences are related to the initial height and robustness of above ground portions of the facilities. At INL, the structural design of the above-grade portions of the buildings is steel frame construction. It is not expected that such facilities would serve as good confinement over the long term. At INL, these were demolished to grade, with the exception of a small section of heavily shielded concrete process cells that were highly radioactive, with a vertical protrusion of about 18 ft (5.5 m) above grade. An earthen cover, primarily gravel, was placed over this portion; the entombed facilities will eventually become part of a much larger area closure with a permanent cap.

At both SRS and Hanford, a substantial part of the structure remains above the site ground level. The P- and R-Reactor buildings at SRS and part of the U Canon at Hanford are very robust, thick walled, reinforced concrete structures. The planned final configuration at these two locations varies as follows:

- At the P- and R- reactors the above grade portion of the reactor building will remain empty, projecting well above the surrounding area. In this case, the primary radiological sources are concentrated with the reactor vessel, which is below ground and has been grouted in place. A permanent cap has been installed above the vessel that is structurally designed to protect the vessel monolith from damage that might be caused by material falling from inside the buildings. The reactor buildings have been sealed and selected roofs have been modified with sloped concrete caps to prevent water intrusion.
- In contrast, the remaining above ground portion of the U Canyon will be filled with grout and a permanent cap will be placed over the entire area. The primary sources of contamination at the U Canyon is equipment that has been grouted within the below grade process cells. Grouting of the remaining part of the canyon is planned to be conducted as a future project.

Another difference of interest among the projects is that at U Canyon and the SRS reactors, equipment and materials associated with the facility mission that were outside of the major structure were moved inside to be grouted within the structure. This was not done at INL simply because there was not a substantial amount of such items. If anything, the cleanout of Buildings 601/640 at INL was considerably more substantial than at the other projects because of the amount of RCRA regulated hazardous materials that had to be removed.

The overall lesson from comparing these projects is that there can be substantial differences in the final configurations among ISD projects. These differences are driven by, but not limited to, original construction and configuration, the site characteristics, and proximity to other large closure projects (as described above for the small reactor projects). Ultimately, such decisions are driven by the CERCLA and RCRA process as applied to the project. Those planning ISD projects at other sites would benefit from reviewing the Engineering Analysis/Cost Evaluations and Action Memoranda for the projects described in this report to gain an awareness of the alternatives considered for each project.

2.3 ISD Project Field Work Management

The complexity of ISD project field work management is similar to a large construction project. However, ISD is made more challenging by: a) working in conditions of radiological and hazardous chemical contamination and materials, b) the need to remove or relocate heavy components, many of which are similarly contaminated, and c) work is conducted within existing, aging facilities with access and space constraints.

Like many industrial projects, ISD projects are complex and massive, involving activities that included contracting, engineering, mobilization, preparing the facilities for extended grouting campaigns, and conducting the grouting along with many parallel tasks; all of which follows prerequisite and ongoing characterization activities to define the physical condition that must be dealt with. Each project presented a huge logistical challenge due to the amount of materials, construction equipment, protective safety equipment, and other requirements, all with varied sources of supply and demanding critical timing to ensure availability when needed. As a result, many of the lessons learned are similar to management and execution of industrial projects.

The mix of construction type activities combined with the above described conditions provides the primary lesson of this report. The project staff that will manage, plan, and implement an ISD project must be prepared to conduct many tasks akin to construction projects in addition to the challenges of and activities for decommissioning a contaminated facility.

2.4 Variation from Initial Plans

A key lesson for all decommissioning projects is the need to be prepared for changes as implementation proceeds. The three major ISD projects reported here have required adjustments and changes because of factors such as the following:

- Details of execution that were not anticipated by those planning the project, in many cases because of information that can only be known as progress is made.
- Physical conditions discovered as the project proceeds that caused difficulties with regard to conduct of work, industrial safety, and /or radiological exposure.
- Inability to meet some individual commitments in environmental and regulatory compliance documents.

Table 1 presents some of these changes; they are described at greater length within the report.

Table 1 - Project Change Examples

Project	Subject	The Need for the Change	Change Description/Resolution/Lesson
U Canyon	Demolition Scope	The original planned final configuration of the U Canyon was that the upper part of the canyon building would be demolished to approximately the level of the canyon deck, and the remnants of the facility would be covered with an engineered cap. The driver for the change was a concern that there would not be sufficient cover material on site.	The record of decision was written with flexibility so as to not define how much of the canyon wall would be demolished. [Ref: UROD-2005] It was decided for future completion of the project to remove more of the upper structure and collapse the roof to the canyon deck. This will significantly reduce the height and footprint of the final engineered cap. The lesson learned is the wisdom in creating a ROD with such flexibility.
U Canyon	Structural Grout Specification	This relates to grout strength specifications. The project team's interpretation of a qualitative requirement from the U Plant ROD, specifically the ambiguous phrase "…flowable, structural grout with good compressive strength," resulted in the somewhat arbitrary specification of grout with a compressive strength of 1,500 psi (10 MPa) at 28 days. This significantly impacted the project schedule with regard to meeting quality control requirements that depended on the length of time for samples to develop the required strength.	Field demonstration tests found that grout with a lower strength (in the 500 to 800 psi [3 to 6 MPa] range) would be adequate for the intended purpose of void space fill; structural stability was not a requirement. Subsequent negotiations with regulators, backed by independent quality testing to confirm whether grout supplied in the field met the specifications, resulted in relief from this inferred design requirement. The change contributed to the ability to meet the project schedule. In this case, those setting the original specification for grout did not consider the effect on project execution. The lessons is that those translating approval documents into project requirements should understand the true need as well as the potential impact on the project.

Project	Subject	The Need for the Change	Change Description/Resolution/Lesson
U Canyon	Tank with transuranic isotopes (TRU).	Tank D-10 contains liquid and sludge contaminated with transuranic isotopes (TRU). The original plan per the record of decision was to remove any material greater than 100 nCi/g. The need for change was a result of being able to obtain better characterization of the tank contents once entry to the canyon was achieved. It was found that compared with the original characterization the tank contents were greater in volume, sludge fraction, and TRU amount. Removing the contents would have been a technically challenging, expensive, and time consuming project.	The revised approach included complete removal of the tank with contents in place and with absorbent added to stabilize the free liquid in the tank. A custom shielded container was designed and fabricated to facilitate removal and transport to the Central Waste Complex where it was placed in interim storage pending eventual treatment and packaging for shipment to WIPP. The lesson is that project planners need to be aware that important characterization results that are difficult to obtain prior to the start of work need to be verified as soon as possible.
P-Reactor	Use of Foam Grout	Filling the void beneath the floor of the transfer canal that runs between the reactor building and the disassembly basin became a problem caused by contamination and exposure from irradiated scrap on the canal floor. This prevented human access to conduct the core drilling in the canal floor for grout fill.	The original plan was to fill the void with grout to prevent collapse of the canal floor after grouting. To prevent canal floor collapse, part of the fill used in the transfer canal was revised from the flowable structural fills to a lightweight (foam) grout. The grout was specified to ensure the canal floor loading would be the same or less than when the canal was water filled. The lesson here is a standard one for decommissioning projects; that is, unexpected conditions will be encountered for which alternate methods will be needed.

Project	Subject	The Need for the Change	Change Description/Resolution/Lesson
P- and R-Reactors	Disassembly Basin Robustness	The demolition proved to be a major challenge because of the robustness of the structure and the presence of significant amounts of reinforcing steel. Even with the larger equipment than planned, demolition took almost twice as long to complete than estimated.	The Project Team recommended that for the remaining three reactors at SRS, the above-grade structure of the Disassembly Basin not be demolished. Rather, all external openings on the above-grade structure would be closed to allow filling the entire above-grade void with non-structural grout resulting in a monolith atop the grout-filled basin. The savings in avoided demolition labor greatly offsets the cost of the non-structural grout required to fill the above-grade void space. Other non-ISD projects have encountered similar demolition issues when there was insufficient knowledge and/or characterization of the strength of a facility's concrete material and rebar. The lesson is that for demolition of robust facilities, advance planning should ensure sufficient information has been gathered to well understand what will be required. If there is insufficient information from drawings and specifications (or doubts as to its validity), the concrete properties (e.g., with a core bored sample) and the rebar configuration and size should be determined.
INL 601/640	Process Cell Sample Blisters	Original planning was to remove all steel-encased lead "blisters" used for removal of sample containers. The blisters were attached to the outer walls of process cells in Building 601. Because of the lead, the intent was to remove the lead to satisfy RCRA requirements. However, removal of many blisters would have been extremely difficult because of tight access and radiation exposure to workers.	Blisters on grade level were removed by demolishing an exterior wall and using an excavator to rip out and handle the sample blisters. The exterior wall was re-formed and rebuilt with structural concrete. A waiver was obtained to leave the lead in place associated with the blisters in difficult to access locations. Worker safety and potential personnel exposure outweighed the benefit of removal. Again, the lesson here is a standard one for decommissioning projects; that is, unexpected conditions will be encountered for which alternate methods will be needed.

Project	Subject	The Need for the Change	Change Description/Resolution/Lesson
INL 601/640	Above grade process cell protrusions	The tops of three process cells that protruded above grade within Building 601 were planned to be demolished. However there were significant safety risks related to cutting equipment in cramped quarters and the associated personnel radiation exposure.	The Citizen's Advisory Board recommended that these cells be left intact to be grouted and integrated into the area cover system. The lesson here is that involved stakeholders with an interest in finding practical solutions can greatly benefit a project.

2.5 Highlights of Lessons from within this Report

A significant challenge of ISD from a project perspective relates to the differences when compared with conventional demolition. On the technical side, placement of huge volumes of grout and the many aspects of doing so are a dominant theme. This summary of lessons learned focuses on these two aspects.

In addition, embedded throughout this report are many other insights, specific problem solving experiences, tools, and methods; all of which constitute lessons learned. By describing these lessons within the context of the projects for which the experience was gained, this report will be most valuable to those initiating, planning and conducting future ISD projects.

Managers, planners, engineers, field personnel, and others with ISD project responsibilities should read through this report and select lessons of value for their objectives. Others who wish to gain a general idea of what it takes to carry out an ISD project should find the report of interest.

2.5.1 Contracting and Subcontractor Management

Companies that supply and install large quantities of grout and concrete are accustomed to major new build projects. In contrast, providing those services to entomb an existing radiological contaminated facility is out of the ordinary.

The overall lesson is to think very carefully as to how much work to subcontract versus self performance by the prime contractor. At SRS it was decided to self perform in those areas where radiological contamination and direct radiation were prevalent and to maximize subcontracting for other work.

Other than that, interfaces between self-performed work and subcontracted work should be minimized. For example, having two separate contracts, one for batch plant operation and a second for supply of raw materials for grout production resulted in the prime contractor being responsible for that interface. It would have been better to make the grouting subcontractor responsible for the batch plant operation and supply of raw materials for grout production. This ensures the production of grout is maintained at a level to support the placement schedule.

The technical interface with subcontractors is also very important. In one case of sealing penetrations within the building prior to grouting, the schedule was impacted because insufficient specificity was provided to the subcontractor for custom fixtures needed to seal penetrations. It was concluded that more details should be provided on design sketches for penetration sealing, that all penetrations should be reviewed for needed variations in fixtures, and that project engineers should work with subcontractors for selection and/or design of devices for sealing of penetrations prior to grouting.

2.5.2 Project Engineering/Technical Planning

Understanding in advance the important engineering and technical challenges is an important aspect of any decommissioning project. The following describe some specific to the ISD projects in this report.

Characterization Technology

Characterization of the ISD facilities can be difficult due to nature and extent of contamination, with many areas inaccessible due to physical constraints and/or safety and health concerns. Remote access technologies were important for enabling the collection of needed data; characterization of these facilities would not have been accomplished to the same degree without them.

Engineering Studies

The U Canyon experience showed that conducting the engineering studies well in advance of the actual need was beneficial in determining the best path forward. Six major studies were conducted; two that were especially important for support of the field work are as follows:

- At U Canyon, many of the systems, equipment and areas such as ventilation system, the canyon crane, railroad tunnel, electric power that were necessary to support the ISD preparation activities had been out of service and not maintained for a lengthy period of time. Due to the age of these systems, the availability of replacement parts was a concern. Engineers assessed the options for each function and recommend a path forward that minimized potential for schedule impacts. In cases for which refurbishment/reactivation of existing systems was chosen, essential components were identified and purchased in advance; provisions for back-up capability (i.e., mobile cranes, localized ventilation units) were included in the project planning.
- After its active mission, U Canyon served as a staging and storage area for a wide assortment of equipment from other canyon facilities. The majority of this material was placed on the canyon deck; items with higher radiation levels were randomly placed inside the process cells. The sizes and weights of this material range from very small (lbs) to very large (tons). Concern was raised as to whether this material could be placed in the process cells, which also contained original process equipment as well as the higher radiation level materials; and whether significant size reduction efforts would be required. By conducting a comprehensive engineering study utilizing still photographs and video footage, engineers were able to evaluate the sizes of the legacy items compared with the available space within the process cells to determine the exact placement location and orientation for each piece. They were able to ensure that all of the material stored on the canyon deck could be placed in the process cells. The upfront planning determined that size reduction was not required, and it eliminated the need for multiple handling of equipment and minimized the number of times the process cell cover block had to be removed. The results of the study were used in work planning and execution.

Understanding Structural Robustness

Demolition of the P and R Disassembly Basin buildings was very difficult because of the robustness of the structure and significant amounts of reinforcing steel. Even with larger equipment than originally planned, demolition took almost twice as long to complete than estimated. In hindsight, the above grade structures could have been grouted in place to function as closure caps for the basins. To do this, all the external openings in the above-grade structure would have been formed up to allow filling the entire above-grade structure with concrete resulting in a robust monolith atop the grout-filled basin. As it was, separate concrete caps had to be placed above the grouted basins. As a result, it has been recommended that the basin buildings at other reactors to be entombed be considered for the revised approach.

This observation is similar to what has been learned at other demolition projects; that investigation of the design and actual construction of reinforced concrete structures is an important part of technical planning. In addressing this, the first step is to retrieve design drawings. However, experience has shown that updating design drawings to as-built status often does not occur or may be unreliable for design features such as rebar size and placement. When understanding the structural robustness is important to planning and decisions, additional measures for characterization should be conducted to define the internal structure using methods such as core bore sampling, acoustic imaging, and radar.

Water and Liquids

Water management plans for radiological demolition areas must be in place early to ensure rain water and water used for dust suppression is contained and managed within the radiation boundaries. Plans for disposition of the water should also be in place early in the project to ensure proper disposition pathways. Sequencing of work on the structure should carefully consider the timing of closing roof drains and sewers to minimize water management issues.

Another lesson is that regardless of whether liquid piping systems are recorded to have been tapped and drained, piping may not be empty of liquid. This may be because complete draining can be difficult without destructively cutting into the system; which is not normally done during deactivation. Where critical to safety or grouting operations, overhead piping system should be assumed to contain residual liquids as part of work planning.

Grouting Impact on Ventilation

Proper ventilation of equipment (i.e., tanks, vessels, and piping) and general areas of facilities is necessary to ensure complete filling of these areas with grout. As the grout is being introduced into these areas, the air that is being displaced must have an exit pathway. Provisions for controlling the spread of contamination while the displaced air is exhausted are often required; for example with placement of filtered vents.

Visualization Planning Tools

Planning and work management can benefit from visualization methods and hardware. Three examples are:

- The use of 3 D physical model at the P and R reactors for sequencing grout placement. The models were also used to familiarize workers with the areas to be grouted. The models are described in Appendix H.
- A graphical method of display at the U Canyon displayed the status of grout lifts throughout the facility (which is enormous). This is shown in Appendix I.
- Sacrificial video cameras used to manage grout fill in selected locations that are difficult to view.

Avoid Implied Technical Requirements

The grout utilized for the filling of U Canyon does not provide any structural stability; it only provides void space fill. The use of the phrase "…*with good compressive strength"* as a descriptor of the grout fill in the 221-U-Plant Record of Decision (ROD) resulted in the project engineers' interpretation that the grout was to provide structural stability and therefore needed to meet specific design criteria. This led to the initial specification of grout with a compressive strength of 1,500 psi at 28 days, which proved to be unobtainable with the flowable mixes that were needed. Subsequent field tests demonstrated that grout with a lower strength (in the 500 to 800 psi range) would be adequate for the intended use. Relief from this implied design requirement was obtained with the regulators and independent quality testing conducted during placement.

The lesson applies more broadly in that awareness is necessary of technical statements that may be casually written in decision documents and they need to be carefully understood with regard to the real needs of the project.

2.5.3 Grout Logistics

One of the fundamental observations of ISD projects is the fact that the project is not just a matter of filling a structure with concrete. The experiences at the three sites clearly indicate the enormity of the challenge with regard to logistics and the coordination of many activities, but in particular for procurement, delivery, and placement of grout. Lessons related to the logistics of grout management include the following:

- All the ISD projects benefited from use of on-site batch plants. Experience at SRS suggests that batch plants be set up on site (even if temporary) should consist of new components to ensure compliance with the latest building codes. Procurement specifications need to delineate all applicable codes that the plant must satisfy.
- When utilizing off-site grout providers, consider a second source of grout (separate company/plant) to ensure or increase productivity.
- At the CPP-601/640 project batch plant capacity was not the limiting factor for grout supply to the project; the pump truck rate capacity was typically the critical element.
- The ISD projects required a significant number of trucks to transport the grout from the batch plant to the job site (i.e., 20 to 22 trucks per shift for the grouting of R Reactor at SRS). The project discovered that the watery consistency of the grout necessitated that the trucks not be filled to capacity so as to prevent spillage during transport. It was also discovered that traffic controls and dedicated haul routes were essential for safety and ability to meet schedule. The increased truck traffic also increased the wear and tear on the roadways and the maintenance of these roads needed to be included in the ISD project baseline.
- Flyash is an essential ingredient for grout that will readily flow through narrow openings and inside of pipes and ductwork ("flowable grout"). At Idaho and Hanford, the delivery of flyash was often on the work schedule critical path. The limited use of coal plants for electricity because of the plentiful availability of hydro power during the time when these projects were conducted meant that concentrated effort was needed to ensure sufficient flyash was delivered when needed.

2.5.4 Grout Placement

The grout formulations used for the INL, Hanford, and SRS ISD projects were designed to fulfill three basic needs: 1) grout for bulk filling of spaces, voids, and tanks; 2) a flowable grout for filling pipes, and 3) a more rigid concrete mix (i.e., with coarse aggregate) for plugs, barriers, replacing walls removed for convenience, and structural reinforcement. Because of the flowable nature of grout, it can be introduced with relative ease into the "nooks and crannies" of most structures. Engineered placement, (i.e., controlled fill in pre-designed lifts) ensured adequate filling of void spaces.

Placement of grout requires systematic attention to details. A few of the lessons within this report that stood out in particular are as follows:

- At INL grouting of piping was accomplished either by directly filling specified pipe runs or by opening the pipe at specified locations to allow grout to enter during filling of the general area. When piping was filled directly, the amount of grout needed to fill a particular pipe run was pre-calculated, and if the operation exceeded this amount by 10 percent, filling was stopped to find out why. The longest pipe run grouted in a single operation was about 100 ft (30 m) based on the configuration and impeding components, such as valves, within the system.

- A lesson learned at U Canyon during grouting of the Hot Pipe Trench, where grout did flow through the inverted P Traps escaping into the ventilation tunnel, was to ensure all possible grout flow paths were identified and appropriate barriers are installed prior to grout addition. And if at all possible, the effectiveness of the barrier with "test pours" should be verified before completely filling the area.
- Core drilling was necessary to provide access ports for the introduction of grout into various areas at SRS and Hanford. The U Canyon Project Team suggested that the use of remote technology should be considered for core drilling to reduce personnel exposure and to free up labor resources for other tasks.
- The ISD projects at SRS discovered that concrete mixes with Integral Crystalline Waterproofing additive tend to be difficult to work with because: 1) of the narrow ambient temperature range required for placement, 2) they are prone to setting at an accelerated rate, and 3) the post placement curing requirements are onerous. Specifying the use of ICW should be minimized.
- The heat generated from the hydration of cement in the grout can potentially raise the temperature of a large grouted mass over 100 degrees if not controlled. High temperature during grout curing can thermally stress the grout mass and the reinforced-concrete canyon structure. Temperature induced expansion of the grout can cause cracking of the concrete structure surrounding the grouted voids. At U Canyon, temperature was controlled by limiting the lift volumes, and sequencing the filling of process cells to prevent damage to the curing grout and canyon structure. It is necessary to ensure that concrete curing is performed in accordance with applicable codes and takes into account prevailing weather conditions.
- Grouting of U Canyon process cells was completed in lifts. Concerns over the amount of heat generated during grout curing drove the Project to specify 48-hour interval between lifts; however, temperature monitoring of early pours showed that 24 hours was sufficient for the heat to dissipate to acceptable levels.

2.6 Appendices

The following are abstracts of the nine appendices that describe a variety of methods used at the projects reported herein:

- Appendix A – Project Design Requirements addressed functional and performance requirements such as waivers, safety basis strategy, design input guidance, and design review for the ISD project.
- Appendix B – Reactivation at U Canyon illustrates how reactivation of a facility's systems and other operational features was evaluated.
- Appendix C – Engineering Planning at U Canyon for Equipment Placement contains the results of a comprehensive engineering study for planning the placement of equipment within the U Canyon into cells and trenches within the canyon prior to grouting.
- Appendix D – Example Checklists for Equipment and Grout Placement were used for the work packages for placement of each individual piece of equipment initially residing on the canyon deck into the process cells.
- Appendix E – Above Grade ISD Hazard Category Evaluation describes the approach taken at SRS to understand the consequences and provide an analysis of an accident in the remaining above-ground structure.

- Appendix F - Work Breakdown Structure used for the P Reactor project.
- Appendix G - Project Risk Management provides an example of a project risk management analysis for an ISD project.
- Appendix H - Use of Three-Dimensional Modeling at SRS shows how this approach can be used for planning, work management, and providing workers with a realistic view of work locations.
- Appendix I - Canyon Grouting Status Display is an innovative status display method developed at U Canyon.

3. Idaho National Laboratory CPP-601/640 Fuel Reprocessing Complex

The Fuel Reprocessing Complex, located at the Idaho Nuclear Technology and Engineering Center (INTEC) at the Idaho National Laboratory, consisted of three adjacent and interconnected buildings: CPP-601 Fuel Reprocessing Facility housed the primary mission, supported by CPP-627 Remote Analytical Facility, and CPP-640 Headend Processing Plant. Figure 1 shows these facilities.

CPP-601 was built in 1953 and was used for reprocessing spent nuclear fuel. The facilities were collectively named the Idaho Chemical Processing Plant (ICPP) prior to designation as INTEC. Operations included fuel dissolution, separation, chemical makeup and transfer, and liquid waste receiving processes. Work included the dissolution of spent fuel with subsequent solvent extraction processes to separate the recoverable uranium from the other highly radioactive waste materials. The uranium reprocessing mission for CPP-601 was terminated in 1992, and no more uranium was introduced into the reprocessing system after that time.

Figure 1 – CPP-601/640 Prior to Decommissioning; CPP-627 in the Background

3.1 Description and Conditions

<u>CPP-601</u>

Figure 2 is an isometric view of the 83,600 gross square feet (GSF) (7,800 sq m) CPP-601. It is essentially rectangular, 244 ft by 102 ft (74.4 m x 31 m) footprint, and consists of six levels mostly below-grade. The lower levels contain 25 process cells (most of which are about 20 ft by 20 ft by 28 ft high [6 m x 6 m x 8.5 m]), as well as numerous corridors and auxiliary cells that house equipment and controls. This figure is of use for later descriptions of the grouting sequence, the location of the deep tanks (at the bottom), and the tops of Cells P, Q, and R that project above ground level.

The floor and part of the walls of each cell are lined with stainless steel and most of the equipment is stainless steel. The in-cell equipment controls are located in an operating corridor that runs the length of the building between the cells. A service (piping) corridor is located below the operating corridor and a cell access corridor is located below the service corridor. Sampling and cell ventilation corridors are located outside the rows of cells. The lower levels are made up of heavily reinforced, 1.5 ft thick (0.5 m) exterior building walls and up to 5 ft thick (1.5 m) interior cell walls providing shielding for the process cells. The CPP-601 Deep Tanks System is located in the lowest level of Building CPP-601 and consisted of four 4,500 gal (17,000 l) stainless steel tanks located in two stainless-steel-lined concrete vaults, approximately 57 ft (17.4 m) below grade. This system collected liquid waste generated from separation processes performed in CPP-601. Process systems in CPP-627 and CPP-640, as well as other facilities,

also sent waste to these tanks. These four tanks, along with the ancillary piping, will be closed in place under the landfill closure plan described in Section 3.2.

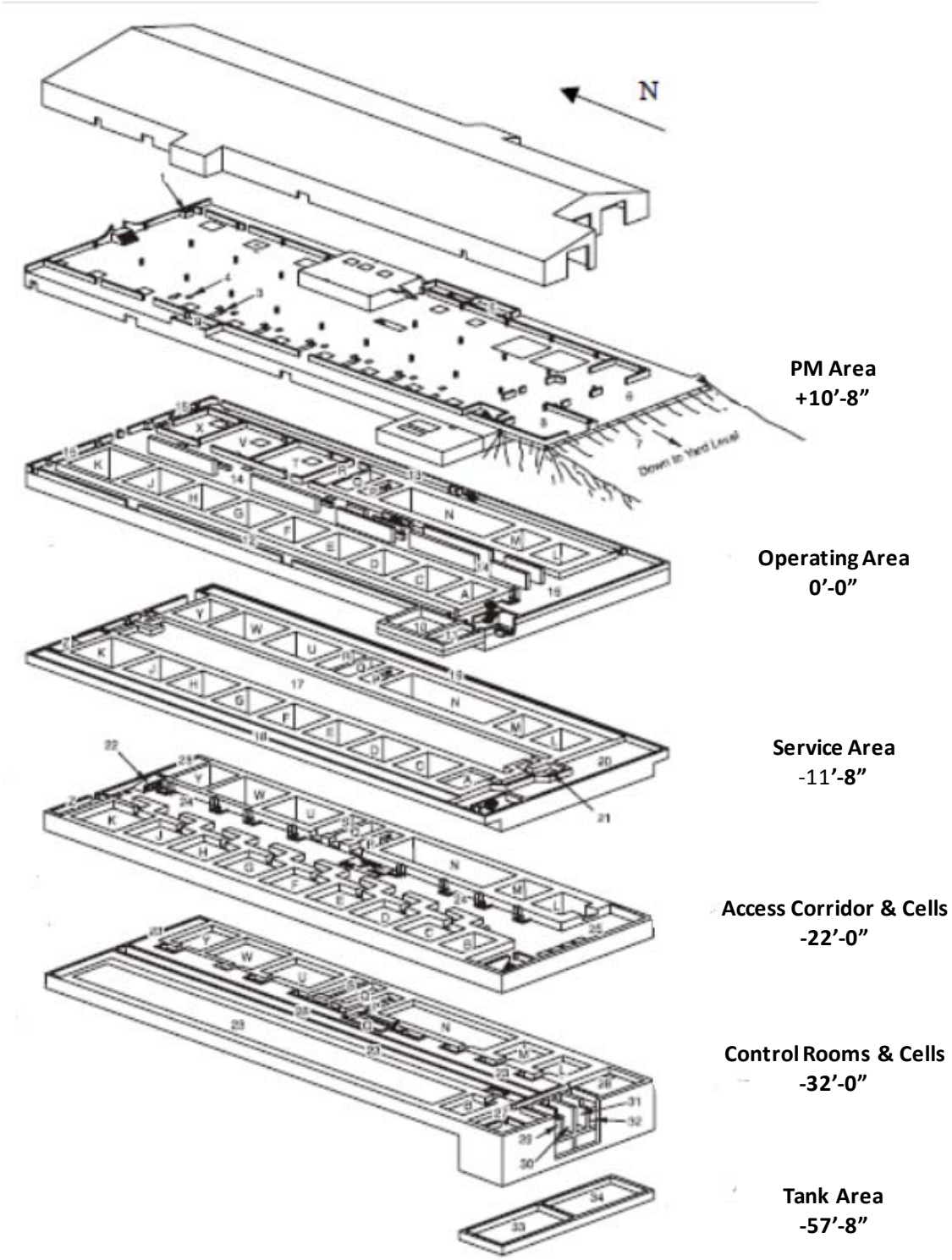


Figure 2 – Isometric View of CPP-601

The top level of CPP-601 is known as the Process Makeup (PM) area. The PM area is an open area that is not partitioned and was used to transfer fuel elements to the process equipment. It contained chemical makeup and storage systems that included tanks, pumps, filters, agitators, related instrumentation, and miscellaneous support equipment. Process Cells P, Q, and R extended approximately 8 ft (2.4 m) above the floor of the PM area. The PM walls and roof consist of structural steel framework covered with insulated Transite panels that are made of asbestos.

The hazards associated with CPP-601 were alpha and beta contamination, lead, asbestos, residual acids (primarily hydrofluoric acid) and many solvents.

CPP-640

The CPP-640 Headend Processing Plant was constructed in 1961 to support research and process development for the uranium reprocessing mission in CPP-601. The CPP-640 facility included the Space Nuclear Propulsion Program (Rover) fuel dissolution process and the electrolytic dissolution process. The Rover facility provided a headend system for reclaiming uranium from both unirradiated and irradiated Rover fuels. The electrolytic dissolution process was specifically used for the recovery of uranium from fuels with stainless steel cladding. The aqueous solution from these processes was then sent to CPP-601 to extract the uranium. Processing of fuel in CPP-640 ended in June 1984. Following the final process operations in each of these buildings, process vessels and process lines were rigorously flushed numerous times with acid and water to reduce radiological contamination and to support the accounting of special nuclear material.

CPP-640 was a five level (mostly below-grade) 17,600 GSF (1,600 sq m) structure with a 66 ft by 89 ft (20 m x 27 m) footprint that is located west of and adjacent to CPP-601. The facility contains two shielded waste-collection tank vaults at the lowest level of the building, five shielded test cells at the mid-level of the building, and an open hot makeup (HM) area with space for chemical makeup equipment and access to the cells through roof hatches at the upper level. The process cell walls are typically 3.5 ft thick (1 m) reinforced concrete. The cell floors are lined with stainless steel that extends up the walls to a height of 4.5 ft (1.4 m). The HM area was formerly used for mixing process chemicals, decontamination solutions, or other chemical solutions used in the CPP-640 process cells. A major modification in the late 1970s added the shielded mechanical handling cave within the HM area. The handling cave has reinforced concrete walls and ceiling; it houses the charging chute for the graphite fuel rods that were handled remotely and dropped into a fluidized bed burner to separate the uranium from the graphite matrix of the Rover fuel. The HM area roof consists of a structural steel framework covered with insulated Transite panels that contain asbestos. Most of the HM area process chemical makeup vessels and piping had been removed prior to the ISD project.

The hazards associated with CPP-640 are the same as those for CPP-601.

3.2 Regulatory Approach and Compliance Summary

The INL Fuel Reprocessing Complex at INTEC, comprised of buildings CPP-601, CPP-627, and CPP-640, is decommissioned under a multi-phased Hazardous Waste Management Act (HWMA)/Resource Conservation and Recovery Act (RCRA) Landfill Closure combined with CERCLA non-time-critical removal actions (NTCRA) ; see [Ref; INL-2008].

Building CPP-627 was removed in 2005 as a CERCLA action. The building structure was demolished to grade; sub-grade areas, such as the valve pits and Multi-Curie Cell well were filled with concrete; and a concrete pad was poured over the slab area to prevent water infiltration. This pad abuts CPP-601 on the east side and CPP-640 on the south.

A difference between this project and the SRS and Hanford projects, described in later sections of this report, is the RCRA element. Specifically, the CPP-601 Deep Tanks System was closed as a landfill because of: a) the presence of chemically-contaminated, abandoned isolated piping runs that could not be flushed; b) waste remaining in the tank system at closure; and c) lead that was impractical to remove, all resulting in hazardous constituents left in place. Buildings CPP-601, CPP-627, and CPP-640 also have radionuclide contamination and lead that was not removed during decommissioning.

The previously completed CPP-627 and the CPP-601/640 completed in 2011 were CERCLA actions that have been integrated with the CPP-601 Deep Tank System HWMA/RCRA landfill closure into a single CPP-601/627/640 "landfill." Achieving regulatory compliance consists of two landfill closure phases. Phase 1 includes actions that have been completed; Phase 2 will be the future establishment of a final end state. (Note these closure phases are different than the ISD project phases described in Section 3.3.)

Phase 1 of the landfill closure consisted of:

- In-situ activities that included the decontamination and grouting of the CPP-601 Deep Tanks System. The Idaho Department of Environmental Quality (DEQ) accepted the Phase 1 closure certification of this system in February 2010.
- Following the certification, the remaining internal void areas of CPP-601 and CPP-640, including vessels and piping, were grouted to the Process Makeup/Hot Makeup deck level, thus creating a monolith. These activities constituted decommissioning of CPP-601 and CPP-640, completed in 2011 as a CERCLA non-time-critical removal action, which is described in the balance of this section.
- Phase 1 post-closure actions installed an interim HWMA/RCRA cover over the monolith; the cover consists of a grout layer over the horizontal surfaces to promote drainage. A sloped concrete pad was poured over the CPP-627 building footprint to become part of the CPP-601/627/640 landfill.

Phase 2 of the landfill closure includes the installation of an earthen weather protection barrier system over the entire RCRA landfill area. The earthen weather protection barrier is sloped to promote drainage and protect the grout layer from freeze/thaw cycling.

The final end state for the CPP-601/627/640 landfill is expected to be integrated with final end states for the surrounding northern INTEC facilities through coordination of the HWMA/RCRA and CERCLA programs. These facilities potentially include the Tank Farm Facility, Calcine Bin Sets, New Waste Calcining Facility, Process Equipment Waste Evaporator, Integrated Waste Treatment Unit, and other miscellaneous facilities. . A Composite Analysis considering the Performance Assessments of all sources will impose the conditions for closure and post closure. This final end state was originally scheduled for 2035, but with the acceleration of the project with ARRA funding, this closure may occur as early as 2017.

3.3 Project Description

Overview - As part of the CPP-601/640 NTCRA, the interior of vessels, interior of large piping and ductwork, process cells, and below-grade internal void areas were filled with grout to create a solid monolith. CPP-601/640 was demolished to the top of the Process Makeup (PM) deck, and everything below the PM deck was grouted. The top of the PM deck sat about 10 feet above grade. The top 8 ft (2.4 m) of the grouted P, Q, and R Process cells were not removed. They sit atop the PM deck. As a result, the top of the concrete monolith is about 10 feet (3 m) above grade, the P, Q, and R grouted process cells stick up above that, and an earthen cover was built over the whole thing. The above-grade

portions of the building superstructure were demolished and removed, including all of the building components above the process cells.

A layer of grout was placed over the horizontal surfaces of the CPP-601/640 monolith. This grout layer was sloped to provide drainage and, along with the CPP-627 pad, will serve as the interim HWMA/RCRA cover (Phase 1 post-closure period) providing precipitation-infiltration coating for the horizontal surfaces of the CPP-601/627/640 monolith. The earthen weather protection barrier was placed over the entire monolith after the grout layer was installed. The major work phases of the CPP-601/640 ISD project are as follows.

Work Phase 1 - Facility Cleanout. At the completion of the fuel reprocessing mission in CPP-601/640, deactivation operations focused on special nuclear material de-inventorying to support material accountability. Process lines and vessels were flushed with multiple flush evolutions to remove and collect any residual uranium holdup. The contamination remaining in the systems at the start of final decommissioning met RCRA limits and was within the assumptions of the performance assessment. In subsequent preparation for ISD closure, the process cells, and auxiliary/make-up system tanks and piping were flushed to reduce residual materials to specified RCRA concentration limits for organics, metals, solvents, etc.

In some cases, systems that contained various acids and solvents and certain identified radiological “hot spots” were removed from the facility. The majority of the chemical support equipment, which was located on the Process Makeup (PM) Deck, was removed. A total of 114 tanks/vessels were removed from the PM Deck. Equipment and piping were also removed from the facility corridors, primarily to ensure complete grout fill of these areas. Sections of the building ventilation ductwork were removed to ensure the ducts would be properly filled with grout along with the corridors. The equipment removed from the facility was disposed in the onsite LLW disposal cell. Equipment within the remaining process cells was left in place. Figure 3 and Figure 4 show some of the cleanout results.

Figure 3 – CPP-601 Operating Corridor Before & After Deactivation

Figure 4 – CPP-601 Process Makeup Deck after Tank Removal

Work Phase 2 - Abatement. In preparation for closure of CPP-601/640, the facility was stripped of RCRA hazards that included asbestos containing material (ACM), lead, mercury, and process chemicals such as acids and solvents. All accessible lead was removed, including lead shot from around shield windows, lead sheets used for shielding between floors, lead floor plugs, lead pipe shields, and lead bricks. In total, approximately 280 tons (250 tonnes) were removed from CPP-601 and 40 tons (36 tonnes) were removed from CPP-640.

CPP-601 contained 10 sample blisters; named as such because of their protrusion from the side of the process cells; see Figure 5. The blisters are constructed with lead encased in steel (resulting in a very heavy object) with the largest being 28 ft (8.5 m) long, and attached to the outer walls of the process cells to support removal of sample containers.

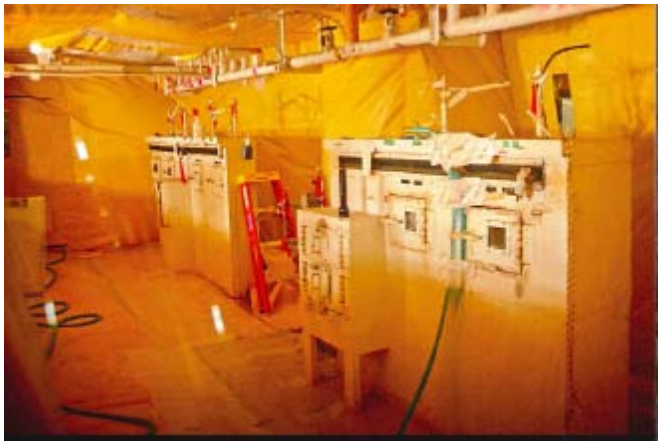


Figure 5 – Sample Blisters in CPP-601

Most of the sample blisters were contaminated with residual U-235 contained within sample vials and sample needles. Because of their weight, radiation, and placement in cramped locations, removal of the sample blisters turned out to be problematic from both a schedule and personnel exposure standpoint. For these reasons, the project was granted a waiver to allow leaving in place the lead associated with these heavy components.

Prior to demolition of the above-grade structure, all Transite panels (containing asbestos) were manually removed from the walls and roof of the steel frame structure as shown in Figure 6. Each panel weighed approximately 150 lbs (70 kg) and was removed following standard ACM removal protocols. A

total of approximately 72,000 sq ft (6,700 sq m) of panels were removed from CPP-601 and 19,000 sq ft (1,800 sq m) of panels were removed from CPP-640.

Figure 6 – Transite Panel Removal

Work Phase 3 - Void Space Grout Fill. ISD closure of CPP-601/640 included filling all levels below the PM Deck with grout including the remaining vessels and piping and encapsulating the residual contamination within the building. The grout serves no structural purpose; it is only intended to fill void space and immobilize contamination. The robust concrete walls of the structure provide the integrity.

A very important point in the RCRA closure plan was that grouting did not have to be done for pipes less than 4 inches (10 cm) in diameter or tanks/vessels less than 50 gallons (190 l) in volume. Based on calculations regarding what could be accomplished, a target for the grout fill was to leave no more than 5 percent void within the total building volume. The calculations for what would be difficult to fill were based on the amount of piping with a diameter less than 4 in (10 cm) and the number of vessels less than 50 gal (190 l) in volume.

Three grout mixes were used for this project: a sand mix was used for filling tanks, voids, and general areas; a flowable fly ash mix was used for filling pipes; and a small amount of structural concrete was used to replace the wall that was removed to provide excavator access for removal of the sample blisters located at grade level.

In preparation for grouting, pipe penetrations through exterior walls were cut and sealed. Utilities to the building were isolated and terminated. Bulkheads were built where doors on the exterior walls had been removed. Openings between CPP-601 and -640 were sealed by the formation of short wall sections that would create a solid monolith when these areas were filled with grout.

Grouting of piping was accomplished either by directly filling specified pipe runs or by opening the pipe at specified locations to allow grout to enter during filling of the general area. When piping was filled directly, the amount of grout needed to fill a particular pipe run was pre-calculated, and if the operation exceeded this amount by 10 percent, filling was stopped to find out why. The longest pipe run grouted in a single operation was about 100 ft (30 m) based on the configuration and impeding components, such as valves, within the system.

Grouting of general areas started at the lowest level and proceeded up. Grout pours were typically in 6 ft (2 m) lifts, alternating between filling the vessels and the area around them to prevent floating of vessels. The process cells were completely grouted before the corridors and the remainder of the building volume. Cell doors were sealed and reinforced with planks attached with HILTI anchors prior to grout filling.

Figure 7 shows some typical grout placement pictures in CPP-601. Pictured from left to right are: 1) pouring grout into the service corridor through the operating corridor, 2) grout visible in the stairway from the operating corridor to the service corridor below, and 3) grouting in the deep tank vault. Figure 8 shows examples in CPP-640.

Figure 7 – CPP-601 Grouting Operations

Referring to Figure 2, the grouting operation began with N-Cell. In succession, grouting was then accomplished for the remaining 24 cells, the Deep Tank Vault, the Control Room, the Access, Service, Operating, West and East Sample Corridors and finally the Vent Tunnel. Grouting activities in CPP-601 began in April 2009 and were completed in June 2010; a period of 15 months. An approximate total of 19,700 cu yds (15,000 cu m) of grout was used in CPP-601. A total of approximately 2,100 cu yds (1,600 cu m) of grout were used in CPP-640 to fill Cells 1 through 5, the Hot and Cold Tank Rooms, the Control Room, the Access and Operating Corridors, and the Vent Tunnel.

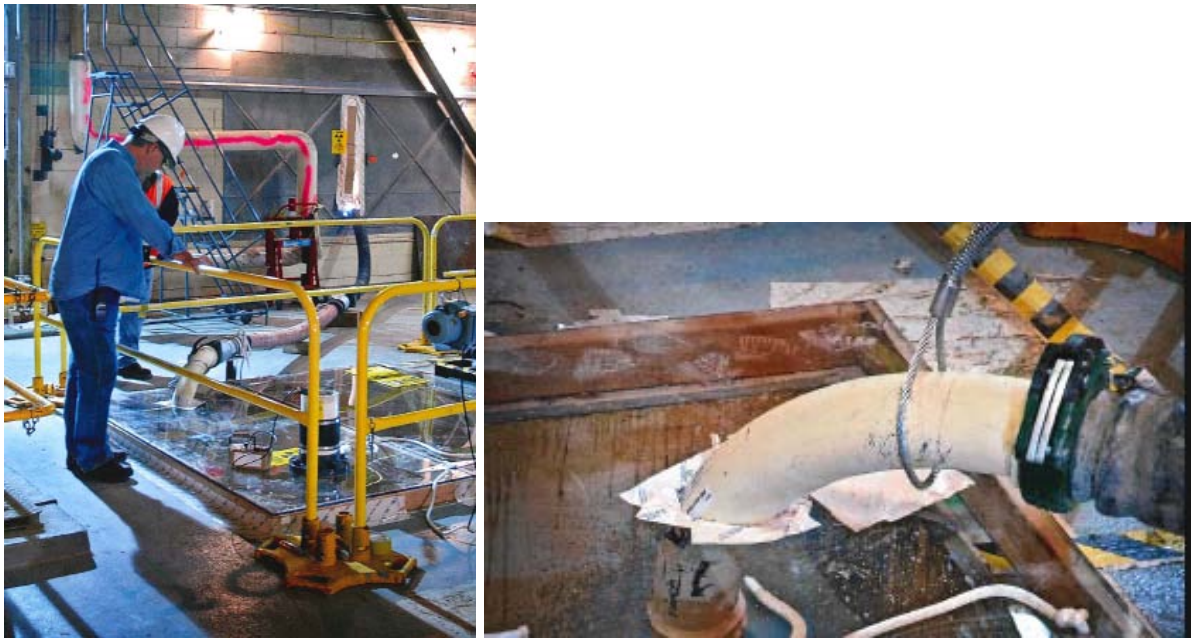


Figure 8 – CPP-640 Grouting Operations

Work Phase 4 - Removal of Above-Grade Structure. Buildings CPP-601 and CPP-640 were partially demolished to approximately 11 ft (3.4 m) above grade in most areas, leaving process cells intact and exposing the resulting concrete monolith (i.e., grouted lower levels). Building CPP-601 consisted of six levels with five located below grade. The uppermost level, the PM area, which was constructed of structural steel with Transite panels, was removed (Figure 9) to support the final configuration of the site closure. Similar treatment was applied to Building CPP-640, which had five levels with three located below grade. Demolition was conducted using traditional methods that employed the use of excavators fitted with hydraulic shears and concrete breakers. The demolition debris was disposed in the onsite LLW disposal cell.

Figure 9 – Structure Demolition

Original planning to remove of the tops of Cells P, Q, and R in CPP-601 that extended a few feet above grade (see Figure 2), was changed. Leaving these cells intact was the result of a Citizen's Advisory Board recommendation to reduce worker risk for removing vessels and piping in this area; the safety risks were personnel exposure and cutting equipment in cramped quarters.

Work Phase 5 - Interim Earthen Cover. After the below-grade void spaces were successfully filled with grout and the above-grade portions of the frame super structure were removed, a layer of grout was applied over the remaining above-grade structure monolith to minimize the migration of liquids through the facility. This grout layer, placed on the horizontal surfaces of the remaining structure is sloped to prevent run-on and run-off from eroding or otherwise damaging the monolith below. Openings (i.e., pipe penetrations, hatches, doorways, etc.) in the remaining vertical sections of the structure were sealed with short wall sections and grout or plugs as necessary to seal off the structure. A layer of gravel, approximately 3 ft (0.9 m) thick, was placed over the monolith and shaped with a 3:1 slope to provide adequate drainage away from the monolith area. The gravel was applied over the monolith in lifts and compacted to achieve the desired slope and minimize long-term lateral displacement and subsidence. The resulting interim cover is shown in Figure 10; the above-grade monolith is a result of leaving in place the tops of three cells described above. Eventually all will be covered with the area cap.

Figure 10 – CPP-601/640 ISD Interim End-State

Project Cost and Schedule

With the ISD closure approach and the acceleration of the project with ARRA funds, it is judged that 2.5 years and approximately $110 million of the original estimate was saved. The original D&D baseline for the facility included a lot of equipment removal, including full strip-out of the process cells, and partial structure demolition such that very little contamination source term would have been left behind. The ISD concept and the HWMA/RCRA landfill closure approach combined with CERCLA actions provided a significant savings in both cost and personnel exposure. Contractual changes resulting from acceleration because of ARRA led to a change in the final configuration. Originally the above grade structure would have remained after grouting, to be demolished later. The change combined demolition, and interim earthen cover and placement later of the final cap above the grouted monolith. This has the effect of achieving area closure well before the prior baseline plan of 2035.

3.4 Change from Original Planning

CPP-601 contained 10 sample steel-encased lead blisters (see Figure 11) that are attached to the outer walls of some of the process cells to support removal of sample containers. The majority of the sample blisters are located in the Service Corridor Shielded Waste Trench and the West Vent Tunnel. Most of the sample blisters were contaminated with U-235 residuals contained within sample vials and sample needles.

Due to the significant quantity of lead associated with these sample blisters, the original intent of the project was to remove the lead to satisfy RCRA requirements. Removal of the sample blisters had, however, proved to be problematic from both a schedule and personnel exposure standpoint. The first attempt was to remove one manually (i.e., hands-on, brute force) from the grade-level, but this proved

to be highly inefficient and very labor intensive due to the weight of the object and the cramped working environment; and because of the length of time required for complete removal, personnel exposure was higher than acceptable. A second attempt was made to remove a sample blister from the lower level utilizing a diamond wire saw in an effort to reduce the degree of labor intensity. This approach however proved to be very costly and inefficient.

Figure 11 – Sample Blisters in CPP-601

The project was able to remove the remainder of the sample blisters on grade level by demolishing an exterior wall and using an excavator to rip out and handle the sample blisters (Figure 12). Prior to demolition of the exterior wall, a heavy coating of fixative was applied to all surrounding interior surfaces. After the sample blisters were removed, the exterior wall was re-formed and rebuilt with structural concrete.

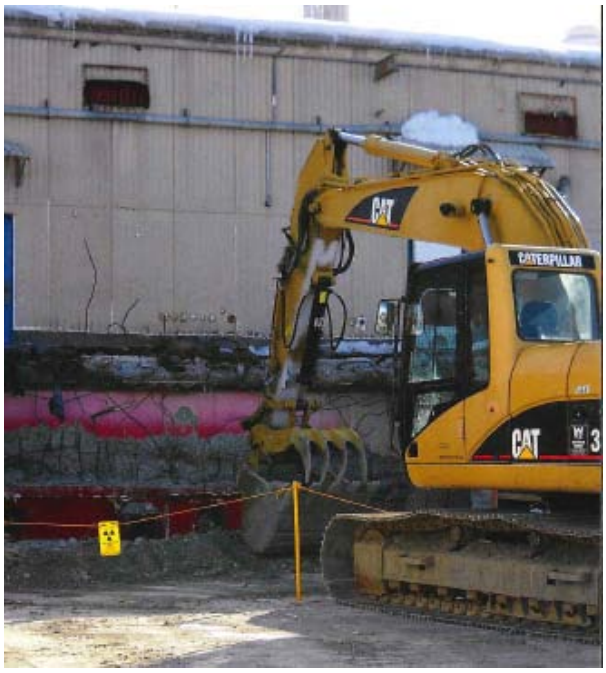


Figure 12 – Sample Blister Removal with Excavator

Because of the difficulty and many physical challenges associated with the removal of the sample blisters from the lower inaccessible levels, the project requested and was granted a waiver to allow leaving in place the lead associated with these heavy components. The benefit of removing them was out-weighed by the impacts on worker safety and personnel exposure. Closure of the CPP-601/627/640 Complex under a HWMA/RCRA landfill closure plan allowed this residual lead to remain in place. Lead in more accessible locations was removed.

4. Hanford U Canyon

4.1 Background

Located within the 200 West Area at the Hanford Site in Washington State, the 221-U Process Canyon Building (aka U Canyon) is one of three nearly identical Hanford Site chemical separations plants constructed from 1944 through 1945 to support World War II plutonium production. A total of 5 canyon facilities were constructed at Hanford.

Along with B Plant and T Plant, the U Canyon was built to extract plutonium from fuel rods irradiated in the Hanford Site production reactors. However, the U Canyon was never used for this purpose due to processing successes at REDOX, B- and T-Plants. Instead, the U Canyon was used to train B-and T-Plant operators until 1952. At that time, it was converted to include a uranium recovery process for waste from other canyon facilities. Process equipment was transferred for storage from other canyon facilities; contamination on and within the transferred equipment were remote-handled materials and materials contaminated with transuranic (TRU) isotopes. The U Canyon was placed in standby in 1958, and was subsequently retired.

In 1996, the DOE initiated the Canyon Disposition Initiative to develop a disposition path for Hanford's five canyons. This initiative was the forerunner of ISD projects across the DOE complex. The U Canyon was selected as the pilot for this initiative; it was chosen from among the five because it had been out of operation for many years, had never been used for plutonium processing, and contamination levels were significantly less than the others. The project involved significant multi-year efforts with a CERCLA Final Record of Decision issued in October 2005.

Of note is that studies were conducted as part of the ISD project planning to evaluate the possible use of the interior and exterior of the canyon for waste disposal. So as to avoid an added complication of obtaining regulatory certification, a decision was made to not use the canyon for disposal of anything other than what was in the CERCLA Area of Concern (AOC). The latter is allowed because any contaminated materials within the AOC are considered related to U Canyon operations. This decision, however, should not preclude consideration of other ISD facilities for acceptance of waste from beyond their AOCs. As a matter of interest, in February 2005 the DOE Office of the Inspector General issued an Audit report [Ref: DOEIG-2005] that questioned this decision; however, DOE decided not to pursue a ROD amendment to include non-AOC waste placement in U-Canyon.

4.2 Description and Conditions

U Canyon is a reinforced concrete structure 810 ft long, 66 ft wide and 77 ft high (247 m x 20 m x 23.5 m), with 51 ft (15.5 m) visible above ground level and 180,000 GSF (17,000 sq m). The operating deck is approximately 25 ft (8 m) above the original grade. The concrete walls and floor range from 3 ft (0.9 m) to 9 ft (2.7 m) thick. One large room extends the entire length with galleries on the other side of a dividing wall from this room. Covered processing cells reside below the deck in a large room. The facility is shown in Figure 13.

<u>The Galleries</u>

The U Canyon galleries run the entire length of the facility and are arranged one on top of the other (see Figure 14). The electrical gallery is located below grade and is split into two by a railroad tunnel that enters the building at the northeast end of the facility. The electrical gallery housed deactivated electrical switchgear and controls for process equipment located on the canyon side of the building. The pipe gallery is located directly above the electrical gallery and is also split into two separate sections by the railroad tunnel. The pipe gallery contains inactive piping and valves for process equipment located on the canyon side of the building. The U Canyon pipe systems were flushed and drained when the

facility was deactivated. However, they were not completely drained as liquids were found in some pipes during conduct of the project.

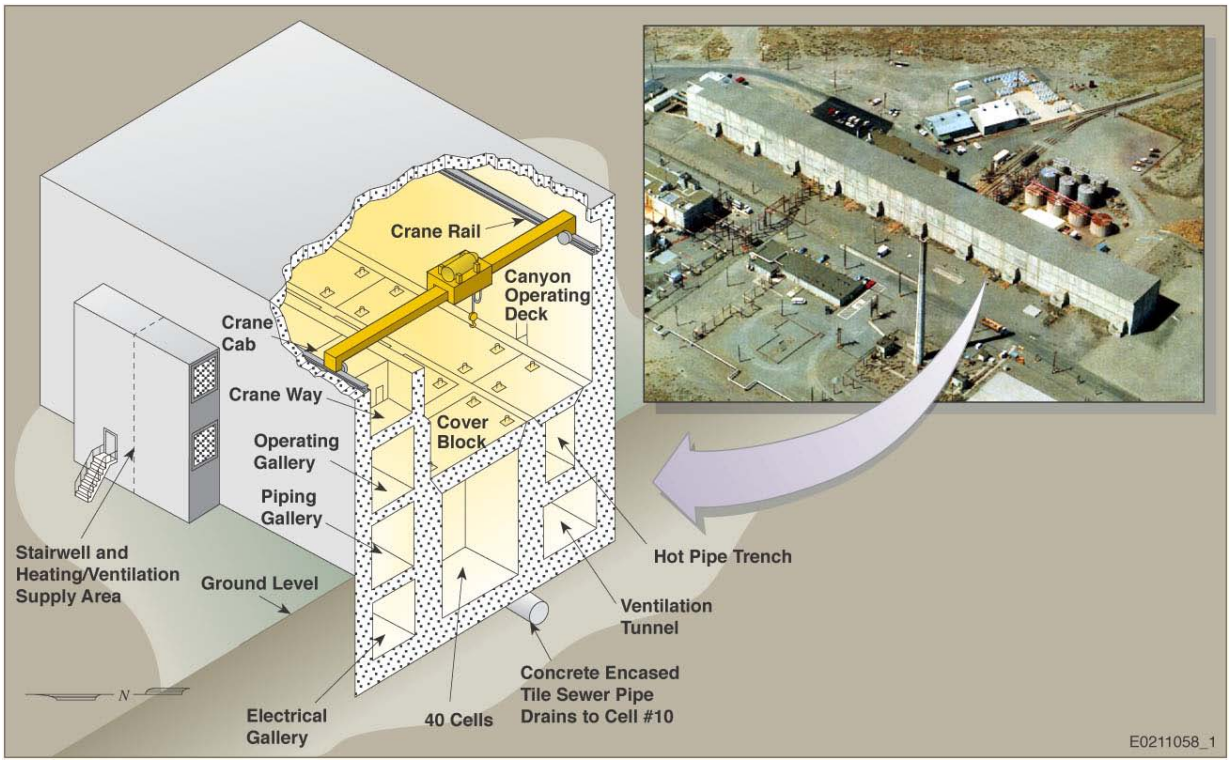


Figure 13 – U Canyon

The operating gallery is located above the pipe gallery and contains deactivated instrumentation and piping manifold stations for controlling the processes in the canyon. The crane gallery (craneway) is located directly above the operating gallery. The crane gallery is the operating area for two overhead traveling cranes that ride common tracks running the entire length of both sides of the facility. The results of radiological surveys and general area dose rate surveys of the crane gallery indicate low levels of process-related radionuclides. The crane gallery was controlled as a radiation zone with restricted access.

<u>The Canyon</u>

The canyon portion of U Canyon is divided into 20 sections as illustrated in Figure 15. Each section of the canyon contains two process cells. Removable concrete blocks that cover each cell provide access. The tops of the concrete cell covers form the canyon operating deck (Figure 16), which constitutes the main floor area of U Canyon.

Located on the northwest end of the U Canyon, a rail line enters the facility through a tunnel that is approximately 150 ft (46 m) long. The tunnel is reinforced concrete and pumice block that penetrates the electrical and pipe gallery portion of the building and continues into the canyon side of U Canyon. Equipment was unloaded from railroad cars using the overhead bridge crane. The railroad tunnel contained low levels of process-related radionuclides and has not been decontaminated for personnel access.

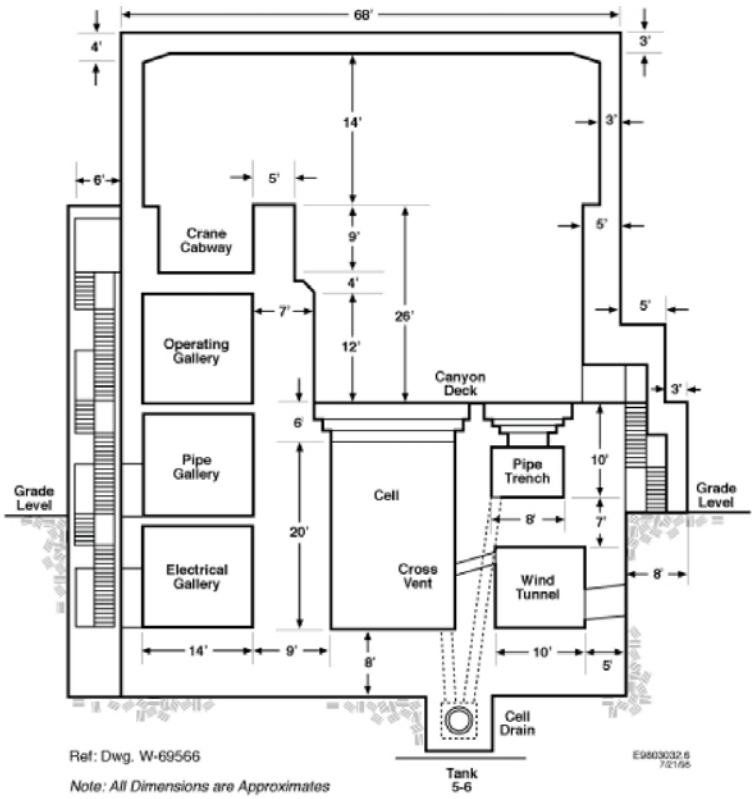


Figure 14 – Canyon Cross Section

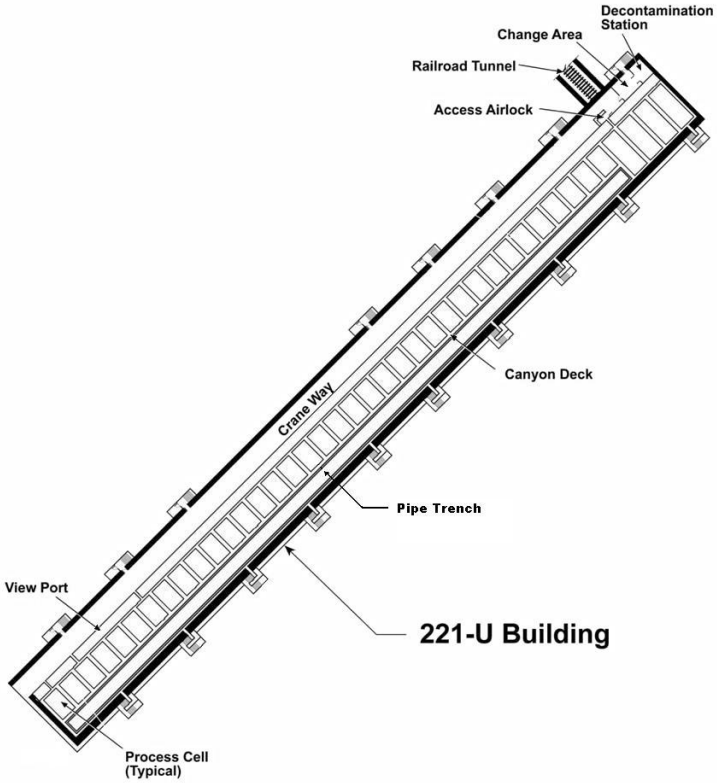


Figure 15 – Canyon Cell Arrangement

The hot pipe trench runs parallel to the process cells and contains inter-cell process piping and residual material transfer piping. Removable concrete blocks, similar to those over the process cells, cover the hot pipe trench and provide access. The piping in the pipe trench was cleaned and flushed when U Canyon was deactivated. Contamination levels in portions of the pipe trench may be as high as in the process cells.

The ventilation tunnel is located directly beneath the hot pipe trench and provided ventilation for the cells and pipe trench. The concrete tunnel exhausts to the stack. Portions of the ventilation tunnel contain high levels of process-related radionuclides in the accumulated dust and particulate material that coats the floor of the tunnel.

The U Canyon process sewer is composed of a process sump and a 2 ft (0.6 m) process drain that is located under the process cells and runs the entire length of the building. During operation, liquid process wastes were flushed from the process cells into the process drain that in turn emptied into the process sump. Residual sludge in the process sewer contained high levels of radionuclides and regulated levels of PCBs and heavy metals.

The process cells contained deactivated process equipment, such as vessels, centrifuges, and piping used for feed concentration and centrifugation, solvent-extraction, waste treatment, and solvent treatment. Much of this deactivated equipment came from other facilities over the years and was stored in U Canyon (in the cells and the canyon deck; see Figure 16). As a result, some of the process cells are contaminated with radionuclides including strontium-90, cesium-137, americium-241, and isotopes of uranium and plutonium. The high radiological dose rates in some of the process cells were a risk to workers.

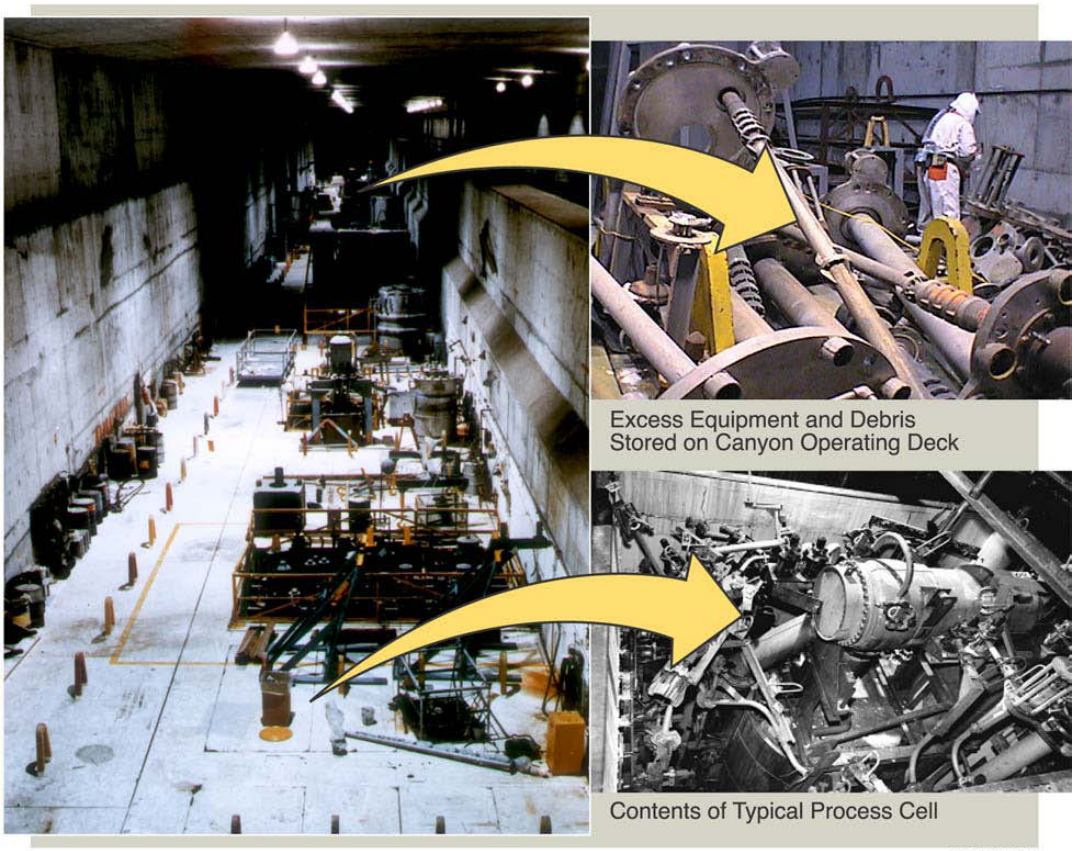


Figure 16 – Canyon Operating Deck

The operating deck of the canyon was decontaminated to a level that allows personnel access with a low level of radiation exposure. Contaminated process equipment stored on the deck substantially contributes to the radiological inventory of the facility. Some equipment contained small amounts of highly radioactive liquid and residue.

4.3 ISD Project

4.3.1 Project Elements

The entire U Canyon ISD project includes four primary components: 1) demolition and barrier construction (the "construction component"), 2) post-remediation care and environmental monitoring, 3) institutional controls, and 4) a 5-year review. The construction component was planned in three phases that included pre-demolition, demolition of some of the above-grade structure, and barrier construction. As of the writing of this ISD experience report, partial completion of the construction phase includes the following major activities:

- Removal of the tank in Cell 30 with its contents;
- Removal of liquids from the facility;
- Partial removal of contaminated equipment and piping from the gallery side of the facility, as needed to facilitate demolition activities, and disposal of this waste at the Environmental Remediation Disposal Facility (ERDF) or other approved facility;
- Consolidation of remaining contaminated equipment from the deck into below-deck locations within the process cells; and
- Grouting, to the maximum extent practical, of internal vessel spaces, as well as cells, galleries, pipe trench, drain header, and other spaces within the facility as well as demolition rubble, as practical. An exception is that the operating gallery was not grouted.

This is the work conducted with ARRA funding. The estimate for this work was $233 million; it was accomplished for $201 million, representing about a 4% under run. The construction phase completion is dependent on future funding; see Section 4.3.7 for a description of future work to complete the project.

4.3.2 Characterization

Well before the construction phase of the ISD project, between 1998 and 2001, structural samples and radiological/chemical characterization data were collected from U Canyon in accordance with a comprehensive sampling and analysis plan. The characterization activities presented many difficulties due to the nature of the contaminants (e.g., physical form and adherance), lack of historical information, and the fact that many areas were not easy to access or were totally inaccessible because of safety and health concerns.

In addition to conventional sampling and surveys, a number of innovative technologies were used. Specific examples, shown in Figure 17, included:

- A remote characterization platform (Andros Mark VI robot) to provide visual records, smear samples, and gamma readings in the inaccessible ventilation tunnel and railroad tunnel.
- A remotely operated, mobile Brokk™ 150 system to obtain concrete core samples in four representative cells.
- The GammaCam™ to gamma-ray image the radiation fields in the various cells for characterization information.

- A drain line characterization robot to obtain visual records, material samples, and gross gamma level readings.

These technologies were considered enabling, as the characterization could not have been accomplished to the same degree without them.

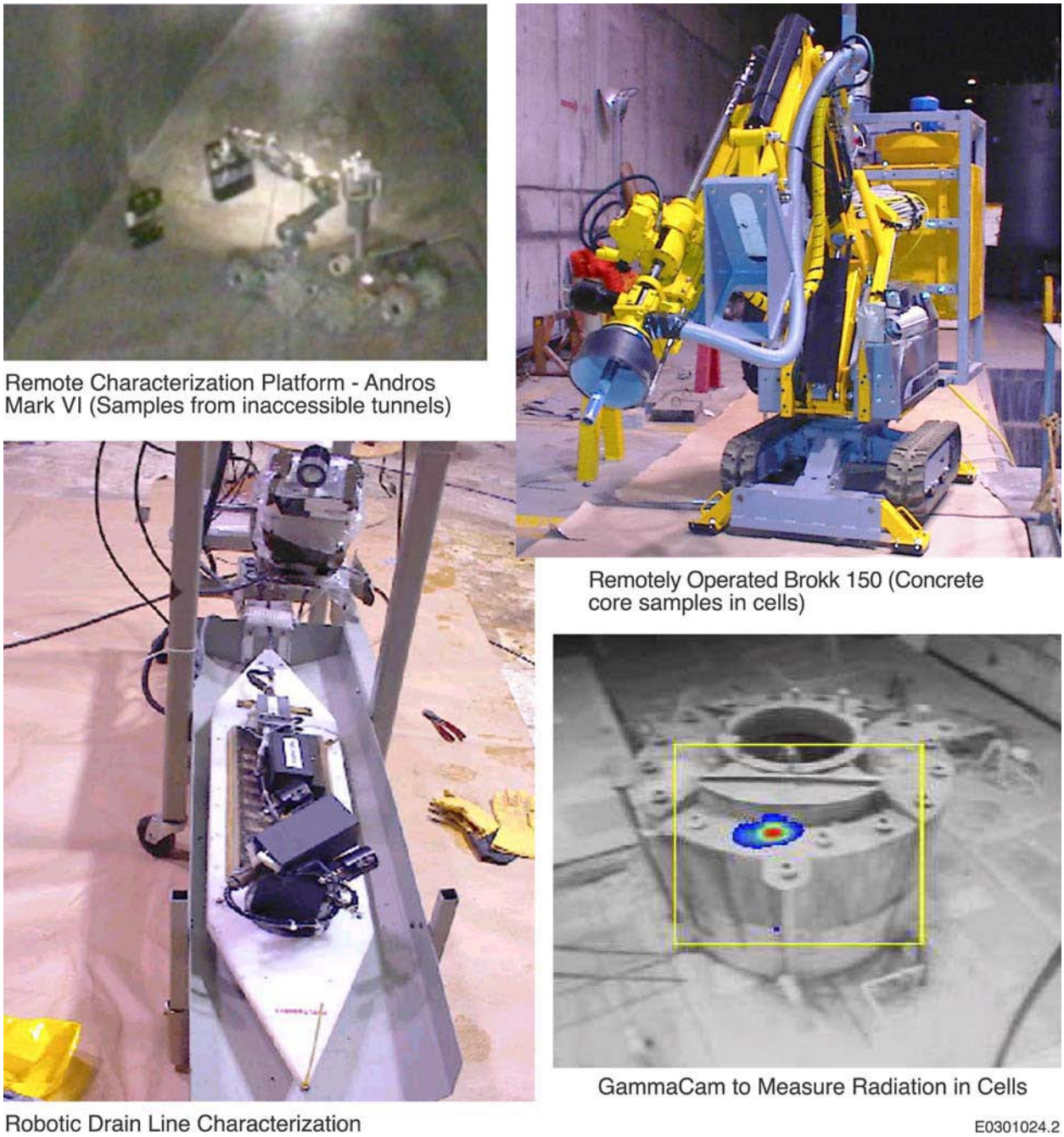


Figure 17 – Remote Technology for U Canyon Characterization

4.3.3 Reactivation

U Canyon had effectively been non-operational since the late 1950s. Facility modifications were required to support the ISD project and the extensive amount of hands-on work required to be performed inside the facility. These modifications primarily involved: a) disconnecting and blanking utility and electrical lines where they are no longer required; b) installing temporary services required supporting planned actions; and c) reactivating ventilation, crane and lifting capacity, electrical power, and the canyon's railroad tunnel. For reactivation, engineering studies were conducted to assess the options for each of these functions (see Appendix B). In summary, the results of these studies and subsequent restoration activities resulted in the following approaches:

- Ventilation Systems- Use of the existing system supplemented with localized units.
- Crane – Recertification and use of the existing main bridge crane for large loads within the canyon (e.g., cover blocks), augmented with mobile lifting equipment for smaller loads.
- Electric Power - Additional 480-V electrical service requirements installed as necessary to support portable ventilation requirements and selected decontamination equipment, such as air compressors for pneumatic tools and temporary greenhouse structures.
- Railroad tunnel – Access via the railroad tunnel was needed for bringing equipment into the canyon and removing waste and equipment (see Section 4.3.5 for the removal of Tank D-10). Reactivation involved making the tunnel's roll-up door operational, adding a personnel access door, housekeeping to clean up the tunnel, verifying the strength of the diamond plate covering the disposition drain trough, improving tunnel access by road straightening and reducing the grade, conducting a roof inspection, improving lighting, and installing remote control articulating cameras.

4.3.4 Equipment Placement

Following its being placed in standby mode, U Canyon served as a staging and storage area for a wide assortment of equipment and debris from other canyon facilities. The majority of this material was placed on the canyon deck; items with higher radiation levels were however randomly placed inside the process cells. The sizes and weights of this material range from very small (lbs) to very large (tons). Figure 18 shows a few examples of these items.

For the ISD closure of U Canyon, most of the equipment located on the canyon deck needed to be placed into the 40 process cells and stabilized in place with grout. Detailed planning was required to ensure that all of this material could be placed in the cells, which also contained original process equipment as well as miscellaneous items (i.e., the higher radiation level equipment). For this purpose, a comprehensive engineering study [Ref: HNF-2006] was conducted to evaluate the sizes of the legacy items versus available process cell space. The study assessed the inventory of material stored in the canyon, evaluated equipment size reduction needs, catalogued size reduction and consolidation methodologies, and recommended specific item disposition locations.

Figure 18 – Equipment on Canyon Deck

The study also included appendices with comprehensive descriptions of generic size reduction methods and a tabulation of fixatives that could be used. It did not, however, address radioactivity loading in the cells because the facility was designed to handle levels much higher than existed on the equipment.

The study's overall conclusion was that all the equipment could be placed inside the canyon cells without extensive size reduction. Some size reduction was identified for agitators and pumps with long tubular sections that could be sheared into shorter sections. It recommended that a mechanical shear, capable of cutting approximately 6 in (15 cm) diameter pipe, be utilized. In general, large tanks would not require size reduction if they are placed in the locations defined by the engineering study.

In summary, the process involved the following actions:

- Inventory each component on canyon deck based on photos
- Calculate size of components on canyon deck from photos
- Calculate process cell size from drawings
- Calculate available space in cell from photos and videos
- Assign each component to a specific cell based on calculated size and available cell space.

The approach used in this study can be of use for future projects; examples are included in Appendix C.

The end result of the study was a tabulated recommendation for cell loading that addressed the placement of each component from the canyon deck. Each cell loading recommendation included specific equipment placement comments to ensure the items would fit into the available space. The project subsequently used the cell loading recommendations from the engineering study to direct the cell loading operations.

All of the 125 major pieces of equipment from the canyon deck was successfully placed into 39 of the 40 process cells. Types of equipment included centrifuges and other process equipment, tanks, lifting yoke and other gear, platforms, and an assortment of others. The amount of space in each cell varied. Equipment sizes ranged from a long dimension mostly from 4 to 10 ft (1.2 m to 3 m), maximum 24 ft (7.3 m), and the narrow dimension ranged mostly from 4 to 10 ft (1.2 m to 3 m), minimum 0.5 ft (0.2 m).

The success was in part due to the planning efforts to develop the tabulated cell loading recommendation list. The skill of the crane operators with their innate abilities to precisely place the equipment into the tightest of spaces was also a key to this success. In total, the equipment placement physical operation took about one year to complete following almost a year for regulatory approvals.

4.3.5 Removal of Tank D-10

Tank D-10 was placed in U Canyon Cell 30 in 1965. It was moved from the REDOX canyon; it contained REDOX ventilation tunnel flush solution. It is important to note that this tank was the only significant source of TRU in the canyon. A criterion of not having to address the broader question of residual TRU greater than 100 nCi/g (3,700 Bq/g) was one of the reasons that U Canyon was selected as the ISD prototype at Hanford.

The tank is approximately 7 ft (2 m) in diameter by 7 ft (2 m) tall and, based on sampling, was estimated to contain a little less than 21 oz (600 g) of plutonium (Pu) in 200 gallons (760 l) of liquid. This translated to a TRU concentration greater than 100 nCi/g (3,700 Bq/g) when averaged over the volume of the cell in which the tank was installed. Averaging the content over the total volume of all the grouted cells, which otherwise would have met the concentration criterion, was judged as not acceptable because the

customary method for TRU concentration calculations use the volume of the waste package. In this case, that would be the individual cell volume.

The initial plan was to absorb the liquid contents of Tank D-10 and transfer the resulting material into containers for shipment to WIPP. The tank would then be grouted in place in Cell 30. The residual material in the tank was expected to be less than 100 nCi/g (3,700 Bq/g) TRU and would be stabilized with grout within the cell.

Subsequent characterization of the tank contents when better access was gained resulted in a decision to modify the disposition approach for Tank D-10; the decision was based on the following determinations:

- Tank D-10 contained more than 500 gallons (1,900 l) of remote-handled TRU mixed waste rather than the less than 200 gallons (760 l) previously estimated.
- The waste in the tank contained a hard, crystalline material that the first probe could not penetrate, and sludgy solid rather than liquid, as previously estimated.
- Both the solid and liquid phases within the tank contain concentrations of TRU in excess of 100 nCi/g (3,700 Bq/g).

To remove the material it would have been necessary to design and install a system for mixing, rinsing, sampling and removal of the waste for shipment to WIPP; along with requisite HEPA ventilation filtering.

There were also non-technical reasons for removal. Specifically, leaving it in its as-found condition would not comply with approvals; and the schedule milestone could have been significantly missed by an approach that involved sluicing the 500 gallons (1,900 l). Removal was an acceptable alternative.

The revised disposition approach included complete removal of the tank with contents in place and with absorbent added to stabilize the free liquid in the tank. A structural evaluation was conducted to confirm the tank's lifting lugs were adequate to support the removal operation. A custom shielded container was designed and fabricated to facilitate removal and transport to the Central Waste Complex where it was placed in interim storage pending eventual treatment (yet to be determined) and packaging for shipment to WIPP. Figure 19 shows removal from the cell, placement in the transport container, and removal from the U Canyon railroad tunnel.

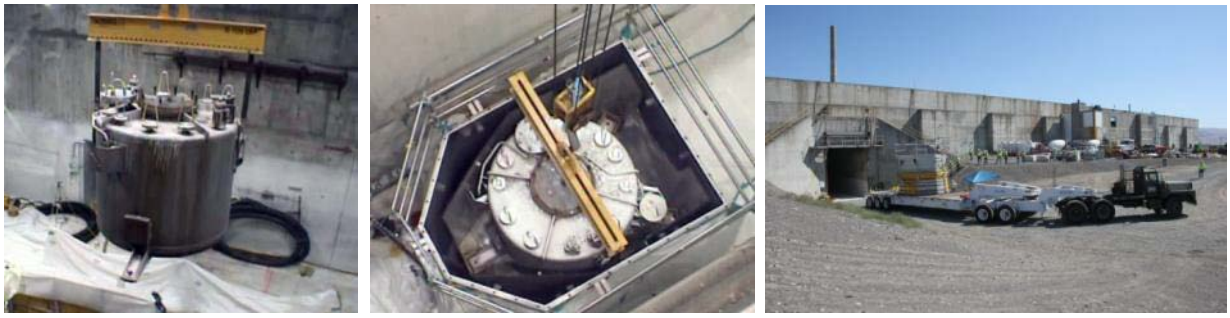


Figure 19 – Removal of Tank D-10 from U Canyon

4.3.6 Grout Campaign

The grout campaign at the U Canyon ISD project was a massive undertaking. About 25,000 cu yds (19,000 cu m) of grout was pumped into the galleries, cell drain header, process cells, and tanks containing residual materials to the maximum extent practical.

Proper flowability coupled with a systematic grout placement approach was essential to filling the Canyon and equipment voids to the extent practical. An engineering study (Reference: D&D-33945, Rev. 0, *221-U Plant Void Fill Analysis and Installation Plan*) was conducted to develop guidelines for filling the lower portions of the canyon structure with grout. For inside-the-canyon issues, criteria used in the evaluations included worker safety, environmental considerations, secondary waste, void space minimization, cost, schedule, and nuclear safety. As it turned out, nuclear safety was not a significant factor for any of the decisions.

The study addressed design considerations, and recommended mix formulations and fill sequence to ensure complete void fill. The issues, considerations, and recommendations from that report are summarized below.

Grouting process cells

Grouting the cells and entombing equipment were activities with the highest contamination levels and posed the greatest safety risk to workers. The evaluation considered three alternatives, which were:

- Grout equipment and process cells after equipment is placed into cells while the cover blocks are off
- Grout equipment and process cells after equipment is placed using pressure grouting through holes in cover blocks
- Grout equipment voids and internals first then flood grout the process cells through the key block opening

The third alternative was recommended base on the stated criteria. However, during implementation the recommendation did not prove practical because of crane reliability concerns and interference with deck operations with multiple cover block movements. As a result, only five cover blocks were removed after equipment placement. The others were core-drilled to introduce grout and provide a vent path. The lesson is that the actual conditions trumped the evaluation assumptions.

Grouting the Balance of the Canyon

This subject addressed the sequence in which voids in the canyon, other than the process cells, need to be grouted. These included the hot pipe trench, the electrical gallery and conduits, the pipe gallery, the operating gallery, and the ventilation tunnel and pipes.

The primary decision was related to whether the hot pipe trench should be grouted separately or together with the ventilation tunnel. It was recommended they should be grouted separately for reasons of flexibility, air control, and obviating the possibility of leaving voids if the tunnel and trench were grouted simultaneously. The results also presented the pros and cons of various sequences, but left it to the project to decide on the specifics. A note of caution was included regarding structural limitations relative to depth of single grout lifts.

Canyon Ventilation

The issue with ventilation was whether to operate the existing system as long as possible or to grout the ventilation tunnel early and provide other means of air supply and exhaust. All criteria supported the conclusion that the ventilation tunnel should be grouted after the most contaminated parts of the

canyon structure. With careful control, the ventilation was kept operating until all other grouting was complete.

Offsite Delivery vs. Onsite Batch Plant

With approximately 25,000 cu yds (19,000 cu m) of grout needed to fill voids in the canyon structure, the potential cost and quality improvements by manufacturing the grout near the canyon structure was evaluated. It was concluded that an onsite, project-specific, grout plant would provide grout at a lower cost with more operational flexibility for reasons of:

- Transportation related savings per cu yd of $30 transportation contract and fuel of ~$5; and no loss of materials in transit for any of a number of reasons.
- Flexibility in that mix design modification could be readily accomplished within a short time with minimal wasted materials. Admixture addition at the batch plant will not result in lost working time.
- Higher production rate because load size could be increased by 2 cu yds (1.5 cu m) per truck for off road verses road transportation.

Temperature Control

The heat generated from the hydration of cement in the grout can potentially raise the temperature of a large grouted mass over 100 degrees if not controlled. High temperature during grout curing can thermally stress the grout mass and the reinforced-concrete canyon structure. Temperature induced expansion of the grout can cause cracking of the concrete structure surrounding the grouted voids. This temperature must be controlled to prevent damage to the curing grout and canyon structure. High temperatures would also create a heat stress hazard for workers in the canyon.

This subject was addressed by providing guidelines and methods to ensure temperature limits were not exceeded. These methods included allowing 24 hours between lifts in the same area, location spacing of sequential lifts, volume of individual lifts, and checking surface temperatures.

Management of Flush Water

Typical concrete or grout pumping operations use water to flush the pump lines before and after pumping. Flushing the grout feed pipes in between grouting pours will require water to flow through pipes in a contamination area. Without proper controls, water can become contaminated, thereby preventing its use for recycle through the batch plant.

It was originally concluded that the flush water should be sent to the evaporation basin or the site's effluent treatment facility rather than attempt recycling.

Further talks with radiation control personnel and grout engineering consultants, indicated that careful pipe joint sleeving and contamination control could keep the insides of lines and flush water from being contaminated. The approach to clearing grout lines inside the canyon was a combination of pneumatic line clearing and careful radiological controls to flush the lines with water. It was therefore decided to recycle the flush water to a storage tank and use it to make additional batches of grout. A backup option was to send excess water to the evaporation basin.

Grout performance requirements

The engineering study specified the performance requirements for the grout. Each of the grout formulations has a unique set of performance requirements. The key requirements were:

- High strength equipment stabilization grout should have a compressive strength >4,000 psi (28 MPa) and a slump rating of greater than 8 inches (20 cm).
- The flowable non aggregate void filling slurry should have a performance similar to:
  - The grout efflux time, using a standard flow cone test, should be under 20 seconds (ASTM C 939 -02).
  - Shrinkage during curing should be limited to less than 0.1 percent (ASTM C 827-01a).
  - Unconfined compressive strength should be at least 150 psi (1 MPa) (ASTM C 109/C).
- The low heat mass void fill grout should have a performance similar to:
  - Flow at a slope less than 3 percent over 50 ft (15 m).
  - Shrinkage during curing should be limited to less than 0.1 percent (ASTM C 827-01a).
  - Unconfined compressive strength should be at least 150 psi (1 MPa) (ASTM C 109/C).
- The pipe plugging grout should have a performance similar to:
  - Flow easily into pipes and expand to seal passageways.
  - No shrinkage that would allow grout to pass through plugged pipes
  - Compressive strength to hold back hydraulic head of a heavy grout lift without breakout
  - The grout must contain adequate cementitious material and other material to stabilize contaminants in the canyon structure.

The specific grout mixes used are described in Section 8.1.

4.3.7 Future Project Completion

The construction phase schedule for the U Canyon project is dependent on future funding; work remaining includes:

- Demolition of the operating gallery.
- Demolition of the railroad tunnel, 271-U, 276-U, 291-U, 2712-U, and 292-U structures and the 291-U-1 and 296-U-10 stacks, and disposal of the resulting waste at the ERDF or other approved disposal facilities (or use of the resulting waste as barrier fill material if the waste is minimally contaminated and does not contain hazardous wastes);
- Closing out the waste sites and underground tanks, which will be under the barrier cap, prior to installation of the cap;
- Stabilization of the former locations of these structures to support construction of the engineered barrier; and
- Demolition of roof and wall sections of the U Canyon down to approximately the deck level and use of the resulting rubble as fill material for the engineered barrier.

Of note is a change from the original disposition concept for U Canyon. Those plans included filling all of the process cells and all of the facility galleries (i.e., Piping Gallery, Electrical Gallery, Operating Gallery, Hot Pipe Trench, and Ventilation Tunnel) with grout resulting in a monolith after partial structure demolition. In an effort to maintain the aggressive schedule of the ARRA funded work (i.e., to prepare

U Canyon for ISD by September 30, 2011), the project elected to not fill the Operating Gallery with grout. The final configuration will be to remove the Operating Gallery and collapse the roof to the canyon deck. This change results in the advantages that include reduction in the amount of grout required and a lower height and smaller footprint of the final engineered cap, resulting in a reduced amount of overburden material. In addition, visual aesthetics will be improved as a result of the cap's lower final elevation.

The primary impact of this change is an increase in the scope of demolition during the final ISD phase; this will result in additional cost and schedule to deal with: a) asbestos removal, b) piping tap, drain and air gap, c) obstruction removal, and d) the management, planning, engineering, and labor for these activities.

Other physical work not associated with the construction phase to be completed in the future includes:

- Treatment, of the contents of Tank D-10 as necessary, to meet waste acceptance criteria at WIPP or elsewhere as appropriate; see Section 4.3.5;
- Constructing an engineered barrier in accordance with an approved remedial design over the remaining above-grade structure and demolition debris used as clean fill material;
- Seeding and planting the engineered barrier surface with native grasses and shrubs to stabilize barrier materials and improve enviro-transpiration rates; and
- Seeding the disturbed areas in the immediate vicinity of the U Canyon with native grasses and shrubs for surface reclamation purposes consistent with the expected future land use.

Eventually this will be followed by post-remediation care and environmental monitoring, institutional controls, and a 5-year review.

5. Savannah River Site P and R Reactors

The decommissioning of the former production reactors in the P-Area and R-Area at the Savannah River Site (SRS) was completed in 2011 with funding provided by ARRA. Both facilities were placed in an ISD final end state in which the facilities were stabilized and entombed for permanent disposition. The successful completion of these ISD projects establishes a precedent for the decommissioning of the remaining three production reactors at the site. Both projects were similar in nature with only minor differences that are described below.

The P-Reactor is located in the east-southeast quadrant of the SRS in P-Area. P-Reactor began operations in February 1954 to support production of materials necessary for the fabrication of nuclear weapons. It was taken off-line for maintenance and safety upgrades in 1987, and placed in warm standby in 1988. The P-Reactor Building (105-P) was put into a “cold standby” status, followed by “cold shutdown with no capability for restart” status in 1991. At this time, all irradiated-fuel and target assemblies had been removed from the reactor vessel, and the heavy-water moderator had been drained from the process systems with moderator heels remaining in the systems. Figure 20 is an aerial photograph of the P-Reactor Building prior to the start of the ISD project.

Figure 20 – P-Reactor circa 2009 Prior to Decommissioning

The R-Reactor is located in the east-southeast quadrant of the SRS in the R-Area, which is approximately 3.5 miles (6 km) from P-Area. R-Reactor is the largest of the five SRS production reactors. It was also the first to achieve operational start on December 28, 1953. Shutdown of the R-Reactor occurred in 1964, due to a reduced need in its defense-related mission. Immediately following the shutdown, R-Reactor was defueled and all fissile materials were removed. The facilities at R-Area had been extensively cannibalized over the years following reactor shutdown, and most materials of value had

been removed for use at other facilities. The facilities in R-Area were deactivated with minimal surveillance and maintenance (S&M) requirements.

5.1 Description and Conditions

The physical arrangement of the P and R Reactor Buildings are essentially identical. The Reactor Buildings are massive reinforced-concrete structures of blast-resistant design, with multiple floor levels over 130 ft (40 m) above grade and 49.5 ft (15 m) below grade. The reinforced concrete walls, floors, and roofing of the building vary between approximately 4.5 ft (1.4 m) to over 10.5 ft (3.2 m) thick. Figure 21 is a graphical illustration of the P-Reactor facility. The general plan of the Reactor Building complex includes the following:

- The Process Area is located in the center of the Reactor Building and contains the shield water system, control and safety rod-actuating mechanisms, heat exchangers, primary coolant circuit pumps, helium blanket gas system, and the main control room.
- The Process Area also houses the reactor vessel, which is recessed below the floor of the process room. The cylindrical reactor vessel contained a pressure tube core configuration with dimensions approximately 15 ft (4.6 m) high by 16 ft (4.9 m) diameter. It was fabricated with 0.5 in (1.3 cm) thick 304 stainless steel plating.
- The Disassembly Basin was used to cool and to process fuel assemblies and target components prior to transfer to the Separations Facilities (F and H Canyons). The irradiated fuel and target assemblies had been previously removed from the basin.
- Other areas of the Reactor Building include the Assembly Area (which was used for fuel rod preparation) and the Purification Area where contaminants were removed from the reactor heavy water moderator and from the blanket gas.
- The two Engine Houses provided standby and emergency power for the reactor.

Both P- and R- Reactor Building complexes contain elevated levels of radionuclides, primarily associated with the reactor vessel and Disassembly Basin. The reactor vessel, together with the thermal and biological shielding around the vessel, has been estimated to contain almost 90 percent of the total building inventory in the form of neutron-activated metal and concrete. The radionuclide contamination associated with the reactor vessel posed the greatest risk to human health and groundwater and is considered principle threat source material. The prevalent isotopes of concern are C-14, Ni-63, and Tc-99. The remainder of the radioactive source term is contained throughout the building in the contaminated concrete and process equipment, and the Disassembly Basin sediment. Hazardous material is also present in the complex, with lead and polychlorinated biphenyls (PCBs) constituting the majority of the hazardous inventory.

These areas were deactivated, de-energized, and drained of radioactive and chemical liquid hazards prior to beginning the ISD project. At the conclusion of the reactors' respective operational missions, all equipment and systems associated with reactor operations had been removed from service and some equipment had been removed from the buildings. The water in the disassembly basins was removed until approximately 2 ft (0.6 m) remained to provide wetted cover and shielding over the residual sludge at the bottom of the basin; it was then grouted in place. Removal was by evaporation, and in the case of R Disassembly Basin, some was trucked to an on-site Effluent Treatment Facility. The volume of water removed from each Disassembly Basin, including potentially contaminated rain water from basins and sumps within the facility, was approximately 4 million gallons (15 million liters).

Subsequent deactivation work to prepare the reactors for decommissioning have eliminated all electrical and mechanical hazards by severing or terminating the original lines that entered P and R Areas, rendering the Reactor Buildings "cold and dark."

5.2 ISD Project

The overall goal of the project was to stabilize the Reactor Building and configure it for In Situ Decommissioning. Grouting serves to stabilize residual contamination by immobilizing it in place and isolates it to prevent inadvertent contact by humans. Figure 21 shows the major features of the ISD closure (these features are identical for R-Reactor). Specific end-state conditions include:

- Process, Purification and the Assembly areas and Actuator Tower were left in place.
- Components above the reactor were moved away from the area directly over the reactor vessel to enable placement of the reactor vessel cap; the cap serves as a barrier from potentially falling objects. These components, which included the Fuel Charging Machine, Control Rod Mechanisms, Instrumentation Assemblies, and other equipment associated with reactor operations, were moved to other locations within the building.
- The reactor vessel and vessel cavity were filled with grout and covered with a concrete cap.
- The purification cells and below-grade areas (- 20 and - 40 ft elevations; - 6 m and - 12 m elevations) were filled with grout.
- Above-grade structure of the Disassembly Building was demolished to grade.
- The ventilation stack was demolished to the + 55 ft level (+17 m) and the plenum was sealed to prevent rainwater intrusion.
- The Disassembly Basin was filled with grout and covered with a concrete cap.
- The Reactor Building was sealed to prevent human and animal intrusion.
- Selected Process and Purification Area roofs were modified to shed water.

An aerial view of the final configuration is shown in Figure 22. Of particular note is the concrete atop selected horizontal surfaces as a barrier against stormwater intrusion.

Maintenance activities to be performed as part of the long term S&M include prevention of vegetative growth on the roofs and sealing any emerging cracks in the cover system to prevent significant rainwater infiltration (see Section 9.1, which describes the post-closure inspection). DOE intends to maintain control of the land that the reactors currently occupy as part of its Long Term Stewardship commitment for the SRS ultimate end state.

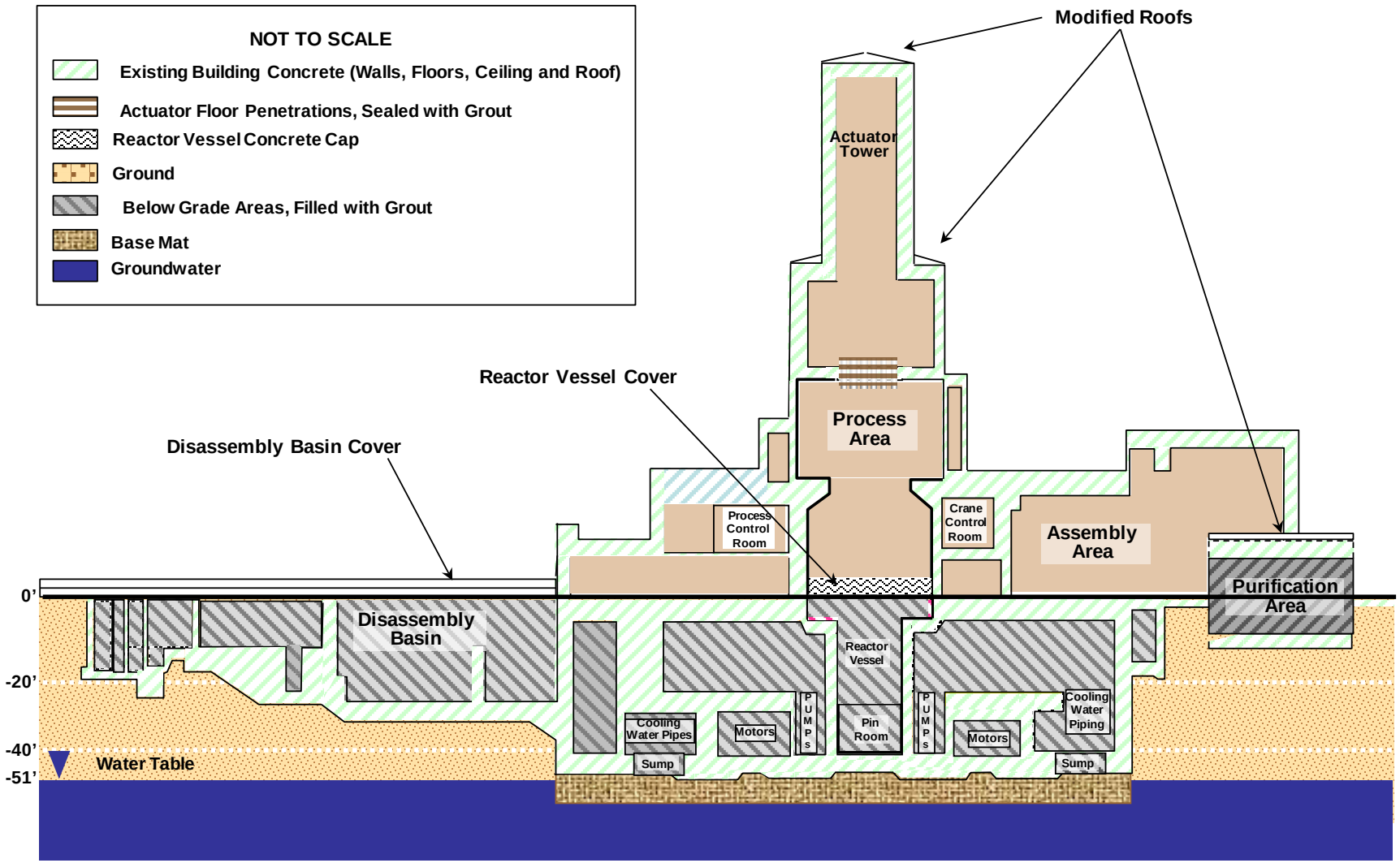


Figure 21 – Graphic Representation of P-Reactor Building In Situ Decommissioning

Figure 22 – In Situ Decommissioning P-Reactor Area

Project Description

The technical scope of the ISD project can be grouped into five major work phases that are summarized on the following pages.

Work phase 1 - Demolition and removal of select Reactor Building structures.

- Demolish stack – Explosive demolition was used to fell the stack from the + 200 ft (+ 61 m) level down to the + 55 ft (+ 17 m) level. The stack rubble was placed below grade in the Storage Tank Room prior to grouting the room to grade. See Figure 23.
- Demolish Gantry – mechanical demolition/physical removal of the shield door gantry structure and all external metallic appurtenances.
- Demolish above-grade Structure of the Disassembly Basin – Mechanical demolition using track hoes was employed to demolish the fairly robust, above-grade portions of the Disassembly Basin (see Figure 24). A total of 1,138 roll-off containers of debris were loaded and transported to the E-Area Slit Trenches for disposal.

Demolition of the above-grade portions of the Disassembly Basin proved to be a major challenge and took almost twice as long to complete than originally estimated [See related discussion and suggestion for future projects at SRS in Section 5.4].

Figure 23 – Stack Rubble Placed in Storage Tank Room

Figure 24 – P-Reactor Disassembly Basin Demolition

Work phase 2 - Placement of cementitious material (primarily grout) in building void spaces to immobilize residual contamination, encapsulate contaminated equipment left in place, and create a physical barrier to inadvertent human or ecological intrusion to prevent contact with contaminated surfaces and equipment. Figure 25 illustrates grouting of contaminated evaporators as an example.

Figure 25 – Grouting of P-Reactor Disassembly Basin Water Evaporators

In the reactor buildings the primary area for grouting was the reactor vessels and other below grade areas of the buildings. The quantity of aluminum components within the P-Reactor vessel necessitated the use of a special near neutral pH grout mix. There was much less aluminum in R-Reactor and therefore a standard flowable structural fill grout mix was used there. See Section 8.1 for a description of the grout characteristics and mix. A cutaway view of the section to be filled with the specialty grout within the vessel is shown in Figure 26; vessel grouting activities are shown in Figure 27.

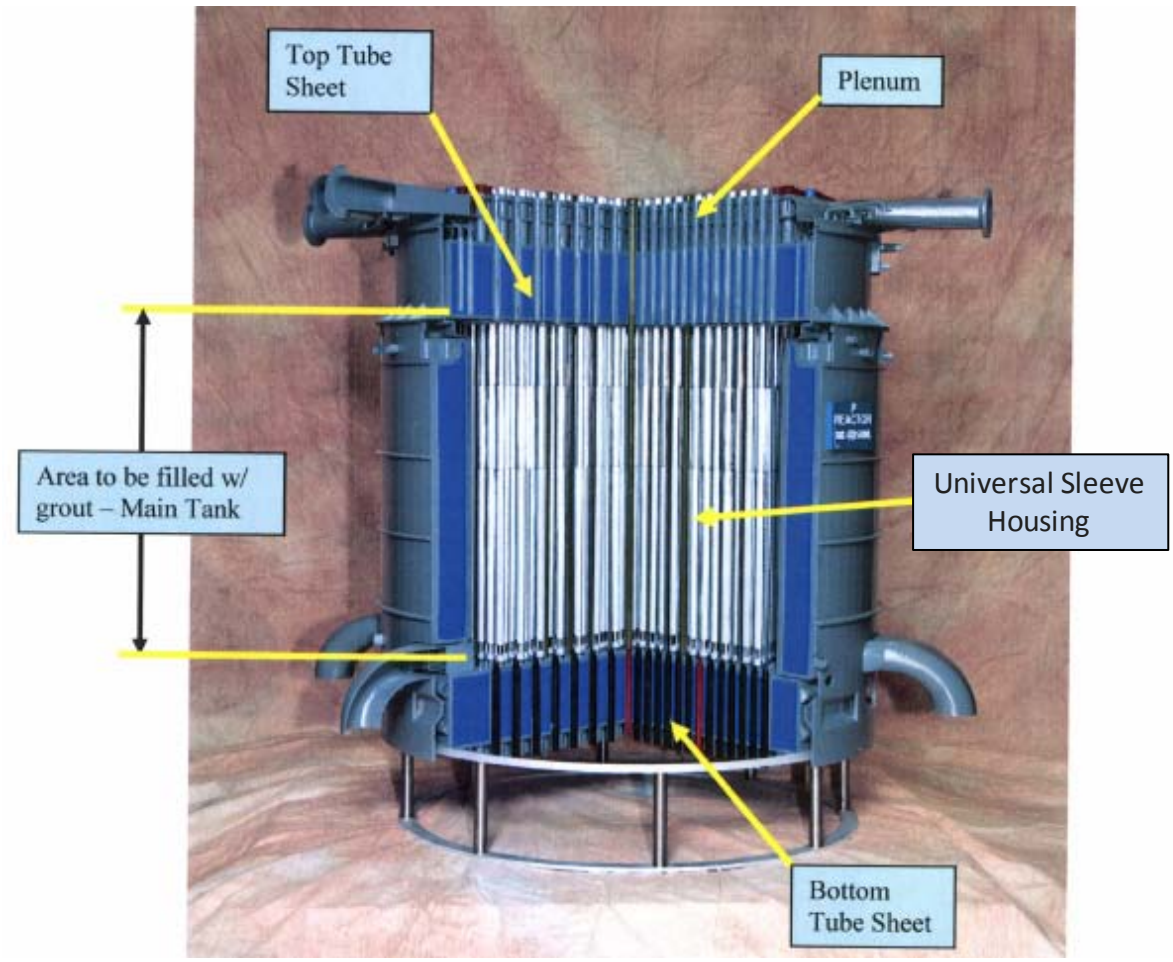


Figure 26 – Cutaway Model of the P Reactor Vessel

Figure 27 – Grouting of P-Reactor Vessel

Major grouting activities in addition to the reactor vessels included the Transfer Canal, the Disassembly Basin, and the seismic gap between the Disassembly Basin and the Reactor Building. Other grouted areas in the reactor building included:

- Two Engine Houses and associated access wells
- Pump Pit (P-Reactor only)
- Purification Area at elevation - 14 ft (- 4.3 m)
- Assembly area pit at elevation - 20 ft (- 6 m)
- Stack void
- Purification cells
- Miscellaneous pits external to the Reactor Building
- Reactor Building areas and spaces in the - 20 ft and - 40 ft elevations (- 6 m and - 12 m elevations) to grade.

In total, approximately 122,000 cu yds (94,000 cu m) of grout and concrete were placed at P-Reactor and 134,000 cu yds (102,000 cu m) at R-Reactor.

The Reactor Building complex was divided into zones for implementation of the ISD project as shown in Figure 21. The type of cementitious fill material used for each zone is identified in Table 2. Details of the respective mixes are discussed in Section 8.1.

Table 2 – P-Reactor and R-Reactor ISD Cementitious Materials

Reactor Zone	Sub-Zone	Fill Material Type
1	Inside Reactor Vessel	P-Reactor: Non-corrosive (near neutral pH), zero-bleed grout with ICW R-Reactor : Zero-bleed CLSM
	Reactor Vessel Cap	Shrinkage-compensating concrete with ICW
2	All Below Grade Spaces to - 2 ft (- 0.6 m) level	Zero-bleed flowable structural fill
	From approximately - 2 ft (- 0.6 m) to grade-level	Shrinkage-compensating concrete with ICW
3	From bottom of Disassembly Basin to approximately - 25 ft (- 7.6 m) elevation (shield layer)	Underwater zero-bleed flowable structural fill
	From top of shield layer of grout to grade-level of Basin	Zero-bleed flowable structural fill
	Disassembly Basin cover	4000 psi low shrink concrete
4	Purification Area	Zero-bleed flowable structural fill
5	Actuator Floor Penetrations	Shrinkage-compensating concrete

ICW = integral crystalline waterproofing CLSM = controlled low strength material

In addition to the previous pictures, for perspective, the D&E Transfer Canal connection to the Reactor Disassembly Basin is depicted in Figure 28, along with other areas within the Disassembly Basin. Depths within the basin range from - 51 ft to - 5 ft below grade (- 16 m to - 1.5 m). The figure also show the Disassembly Basin 3-D model discussed in Appendix H. Below-grade areas and spaces of the Disassembly Basin were grouted as shown in Figure 29 and Figure 30.

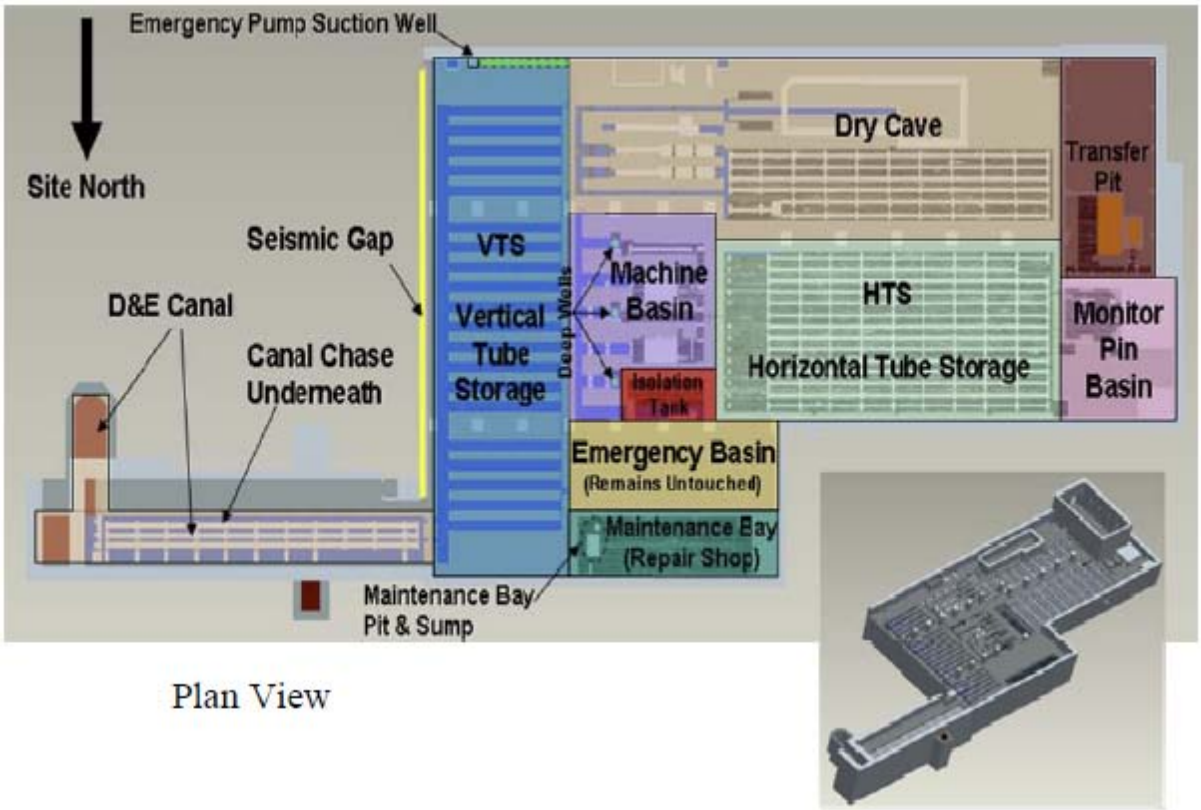


Figure 28 - 105-R Reactor Disassembly Basin Areas

Figure 29 – Disassembly Basin Before and During Grouting

Figure 30 – Completed Grouting of the Disassembly Basin and Transfer Canal

Work phase 3 - Construction of a concrete cap over the reactor vessel and the Disassembly Basin to restrict inadvertent human or ecological intrusion and, in the case of the cap over the reactor vessel, to provide a structural barrier to protect the encapsulated reactor vessel from falling objects.

Figure 31 – Forming the Reactor Vessel Cap and as Completed

Work phase 4 - Construction of physical barriers and seals in and around openings, penetrations, and other access locations into the building to prevent inadvertent human or ecological intrusion (see Figure 32).

Figure 32 – Typical Door Opening Sealing

Work phase 5 - Modification of building tops and other elevated flat surfaces, including the sealing and sloping of selected roof surfaces and installation of scuppers to promote runoff of rainwater (see Figure 33).

Figure 33 – Construction of New Roofs

Baseline Performance

The prime contractor, Savannah River Nuclear Solutions (SRNS), provided project management and oversight of these projects that included engineering, radiological controls, regulatory integration, and safety and health. Subcontractors were used to operate the grout batch plants, deliver grout to the jobsites, place grout (in all low-risk areas), and perform all construction-related field operations. SRNS self-performed the placement of grout in the high-hazard areas (i.e., the reactor vessel and Disassembly Basin).

The total project cost for the P-Reactor and R-Reactor decommissioning projects is summarized in Table 3. In both cases, the projects came in under the approved baseline. The site credits cost efficiencies, including mitigated and unrealized risks during project execution for the under runs.

Table 3 – P-Reactor and R-Reactor Decommissioning Cost Summary ($millions)

Cost Element	P-Reactor	R-Reactor
Cost baseline with Approved Changes	$142.2	$149.2
Final Cost at Completion	$ 80.9	$ 76.4
Cost Under Run	$ 61.3	$ 72.8

Both the P- and R-Reactor decommissioning projects field activity durations were approximately 20 months; they were completed 3 months ahead of their approved baseline dates. Field work was completed in August, 2011.

5.3 Changes from Original Planning

Minor strategy changes from the design of selected alternatives presented in the respective Record of Decisions for the P-Area Operable Unit and the R-Area Operable Unit were necessary to achieve completion of the ISD closure projects. All deviations/changes were reviewed by the project team to ensure compliance with regulatory requirements and appropriate notifications were made as needed. The notable changes and the reasons for the changes were:

- The fill in the D&E Transfer Canal between the - 24 ft elevation to the - 1 ft elevation (- 7.3 m to - 0.3 m elevation) of the P-Reactor Disassembly Basin was revised from the flowable structural

fills initially specified to a lightweight grout. The original plan was to fill a void beneath the transfer canal floor with grout through core drilled holes; this would provide support to prevent collapse of the canal floor after grouting. However, levels of contamination of irradiated scrap on the canal floor prohibited human access to conduct the core drilling. Therefore, to ensure prevention of canal floor collapse, part of the fill used in the D&E Transfer Canal was revised from the flowable structural fills to a lightweight (foam) grout, which was specified so as to limit the canal floor loading to be the same or less than when it was water filled.

- The Disassembly Basin cap fill material was revised to use CLSM rather than filling with compacted soil. The reasons were limited availability of the type of soil needed and placement difficulty. The bearing pressure of Controlled Low Strength Material (CLSM) meets or exceeds that of compacted structural fill. Note that the basin fill below grade was always CLSM.
- The Disassembly Basin cover material was changed from 3,000 psi (21 MPa) Integral Crystalline Waterproofing (ICW) concrete to 4,000 psi (28 MPa) low shrink concrete without ICW. The reason was inconsistencies in the curing characteristics of the ICW concrete provided by the batch plant. The change allowed for a uniform product that met the requirements for the cover material.
- Concrete at the + 55 ft (+ 17 m) roof edge and vertical expansion joint seal for both sides of the stack area was added to the scope. As a result of discovering gaps in the vertical expansion joints at P-Reactor stack area, modifications were implemented to install a seal in the expansion joint for both sides of the stack area where it connected to the building.
- Interior and exterior horizontal openings to the Reactor Building Complex required 2 ft (0.6 m) of ICW concrete to be placed for the final layer. The change was needed because excessive cracking occurred in the initial external concrete coverings on vertical access wells at engine houses, heat exchanger rooms, and a storage tank room. The cracking was a result of having not required steel reinforcement in the original design of the external covering. The change was placement of an additional minimum 7 in thick (18 cm) reinforced ICW concrete cover with a 6 in (15 cm) overlap on all sides over each location where the cracking occurred.

5.4 Future Considerations for Reactor Disassembly Basins at SRS

In support of the decommissioning of the P-Area and R-Area reactors, the above-grade portions of the Disassembly Basin structures were demolished and replaced with a concrete cap after the completion of filling the basins to grade-level with grout. Mechanical demolition was achieved with track hoes fitted with hydraulic rams for breaking up the concrete, and track hoes fitted with sheers for cutting metal components (i.e., duct work, reinforcing steel, conduit, structural steel, piping, etc.).

The demolition proved to be a major challenge because of the robustness of the structure (in particular, the Basin roof) and the presence of significant amounts of reinforcing steel. In order to overcome this problem, larger-sized track hoes capable of asserting more “muscle” for the demolition were brought in. Even with the larger equipment, demolition took almost twice as long to complete than estimated. The original estimate was for demolition to take about 8 weeks; however, the demolition of the P-Reactor Disassembly basin took approximately 16 weeks and the R-Reactor Disassembly Basin took approximately 18 weeks.

The Project Team recommended that for the remaining three reactors at SRS, the above-grade structure of the Disassembly Basin not be demolished. In lieu of a concrete cap, advantage could be taken of the robustness of the Disassembly Basin structure using it as the closure cap for the grouted basin below. All of the external openings on the above-grade structure would be closed to allow filling the entire above-grade void with concrete resulting in a monolith atop the grout-filled basin. The roof of the Basin

structure is approximately 10 ft (3 m) above grade level, so in effect the closure cap, which for P-and R-Reactors was placed directly over the grouted basins, would be approximately 10 ft (3 m) high and several times thicker. The savings in demolition labor is estimated to offset the cost of the concrete required to fill the above-grade void space.

Other non-ISD projects have encountered similar demolition issues when there was insufficient knowledge and/or characterization of the strength of a facility's concrete material and rebar. The lesson is that for demolition of robust facilities, planning should ensure sufficient information has been gathered to well understand what will be required. If there is insufficient information from drawings and specifications (or doubts as to its validity), the concrete properties (e.g., with a core bored sample) and the rebar configuration and size should be determined.

6. Small Reactor Projects

Several small reactor facilities have been entombed after the reactor vessel and all above grade structure was removed before backfilling the below grade structure with grout. These projects include the Heavy Water Components Test Reactor (HWCTR) at SRS and the Loss of Flow Test (LOFT) facility, the Power Burst Facility (PBF), the Engineering Test Reactor (ETR) and the Materials Test Reactor (MTR) at INL.

The INL projects are briefly described in the next subsection followed by a more detailed description of the HWCTR entombment.

6.1 INL Small Reactor Project Descriptions

In these projects the significant radioactive items, including the reactor vessels, were removed for burial at the on-site Idaho CERCLA Disposal Facility (ICDF). The below-grade portions were partially cleaned out and decontaminated (to ensure consistency with assumptions used for the Performance Assessment source term); the superstructures (generally non-masonry, steel framed structures) were demolished to grade; and the remaining basement were filled with grout and/or clean backfill material.

The remaining structure was capped with concrete; an earthen cover was added for weather protection. Grout was used as fill material simply because of the ease in which it could be introduced into the volumes that required void filling; the grout did not serve functions of structural stability or contaminant immobilization.

Loss of Fluid Test Facility (LOFT)

INL's Test Area North-630 (TAN-630), the LOFT Control and Equipment Building, and TAN-650, the Containment Service Building, were constructed in 1959, as an integral part of the Flight Engine Test facility to prove the feasibility of nuclear powered flight. The TAN-630 structure was constructed to house remote control, measuring, and data analysis equipment associated with the nuclear airplane. The project was cancelled in 1961 before the airplane was built, and TAN-630 was never used for its originally intended purpose. Several other activities and experiments were conducted at TAN-630 between 1961 until 1986.

ISD removed above ground components and structures (e.g., the overhead crane and borated water storage tank), ducting and piping from within the TAN-650 containment, collapsed and removed floors and concrete walls to 3 ft (0.9 m) below grade for TAN-630 and TAN-650 and filled them to grade with solid inert material (an undefined mixture of sand, gravel and uncontaminated demolition rubble). Contaminated sumps were filled with a solid inert material and the piping capped. These sumps and embedded pipes were encased in high density, reinforced concrete as far as 30 ft (9 m) below grade.

The LOFT containment building was constructed of high density concrete reinforced with #8 and #11 rebar with sumps and embedded pipes running throughout the structure. The upper containment floor, which also has sumps and embedded lines, is constructed of approximately 5 ft (1.5 m) of high density, reinforced concrete.

Demolition of the dome, 62 ft (19 m) above grade, presented significant worker safety hazards and prohibited traditional demolition techniques. The LOFT D&D team used horizontal cuts made to weaken the dome; leaving tabs to support it prior to demolition. Simultaneous explosive charges attached to the remaining material near the top severed and felled the dome as shown in Figure 34.

Figure 34 – Loss of Fluid Test Facility during Demolition

A long-term viable cover (e.g., native soils) encompasses the footprint of the containment dome and the previously grouted filter housing room to the east. The annulus voids under this area are filled with grout providing a stable long-term foundation for the cover. The adjacent areas of TAN-630 and TAN-650 that are demolished to 3 ft (0.9 m) below grade are backfilled with site soils and compacted. These areas are not under the "long term viable cover" but were compacted with proper moisture addition to minimize subsidence and safely support equipment and vehicle traffic for the demolition of the containment dome. Figure 35 illustrates these processes during demolition.

Figure 35 – Processing LOFT to 3 ft below Grade and the Lower Containment Vessel after Grouting

The long-term cover is overlain with rock armor to prevent inadvertent intrusion on the cover during the DOE institutional control period, and to provide erosion control during heavy runoff events.

Power Burst Facility (PBF)

Built in the 1970s, the PBF (Figure 36) supported studies of reactor fuel during extreme operating conditions. The unique three-story, 19,000 GSF (1,800 sq m), test reactor facility was designed to subject fuel samples to extraordinary power surges in milliseconds, causing the fuel to fail in an isolated, contained system. Knowledge gained from PBF tests has helped determine safe operating limits for the commercial nuclear industry. The facility was shut down in 1998.

Figure 36 – Power Burst Facility before Demolition in 2008

ISD removed the PBF vessel and other radioactive sources per the assumptions in the performance assessment. The reactor building was demolished to below ground level. Void spaces were backfilled, including the void left by removal of the PBF reactor vessel. Backfill consists of grout and/or inert demolition waste from the above ground level structure, and clean backfill materials. As shown in the conceptual end-state (Figure 37), less than 0.2 Ci (8 GBq) of total activity, including Cs-137, would remain from 0 ft to 10 ft (3 m) below ground level. Approximately 4.7 Ci (180 GBq) of total activity would remain below the 10 ft (3 m) interval.

In July 2008, D&D crews demolished the last structure at the PBF complex – the reactor building. The most significant D&D challenge at PBF was removal of the 61 ton (55 tonnes) reactor vessel. The reactor lift required two cranes; one to remove the vessel from the basement of the reactor building, and the second to swing the vessel into a horizontal position for placement onto a trailer for transport. The reactor vessel was disposed at the ICDF.

PBF is now managed under the Site-wide Institutional Control Program.

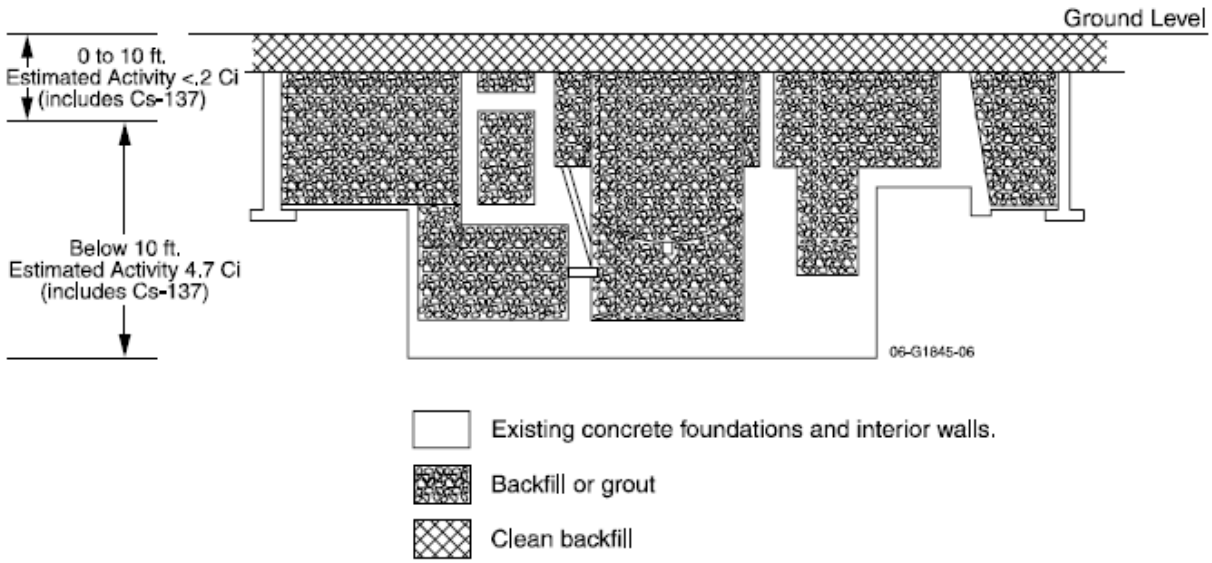


Figure 37 – PBF End-State

Engineering Test Reactor (ETR)

When the ETR became operational in 1957, it was the largest, most advanced nuclear fuels and materials test reactor in the United States. In 1973, the ETR mission shifted to support the DOE's breeder reactor safety program.

Deactivation of the ETR Complex (reactor building is 56,000 GSF [5,200 sq m]) was initiated in December 1981. The neutron startup source was removed. Radioactive water was drained from the ETR vessel, primary coolant system, water loop experiment piping and vessels, both canal sections, degassing tank and associated piping, and resin tanks. Other water systems were drained, including the secondary coolant water (including heat exchangers), utility water, the two demineralized water systems (low and high pressure), and water in heating and cooling units. The fuel in the ETR, as well as irradiated fuel in the ETR storage canal, was removed and shipped to INTEC for storage.

The ETR reactor vessel was installed in a single piece and similarly removed (Figure 38) with vessel internal components intact. The ETR vessel was disposed at the ICDF.

The reactor building was demolished to ground surface. Below grade structures and systems consisting of inert materials, such as piping, tanks, structural metal, and utility systems, were abandoned in place. Residual radioactive materials in the ETR Complex remaining after D&D activities were completed will be managed under the Site-wide Institutional Control Program. Void spaces were backfilled, including the void left by removal of the ETR vessel. Backfill consists of grout, inert demolition waste from the above grade structures, and clean backfill materials.

Figure 38 – ETR Vessel installed in 1956, and during removal for disposal in 2007

Materials Test Reactor (MTR)

Built in 1952, the MTR operated as a high flux nuclear test facility to allow testing of materials in high intensity radiation fields. More than 15,000 different irradiation experiments were performed in MTR, which (like ETR) provided findings that were critical in developing safe reactor operations and for testing components of future reactors.

The MTR facility, 45,000 GSF (4,200 sq m), is a steel-framed facility with a main floor, a basement, and two above-grade floors. The facility measures 130 ft by 131 ft (39.6 m x 39.9 m) and extends 58 ft (17.7 m) above grade and 38 ft (11.6 m) below grade. The reactor facility houses the multi-tank reactor vessel, along with the canal, subpile room, and the VH3 experiment cubicle in the basement. The reactor vessel is comprised of five integral reactor tanks and one tank extension.

Unlike the other reactors for which there is a single vessel. The MTR, shown in Figure 39, was built as a series of connected tanks and had to be removed in pieces, making it the most complex and difficult of the small reactor demolition projects at INL. By the end of 2008, D&D crews had removed the concrete shielding monolith that surrounded the above-grade portion of the reactor prior to removal of the vessel. The MTR vessel was subsequently removed and the facility was demolished to below ground level. The project was completed 2010.

The MTR vessel was disposed of at ICDF. Radiologically contaminated debris that met the removal action objectives was left in the sub-grade portions of the MTR facility. Upon completion of demolition, the remaining void was backfilled with solid inert material and graded to meet the natural contour of the area.

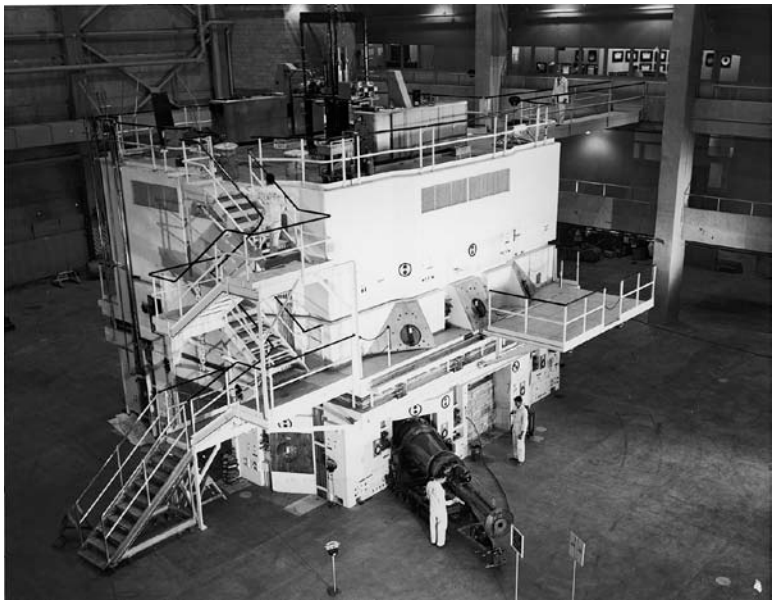


Figure 39 – The Materials Test Reactor

6.2 Heavy Water Component Test Reactor (HWCTR) Project Description

The HWCTR facility at SRS operated from March 1962 until December 1964 when operations were terminated and the facility was placed in a standby condition. All nuclear fuel was removed from the reactor and the reactor building in the 1970s. Characterization of the building and systems was conducted in the 1990s when all systems that contained heavy water were drained, de-energized, vacuum dried and disconnected from plant services. The spent fuel basin and its circulating system were drained. All support buildings were removed. Ventilation systems continued to operate in the reactor building and control building to prevent deterioration. Site personnel maintained the facility in a standby status for one year and then retired the reactor in place.

6.2.1 Description and Conditions

The HWCTR was a pressurized heavy water test reactor used to test fuel designs for heavy water power reactors. The 8 ft (2.4 m) diameter, 36.5 ft (11 m) tall reactor vessel was fabricated of 3 to 5 in (7.6 to 12.7 cm) thick carbon steel. Its weight was 98 tons (89 tonnes) including internal components of a stainless steel thermal neutron shield and 18 control rod housing and guide tubes and support structure. Surrounding the vessel was a reinforced concrete biological shield and a lower axial shield of concrete with embedded steel shot (spheres) that became radiologically activated during reactor operations.

The containment building for HWCTR was 70 ft (21.3 m) in diameter, rising 65 ft (20 m) above-grade and extending approximately 52 ft (16 m) below-grade. The above-grade portions of the facility include a steel dome shell, and numerous primary system and support equipment such as recirculating pumps, piping, tanks, compressors, and shielded transfer fuel coffin. The two steam generators, located below grade, were fabricated of carbon steel and weighed 19 tons (17 tonnes) each. The containment also included a below-grade, stainless steel-lined, reinforced concrete spent fuel basin and shipping cask pit. Figure 40 shows an aerial view of the HWCTR, circa 1960 and the HWTCR containment prior to its final decommissioning.

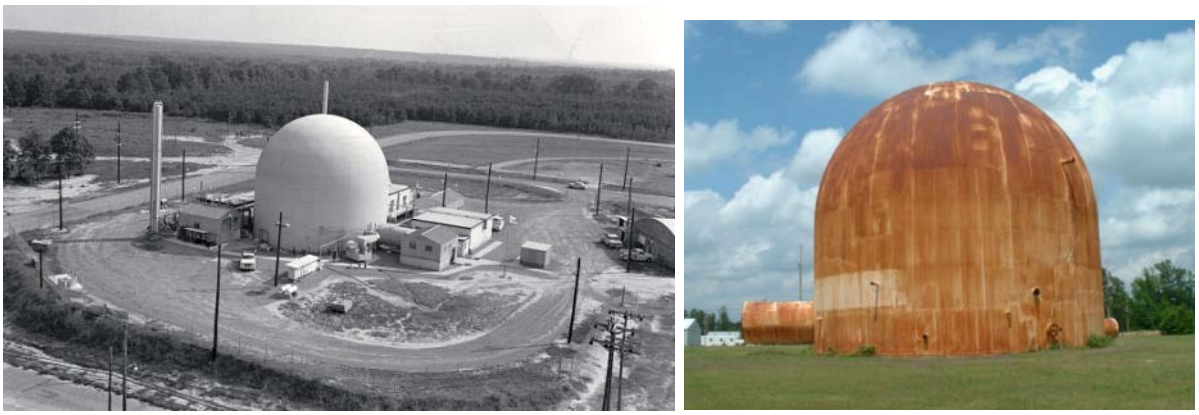


Figure 40 – HWCTR circa 1960 and Prior to D&D

During operation, 10 of 36 test fuel assemblies had cladding failures, releasing fission products, uranium, and transuranics into the reactor system loops. The steam generators had leaks and thus the steam system also became contaminated. In addition, heavy water leaks occurred within some areas of the building. The facility contained hazardous materials such as lead, mercury, asbestos, and polychlorinated biphenyls (PCBs) associated with existing equipment or previous operations (e.g., lights, piping, paints, etc.).

In 2009 the total amount of radioactivity remaining in the facility was estimated to be approximately 2,100 Ci (78,000 GBq). More than 99 percent of the radioactivity in the HWCTR facility was associated with activated metal in the reactor vessel in its internal structure, primarily the thermal shields. Radioactivity was also present in the concrete biological shield surrounding the reactor vessel to a maximum depth of 3.3 ft (1 m). At that time the predominant radionuclides present in the reactor vessel were Ni-63 (2,020 Ci; 75,000 GBq) and Co-60 (107 Ci; 4,000 GBq).

The total project cost for the decommissioning of HWCTR was $25.2M, which compares favorably (within 5%) to the estimated cost baseline of $26.5M. The project was completed two weeks ahead of schedule.

6.2.2 ISD Project

The overall approach to In Situ Decommissioning of the HWCTR was that the reactor vessel, steam generators, steel containment dome, and all above-grade components of the facility (with the exception of the shielded transfer fuel coffin) were removed and disposed. See Figure 41 for the discussion that follows. The major steps in the HWCTR ISD project were:

- Preliminary Activities. Preliminary activities included mobilization at the job site; establishing cold and dark isolation; water, hazards and asbestos removal; moderator heel removal; engineering inspections; radiation surveys; sample well installation; temporary power installation; dome access openings; and waste stream characterization.
- Grout Spent Fuel Basin. The Spent Fuel Basin was grouted early in the decommissioning process in order to remove the fall hazard and to provide access across the zero elevation to maneuver D&D support equipment (e.g., man-lifts, waste containers, cranes, etc.).

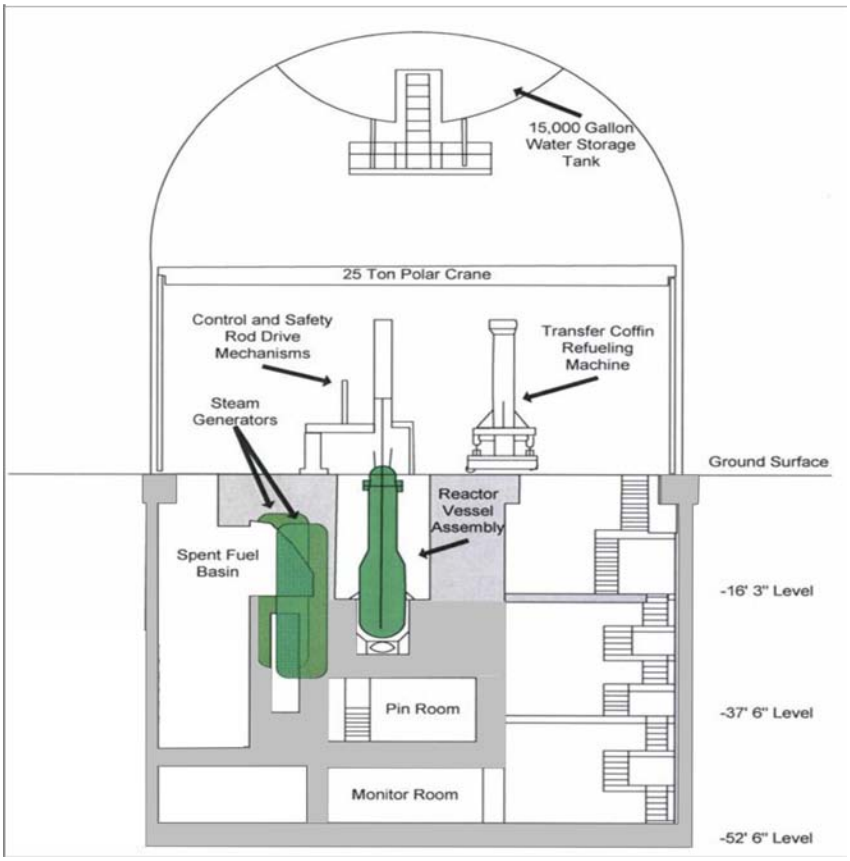


Figure 41 – HWCTR Schematic Cross Section

- Provide Access to Reactor Vessel - The Control Rod Drive Mechanisms were cut from the top of the reactor vessel and the platform rotated away from the reactor vessel in order to allow access to the reactor vessel cavity. Insulation was removed from the top of the reactor vessel head and the poured concrete cover was cut and removed allowing access to the concrete shield blocks in the reactor vessel cavity. Approximately 4,700 shield blocks and the reactor vessel insulation were removed from the area that surrounded the reactor vessel.
- Dome Removal - The steel dome was removed down to the + 30 ft elevation (+ 9 m) to facilitate removal of the steam generators and reactor vessel. Preparations for dome removal included removing interferences inside the containment building, cutting slots in the dome and installing safety alignment chocks, welding lifting lugs on the top of the dome, cutting the dome, and removing the dome by lifting it in one piece; shown in Figure 42.
- Polar Crane Removal. Preparations for Polar Crane Removal included disconnecting the electrical and control interfaces; removing interferences; and welding lifting lugs on both the bridge and trolley assemblies. The polar crane was removed by two lifts; the trolley lift and the bridge lift.

Figure 42 – HWCTR Containment Dome Lift and Demolition

- Steam Generator Removal - Preparations for the removal of both Steam Generators included removing all attached piping from the generators; fabricating and welding covers and blank flanges over the nozzles; removing interferences; and welding additional support chocks on the existing lifting lugs. They both were then removed, loaded for transport, and placed in a solid waste disposal trench.
- Reactor Vessel Removal - Preparations for removal of the reactor vessel included removal of the reactor vessel piping and instrumentation, and capping and seal welding the reactor vessel nozzles. Special designed lifting bosses were welded on the reactor vessel and lifting swivels attached to the bosses. Incore instrumentation from the bottom head of the reactor vessel was removed and the reactor vessel was prepared for removal. The vessel was then removed, loaded for transport, and placed in a solid waste disposal trench. The lift is shown in Figure 43.
- Transfer Coffin Refueling Machine Relocation - Once the reactor vessel was removed from the reactor vessel cavity, a support platform was lowered in the cavity. The Transfer Coffin was cut away from its trolley, lowered into the cavity, and placed on the support platform.

Figure 43 – HWCTR Reactor Vessel Removal

- Grout Below Grade - The below grade space was filled with grout, using approximately 5,155 cu yds (3,940 cu m) of flowable structural fill grout from the - 52 ft elevation (-16 m) to the zero elevation (at grade); the grouted volume included the spent fuel pit. Figure 44 shows the Transfer Coffin being grouted in place.

Figure 44 – Transfer Coffin Grouting in the HWCTR Basement

- Above Grade Demolition - Once the below grade space was filled with grout, the dome, shell and all other above grade components were sheared and disposed in the solid waste burial facility.
- Closure Cap Installation - Following the removal of components, the below-grade portions of the facility were sealed in place with a grout material to form a stabilized structure. The area was then covered with concrete at the ground surface to prevent infiltration of precipitation and eliminate direct exposure. A concrete closure cap was installed over the HWCTR facility footprint. The completed installation is shown in Figure 45.

Figure 45 – HWCTR Closure Cap

6.2.3 Secondary Waste Disposal

About 110 cu yds (85 cu m) of non-hazardous solid waste was disposed. It included scrap metal and lumber generated from the construction and tear down of the reactor vessel, mock-ups used in planning and preparation for the actual reactor vessel and other work, and miscellaneous waste associated with setting up and dismantling the cranes. Another 110 cu yds (85 cu m) consisted of mixed waste, oily water, and mixed waste oil from draining equipment.

The majority of the waste (1,300 cu yds; 960 cu m) was low level radioactive waste dispositioned to Savannah River shallow land burial site; it included pump cooling motors, piping and conduit, the polar crane, trolley, and crane bridge, reactor shield ring, equipment cabinets, the reactor vessel top drive platform, and the containment dome.

7. Management Insights

This section is a "catch-all" for several types of information gleaned from the site interviews that do not readily fit elsewhere. These examples and lessons learned may provide insights of interest to management for planning and for work management.

7.1 Health and Safety

The types of hazards and risks for an ISD project are generally the same as for standard D&D and for conventional construction; in the latter case, complicated by the presence of radiation and both radioactive and chemical contamination. However, the nature of ISD projects may increase the exposure to certain hazards. Examples include:

- Vehicular traffic can be expected to be heavy, in particular for the number and frequency of trucks bringing grout from either the on-site batch plant or from off site. Anticipate 10 to 25 trucks in a continuous circuit during working hours meaning there can be one to two hundred per day. In addition to grout trucks, there will be significant additional traffic for delivery of large quantities of materials to an on-site batch plant.
- Heavy lifting is a very frequent occurrence for placement of equipment, cell covers and other closures for grouting, and for other material staging. In a project such as U Canyon, this can be considerably greater than for many demolition projects.
- Respiratory protection is required while preparing areas for grouting in radiological areas. Dust and particulate protection is required in many non-radiological areas.
- Skin contact from exposure to airborne grout dust is prevalent; it is comparable to large new construction projects.
- Skin exposure to splatter requires consideration of barriers; for example when pneumatically cleaning out the grout feed piping after final cap lifts. During this activity, grout can splatter in a 15 ft (4.6 m) radius as a result of the pipe being submerged in the grout layer.
- Fall protection and air quality management are needed while preparing pits, floor cavities, and voids for equipment placement and grouting.
- Confined space access is required in areas that may not have been entered for years prior.
- Cast in place foam barriers are used to direct flow of grout through small openings and pipes. Some foaming products are high in isocyanates, leading to an industrial health hazard during its placement. To compensate for this hazard, their use should be restricted to vertical applications where a fast cure time is important.

Development of the health and safety management approach should consider use of expertise familiar with large concrete and grout projects.

Site-specific radiological hazard management examples are:

- SRS subcontractors performed extensive grout placement in radiological areas. However, the prime contractor self-performed grout placement in areas where radiation dose readings were greater than 100 mrem/hr (1 millisievert/hr) and in areas where there was an increased potential for airborne radiological issues; the below grade disassembly basins and the reactor vessels were examples of where both of these conditions existed.
- At U Canyon, the initial radiological survey did not sufficiently characterize all of the canyon areas such as closets, equipment areas, sumps, external vent duct, etc. This meant that large

portions of the galleries were classified as contamination areas when all that was needed was to do a primary survey and spray fixative if needed to lock down contamination. This limited access to pipe chases, piping, and made work in the galleries much more difficult than should have been the case.

- Removal of the extremely heavy lead/iron "sample blisters" in confined areas at INL project presented an ALARA challenge. The sample blisters are attachments to hot cells for removal of sample containers. Because of the lead content, their removal would normally be required as part of the abatement activities. The project removed one manually from the grade level, but this proved to be very labor and radiological exposure intensive. One blister was removed by diamond wire saw, but this proved to be very costly and inefficient. As a result, those at grade level inside the building were removed by demolishing an exterior wall (much fixative was first applied to the interior) and using an excavator for handling. The exterior wall was re-formed and rebuilt with structural concrete. For the others that were at the lowest elevations and presented many physical challenges associated with their removal, a waiver was requested and granted to allow them to be entombed within the facility.

7.2 Logistics

A common characteristic of all ISD projects is the major logistics challenge because of the large quantities of materials being managed, primarily for grout and concrete placement. An added complication compared with a new construction project is working within a contaminated facility with much physical interference from installed equipment and systems; both factors can significantly limit access. As a result, the day to day scheduling is very dynamic. Many decisions and schedule developments are made in real time for activities such as the placement of equipment, delivery and staging of materials, batch plant operation, and the sequence of grouting. A prime example of a logistical complication not originally anticipated was the limited supply in the northwest of flyash required for U Canyon grouting; as a result, flyash delivery often was on the critical path during placement operations. The SRS and INL projects had similar challenges with scheduled delivery of sand and flyash.

Another few examples of supply chain intensity experienced at U Canyon in addition to grout constituents and supply include:

- Personal Protective Equipment, waste drums, Soil Lock, Absorbent Socks, etc.
- Grout totes – 2 cu yds (1.5 cu m) grout totes were needed for QA operations and for wash out of the pumps and trucks. Each location needed at least two totes available, with a contract that allows for the acquisition of more as they wear out. The QA operations were for verifying viscosity in terms of pouring, cylinder casting, etc. in compliance with the applicable ASTM procedures. (Note; the SRS reactor projects used children's plastic swimming pools from a discount store for these functions.)
- Ecology Blocks[2] have a long lead time and needed to be ordered early. The primary use of the ecology blocks was in the construction of the above-grade rinse/wash pit at the concrete batch plant operations.

[2] Ecology blocks are large concrete block with a groove in the bottom face and a tongue on the top face to eliminate slippage when they are stacked. There is also a steel loop on the top face to facilitate lifting. The blocks are stacked in an offset manner to create a wall for retaining earth by means of their great mass. A wall built with them can be readily dismantled and the blocks reused (in ecological fashion).

- Scaffolding - A large amount of scaffolding was needed in the railroad tunnel, in the galleries for bulkhead construction, in the galleries for obstruction removal, and outside for core drilling. Due to work in the controlled areas, sufficient scaffold with steps taken to protect the scaffold from internal contamination were needed. Enough scaffolds for multiple work platforms were required. This allowed the scaffold to be leapfrogged ahead of the workers to keep efficiency as high as possible. The amount of scaffolding needed varied considerably from a pure demolition project in that more internal work is required to prepare the facility and place grout.

Standard D&D projects tend to be labor intensive and have special equipment needs. In contrast, an ISD project will be considerably more intensive with regard to materials supply. Project managers with experience in standard D&D must understand this difference and plan accordingly for staffing skills, staging areas, and procurement support.

7.3 Project Planning Examples

In the course of reviewing information at SRS, several project management deliverables were observed for which existing methods were adapted to the ISD project needs. Four are described briefly here and are presented by example in appendices to this report for consideration by future project managers. They are as follows.

Appendix A – Specifying Project Design Requirements

At SRS, a site-standard engineering procedure called a “Modification Traveler” was used to specify the technical requirements for execution of ISD. As the name implies, the procedure is usually for the purpose of specifying facility modifications. Of interest is that this approach avoided the need to create something specific to the ISD project. The executed procedure from which this was taken addressed functional and performance requirements such as waivers, safety basis strategy, design input guidance, and design review for the ISD project. Appendix A provides an example of how the Modification Traveler was used to specify the ISD project for the R Reactor Building Complex project.

Appendix E - Above Grade ISD Hazard Category Evaluation

The P- and R- Reactor ISD projects at SRS differ somewhat from those at Hanford and INL in that a significant amount of the facilities’ superstructure remains above grade for the project end state. As a result, it was important to understand the consequences of an accident involving the above-ground structure. Appendix E describes how this subject was addressed. The approach used was to determine the Facility Hazard Category (FHC) of the ISD Reactor facility for the conditions of the facility after the completion end state. Prior to ISD, the buildings contained enough dispersible radiological material for a FHC of "radiological.” If it could be shown that enough removal, cleanout, stabilization and encapsulation had been conducted such that the amount of materials released under accident scenarios would be lower than the release quantity criteria of 40 CFR 302.4 for reporting, the facility could be categorized as “other industrial” (that is, not nuclear and not radiological). This would then minimize the degree of monitoring and inspection compared with a facility that would have an FHC of radiological.

Appendix F - Work Breakdown Structure

This appendix provides an example of a Work Breakdown Structure (WBS) that was used for the P-Reactor project. The example elements are at the project level and one level lower.

Appendix G - Project Risk Management Example

This appendix contains an example of a project risk management analysis. The example shows selected aspects used for the P Reactor project. It provides information for an ISD project regarding the method

used, types of risks considered, and the results of the technical, schedule, and estimate risk assessment. The standard aspects of risk management methods and tools are only briefly addressed as each future project should have its own well established.

The significant project risks in the P-Reactor risk assessment are identified. Some were specific to ISD and others would apply to any decommissioning project. Risks identified fall into two groups; a) those that were closed and not included in the Technical and Programmatic contingency calculation; and b) those used in the contingency calculation.

7.4 Advance Preparation

Examples of pre-planning experience follow addressed in topics of the overall site, structures, and systems are discussed below.

Site Related Pre-Planning

For an ISD project compared with D&D, more areas are potentially required for material staging, grout plant, grout delivery, etc. As a result, the entire area surrounding the facility needs to be evaluated well in advance for use during the project. A good example is at the U Canyon, where clean demolition waste from other projects was staged to be used later for the cover system. However, planning was after-the-fact and presented a challenge to ensure environmental and cultural requirements for placement of the material in that area was properly managed.

In particular, batch plant location and grout truck routing on site is very important. Section 8.2 describes experience at the three sites for batch plant location and operation.

Structure Related Pre-Planning

Some pre-planning examples related to facility structure include:

- Visualization - Pictures of all rooms, doors, penetrations, cells, cavities, voids, galleries, rooms, oddities, indoors, and outdoors, etc. A photo storage methodology/system for retrieval should be maintained. Photos are useful for work planning, placement of equipment planning, engineering, contracting, and table top task walk-through, among others. In all projects they have been used for project-completion/Remedial Action Reports and for communication with regulators and other stakeholders. Videos are very useful for work planning. Work planning using 3-D modeling is described in Appendix H.
- Rebar Scans - At Hanford, there are only two qualified persons available to perform rebar scans for the project. Since the project engineers already knew the general locations where they wanted to core drill, scheduling the rebar scans would have been more efficient performed over a one- to two-week period, rather than on an as-needed schedule. Similarly, scans for anchor penetrations, embedded piping, and embedded wiring should be performed early.
- Clearance for barrier construction - At U Canyon a lesson learned is to remove obstructions for the bulkhead construction locations well in advance of the bulkhead work. Since the facility was not electrically isolated, each bulkhead electrical obstruction had to be individually determined to be safe.
- Penetrations - At SRS, it would have been more efficient to conduct a 100 percent inventory of building and reactor vessel penetrations in advance as part of engineering and work package planning. A subcontract was awarded to seal the above-grade, exterior openings. The Statement of Work provided a listing of approximately 75 major openings (primarily doorways) and a design for each opening. It also specified that minor openings (conduit and piping

penetrations) were also to be sealed; however specific designs for minor seals were not provided: it was assumed that the subcontractor would pack the minor openings with grout (skill-of-the-craft activity with no formal engineering). In practice, many minor openings required engineering evaluation and a specific set of instructions (and/or a formal design) to achieve a proper seal. In hindsight, it would have been best to identify all openings, and the applicable seal design, prior to contract award rather than relying on the subcontractor to evaluate the opening and then have to negotiate changes after subcontract award.

- Volume Calculations - It is recommended that all void volumes be calculated by two engineers independently, followed by comparison for consistency. This is opposed to simply having one person review another's calculations.

  An example of a complication is a doghouse style cover block as shown here needs to be accounted for in the volume calculation. While this may be canyon specific, the lesson is to account for large protuberances when calculating grout volumes.

Systems and Utilities Pre-Planning

Reactivation at U Canyon is discussed briefly in Section 4.3.3 and in detail in Appendix B, which describes evaluations that were conducted for using and reactivating the canyon ventilation, bridge crane, and electrical service systems; it also discusses what was needed to reactivate the railroad tunnel connected to the canyon.

Other examples of pre-planning for systems and utility services resulting from site interviews include:

- IT Support – at the R-Reactor, installation of a wireless internet link saved considerable time in generating reports, labor time recording, and other administrative activities that would have otherwise required driving to a location several miles away.
- Piping Systems Tap and Drain - All piping systems should have been characterized to determine or verify their status. Preferably during characterization, all systems that have not been air gapped should be tapped, drained, and air gapped. The U Canyon project tapped and drained 240 of 540 pipes; pipes that were supposed to be empty were not. Tap and drain criteria used were that any pipe over 6 in (15 cm) diameter or 10 ft (3 m) in length had to be open ended; the project include 4 in (10 cm) lines as well. The 6 in (15 cm) criterion was based on the Hanford CERCLA Cell waste acceptance criterion, regardless of the fact that these pipes were not to be disposed there.
- Piping Systems Tap and Drain - Acidity determination strips were utilized for residual liquids, primarily during tap and drain, to check for pH. In retrospect, pH meters would have been useful to provide immediate measurement. Considerable time was lost by using test strips. The combination of low light and face shields contributed to the misreading of a test strip, which would have been avoided with a digital meter display.
- Canyon Crane - A planning study at U Canyon concluded that use of the canyon crane with augmented portable equipment would suffice. Use of mobile cranes with sufficient lifting capacity presented its own set of complications for bringing them into the building. However,

the canyon crane required considerable unbudgeted effort and time to maintain due to its advanced age and lack of available replacement parts. For future such projects, in addition to preventative and corrective maintenance management, consideration should be given to securing replacement parts from the other similar canyon cranes on site.

- Electrical Service - Generators or external in-line power feed are acceptable for internal temporary use. Generators were used for the U Canyon crane power, however every 200 to 300 hours the generators had to be shut down for servicing, causing delays. In future similar cases an evaluation should be performed for providing electrical power from outside the building; designed with an easy disconnect at the conclusion of the project. The purpose would be to de-energize all permanent electrical conductors.
- Temporary Electrical Power Accessibility - The U Canyon project used temporary power in the canyon with spider boxes placed at 15 to 20 percent of the canyon length. This proved to be insufficient.
- A dedicated power feed from the site's electrical grid fed power to the SRS batch plants in P Area; generators were utilized for emergency backup power.
- Lighting – Consideration should be given to providing temporary lighting electrical supply from outside the building. SRS found that switching to compact florescent light bulbs in temporary string lighting significantly reduced re-lamping. One complication at U Canyon was that replacing installed light bulbs within the canyon was manually conducted and could take a day or more because of difficulty of access and need for personal protective equipment within the canyon. Consideration should be given to using remote-reach technology for light bulb change out in cases where access is difficult.
- Batch Plant Utilities - Batch plant utilities include electrical feed and raw water. The use of portable, diesel-powered generators for supplying grout batch plant electrical power proved to be successful, cost effective and timely at SRS.

8. Grout and Concrete Experience

8.1 Grout and Concrete Mix Experience and Specifications

For ISD, the primary function of grout is the filling of void spaces; which in turn creates a barrier to human and ecological intrusion into the entombed facilities. It also serves the function of isolating and locking contamination in place to prevent migration within the entombed facility.

Because the facilities have very large volumes to be filled, grouting operations can easily be the most significant overall activity in a project with regard to materials, labor, schedule, and cost. Whereas grout is used for bulk filling, concrete is differentiated from grout as being used for robust applications, such as structural support.

The flowable nature of grout allows filling with relative ease the "nooks and crannies" of most structures so as to impede infiltration of water, prevent human access, and exclude ecological intrusion. Filling decommissioned structures with grout also provides a visual image of end-state permanence. Grout mixes can be adjusted to provide a variety of secondary functions; these include adding sequestering agents to enhance immobilization of selected contaminants to limit their mobility; increasing the density to provide shielding/dose reduction of radiological source terms; and increasing the compressive strength to prevent subsidence of the structure over time.

Regardless of the additional barrier that grout provides at Hanford and INL, the projects described in this report did not credit the grout for impeding contaminants' transport for dose pathways modeling assumptions; only the walls and foundations of the structure were considered in pathways analyses. Similarly, no credit was taken for providing resistance to subsidence or other types of structural integrity. However, in the Fate and Transport models used at SRS, some credit was taken for non-structural grout impeding the contaminants.

The grout formulations and concrete used for the ISD projects were designed to fulfill three basic needs: a) grout for bulk filling of spaces, voids, and tanks; b) a flowable grout for filling pipes, and c) a more rigid concrete mix (i.e., with coarse aggregate) for plugs, barriers, replacing walls removed for convenience, and structural reinforcement. In total, INL utilized three different mix formulations; Hanford utilized four. The ISD projects at SRS required eight different mix formulations, in part due to the more complex initial conditions, and the above-grade final configuration of the reactor buildings. Of specific note is the presence of substantial amounts of aluminum in the P-Area reactor vessel, which required a highly specialized mix formulation that is addressed in detail within this section.

INL CPP-601/640 Project

Three grout mixes were used for this project: a sand mix was used for filling tanks and general areas; a fly ash mix was used for filling pipes; and a small amount of structural concrete was used to replace the exterior wall that was removed to provide excavator access for removal of the sample blisters located at grade level. The two non-structural batch formulations used for fill are shown in Table 4.

Table 4 – INL Grout Mixes Used for Fill

Mix Component	Sand Mix: Controlled Low-Strength Material (CLSM) Grout	Fly Ash Pipe Fill Grout
Cement	300 lbs (140 kg)	750 lbs (340 kg)
Pozzolan Class C[3]	200 lbs (90 kg)	NA
Pozzolan Class F	NA	1831 lbs (830 kg)
Fine aggregate (sand)	1890 lbs (860 kg)	
Water	38 gal (140 l)	Up to 84 gal (320 l)
Air Entrainment Rheocell 30	14.5 oz per cu yd (540 g/cu m) or amount to meet specification	NA
Glenium 3030	18 oz per cwt cementitious material or amount to meet specification	NA
High range water-reducer	NA	5 oz per cwt cementitious material or as required to obtain flow

Hanford U Canyon Project

An alternatives evaluation workshop and subsequent engineering evaluation conducted by the Project Team developed guidelines for filling the lower portions of the canyon structure with cementitious grout [Ref: FLUOR-2007]. The primary conclusion was that specifically formulated and controlled grouts can successfully fill voids and stabilize wastes to the maximum practical extent. The grout mixes for the U Canyon ISD project were required to meet specific functional requirements to comply with the intent of the ROD and to satisfy good engineering practice. In particular, it was desirable that the grout material should not add excessive physical stress to the canyon structure. High temperatures from heat of hydration were to be minimized to prevent steam flash, excessive shrinkage cracking, and thermal expansion damage to the existing structure.

An independent grout engineering consulting firm was contracted to review the grouting plans and provide recommendations for grout materials and mix formulations. A total of six different mix formulations were originally presented for use in U Canyon; however only four mixes were used, which were:

- Type A (sand) - a low density grout with only sand for aggregate; used for major void and bulk filling of process cells, tanks, and Canyon galleries. High grout temperatures caused by cement hydration were controlled by developing a lean grout formulation (i.e., less Portland cement mass in the mix) and also by limiting the amount of grout placed in an individual pour.
- Type B (flyash) - a self-leveling mix with high flowability, used for the top cap (approximately 2 ft [0.6 m]) of the operating deck and the process cells.

[3] A pozzolan is a material which, when combined with calcium hydroxide, exhibits cementitious properties. Fly ash is fine-grained particulate produced from coal combustion that is a pozzolan.

- Type I Portland Cement with course aggregate - a "plugging" mix used in the ventilation shaft in two locations (between the Canyon & the Sand Filter; and between the Sand Filter & the exhaust stack).
- Redimix™/low density slurry with coarse aggregate - another "plugging" mix used for plugging core bored holes that were used to provide access for the grout tremie lines.

With regard to design considerations, specific challenges encountered during the grout mix development were:

- **Grout Flowability:** The project team determined that flowability was the most important factor in assuring that the majority of the voids in the canyon will be filled with grout. Proper flowability coupled with a systematic grout placement approach was essential to filling the canyon and equipment voids to the extent practical. In order to ensure adequate grout flow in remote, narrow, long void spaces such as the process cell drain header, 80 ft (24 m) was specified as the maximum allowable flow distance. Large scale flow demonstration tests showed that the grout formulation needed to be adjusted to achieve this flow distance.
- **Grout Strength:** The project team's interpretation of a qualitative requirement from the U Plant ROD, specifically the ambiguous phrase "*…flowable, structural grout with good compressive strength,"* resulted in the somewhat arbitrary specification of grout with a compressive strength of 1,500 psi (10 MPa) at 28 days. However, the dose pathways performance assessment only took credit for the building structure as the primary barrier for containment of the contaminants. Field demonstration tests found that grout with a lower strength (in the 500 to 800 psi range [3 to 6 MPa]) would be adequate for the intended use of void space fill; structural stability was not needed. Subsequent negotiations with regulators, backed by independent quality testing to confirm whether grout supplied in the field met the specifications, resulted in relief from this inferred design requirement. This significantly benefited the project schedule with regard to meeting quality control requirements that depended on the length of time for samples to develop the required strength, which in turn would significantly impact the project schedule.
- **Field Demonstration Tests:** Grout produced on-site failed to meet the compressive strength requirement at 28 days of curing; it did develop sufficient strength in time at 56 days. Part of the reason was that initially, grouting occurred in March when the grout arrived at around 55º F (13°C); bringing in the grout at around 70° F (21° C), helped. In addition the concrete canyon was an immense heat sink that tended to maintain a low temperature. In hindsight, thorough field sample testing could have been done before beginning large scale grout production to ensure the design mix performs as specified; and if not, the specifications can be tailored to conditions.

<u>SRS P-Area and R-Area Reactor Projects</u>

A total of five basic types of grout were used at SRS to accomplish the ISD activities at the P-Area and R-Area reactors [Ref: WM-2011]. In addition, three concrete designs were utilized to complete the ISD closure of the Reactor Building complex structure. The Reactor Building complex was divided into zones for implementation of the ISD project as shown in Figure 21. The type of cementitious fill material used for each zone is identified in Table 5. Of the five types of grout used in the SRS ISD projects, the first three types described below were used at both P-Area and R-Area reactors, and the last two were used at P-Area exclusively. Details on the respective mixes are discussed following the table.

Table 5 – P-Reactor and R-Reactor ISD Cementitious Materials

Reactor Zone	Sub-Zone	Fill Material Type
1	Inside Reactor Vessel	P-Reactor: Non-corrosive (near neutral pH), zero-bleed grout with ICW* R-Reactor : Zero-bleed flowable structural fill
	Reactor Vessel Cap	Shrinkage-compensating concrete with ICW
2	All Below Grade Spaces to - 2 ft (- 0.6 m) level	Zero-bleed flowable structural fill
	From approximately -2 ft (- 0.6 m) to grade-level	Shrinkage-compensating concrete with ICW
3	From bottom of Disassembly Basin to approximately - 25 ft elevation (- 7.6 m, shield layer)	Underwater zero-bleed flowable structural fill
	From top of shield layer of grout to grade-level of Basin	Zero-bleed flowable structural fill
	Disassembly Basin cover	4000 psi low shrink concrete
4	Purification Area	Zero-bleed flowable structural fill
5	Actuator Floor Penetrations	Shrinkage-compensating concrete

*ICW = integral crystalline waterproofing

Standard Controlled Low Strength Material (CLSM)

CLSM is a self-compacting, cementitious material used primarily as a backfill alternative to compacted structural soil fill. CLSM typically requires no compaction (consolidation) or curing to achieve the desired strength. Long-term compressive strengths of 50 to 300 psi (0.3 to 2 MPa) are low when compared with concrete. In terms of allowable bearing pressure, however, which is a common criterion for measuring the capacity of a soil to support a load, this compressive strength is equivalent to a well-compacted fill.

Dry Area Zero-Bleed Flowable Structural Fill

Dry area zero-bleed flowable structural fill grout was specifically developed for ISD activities performed at both P- and R-Reactor complexes by the Savannah River National Lab (SRNL). Dry area zero-bleed flowable structural fill (grout) is cementitious material consisting of cement, fly ash, coarse aggregate (3/8 in [1 cm] gravel), fine aggregate (sand), water, a high range water reducer to reduce the volume of water and improve workability, and a viscosity modifying admixture. Cementitious materials with a viscosity modifying admixture exhibit superior stability, thus increasing resistance to segregation and facilitating placement and consolidation. Dry area zero-bleed flowable structural fill (grout) easily enters difficult access areas and it provides a relatively uniform compaction density; the strength can be controlled; it is self-leveling, and requires minimal crew and equipment for application. In controlled laboratory conditions this type of mix can achieve compressive strengths up to 600 psi (4 MPa) at 28 days.

Underwater Zero-Bleed Flowable Structural Fill

Underwater zero-bleed flowable structural fill grout was specifically developed for ISD activities performed at both P- and R-Reactor Complexes by SRNL. This specialty grout is a flowable mix designed

for underwater placement. This mix was formulated to be less dispersible in standing water than the bulk fill mix designed for dry area placements. This mix consists of Portland cement, fly ash, coarse aggregate (3/8 in [1 cm] gravel), fine aggregate (sand), water, and a high range water reducer to reduce the volume of water and improve workability. Unlike the dry area placement mix, the underwater mix does not include a viscosity modifying admixture. Underwater zero-bleed flowable structural fill (grout) easily enters difficult access areas, provides a relatively uniform compaction density, the strength can be controlled, is self-leveling, and requires minimal crew and equipment for application. In controlled laboratory conditions this type of mix can achieve compressive strengths up to 800 psi (6 MPa) at 28 days.

Lightweight (Foam) Grout (P-Area only)

The network of interlocking beams under the Transfer Canal floor created some void spaces that were not completely accessible for grout addition. There was some load bearing concern with the Transfer Canal being filled with traditional grout. It was decided to maintain the design safety factor for when the canal was filled with water, therefore a lighter weight grout was required. Section 8.1 provides additional description of the issue.

A commercially available lightweight grout was required for the filing of the P-Area D&E Transfer Canal from the - 24 ft elevation (- 7.3 m) to the - 1 ft elevation (- 0.3 m). This material is a closed cell lightweight grout with a dry density of 25 to 35 lbs/cu ft (400 to 560 kg/cu m).

Specialty Noncorrosive Grout (near neutral pH) (P-Area only)

The presence of a significant number of components made of aluminum within the P-Area reactor vessel raised concern for the potential generation of explosive hydrogen gas caused by the alkalinity of cementitious grout reacting with the aluminum components. As a result, the Project Team decided that a noncorrosive grout material would be required for filling the reactor vessel. SRNL was requested to support the development of this specialty material. A calcium sulfo-aluminate grout material was developed, tested, and evaluated. This mix also included an integral crystalline waterproofing (ICW) component to lessen the hydraulic conductivity of the overall mix. The calcium sulfo-aluminate grout mix used in the filling of the Reactor Vessel had a 28 day compressive strength of 980 psi (7 MPa) in scale up testing. Attributes of this mix were as follows:

Design Requirements: General requirements for the reactor vessel grout were the same as for the I05-R and I05-P Buildings except that the flow paths in the 105-P reactor vessel are especially constricted due to numerous internal components. In addition, the need for material compatibility between the grout and reactor materials imposed additional requirements. Both the reactor vessels contain aluminum components which were left in place as part of the ISD closure.

After estimating the amount of aluminum metal abandoned in each reactor vessel, calculations were performed to estimate the potential for exceeding 60% of the Lower Flammability Limit (LFL) as a result of hydrogen generation from corrosion of the aluminum in a caustic media. Results indicated that the limited amount of aluminum metal in the 105-R reactor vessel did not pose an LFL issue if portland cement-based grout was used to fill the vessel. However, the safety factor calculated for the portland cement fill for the 105-P reactor vessel, which contains significantly more aluminum metal, was such that the decision was made to investigate alternative low pH grout systems. The corrosion calculations indicated that a higher safety factor could be achieved for grouts with a pH equal to or less than 10.5.

Based on estimates of the amount and rate of hydrogen generated as a result of corrosion of the aluminum components abandoned in place in the P-reactor vessel and the desire to maintain a high safety factor by not exceeding 60% of the LFL, a new flowable calcium sulfo-aluminate grout was designed and tested by Savannah River National Laboratory to meet the unique material and placement requirements. Table 6 shows the specified properties and requirements.

Chosen Mix: Calcium Aluminate Sulfate was chosen for this application due to its relatively neutral pH level and other performance criteria that demonstrated its suitability for the application [Ref: SRNL-2011, WM-2011]. Details of the qualification and testing are in the footnoted reference. The mix that was decided upon is shown in Table 7.

It is noted that another formulation that had lower hydraulic conductivity and higher strength was also tested; however, it was not used because acceptable full scale processing and vessel mock up testing had been demonstrated with the selected mix.

Application and Results: A total of 118 cu yds (90 cu m) of material was placed in the vessel during the two days of fill operations using three fill points and two vents; these opening were created by pulling plugs at the top of the reactor vessel. Disposable video cameras were installed in both vent holes to monitor the filling of the vessel. Cutaways view and cross section drawing of the pressure tube designed reactor vessel are shown respectively in Figure 26 and Figure 46, indicating the location of fill for the specialty grout described above. All requirements were met. The overall average 4 day compressive strength was 956 psi (6.6 MPa) and at 28 days was 1090 psi (7.5 MPa).

Table 6 – 105-P Reactor Vessel Low pH Grout Properties & Requirements

Property	Requirement
Slurry Properties (Fresh Properties)	
pH of grout for the P-RV (fresh and cured grout)	≤ 10.5
Flow Cone (ASTM C-939)	< 50 s
Static Working Time (SRNL Test)	> 30 min
Dynamic Working Time (SRNL Test)	> 60 min
Set Time (SRNL Ultrasonic Pulse Velocity test)	2 to 24 hr
Density (wet unit weight) (ASTM C-138)	80 to 140 lbs/cu ft (1282 to 2243 kg/cu m)
Air Content (ASTM C-231)	< 8 vol. %
Bleed Water (modified ASTM C-232)	None
Segregation (visual exam)	None
Maximum particle size	0.1 in (0.3 cm) maximum
Cured Properties	
Compressive Strength (ASTM C-39A)	
3 days	> 50 psi (0.34 MPa)
28 days	> 50 psi (0.34 MPa) required > 200 psi (1.38 MPa) desired
Adiabatic temperature rise (SRNL method)	< 140°F (60°C)
Maximum placement temperature	95°F (35°C)

Table 7 – Calcium Aluminate Sulfate Grout Proportions

Identification of companies in this table is for factual information and should not be interpreted as this report's recommendation.

Material/Ingredient	Weight Percent
ASTM C-404 masonry sand or ASTM C-637 sand for grout for pre-placed aggregate	51.56
KIM® 301 (an integral water proofing admixture by Kryton, International, Inc.)	1.135
Boric Acid (technical grade)	0.1
Diutan Gum (CP Kelco, Inc.	0.015
Plaster of Paris(US Gypsum Company)	4.53
Class F Fly Ash ASTM C-618	15.32
Ciment Fondue®[4] (Kerneos Aluminate Technologies)	9.06
SIKA ViscoCrete® 2100 (W.R. Grace, Inc.)	0.92
Water	19.18

[4] Cement Fondue has a different composition to "normal" cement - it has high aluminum content; sets in about 6 hours, cures to full strength in 24 hours without any shrinkage or cracking, and is heat-proof.

Structural Concrete

In addition to the grout mixes described above, the following three concrete designs were utilized at the SRS projects:

- 3000 psi (21 MPa) concrete (with epoxy coated reinforcing steel) was used for sealing all the vertical exterior Reactor Building above grade openings, with the exception of one personnel door that was welded shut with a stainless steel plate. 3000 psi (21 MPa) concrete (unreinforced) was also used for the final two lifts of the evaporator entombment within the Assembly Area Receiving Room.
- 4000 psi (28 MPa) low shrink concrete (with epoxy coated reinforcing steel) was used in the construction of the footing, knee walls, and cover for the Disassembly Basin. The addition of a shrinkage reducing and compensating admixture results in a structure with reduced cracking, producing a higher quality concrete.
- Integral Crystalline Waterproofing Concrete - ICW Concrete, which includes the addition of a shrinkage reducing and compensating admixture and a waterproofing admixture results in a concrete structure with reduced cracking, enhanced self-sealing and waterproofing abilities which provide additional protection against water damage and corrosion of reinforcing steel. This application was specifically used for the modification of select roofs over the shield door slots, Process Area, and Purification Area; plugging of exterior and interior horizontal openings of the Reactor Building, the reactor vessel cover; and the final covers for all horizontal exterior openings associated with the Reactor Building complex. The ICW Concrete did not contain epoxy coated reinforcing steel for applications used within the facility, with the exception of the reactor vessel cover. For the final caps used exterior to the facility and on the reactor vessel, the ICW concrete was reinforced with epoxy coated reinforcing steel. Concrete mixes with ICW additive tend to be difficult to work with because: 1) of the narrow ambient temperature range required for placement, 2) they are prone to setting at an accelerated rate, and 3) the post placement curing requirements are onerous.

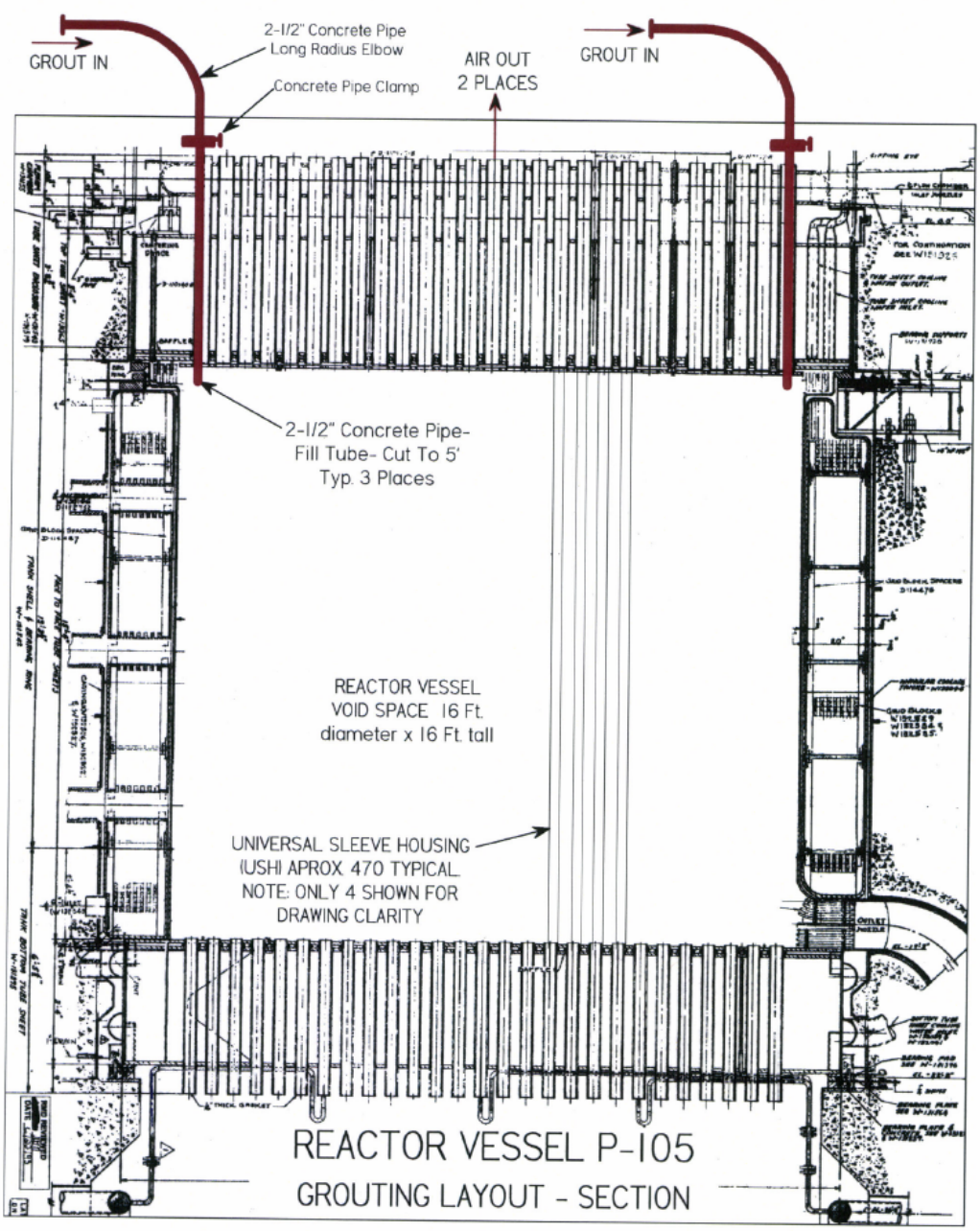


Figure 46 – Cross Section of the P Reactor Vessel

8.2 Batch Plants

With the large quantities of grout needed for ISD projects, utilization of on-site batch plants for grout production provides several benefits including schedule logistics, operational flexibility, and to some degree cost savings (over the purchasing of delivered grout). The ISD projects at INL, Hanford, and SRS all utilized a localized, on-site (and one case, a shared) batch plant for grout production.

INL

The on-site batch plant was physically located approximately a half mile (0.8 km) away from CPP-601/640. The CPP-601/640 project had to share the batch plant with other site projects, primarily the Integrated Waste Treatment Unit being constructed to support the Sodium Bearing Waste Disposition Project, and therefore the grout supply for the CPP-601/640 was prone to interruption. Despite this, the project still progressed on schedule (even under the aggressive ARRA schedule).

The primary benefit of the on-site batch plant was the ability to maintain project schedule. The fact that the INL site is located approximately an hour away from the town of Idaho Falls (closest commercial district) would have resulted in project delays stemming from transportation scheduling and the ability to maintain mix integrity during the lengthy commute. The use of an on-site batch plant also provided some cost savings ($135 per cu yd versus $165 per cu yd; $177 per cu m versus $216 per cu m). Not a huge amount on a per cubic yard basis; but for the total 19,725 cu yds (15,100 cu m) used in CPP-601, this was about a $600K savings.

The batch plant had a typical yield of about 500 cu yds per day (380 cu m/day); although it was capable of providing up to three times that amount at peak capacity (it in fact did support the placement of 1,500 cu yds [1,150 cu m] in one 10 hour shift on a different project). The highest production experienced for the CPP-601/640 project was a sustained average of 150 cu yds/hr (115 cu m/hr) in one day.

Experience at the CPP-601/640 project revealed that typically the batch plant wasn't the limiting factor; the pump truck rate capacity was the critical element. The project team overcame this obstacle by connecting two trucks to the pump, staggering operations so that one truck is emptying while the other is being connected (it takes about 6 minutes to empty a 10 cu yd [8 cu m] truck into the pumper). This maintained a degree of continuity that contributed to schedule adherence.

Hanford

The U Canyon ISD project utilized a dedicated on-site batch plant that was set up in close proximity to U Canyon (see Figure 47 and Figure 48). The on-site batch plant ensured a constant supply of grout, reduced delivery times, and reduced transportation costs. This plant had an instantaneous capacity of 160 cu yds/hr (120 cu m/hr); in effect about 1,000 cu yds/day (760 cu m/day). The best day's production and usage was about 2/3 the capacity. The typical production range of the U Canyon batch plant was between 300 and 800 cu yds/day (200 and 600 cu m/day).

The batch plant was provided by and operated by a subcontractor. The site provided the electrical power and raw water to operate the batch plant. The electrical feed was from portable, diesel-powered generators that proved to be successful and cost-effective (although generator servicing was an inconvenience to the site). A sediment pond was established next to the batch plant to receive rejected batches.

A dedicated round trip travel route from the batch plant to the pumper located at U Canyon was established. Maintaining a one-way travel direction on this route promoted efficiency and greatly enhanced safety. Truck cycle time was 20 minutes. Each truck carried 9 cu yds (7 cu m) of grout. 10

cu yd (8 cu m) trucks were utilized but because of the watery nature of the grout mixtures only 9 cu yds (7 cu m) of material could effectively be carried.

Figure 47 – Placement of U Canyon Grout Plant

Contracting for grout delivery and placement has many considerations; for example, the U Canyon team offered the following lessons:

- Grout supply - In order to save grout pumping contractor mark-up costs, grout supply may be contracted directly from the grout producer.
- Grout Pump - The rental of grout pumps directly from the pump distributor can be considered to avoid grout pumping contractor cost mark-ups for grout pump supply. Grout pump performance was reliable; therefore a back-up grout pump may be an unnecessary expense.
- Grout Conveyance System Procurement - In order to save grout pumping contractor mark-up costs, the procurement of the grout conveyance system may be self-performed.
- Structural Bulkheads - The separate, direct subcontract for grout structural bulkheads saved grout pumping contractor mark-ups. It also resulted in the lower cost, subcontractor-proposed alternative concept of constructing concrete masonry unit bulkhead walls rather than the original concept of traditional structural formwork.

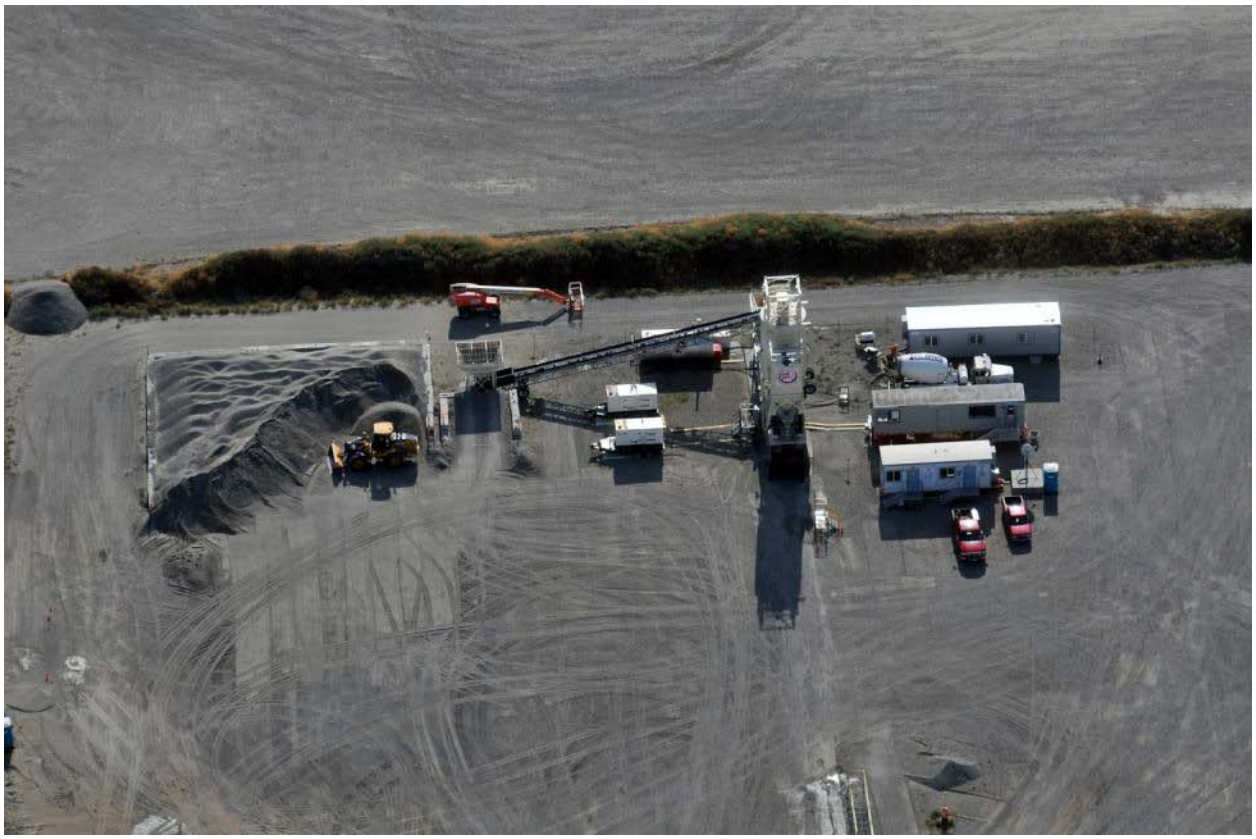


Figure 48 – U Canyon Grout Plant

SRS

To support the P-Reactor and R-Reactor projects, a subcontract was issued to provide, operate, and maintain a batch plant capable of producing specified grout mixes. The scope included providing the necessary equipment for batching, mixing, and delivery. The Project Team ultimately decided on utilizing two batch plants to ensure that two different types of grout could be delivered to either job site simultaneously and to ensure that grout deliveries were not interrupted during batch plant down times (i.e., scheduled maintenance or problems).

A lesson of interest relates to the contracting strategy. The approach of the prime contractor was to solicit bids and award separate contracts for grout supply and for grout placement. The SRS project team then became responsible as a government furnished supplier between the first and the second contractor, thus placing themselves in the critical path between two suppliers, both of which had other outside contracts as well. This created a complication that could have been avoided by using one contractor for both aspects or by self performing the placement operation.

8.3 Preparation for Grouting

8.3.1 Management Center Tracking Tools

Maintaining an up-to-date status of grouting progress is essential for managing operations and logistics for projects as massive as ISD. In preparation for grouting, it is essential to prepare planning and communication tools for tracking progress. For example, use of white boards for equipment disposition, core drilling, and grout placement were a valuable tool. Akin to a white board is a method shown in Appendix I; it is a graphic status display method used at the U Canyon to display the physical

and numerical progress of grouting each gallery and cell in the canyon. Each lift by quantity of grout and date of pour is shown for each location. While this example is specific to a canyon configuration, the concept can readily be applied to other projects.

In addition, three example checklists used at the U Canyon for preparation of grout placement are shown in Appendix D. They are:

- The checklist for equipment placement prior to grouting provided detailed planning for the placement of each individual piece of equipment on the canyon deck into the process cells. This proved to be invaluable in ensuring proper space allocation and work package definition.
- The checklist for grout placement readiness was used to ensure an area to be grouted was properly cleared and prepared prior to preparation for grouting.
- The checklist for grout placement made grout placement clear and concise. It ensured all prerequisites had been completed and specified the quantity of grout to be delivered.

Emulating these checklists can be of value to any project regardless of the type of facility.

8.3.2 Closures and Seals

One of the keys (and one of the challenges as well) to successfully filling a large facility with grout is to prevent grout from flowing uncontrollably out of the target fill area and prematurely filling other spaces. Careful planning and sequencing of the grout pours is required to accomplish this. The use of physical barriers also helps to control the flow of the grout.

A lesson learned at U Canyon during grouting of the Hot Pipe Trench, where grout did flow through the inverted P Traps escaping into the ventilation tunnel, was to ensure all possible grout flow paths were identified and appropriate barriers are installed prior to grout addition. And if at all possible, the effectiveness of the barrier with “test pours” should be verified before completely filling the area.

Some specific examples of physical barriers utilized in the projects at INL, Hanford, and SRS are described below.

In preparation for grouting, pipe penetrations through exterior walls were cut and sealed. For 10 in (25 cm) or smaller openings foam or caulking is sufficient. At Hanford, 3M Fire Barrier RTV was used for most applications; however, the cure time was too slow for vertical applications, so DAP Kwik-Foam and Versa-Foam (both of which contain isocyanides and require appropriate IH precautions) were utilized for vertical applications. At SRS, 4 psi (0.03 MPa) polyurethane expandable foam was used for the sealing of penetrations.

At Hanford, 10 in (25 cm) or larger openings were secured with sewer plugs, examples of which are pictured below.

For larger openings, like doorways and equipment hatches, bulkheads were built to secure the openings. At INL, doors were sealed and reinforced with planks attached with wall and floor anchors. Other openings were sealed by the formation of short wall sections that would create a solid monolith when these areas were filled with grout. At Hanford, bulkhead forms were made of 1/4 in (0.6 cm) plate steel. All double doors in the canyon galleries were caulked/sealed, braced with 3 in x 3 in (7.6 cm x 7.6 cm) angle iron, and kicked with a single angle iron in the middle, as pictured here.

In U Canyon, the rollup doors at the end of the galleries were removed and a cinderblock wall was installed to bear the weight of the gallery grout. These masonry structural bulkheads were cost efficient and effective; only minimal leakage was observed with the majority being bleed water from the grout mix.

The need for replacing exterior doors with more rigid barrier is driven by grout loading calculations (which should be completed before grouting begins). It is best to determine which openings in the facility will be needed for access into the facility during grouting preparations and subsequent grouting operations at the start of the project. If an opening is not needed for access, it should be permanently sealed as early on in the project as possible to eliminate the need for temporary barriers (e.g., Transite sheeting to keep birds out of the facility during decommissioning work, and/or fall protection for worker safety) that will require eventual removal and replacement with a rigid barrier.

8.3.3 Fixtures, Devices, and Gadgetry

Venting

Proper ventilation of equipment (i.e., tanks, vessels, and piping) and general areas of facilities is necessary to ensure complete filling of these areas with grout. As the grout is being introduced into these areas, the air that is being displaced must have an exit pathway. Provisions for controlling the spread of contamination while the displaced air is exhausted are often required.

At U Canyon, Negative Air Machines (NAMs) were used for venting through core holes. Extra care was required to prevent the grout from overrunning the vent hole and contaminating the entire NAM. The site reported that no NAMs were “lost” during grouting operations. The use of a HEPA filter rather than a NAM would limit the loss to only a filter rather than an entire NAM if the grout overruns the vent hole.

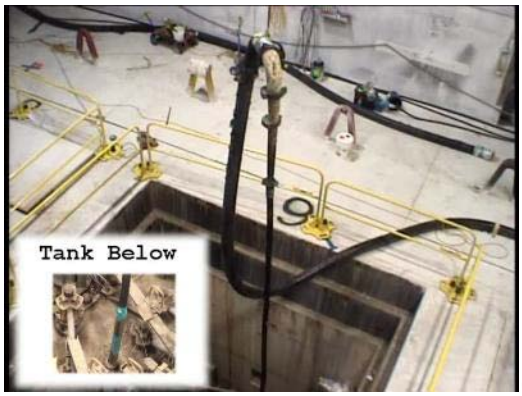
At INL canister HEPA filters were used to passively vent areas being grouted. The filters were fitted to either core-bored vent holes or existing penetrations located at the top of the cell or corridor being grouted. The site reported that these devices did not have any problems with particulate loading during grout filling operations despite not utilizing a roughing filter placed ahead of the HEPA.

The buildings at INL (CPP-601/640) and SRS (P-Area and R-Area reactors) were already in a cold and dark configuration when ISD activities started, therefore the ventilation systems in these buildings were not operational. The ventilation system in U Canyon was kept operational during grouting until the very end (when the ventilation tunnel was filled with grout, that last area to be filled). The system had to be “adjusted” as void fill progressed to prevent overloading the ventilation fans. Since the building ventilation system was operational, grouting of the Process Cells required close attention to prevent grout from escaping the cell through the ventilation chase located in each cell. Engineered lifts were

utilized to seal off the ventilation chase in steps without compromising the remainder of the building ventilation flow.

Filling Awkward Spaces

The project team at U Canyon came up with an innovative way to assist with introducing grout into vessels with small diameter port holes. Some of the tanks/equipment that was placed into the process cells were determined to present buoyancy issues and therefore needed to be filled before the process cell to avoid "floating" the vessel. A reducing flexible line was used in conjunction with a funnel that was fashioned out of a modified/inverted cigarette butt can. The butt can was suspended from the overhead crane while grout was poured into the vessel.



8.4 Core Drilling

While grout mix formulations can be engineered to provide maximum flowability to ensure the filling of facility void spaces, there is a limit to the extent to which the grout will travel from the point of introduction. Continued pouring of grout in one location produces "mounding" that can reduce the effectiveness of the fill and result in the formation of unacceptable void pockets. To overcome this phenomenon, multiple fill locations must be utilized, especially for long corridors (like the CPP-601 Operating Corridor) or gallery/tunnel areas (like the U Canyon Piping and Electrical Galleries and Ventilation Tunnel).

In all likelihood the structure to be filled with grout will not have enough access ports (i.e., windows, doors, pipe penetrations, etc.) in the exact location to support grout filling operations. Therefore, it will be necessary to install appropriate access ports during the preparation phases of the grouting campaign. In some instances, certain areas of a facility may not have any access ports at all (like the dark tank cubicles in the Salt Waste Processing Facility being constructed at SRS); clearly there is a need for decommissioning considerations to be factored into the design of these facilities to incorporate provisions to allow the introduction of grout into these areas.

Since the majority of facilities considered for ISD closure are of robust concrete construction, the installation of grouting access ports will require core drilling. Core drilling is a standard industry practice that is fairly well understood, and many vendors of equipment and/or services are readily available to support these efforts. The core drilling done at the INL, Hanford, and SRS ISD projects was relatively straightforward; however, certain unique aspects are worth mentioning.

U Canyon

The decision was made to core drill the process cell cover blocks to provide access for grout addition instead of physically removing each cover block. This allowed the cover blocks to remain in place which

avoided canyon crane availability conflicts as well as interferences with other operations on the canyon deck. Each cover block was provided with two 8 in (20 cm) holes, one for filling and one to serve as a vent. The drilling was accomplished with penetration rates of about two ft/hr (0.6 m/hr). All holes were visually inspected to ensure the core had completely dropped out of the block after drilling was complete.

The Project did pull five cell cover blocks to support grouting of vessels with buoyancy issues. It was necessary to fill these vessels completely before filling the process cell to prevent the vessels from floating. In total, ninety 8 in (20 cm) holes were drilled for the U Canyon grouting campaign; 70 for the process cell cover blocks, and an additional 20 for grout access (and venting) in other locations throughout the Canyon, like the Hot Pipe Trench and the Ventilation Tunnel which needed extra access points to ensure that the flowable grout would have sufficient dispersion to completely fill the void space.

Of particular note, is the situation encountered during the drilling of access holes to the Ventilation Tunnel. The resulting core from this hole was 17.5 ft (5.3 m) long and weighed approximately 1,000 lbs (450 kg). A special lifting rig was required to handle and remove this core since the off-set from the Canyon wall was only 6 in (15 cm, see photo).

Although the Project Team did not use vibrators to aid in grout dispersion during the U Canyon grouting campaign, the consensus is that they may have been useful, especially for the grouting of the Canyon gallery spaces. The galleries are rectangular in footprint configuration (long and relatively narrow). Located along the interior and exterior walls (long side of the rectangle) are pipe chases which were utilized as access points for the grout tremie lines. This reduced the number of core bores required; however this approach required extra effort to move and reposition the grout tremie lines so that the grout would not “mound” at the point of the pour. In hindsight, the Project Team feels that core drilling holes down the middle of the floor (above the target fill area) to allow insertion of vibrators would have aided in dispersing the grout and improved the efficiency of these pours.

The Project Team also suggested that the use of remote technology should be considered for core drilling. This would reduce personnel exposure and also free up labor resources for other tasks.

SRS

Extensive core drilling was performed by SRS subcontractors in the -20 and zero elevation floors in the reactor buildings to provide the needed access for grout placement. An important use of core drilling for the R-Area Reactor project was to provide access for grouting of the portions of the void space below the D&E Transfer Canal in the Disassembly Basin. It was necessary to grout this area to fill the void spaces created by interlocking beams inherent in the structural design under the floor in order to support the weight of the demolition equipment used to remove the Disassembly Basin roof structure.

8.5 Grout Delivery and Conveyance

The large volumes of grout required for an ISD closure project presents a unique challenge with respect to getting the grout into the building. The sheer magnitude of the grouting campaign requires a considerable amount of logistics to coordinate getting the grout from the batch plant to the job site in a timely manner.

Hauling grout is tricky because of the watery consistency of the mix. Typically, only 9 cu yds (7 cu m) of grout are hauled in a standard 10 cu yd (8 cu m) truck. Therefore, a considerable number of truck loads are required and should be considered when you are looking at trucks quantities to support the project. At SRS, the P-Area Reactor project utilized 12 trucks for grout delivery; the R-Area Reactor project used between 20 and 22 trucks. At Hanford, about a dozen trucks were used to support the U Canyon project. Clearly, with this number of trucks in motion it is prudent to establish a dedicated haul route with a prescribed traffic flow path for efficiency and safety. With this much traffic intensity, the project must also address the wear and tear on the road surface during this phase of the project.

Once delivered to the job site, the grout is transferred from the haul trucks to the building via pumper trucks (Figure 49). Experience has shown that connecting two trucks to the pumper at a time and staggering them so one is emptying while the other is hooking up helps sustain continuity.

Figure 49 – Pumping Grout at U Canyon

The pumper trucks feed the grout into the building with rigid pipe slick lines and/or tremies. The P-Area Reactor project at SRS utilized a manifold to facilitate simultaneous pours for grouting the reactor vessel. The Hanford Project Team claims that the grout delivery system should maximize the use of rigid pipe slick lines because the friction losses in rigid pipe are far less than with flexible pipe.

Specific points of interest with respect to grout delivery as encountered in the projects at INL, Hanford, and SRS are described below.

INL

Grout lines were fed into the CPP-601/640 buildings through accessible opening and penetrations. The grout fill was typically in 6 ft (1.8 m) lifts, starting at the lowest level of the building and working up to grade level. To prevent the floating of vessels, the fill alternated between filling the vessels and the area

around them. The tall vertical process cells were completely grouted before the corridors and the remainder of the building volume.

A total of 19,725 cu yds (15,100 cu m) of grout was used in CPP-601. It took approximately fourteen months to complete this grouting campaign; however, work was not continuous as other demands on the batch plant (most notably, the Integrated Waste Treatment Unit construction project) interrupted the supply of grout to the project. The twenty five process cells were filled first; then the Deep Tank Vault and the Control Room; the corridors were filled next, in succession the Access, Service, Operating, West, and East Sample Corridors; the Vent Tunnel was the final area to be grouted.

A total of 2,052 cu yds (1,570 cu m) of grout were used in CPP-640. The five process cells were filled first, then the Hot and Cold Tank Rooms, the Control Room, the Access and Operating Corridors, and finally the Vent Tunnel.

SRS

In support of the grouting campaigns at the P-Area and R-Area Reactor ISD projects, grout lines were run through existing openings and penetrations. Access to the - 40 ft and - 20 ft elevations (- 12 m and - 6 m elevations) was gained through stairwells, equipment hatchways, and core drilled holes in the floors. Visual confirmation was used for verification of grout fill adequacy. Sacrificial cameras were utilized in the lower elevations and in the reactor vessel areas that were inaccessible after grouting activities started.

Grouting was started at the R-Area Reactor project first. The Disassembly Basin, the - 40 ft and - 20 ft elevations (- 12 m and - 6 m elevations) of the reactor building, and miscellaneous pits/cells in the reactor building were filled first over a period of approximately 7.5 months. The D&E Canal (approximately 2 weeks), the Reactor Building/Disassembly Basin seismic gap (approximately 1 week), and finally the reactor vessel (approximately 1 week) were filled in sequence with some parallel activity overlap. In total, 133,999 cu yds (102,450 cu m) of grout were place in the R-Area Reactor ISD project.

Grouting at the P-Area Reactor ISD project ran in parallel with the R-Area project, starting approximately 4 months later. The fill sequence at P-Area reactor was pretty much the same as R-Area with similar durations. A total of 122,464 cu yds (93,630 cu m) of grout were placed in the P-Area Reactor ISD project.

Hanford

The physical arrangement of U Canyon (i.e., long and narrow) required multiple grout addition locations to ensure all the targeted void areas were properly filled with grout. Because of the design of the Canyon structure (i.e., no real doors or windows) grout addition points had to be made by core drilling through the structure walls (core drilling is discussed in Section 8.4). Figure 50 shows the various locations at which the grout was pumped into the building.

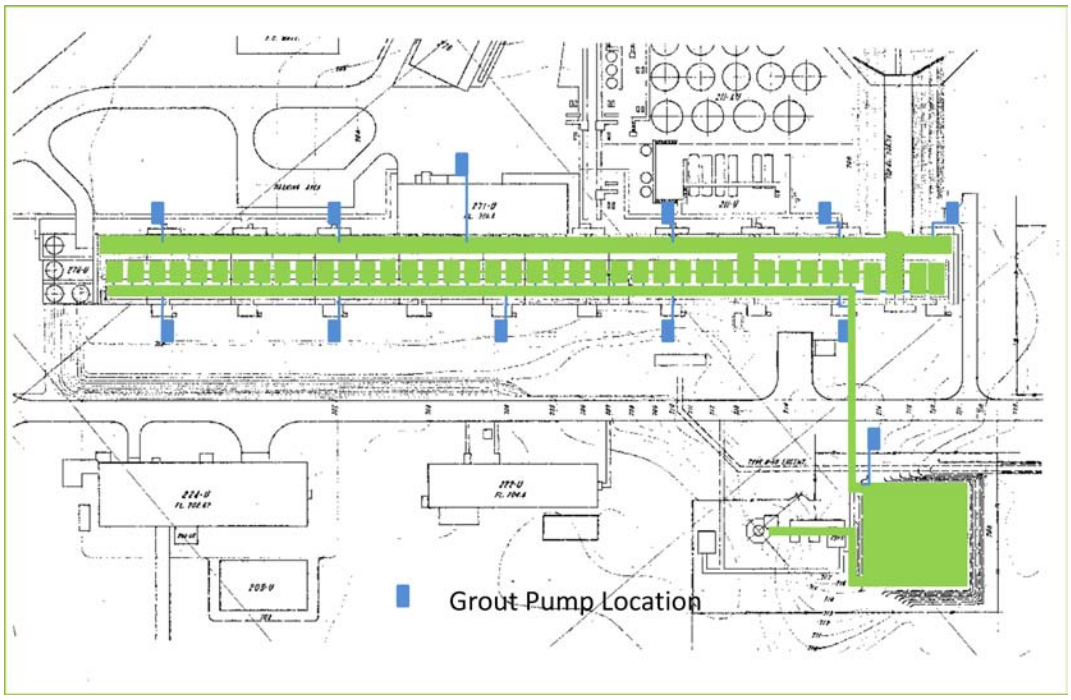


Figure 50 – U Canyon Grout Addition Points

Grout fills were in 6 ft (1.8 m) lifts for most of the Canyon areas; the lifts for some of the process cells were 28 ft (8.5 m) (i.e., a complete fill). Concerns over the amount of heat generated during grout curing drove the project to specify a 48-hour interval between lifts; however, temperature monitoring of the early pours showed that 24 hours was sufficient time for the heat to dissipate to acceptable levels.

The total amount of grout used in U Canyon 20,318 cu yds (15,534 cu m). The distribution by area is depicted in the following table.

Location	**Amount of Grout** cu yds (cu m)
Drain Header	110 (84)
Process Sewer	93 (71)
Buoyant Vessels	670 (512)
Process Cells	6,084 (4,652)
Hot Pipe Trench	1,029 (787)
Electrical Gallery	4,497 (3,438)
Piping Gallery	4,314 (3,298)
Ventilation Tunnel	2,940 (2,248)
Vent Ducts to Stack	581 (444) *
TOTAL	**20,318 (15,534)**

** Included Sand Filter cap*

The grout fill sequence for the major Canyon areas was as follows:

- North Electrical Gallery
- North Pipe Gallery
- Drain header

- Process Cells (in specified sequence to insure adequate dissipation of hydration heat)
- Remainder of Galleries (Hot Pipe Trench, Electrical Gallery, Piping Gallery, and lastly the Ventilation Tunnel).

Hanford experienced the following approximate rates for various operations related to grouting:

- Conservatively 35 cu yds/hr (27 cu m/hr) could be placed in the canyon cells per pump
- Conservatively 50 cu yds/hr (38 cu m/hr) could be placed in the galleries per pump
- Conservatively 2 ft/hr (0.6 m/hr) could be core drilled per drill
- To switch conveyance from one location in the canyon to another took approximately 45 minutes
- To switch conveyance from one location in the galleries to another took approximately 1 hour
- To move an inline pump took approximately 1 hour
- To move a boom pump took approximately 45 minutes
- Using the overhead crane to move internal conveyance reduced the move time from 45 minutes to 10 minutes

9. Post-Closure Examples

This section includes examples of post-closure configurations and monitoring.

9.1 U Canyon

Overview

The U Canyon cap design is illustrated in Figure 51 in which the upper part of the canyon building would be demolished to approximately the level of the canyon deck, and the remnants of the facility would be covered by an engineered barrier. The cap has not yet been placed as the project will not be completed until further demolition is budgeted and conducted. The original design configuration of the cap will be modified because of a decision to remove the Operating Gallery and collapse the roof to the canyon deck. This will reduce the height and footprint of the final engineered cap, which will result in less visual impact from the final cap elevation.

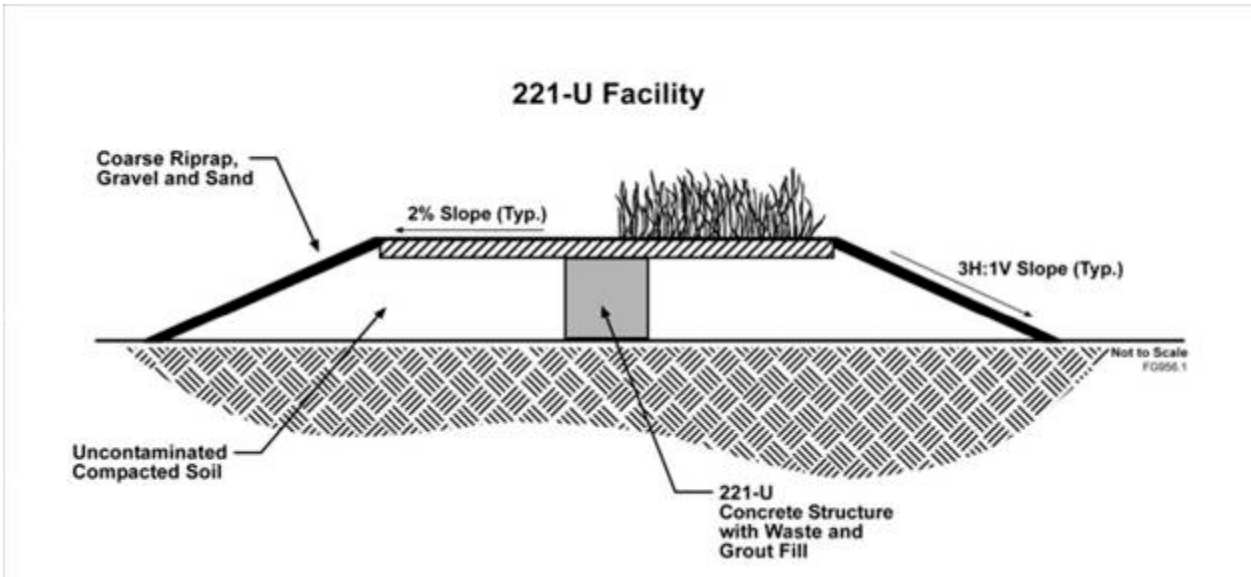


Figure 51 – U Canyon Engineered Barrier Components

Closure will be followed by a program that includes post- remediation care, environmental monitoring, a 5 year review, and institutional controls.

Of note is a change from the original closure concept because of a concern that there would not be sufficient cover material on site for use with remediation of waste sites combined with cap placement for all canyons ISD. The record of decision was written with flexibility so as to not define how much of the canyon wall would be demolished. For final closure, the Operating Gallery will be removed and the roof collapsed to the canyon deck. This change results in improved visual aesthetics as a result of the cap's lower final elevation and reduced footprint.

Engineered Barrier Plans

The following description is taken from [Ref: CH2M-2011].

The engineered barrier for U Canyon will consist of three parts: engineered fill, engineered barrier (the functional portion of the barrier), and erosion protection. In U Canyon's case, the engineered barrier planned is unique in that the top of the barrier is approximately 35 feet above the surrounding grade.

The performance criteria developed for the engineered barrier design are:

- Prevents recharge rates greater than 3.2 mm/yr long-term average in order to mitigate, or eliminate, the potential for contaminants to migrate to groundwater
- Provides the required containment during a minimum 500-year life
- Constructed with the minimum potential impact to worker safety and the environment, using established/proven technologies also responsive to cost and schedule concerns

Engineered Fill: The engineered fill will be clean, compacted, granular material that will be placed in lifts. Borrow materials for the engineered barrier will be taken from approved areas of the Hanford Site including recycled concrete from other demolition projects on site. The approximate extent of the engineered fill and engineered barrier is shown in Figure 4. Final design of the engineered fill will determine the compaction requirements and the material specifications. Where fill material consists mostly of rubble or very large particles, finer grained fill soils may gradually settle into the open pores or spaces of the coarser material, which eventually may cause localized subsidence. To counteract subsidence, graded filters may be required. These filters likely will consist of commercially available gravels, with the gradation selected on the ability to bridge the openings in the previously placed material.

Engineered Infiltration Barrier: The engineered barrier will be designed to control potential contaminant migration by preventing water infiltration, as well as minimize potential human and biotic exposures due to biotic and unintentional human intrusion. To accomplish this, the engineered barrier, in combination with the remaining grouted, substantial concrete substructure, will effectively break the pathway for direct contact with contaminants. The upper portion of the barrier will consist primarily of a fine soil, such as a silt or silt-loam, which will be specifically selected for its ability to hold and store infiltrating water for eventual evaporation and plant transpiration. The lower portion of the barrier will consist of engineered or grading fill that will form the basic shape/slope of the barrier, provide a stable sub-grade for constructing the overlying layers, and provide the balance of the barrier thickness. The barrier will be vegetated to control soil erosion and promote transpiration. The total volume of material that will be required for the engineered barrier will be determined during final design.

Erosion Protection: The top of the engineered barrier will be sloped at a nominal 2 percent; the top layer will be vegetated and likely will consist of pea gravel and mix. Therefore, once vegetation is established, erosion from precipitation and wind should not be a concern. To reduce the volume of the engineered fill while providing stability during a seismic event, it is likely that a 3:1 horizontal to vertical side slope will be selected for the engineered fill. This slope will require placement of a basalt riprap-type layer for erosion protection. The erosion protection layer may include

Re-vegetation: The excavations from demolition activities will be backfilled, and fill contours will match adjacent contours. Areas disturbed by demolition activities will be prepared for surface restoration. As required for industrial land use in Hanford's 200 Areas, the majority of restoration will consist of the application of an approved native seed mixture with input from various interested local tribal nations.

9.2 Savannah River Site

<u>SRS P-Reactor Vessel Cap</u>

As a basis for the P-Area Performance Assessment, a period of 1300 years corresponds to the approximate time the structure over the Reactor Vessel should remain intact, provided S&M is performed to prevent vegetative growth. Industrial worker exposure to radionuclides (via all pathways including inhalation, ingestion and direct exposure) is within EPA risk guidelines, while contaminants in

groundwater slightly exceed EPA primary drinking water standards about the same time the structure starts to fail.

The P- Reactor Vessel was filled with calcium sulfo-aluminate grout. The average compressive strength at 28 days was 1090 psi (7.5 MPa) for the calcium sulfo-aluminate grout to fill the Reactor Vessel. This grout was custom formulized for the application to prevent reaction with the aluminum in the reactor vessel internals that would have resulted in the release of hydrogen gas. A structural (ICW) concrete cover was placed over the grouted Reactor Vessel. A minimum cover thickness of 4.0 ft (1.2 m) was required to be placed over the reactor head.

SRS Disassembly Basin Cap

The above grade structure of the Disassembly Basin was demolished to grade level and the debris was removed. Evidence that the SRS Disassembly Basin Cap was completed as specified combined surveillances, inspections, and documented evidence. Ongoing surveillance activities during construction and final inspections determined that:

- All water had been removed from the basin prior to placing the final lifts of grout.
- The seismic gap had been filled with grout.
- Along with inspections in core bore locations and other locations, that grout was placed to the bottom of void spaces beneath floors, slabs, and walk ways.
- In each open area the basin was grouted to the zero (0) ft elevation.
- The sloped, 0.6 ft (0.2 m) thick, low shrink 4000 psi (28 MPa) concrete cover was placed over the Disassembly Basin.

In addition documented evidence showed that grout materials met design requirements (air content, slump flow, bleed water and compressive strength). Grout testing was performed by the onsite independent testing lab.

Heavy Water Component Test Reactor (HWCTR) Closure Cap

The HWCTR concrete closure cap was designed to:

- Prevent infiltration of precipitation to the remaining underground portions of the closure area with sufficient slope (2% minimum) to shed water away from the footprint of the facility
- Eliminate direct radiological exposure from the portions remaining
- Remove pathways for human and ecological exposure to the remaining contaminants
- Be of sufficient height above the ground so as to preclude vehicle access
- Be centered over the facility footprint and extend a minimum of 3 ft (0.9 m) past the footprint
- Meet concrete specifications as described elsewhere in this report for the structural and mud mat[5] portion of the pad
- Meet concrete testing national standards.

Three separate concrete pours were made for the construction of the closure cap, as follows:

[5] Mud Mat - A term used to describe a very low strength concrete whose sole purpose is to hold loose soil or embankments in place. It is not structural concrete.

- The first pour was for the construction of the walls. The results show that the wall conformed to the specifications of a minimum requirement of 4000 psi (28 MPa) with an average compressive strength of 5210 psi (36 MPa).
- The second pour occurred three days later for the installation of the mud mat. This pour met the specifications of a minimum requirement of 2000 psi (14 MPa) with an average compressive strength greater than 2860 psi (20 MPa). The 2000 psi (14 MPa) concrete mud mat was specified as filler material for the purpose of shaping the cap and eliminating any discontinuities prior to installing the structural concrete. This filler material was selected in lieu of compacted fill due to the ease and uniformity of installation. To allow for expansion and contraction of the concrete, bond breaking material was installed between the two layers to prevent adherence of the two layers of concrete.
- The final pour (structural cap) occurred 5 days later and met the specifications of a minimum requirement of 4000 psi (28 MPa) with an average compressive strength of 5070 psi (35 MPa).

Verification of construction completion was accomplished 2 days after the final pour of the closure cap. The final walkdown that included all required federal and state inspection personnel was accomplished two weeks hence.

After the closure cap was completed and inspected, the HWCTR footprint was covered with a final layer of concrete at the ground surface. Land use controls and ongoing surveillance and maintenance activities will monitor the integrity of the closure cap.

SRS Post-Closure Monitoring

The P- and R-Reactor projects at the Savannah River Site differ from the Hanford and Idaho projects in that a substantial amount of superstructure, albeit permanently entombed in concrete, remains significantly above grade, capping only the external sub-grade entombments with post-decommissioning monitoring routine including additional inspections. For example the P-Reactor inspections are:

- Verify that roads are accessible
- Verify that the waste unit signs are in acceptable condition, that they have the correct information, and are legible from a distance of 25 ft (7.6 m).
- Verify that roof structure of 105-P Reactor Building Complex is free of woody vegetation.
- Verify that doors to 105-P Reactor Building Complex are sealed.
- Verify that excessive deterioration of the disassembly basin cover has not occurred and that the disassembly basin cover is free of woody vegetation.
- Verify that no woody vegetation is growing on the P Ash Basin soil cover. Remove or identify as needed.
- Verify that the P Ash Basin soil cover has no signs of unacceptable erosion (subsidence).
- Verify that signs of burrowing or mounding animals are not present at the P Ash Basin soil cover.
- Verify that there are no unauthorized excavations, digging, or construction activities within the land use control boundary in P Area.

In addition, the checklist instructs that “the inspector shall immediately notify the Post-Closure Manager and Environmental Compliance Authority if there has been a beach or compromise of the land use controls of this waste unit.”

10. References

CH2M-2011 Kurt Kehler, Accelerated Pilot Project for U Canyon Demolition, , WM2011 Conference Paper 11434, Phoenix, AZ, March 2011

DOEIG-2005 DOE/IG-0672, Audit Report, Department of Energy Efforts to Dispose of Hanford's Chemical Separation Facilities, February 2005

DOE-2007 DOE's Waste Management Order, DOE O 435.1, Certified January 2007; located at: https://www.directives.doe.gov/directives/0435.1-BOrder-c1/view

EM-2009 DOE EM Strategy and Experience for In Situ Decommissioning, Prepared By the U.S. Department of Energy Office of Environmental Management, Office of Engineering and Technology, EM-20, September 2009; located at: http://www.em.doe.gov/EM20Pages/PDFs/ISD_Strategy_Sept_4_2009.pdf

FLUOR-2007 221-U Plant Void Fill Analysis and Installation Plan, D&D-33945, Rev. 0, May 2007

HNF-2006 Brantley, W. M., 221-U Facility Canyon Equipment Size Reduction Engineering Study, D&D-29932, HNF-EDC-06-30443, Prepared for the U.S. Department of Energy, Hanford Site, July 2006

INL-2008 Action Memorandum for Decommissioning CPP-601/640 Fuel Reprocessing Facilities, DOE/ID-11360 Revision 0, August 2008.

http://ar.inel.gov/images/pdf/200808/2008081800484TUA.pdf

SRNL-2011 C.A. Langton and D.B. Stefanko, Blended Calcium Aluminate-Calcium Sulfate Cement-Based Grout for P-Reactor Vessel In Situ Decommissioning (U), SRNL-STI-2010-00427 Revision 0; March 2011.

UROD-2005 Record of Decision 221-U Facility (Canyon Disposition Initiative), Hanford Site, Washington, 2005; located at: http://yosemite.epa.gov/r10/cleanup.nsf/sites/hanford2/$FILE/cdiROD.pdf

WM-2011 C.A. Langton, et al, Use of Cementitious Materials for SRS Reactor Facility In-Situ Decommissioning, WM2011 Conference Paper 11620, Phoenix, AZ, March 2011.

Appendix A – Project Design Requirements

A.1 Purpose

At SRS a site-standard engineering procedure called a "Modification Traveler" was used to specify the technical requirements for execution of the R- Reactor Building Complex project; the project itself is described in Section 5.2. As the name implies, the procedure is usually for the purpose of specifying facility modifications. Of interest is that this approach avoided the need to create something specific to the ISD project. The executed procedure from which this was taken addressed functional and performance requirements such as waivers, safety basis strategy, design input guidance, and design review for the ISD project.

The entire procedure is not reproduced here; the substantive technical content has been extracted to provide an example of the project design requirements.

A.2 Modification Traveler Elements

The scope of the Modification Traveler described in this appendix was stated as: "In Situ Decommissioning for the R-Areas Reactor Building Complex (RBC), including Engine House 108-1R and 108-2R, with Institutional Controls." This example for the Reactor Building Complex was the one of six Travelers that were used for the entire project. The other five were related to support features and area remediation; they addressed:

- Cask car railroad tracks abandonment
- Sewer lines termination
- Contaminated area isolation
- Area remediation
- Ash basin remediation

The following elements were included in the RBC Modification Traveler:

1. The project scope, purpose, basis and justification were defined.
2. Identification of the sources of data used from documents that included Facility Investigation/Remedial Investigation reports and Corrective Measures Study/Feasibility Studies (CMS/FS) for the R-Area Operable Unit.
3. The project physical boundaries were identified. Key interfaces identified included a waste management plan, a health and safety plan, and environmental evaluation checklist.
4. The project classification that included: a) a functional classification as "General Services;" b) a facility hazard classification as "Radiological;" c) a design classification for "Natural Phenomena Hazards Mitigation" as PC-1[6], which is justified because the project involves D&D; and d) a conservative structural evaluation for the long-term strength of the structure.

[6] Per DOE G 420.1-2, Guide for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and Non-Nuclear Facilities. For PC-1, the guidance states: "The primary concern is preventing major structural damage, collapse, or other failure that would endanger personnel (life safety). Repair or replacement of the system, structure, or component; or the ability of the system, structure, or component to continue to function after the hazard has occurred is not considered."

5. The Modification and Performance Requirements detailed the level of modifications, which are described in more detail in the following subsection.
6. Technical requirement references that included: a) civil and site design criteria; b) waste management requirements; and c) industrial safety and health requirements; and d) reliability, availability, and requirements related to the cap. The latter included:
   - All caps shall be designed to function with minimum maintenance.
   - All the additions and/or repairs (installation of roof caps, other caps, sealing the building openings, etc.) shall be designed and constructed to be robust and permanent for the maximum life expectancy.
   - Inspection of the Reactor Building Complex is anticipated at least once every five years to visually ensure the integrity of the building and sealed openings on the outer portions of the structure.
7. Reference to applicable codes and standards that included National Consensus Codes such as National Fire Protection Association (NFPA) and the National Electrical Code. Site Standards and Guides listed as well as directly applicable federal regulations, orders, and standards.
8. Identification of potentially applicable permits related to NEPA, storm water management, and emissions.
9. References such as site drawings, other site documents, regulatory documents, and miscellaneous references (e.g., strategy for grout placement). Three types of design deliverables required for this modification are shown in Table 8.

Table 8 – Modification Design Deliverables

Technical Plans	Drawings and Calculations	Subcontractor Statements of Work
Demolish Above-Grade Structure	Cap Reactor Vessel	Cap/seal exterior plugs
Fill below grade Spaces	Cap/Slope roofs	Demolish Stack
Fill Reactor Vessel	Seal Vertical Surfaces	Fill 108-1R/108-2R Access Wells
Seal +66 Floor		Fill Below-Grade Spaces
Seal zero Level Floor		Fill Cells and Basement
		Remove Gantry
		Seal Zero Level Floor
		Seal Zero Level Floor Including 108 Access Wells

A.3 General Performance Requirements

General performance requirements focused on the overall as-left condition and scope of grout placement. They included:

- The Process, Purification and Assembly Areas of the Reactor Building Complex will be left in place. The stack will be removed above the + 55 ft (+ 17 m) level. The shield door gantry will be

removed and a new partial roof will be constructed over the shield door slots to prevent rainwater ingress.

- The Reactor Vessel will be grouted in place and a concrete cover placed above the vessel at grade-level. This cover will be sloped to allow any water that has intruded into the process room to run away from the vessel area. The process room will remain as is.
- All spaces below grade, including the Disassembly Basin, will be grouted in place to the extent practical. The contents of the Disassembly Basin, including the sludge, activated metal, and a small portion of the remaining Disassembly Basin water, will also be grouted in place.
- All vacant spaces (not to include inside contaminated equipment other than the reactor vessel) down to the - 49.5 ft (- 15 m) basement elevation will be grouted in place, along with the contaminated equipment. The Purification cells will be grouted to the top of the cell wall at the + 20 ft (+ 6 m) elevation. The below-grade portions of the Purification Area will be grouted to the + 3.6 ft (+ 1 m) elevation finished floor level with the exception of the zero level floor in the Trailer Space and the Refrigeration Equipment Room. All cements and grouts shall be poured to minimize void spaces when poured below grade. Void space in piping and equipment is acceptable.

A.4 Specific Performance Requirements

The following technical requirements are on a location basis within the project facilities and area. Figure 52 shows the Zone references in the descriptions that follow.

Reactor Vessel / Reactor Vessel Cap (Green Zone 1)

The Reactor Vessel cap shall remove at least 99% of rainwater. The Reactor Vessel cap shall be designed to route water runoff away from the process room to the crane maintenance area. The Reactor Vessel cap shall extend from the north wall of the process room and be sloped to the south (shall not trap water, minimum 2% slope).

Reactor Vessel cap shall be shrinkage-compensating concrete (minimum strength of 3,000 psi [21 MPa]) with Integral Crystalline Waterproofing (ICW) and shall be a minimum of 4 ft (1.2 m) thick above the top of the reactor vessel. The Reactor Vessel shall be grouted with zero-bleed grout with ICW (minimum strength of 50 psi [0.3 MPa]). Minimize fast paths. All floor holes/openings at zero grade elevation shall be filled with shrinkage-compensating concrete with ICW.

Below Grade (Pink Zone 2)

All external at-grade access plugs (i.e., to the heat exchanger bays, storage tank room, etc.) will be pulled. At zero elevation grade, the top two feet (floor penetrations and all openings to below grade, as possible; 0 to - 2 ft [- 0.6 m], approximate) shall be filled with shrinkage-compensating concrete with ICW (minimum strength of 3,000 psi [21 MPa]). The remainder shall be grouted with zero-bleed grout (minimum strength of 50 psi [0.3 MPa]).

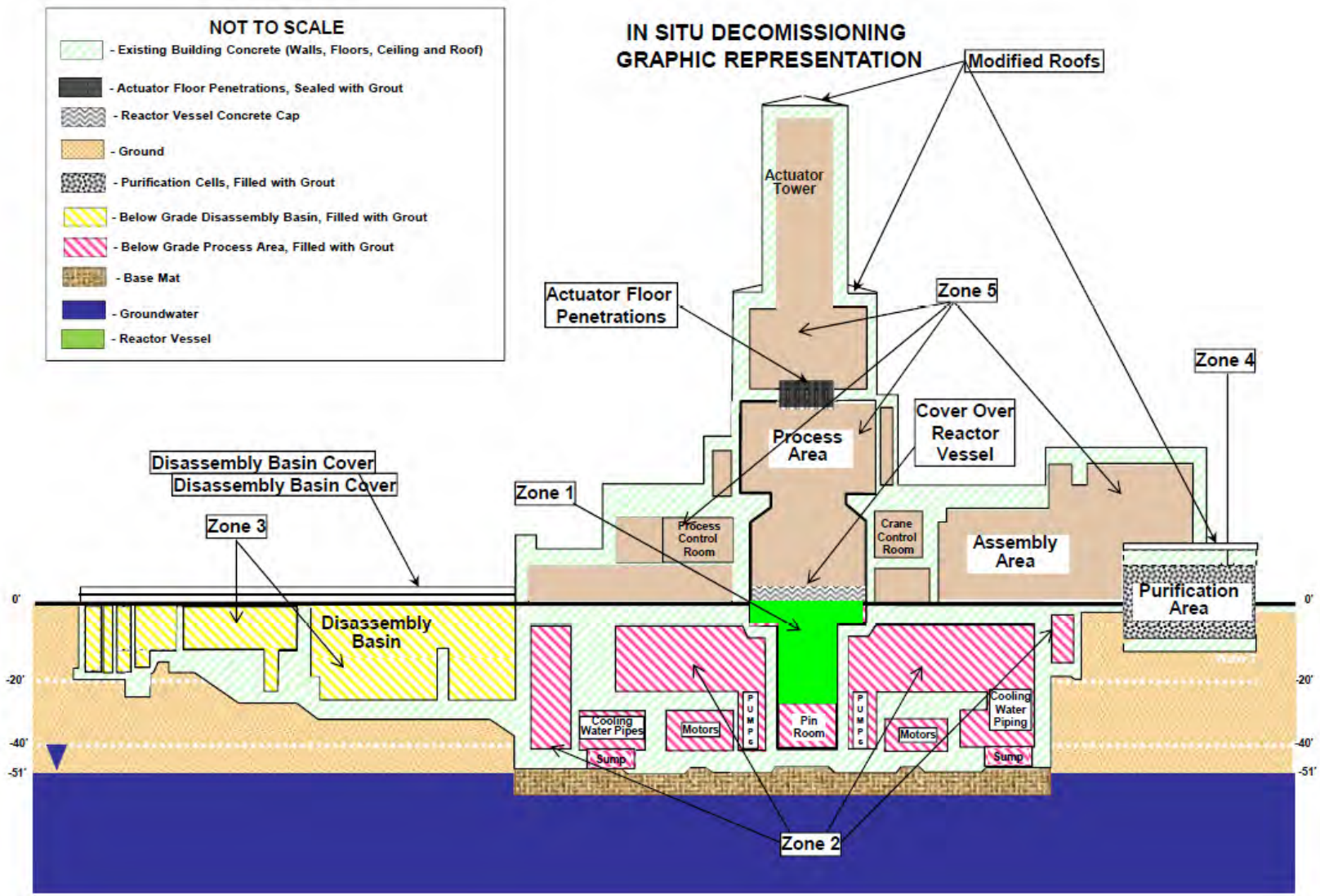


Figure 52 – Zone Diagram for Project Design Requirements

Disassembly Basin / Disassembly Basin Cap (Yellow Zone 3 & Brown Zone 3)

- The cementitious material used immediately over and in contact with irradiated aluminum scrap at the bottom of the basin shall be non-corroding, if modeling shows hydrogen generation to be a problem.
- Zero-bleed CLSM will be placed above this layer to grade.
- The above-grade structure of the Disassembly Area, including the Decontamination Facility to the north of Disassembly Building, will be demolished to grade-level. The debris will be collected and disposed of at the E-Area Slit Trenches.

Purification Area (Gray Zone 4)

- The Purification cells will be grouted to the top of the cell wall at the + 20 ft (+ 6 m) elevation.
- The below-grade portions of the Purification Area will be grouted to the + 3.6 ft (+ 1 m) elevation finished floor level with the exception of the zero-level floor in the Trailer Space and the Refrigeration Equipment Room (Detail is not shown in Figure 52 for clarity).
- The purification cells shall be grouted with zero-bleed grout (minimum strength of 50 psi [0.3 MPa]).
- If feasible, cementitious material with ICW will be placed in the top, approximately 2 ft (0.6 m) of these areas.

Outer Area of Reactor Building Complex (Brown Zone 5)

- One entry will be possible via sealed door.
- Floor penetrations used by the actuator system at + 66 ft (+ 20 m) will be sealed. All outer openings, including roof drains, will be sealed.
- New partial roofs will be constructed over the shield door slots, and the Purification, and the Process Areas to promote drainage and prevent rainwater ingress. Remaining roofs will be modified to promote drainage and minimize standing water.
- Vertical openings in the Reactor Building Complex exterior walls shall be sealed to prevent intrusion by intruders, animals and rainwater/flooding. A list of the openings is being provided by D&D Engineering.

Major Contaminated Equipment to be Abandoned-In-Place

A considerable amount of attached equipment will remain to be grouted within the structure. This includes:

- Primary process water pumps, - 40 ft (- 12 m) level
- Primary loop process water piping
- Shield water heat exchangers, tanks, piping, and valves
- Control rod cooling piping and valves. Pin room tubing, piping, and thermocouples, - 40 ft (- 12 m) level
- Transducer room tubing, tanks, racks, and gauges. Drain piping, valves, and pumps
- 204, 205, 205-2, 208, and 208-1 Drain Tanks, - 40 ft (- 12 m) level
- Overflow piping, Tank 214, and pumps
- Purification cell piping and pumps
- Purification cubicle valves at - 14 ft (- 4.3 m) elevation

- Contaminated cooling water piping. Pump room water removal pumps 1206A, 12068, 1207A, 12078, and piping, - 40 ft (- 12 m) level
- Reactor tank, including remaining internal components
- The component holding rack to be grouted within the reactor vessel cap

Appendix B – Reactivation at U Canyon

B.1 Purpose

An ISD project may need to reactivate, or consider reactivation, of systems or other operational features to support the project activities. While this appendix provides examples specific to the U Canyon at Hanford, the method and approach can be of use for future projects facing the need to conduct ISD activities within a deactivated facility.

U Canyon Overview for these Evaluations

Planning well ahead of the project field work included engineering evaluations for ventilation, cranes, electricity, and a railroad tunnel for access. The facility continued to be classified as a Hazard Category 2 nuclear facility until demolition preparation activities had been completed. In deciding among alternatives, general criteria were:

- Effectiveness: Alternatives are evaluated to determine whether they meet capacity, reliability, and suitability requirements of the planned demolition preparation work.
- Cost and Schedule: Costs and schedule impacts associated with the reactivation or replacement of the canyon systems are considered.
- Nuclear Safety Considerations: Alternatives are evaluated against nuclear safety considerations to determine potential nuclear safety impacts and actions that would be necessary to address any such impacts.
- Compliance with Environmental Requirements: Alternatives are evaluated against environmental requirements to ensure compliance.
- Radiological Considerations: Alternatives are evaluated to determine what effects each may have on radiological conditions and what system attributes need to be implemented to meet regulatory requirements. Radiological conditions must not expose workers and/or the public to unacceptable hazards.
- Industrial Safety Considerations: Alternatives are evaluated to ensure that worker exposure to hazards is controlled or eliminated to meet industrial safety requirements.

With the exception of cost, an example of the use of these general criteria is provided for the railroad tunnel evaluation, for which there were no system-specific criteria as there were with the ventilation, electrical, and crane systems. In that case, only options as how to proceed were included.

For the ventilation, electrical, and crane systems, alternatives were evaluated against system-specific criteria, which are summarized in the following descriptions.

B.2 Ventilation

Pre-existing Conditions

The original design of the ventilation system provided a nominal flow of 30,000 cfm (850 cu m/min) by operating two 20,000 cfm (570 cu m/min) exhaust fans in parallel. An emergency back-up steam powered fan was available. The supply and exhaust fans and control dampers were set to control primary air flows depending on the canyon activities. Work in the cells was performed remotely using the crane with selected cells having adjustable dampers to the air tunnel. In 1950, the exhaust fan flows were increased, and the sand filter was installed.

Currently, one of two functional exhaust fans (291 U-EF-I & 291 U-EF-2) normally operates to maintain nominal air flow of 25,000 cfm (700 cu m/min) from areas of lesser-to-greater contamination and moves

the air through the sand filter and up the 291-U-I stack. The current building configuration and exhaust air flow rate typically results in a canyon-to-atmosphere differential pressure greater than 0.05 in. water gauge (wg). A 0.01 in. wg pressure differential is also maintained between the galleries and canyon deck. Because the supply fans have been deactivated and the dampers closed, the stairwells provide the majority of the in-leakage to the facility. The exhaust system has no active damper modulation to compensate for changes in the building envelope, increased filter loading, wind effects, etc. Therefore, maintaining an acceptable building pressure throughout D&D will require frequent monitoring of building pressure and controls to ensure changes in building configuration and/or envelope leakage do not adversely affect building air balance.

The 291-U-I ventilation stack is a 200 ft (61 m) high, steel-lined concrete stack located south of the facility. Air from the facility is filtered through sand filters located in the 291-U filter building before being exhausted up the 291-U-I stack. Exhausted air enters the filter building through its floor and is directed upward through sand beds held in wooden trays prior to being released to the 291-U-I stack.

The Need

The needs for the ventilation system were stated as:

- Emission Point - The existing stack system will be operated to provide ventilation and emission control. The sampling system is operational for confirmatory measurements and could be continuously operated. The substantive requirements associated with operating the stack and the methodology that will be used to demonstrate compliance with the requirements will be identified in the approved CERCLA Remedial Action Work Plan (RA WP).
- Radiological Considerations - Potential personnel airborne radiation exposures should be limited to levels not exceeding the safe limits for use of air purifying respiratory protective equipment to support efficient operations during canyon deck clean-up and cell loading. Such exposure can be controlled through use of fixatives, by using equipment handling methods that result in minimal disturbance of contamination, and by supplementing existing ventilation by increasing air flow in the vicinity of the work (e.g., through use of localized supplemental ventilation), as necessary.
- Non-radiological Considerations - Intrusive activities in the 221-U Facility galleries will increase the risk of industrial hazards exposure to workers (e.g., asbestos, lead, mercury) as well as radiological exposures. Engineering controls using fixatives and localized exhausters at the point of generation and to provide negative air flow in the work area to reduce the risk of exceeding the level of personal protective equipment (PPE) are required for asbestos work and other hazardous materials. Industrial hygiene sampling and monitoring, especially heat stress control, will also be required for compliance.

Results

The study determined that use of the existing ventilation system, supplemented with localized units to ventilate small working areas as needed, is the most favorable to waste handling, cost, and schedule considerations. The existing ventilation system is adequate for the reactivation activities that are non-intrusive (e.g., re-lamping and crane lubrication). Intrusive activities that disturb radioactive materials will likely require localized units to control airborne contaminants.

Evaluation Considerations

Criteria used for evaluating the ventilation alternatives were:

- Ventilation will allow workers to be in air purifying respirators.

- Ventilation will limit temperature extremes in work areas.
- Ventilation will prevent unmonitored releases to the environment.
- Ventilation must be reliable during routine activities.
- Ventilation will provide a range of 4 to 20 air changes per hour in work area containments.
- Ventilation will prevent unacceptable airborne inhalation dose potential to the onsite worker and public.

B.3 Cranes

Pre-existing Conditions

The facility is currently equipped with an overhead 75-ton bridge crane (Figure 53) and a smaller 10-ton slave bridge crane that run on a common set of rails. These cranes have been specifically designed and constructed to lift process cell cover blocks and move equipment into and out of cells.

Figure 53 – Existing Bridge Crane

The Need

Demolition preparation activities include removal of fissile waste contained in a tank within a process cell and equipment size reduction and consolidation into canyon process cells. These activities require the ability to remove and replace the concrete cover blocks, move items around on the canyon deck, size reduce, and relocate equipment into cells. There is a complex logistical challenge in moving the many items on the congested canyon deck. Some items already within process cells may also need to be moved and/or size reduced.

Crane lifting activities in the canyon were anticipated to be "heavy" both in weight and frequency of use. There were approximately 100 very heavy (greater than I ton) items and hundreds of heavy (0.05 to 1 ton) items on the deck. Requirements included lifting the following items (weights approximated):

- Cover blocks: 32 tons (29 tonnes)
- Two shipping casks: 50 tons (45 tonnes)
- Nine shipping casks: 10 to 20 tons (9 to 18 tonnes)

- Large/small tanks: 2 to 5 tons (1.8 to 4.5 tonnes, estimated)
- Centrifuges: 2 to 10 tons (1.8 to 9 tonnes, estimated)
- Concentrators: 5 to 15 tons (4.5 to 14 tonnes, estimated)
- Small equipment: 0.025 to 1 ton (50 to 2,000 lb; 23 to 910 kg)

The very heavy items and some of the larger heavy items needed to be lifted multiple times during size reduction and consolidation activities. Because there was limited space in the cells, strategic relocating of equipment into each cell was essential. Sorting, pre-staging, consolidation, and systematic relocating of each piece required multiple lifts of each item. Cover blocks will be repeatedly removed and replaced to accommodate these moves. Other requirements for the crane included updating the wiring, HEPA ventilation for the cab, and video recording.

Results

Lifting process cell cover blocks weighing 32 tons (29 tonnes) will require use of the existing bridge crane. Floor loading restrictions, cover block weight restrictions, and the need for flexibility in crane use effectively preclude an auxiliary crane from being used to lift cover blocks. Installation of a supplementary or replacement bridge crane is cost prohibitive due to the equipment size, limited access to the interior of the canyon for installation, and problems associated with assembling large pieces of equipment in the canyon.

The use of mobile lifting equipment that run on tracks installed on the canyon deck could provide some flexibility in lifting capabilities to support equipment size reduction and consolidation activities. However, this alternative is not practical as a sole type of lifting device due to floor loading limitations, limited reach of the lifting equipment, and difficulties associated with track installation and lifting equipment maneuverability on the cluttered canyon deck.

Regardless of which primary lifting device is chosen, provision of supplemental lifting capability (e.g., forklifts and loaders) could expedite the work by performing the smaller lifts to support equipment size reduction and consolidation and material staging activities.

Evaluation Considerations

Criteria for the decision regarding methods to perform lifting activities inside of the U Plant canyon were:

- Weight lifting/moving capabilities
- Ability to accommodate congested deck
- Compliance with deck load limits
- Reliability
- Requirements for high usage
- Cost
- Radiological exposure to workers
- Training requirements
- Ease of installation
- Ability to accommodate primary/existing access
- Spare parts availability
- Equipment documentation
- Procedure development
- Contribution to facility waste generated during D&D.

The most significant criteria that should be recognized while considering alternative approaches include deck-level floor load limits, and existing access to the canyon for introduction of new crane systems.

B.4 Electrical Power

Pre-existing Conditions

The U Plant facility was in an unoccupied, S&M mode prior to commencing the ISD field work. The only operable power systems were portions of the electrical lighting and power distribution, cranes, an elevator, fire detection, canyon exhaust, stack sampler, and remote monitoring. There are two electrical services to the facility (one on the north side, one on the south side).

The existing electrical system was safe to use and expected to be reliable and serviceable for up to 20 years. The U Plant electrical distribution system one-line diagram drawings were accurate. The accuracy of lighting panel drawings was unknown; however, the panel circuits and distribution feeders could be verified as needed, and drawings updated as required. The existing lighting panels and circuits to the galleries and canyon lighting fixtures were considered to provide adequate general lighting. The lighting fixtures could be relamped and repaired as needed; the canyon crane is used to service the canyon ceiling lights. The feeder portion of the crane power circuit from the new power panel in the 271-U basement to a junction box in the electrical gallery was upgraded when the new distribution system was installed in the mid 1990s. The remaining portion of the crane power circuit conductors were considered to be operationally satisfactory for the duration of the canyon reactivation and demolition.

The Need

The power distribution system recommended for the canyon and gallery reactivation and demolition preparation will meet the needs of the equipment disposition and grouting tasks, and portions will also support follow-on final demolition. More specifically, the following was required:

- Power inside the canyon and at the canyon access and egress locations for lighting and contamination monitoring and control equipment. The existing canyon access and egress locations are the back stairwells, the railroad tunnel/cell 3, and the operating gallery. The crane cab gallery access is from the 271-U third floor.
- General area lighting in the canyon. Additional specific area lighting, if needed, for work in areas on the canyon deck will be dependent on the level of illumination provided by the general area lighting and on the degree of lighting needed for the specific tasks.
- Electrical power inside the 221-U Canyon to support clearing the equipment from the canyon deck and preparing the canyon internal area for the canyon grouting and demolition. To clear the deck, the cell cover blocks will need to be lifted and moved out of the way to consolidate the abandoned equipment on the deck into the cells. The existing overhead cranes will require electric power.
- Additional power arrangements may be needed if special equipment (e.g., localized supplemental ventilation) is required inside the canyon. After the internal canyon and galleries work is complete, power will be needed outside the building to support the structure demolition.
- New electrical power sources will be required outside the canyon building near the facility grounds perimeter for environmental protection monitoring, structural demolition equipment, and support facilities.

Results

The existing power systems to the 271-UI221-U Buildings and the 291-U structures/equipment should be used in conjunction with new portable electrical stations to serve the north and south sides of the 221-U Building. The existing power systems are expected to be reliable for at least 10 years, based on engineering judgment.

Portable stations can be staged on the north and/or south sides to feed portable equipment inside and outside the canyon. The portable equipment will be useful for the demolition phase as well, and can be used in future missions at other facilities. After transition to the demolition phase, the building's permanent electrical system will be isolated, and the portable stations will be the only source of power.

Evaluation Considerations

Criteria for the evaluation included:

- Electrical power will be required in a variety of configurations to support equipment (i.e., 208 and/or 480V 3-phase; 120 and/or 240V single phase).
- All electrical equipment must meet the requirements of HNF-RD-11827, Hanford Electrical Safety Program, which implements the current editions of the National Fire Protection Agency (NFPA) 70, National Electric Code, and the NFPA 70E, Standard for Electrical Safety in the Workplace.
- When the existing fixed electrical system is isolated, power from a portable source will be required to complete the demolition preparation, grouting, and facility demolition.
- Portable power centers will be needed so that power will be available while demolition preparation activities move from cell to cell inside the canyon and to support activities at the canyon access points and outside the facility.
- The portable electrical distribution and utilization equipment and tools must be rated for use in an environment where water-based solutions might be used for spray washing of equipment, suppression of dust, or weather-related water is encountered inside or outside the structures.
- The S&M of 271-U and 221-U will continue until the facility is officially released to be demolished. The existing electrical system will be kept active and maintained to support the S&M phase until it is officially ended.

B.5 Railroad Tunnel

Pre-existing Conditions

The tunnel, which allowed train car access into Cell 3, extends westward from the northwest side of the canyon building (see Figure 54). The tunnel, which is 150 ft (46 m) long and 16 ft (5 m) wide, is a reinforced concrete structure with a soil cover about 5 ft (1.5 m) thick. There are unreinforced wing-wall retaining structures at the end of the tunnel. Access to the Railroad Tunnel is through a 16 ft by 22 ft (5 m by 6.7 m), motor-driven, roll-up steel door. Prior to reactivation the tunnel was effectively empty except for some piping debris, electrical panel, a few plastic liquid containers, ladders, brooms, cables, hoses, accumulated dirt, and an assortment of trash. There was no active lighting.

Figure 54 – U Canyon Railroad Tunnel

<u>The Need</u>

Reactivation of the U Canyon railroad tunnel was needed for delivery of equipment and supplies and to remove equipment, materials, and waste from the canyon. Large items, such as waste boxes/drums, skid systems, load test weights, size reduction equipment, etc., were brought into and out of the canyon through the railroad tunnel using large trucks.

<u>Results</u>

Reactivation activities included:

- The roll-up door was reactivated and returned to operational status.
- Housekeeping was performed to remove debris and unneeded items and materials. Radiological surveys were conducted prior to performing this work. The surveys, along with initial characterization of the tunnel interior, were used to establish radiological and IH controls.
- The strength of the diamond plate covering the drain trough was verified for projected loads during canyon cleanout. The most significant requirement was the 23 tons (21 tonnes) RH-TRU 72-B cask with trailer.
- Tunnel access was improved by straightening the road and reducing the grade to no more than 8 percent.
- A roof inspection was performed and repairs conducted as needed.
- The tunnel lighting was made operational by re-energizing the system, re-lamping and adding lights.
- Two remotely controlled video surveillance cameras were installed.

Installation of an “air lock” was considered, but was not included.

Evaluation Considerations

This evaluation addressed the functions needed and suggested options as how to proceed with each function needed for the railroad tunnel. There were no alternatives studied for the railroad tunnel as there was with the ventilation, electrical, and crane evaluations described above. The following is an example of considerations for the general criteria identified at the beginning of this Appendix.

- Nuclear Safety Considerations - The documented safety analysis (DSA) needed updating to account for the change of operations in the tunnel and associated fuel/fire loads. These include opening the roll-up door with the cover block off, bringing trucks into the tunnel, operating forklifts in the tunnel, as well as personnel working in the tunnel. D&D preparation process operations such as removal of Cell 30 waste drums, cranes drops, vehicle fires, etc., were addressed in the DSA revision.
- Radiological Considerations - The overall radiological condition of the railroad tunnel needed assessment for dose rate to workers including ALARA application. Continuous air monitors, dosimetry, and personal contamination monitoring was required in the early stages of work planning to assess the working conditions and specify personnel protection requirements.
- Industrial Safety Considerations - Consideration was given to emissions from internal combustion engine exhaust, radioactive material disturbance, and temperature extremes. The railroad tunnel was considered a "non-permit confined space" due to the fact that there is only one egress for the tunnel. In addition the railroad tunnel was included in the fire protection plan for the U Canyon.
- Environmental Air Emissions Considerations; Nonradioactive Emissions - The primary nonradioactive emissions resulting from this portion of the remedial action will be fugitive particulate matter. Reasonable precautions were necessarily taken to (I) prevent the release of air contaminants associated with fugitive emissions resulting from materials handling or other operations; and (2) prevent fugitive dust from becoming airborne from fugitive sources of emissions. The use of treatment technologies that would result in emissions of toxic air pollutants were not anticipated to be needed.
- Environmental Air Emissions Considerations; Emissions of Radionuclides - The Washington State implementing regulations are as stringent as or more so than the federal standards. The substantive provisions of these regulations that require monitoring of radioactive airborne emissions were applicable. In addition, if it were to be determined that there are substantive aspects of the requirement for control of radioactive airborne emissions, then controls will be administered as appropriate using reasonable and effective methods, with the general intent of maintaining airborne emissions as low as reasonably achievable.

Appendix C – Engineering Planning at U Canyon for Equipment Placement

The purpose of this appendix is to illustrate the results of a comprehensive engineering study [Ref: Fluor-2007] for planning the placement of equipment within the U Canyon into cells and trenches within the canyon prior to grouting. The detailed methods described here provide a model for future projects having to plan the placement of equipment prior to grouting. It is especially useful where there are a large number of items combined with physical constraints on the space to which they will be relocated.

The canyon portion of the 221-U Building was not entered during preparation of the study. Estimations of equipment size and configuration were made from examination of photographs and video footage. Nearly all of the equipment on the canyon deck was to be consolidated in the process cells, and the remainder will be dispositioned to the pipe trench. The study established the following:

- Approximate dimensions of each substantial equipment item currently on the canyon deck;
- Available space within the process cells;
- Equipment positioning within the cells;
- Size reduction technologies appropriate for this task;
- Material handling equipment appropriate for this task;
- Hazards associated with this task.

There was a wide assortment of equipment and debris on the 221-U Canyon deck. Sizes and weights ranged from very small (lbs) to very large (tons). As a basis to determine whether or not all of the equipment would fit into the cells, the study identified for detailed consideration equipment large enough to take substantial space in a cell and equipment of strategic importance (e.g., lifting yokes). All remaining equipment was deemed to be able to fit into the many small void spaces in the cells. The selected equipment items were assigned an arbitrary number for tracking purposes, and dimensions were estimated. Photographs of the canyon deck and along the pipe trench identifying the numbered equipment were included in Appendices.

The primary basis for establishing the vertical dimensions of the on-deck equipment was through assessment of hundreds of photographs that had been taken at deck level. The primary basis for establishing the horizontal dimensions was through assessment of six different montages of overhead photos above the cells. Relative sizes were established by comparing the equipment against items of known size (e.g., cover blocks, lifting bails, 55 gallon drums, etc.). The sizes that were ascribed to each piece of identified equipment were intended to conservatively envelop the largest “outline” of the item. For example, a tank that is nominally 8 ft (2.4 m) tall and 8 ft (2.4 m) in diameter, but has flanges or attachments that extend 2 ft (0.6 m) horizontally in one direction and 1.5 ft (0.5 m) vertically would be assessed as 10 ft x 8 ft x 9.5 ft (3 m x 2.4 m x 2.9 m) high.

For purposes of this report, two pieces of equipment are used to illustrate the study’s process. They are labeled #12 above Cell 8 and #113 above Cell 32; see Figure 55. Altogether 125 pieces of equipment and items were selected for evaluation, their dimensions were noted, and they were cataloged as shown in Table 9. Ultimately the recommended placement was added to the table.

The recommended placement for these two items was Cell #20. It is shown in Figure 56 in a photo taken from video footage. Table 10 is an example of the recommended placement of all equipment in the 40 cells and pipe trench; in this case for the two pieces of equipment used as an example.

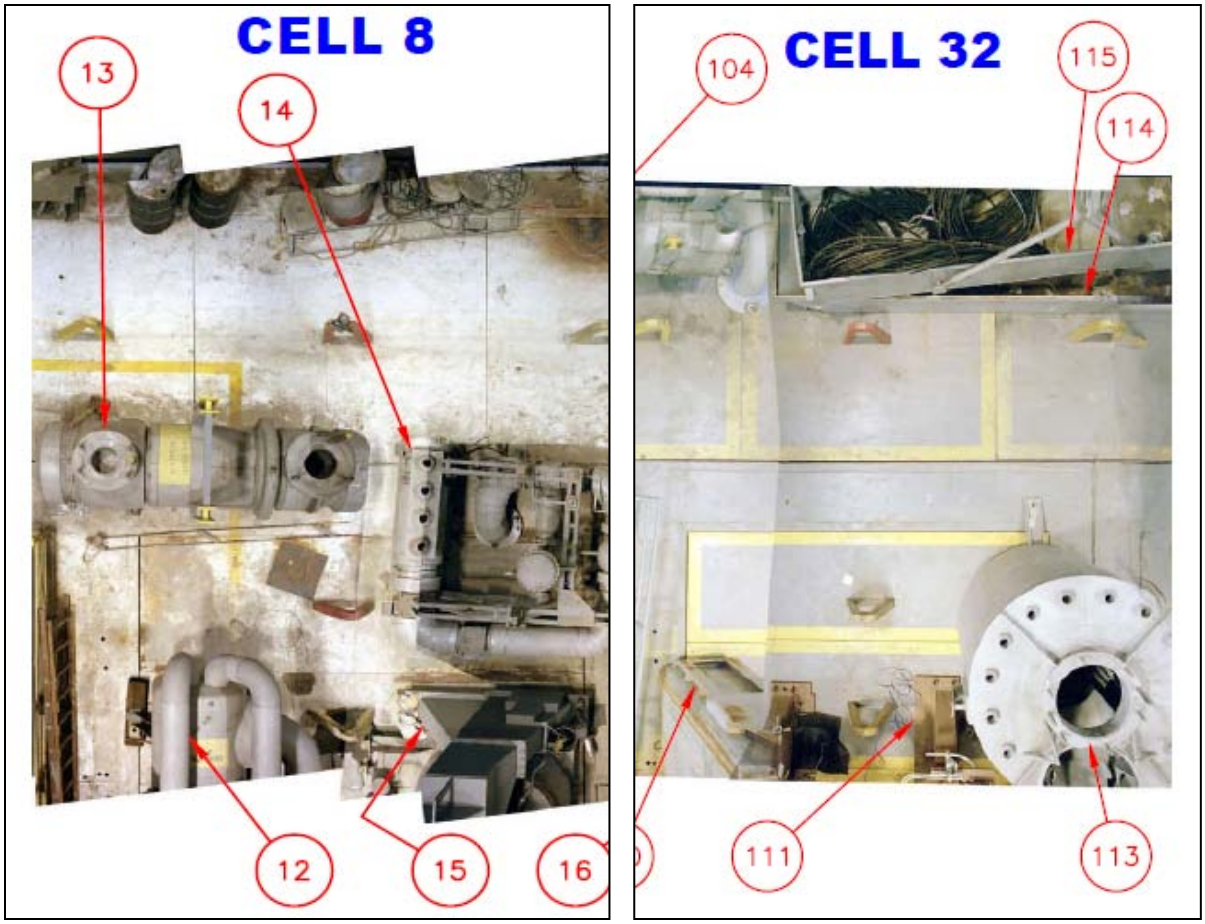


Figure 55 – Equipment above Cells 8 and 32

Table 9 – Example of Canyon Equipment Tabulation

Equip #	Description	Cell #	Cell/Pipe Trench/ Middle	Size Reduce (Y/N)	Height (ft)	Wide Dim W1 (ft)	Narrow Dim W2 (ft)	Map to Cell #	Comments
12	Condenser	8	C	N	7	15	10	20	Place on top of existing tanks and equipment item #113.
113	Tank	32	C	N	8	8	8	20	Place on floor after existing tanks are moved to edge of cell.

The explanation of the columns in Table 9 is as follows:

- Equip #: Arbitrary number assigned to equipment as shown in the photos in Figure 55.
- Description: Equipment description; may be non-technical, based on appearance of the item in the photos.
- Cell #: Cell number where the equipment is located on the canyon deck as shown in the photos. Note: equipment may be located adjacent to noted process cell, along pipe trench.
- Cell/Pipe Trench/Middle: This denotes whether the equipment shown in the photos is nearer to the process cells, the pipe trench, or between the process cells and pipe trench.
- Size Reduce (Y/N): This is a subjective assessment as to whether (Y) or not (N) the piece of equipment will require size reduction before placing into the cells.
- Height (ft): Estimate of the maximum height (in feet) of the equipment based on photos, video footage and interviews with facility personnel.
- Wide Dim W1: (ft) Estimate of the maximum width (in feet) of the widest side of the equipment based on photos, video footage and interviews with facility personnel.
- Narrow Dim W2: (ft) Estimate of the maximum width (in feet) of the narrower side of the equipment based on photos, video footage and interviews with facility personnel.
- Map to Cell #: Recommended process cell for final placement of equipment.
- Comments: Miscellaneous comments, including instructions for placing equipment into cell for final dispositioning.

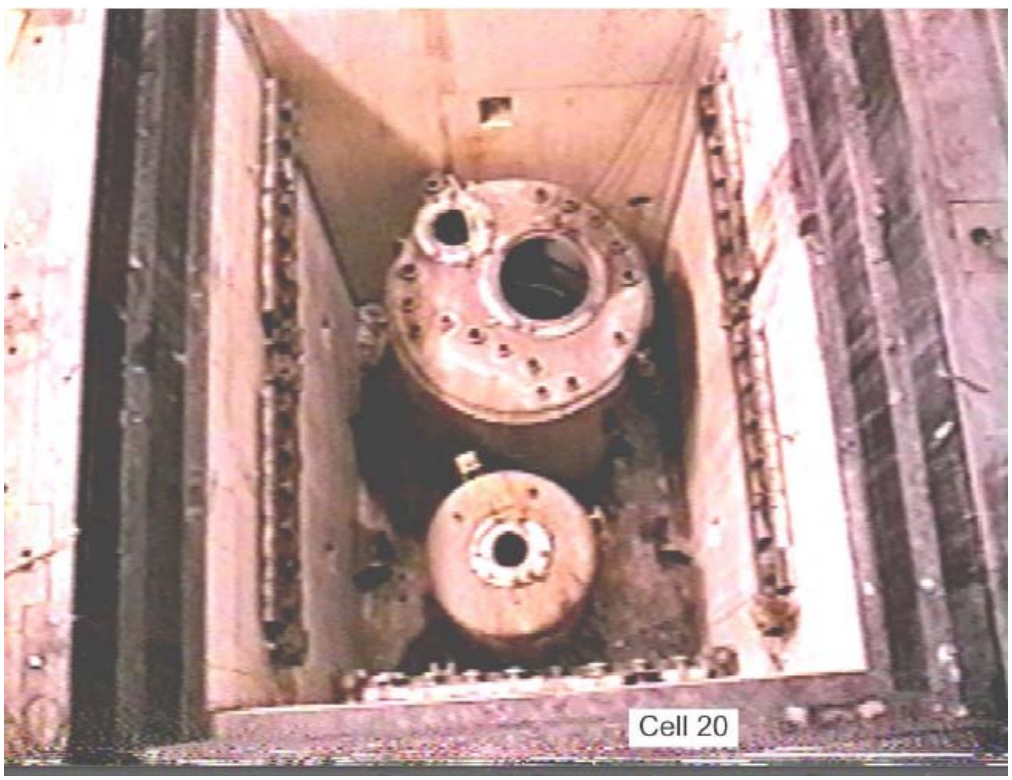


Figure 56 – Cell 20 with Cover Block Lifted

Table 10 – Example of the Recommendations for Canyon Cell Loading

Cell #	Empty Cell Dimensions (feet)			Available Space based on Video Footage (feet)			Equip Item	Cell Configuration Comments	Equipment Placement Comments
	H	L	W	H	Wide Dim	Narrow Dim			
20	22	17	13	22	8	8	113	Move tanks to edge of cell.	Place on floor after existing tanks are moved to edge of cell.

The explanation of the columns in Table 10 is as follows:

- Cell #: Process cell number where equipment will be placed.
- Empty Cell Dimensions:
  - H (ft) Height of the cell (in feet) from the floor to the bottom of the cover blocks.
  - L (ft) Length of the cell (in feet) below the cover blocks.
  - W (ft) Width of the cell (in feet) below the cover blocks.
- Available Space Based on Videos
  - H (ft) Height (in feet) of a given open space within the cell (available for equipment placement).
  - Wide Dim (ft); the larger of the horizontal dimensions (in feet) of a given open space within the cell (available for equipment placement).
  - Narrow Dim (ft); the smaller of the horizontal dimensions (in feet) of a given open space within the cell (available for equipment placement).
- Equipment Item: Number of the equipment shown on the photos.
- Cell Configuration Comments: Describes the available open space before a given piece of equipment is placed into the cell, or what must be done to make the space available.
- Equipment Placement Comments: Instructions for placing the given piece of equipment into the open space.

Appendix D – Example Checklists for Equipment and Grout Placement

D.1 Purpose

Equipment associated with the facilities was embedded within the grout fill in the U Canyon at Hanford and the Reactor buildings at SRS. In particular, at Hanford because of the constrained space in each canyon cell and the limited crane access, detailed planning for the placement of each individual piece of equipment initially residing on the canyon deck into the process cells was essential in ensuring proper space allocation and work package definition.

The purpose of this appendix is to provide three example checklists used at Hanford for equipment and grout placement in the U Canyon cells. The three checklists are for:

- Equipment placement prior to grouting
- Readiness for grout placement
- Grout Placement

Shown here are the checklist items that have been extracted from three procedures. Other procedural content, such as approvals, instructions, and directions on how to conduct walkdowns are not included.

These examples can be used as starting points for future projects faced with the need to carefully plan the grouting activities.

D.2 Example Checklist for Equipment Placement Prior to Grouting

This example was used for the following equipment that resided on the operating deck of the U Canyon.

EQUIP ITEM #	DESCRIPTION	HEIGHT (Approx. ft)	DIMENSION (Approx. ft) WIDE	NARROW
#15	Centrifuge	15	11	8
#8	High Rad Condenser	6	12	5
#11	Miscellaneous agitators/pumps	Varies	Varies	Varies
#37	Off-gas Heater	6	15	5
#52	Purex Off-gas-Heater	4	12.5	5
#87	Miscellaneous agitators/pumps	Varies	Varies	Varies
#39	Miscellaneous agitators/pumps	Varies	Varies	Varies

STEP	ACTIVITY 2U-09-5562 ATTACHMENT 1 SHEET FOR PROCESS CELL #4
1	Any temporary covers that would restrict internal grouting of potentially buoyant vessels should be removed. This may occur at any convenient time during the following steps prior to grouting of that vessel.
2	DO NOT INTERFERE WITH PLACEMENT OF EQUIPMENT ON TOP OF EXISTING TANK Move existing dunnage from bottom of cell to inside of existing "bath tub" tank or cell corners sufficient to allow placement of #15 on floor.
3	DO NOT INTERFERE WITH PLACEMENT OF #15 ON CELL FLOOR DO NOT INTERFERE WITH PLACEMENT OF EQUIPMENT ON TOP OF EXISTING TANK DO NOT INTERFERE WITH CELL BLOCK REPLACEMENT OR ACCESS FOR INTERNAL GROUTING OF EXISTING "BATH TUB" TANK. • Place small shuttle boxes containing leaking sources, as identified by the RCT, in the cell at any convenient location. • Place #15 on cell floor • As room permits, transfer High Rad jumper assembly from the area of Cell 39 PT, to inside of existing "bath tub" tank and/or other convenient locations. • Place #8 High Rad Condenser in cell • Place #37 Off-gas Heater in cell • Place #52 Purex off-gas heater in cell • Fill void space in Cell to extent practical using #11, #87, #39, identified items mapped to "Misc" and/or unidentified items from canyon that have no further use. Size reduce as required. Record any Identified Equipment Item numbers below.
4	Cell is ready for any initial internal grouting and/or initial void space grouting.
5	Initial internal grouting and/or initial void space grouting (as required) has been completed.
6	DO NOT INTERFERE WITH CELL BLOCK REPLACEMENT Following internal grouting and initial void space grouting, if space becomes available, fill void space in Cell to extent practical using #11, #87, #39, identified items mapped to "Misc" and/or unidentified items from canyon that have no further use. Size reduce as required. Record any Identified Equipment Item numbers below. This activity may be repeated as additional lifts of grout are performed.
7	Final grouting may proceed as desired. Step 6 may be performed in parallel with grouting if additional space becomes available.

D.3 Example Checklist for Grout Placement Readiness

PRE-GROUT PLACEMENT READINESS CHECKLIST	
No.	**Building: 221-U Location: Northern Electrical/Piping Galleries Work Package #: 2U-10-05485**
1	Electrical conduits have been isolated in the area to be grout filled: (Work Package 2U-11-01218, step 5.4.2)
2	Pipe penetration grating removed (Work Package 2U-11-01218, step 5.4.4)
3	Pipe 2-in or larger air gapped below ceiling level (Work Package 2U-11-01218, step 5.4.7)
4	Supply Air Duct removed (Work Package 2U-11-01218, step 5.4.8)
5	Northern electrical gallery fan, utility, pipe penetrations and lower door bulkheads are in installed (Work Package 2U-10-07212; step 5.2.6.6)
6	All free liquids have been removed or stabilized or approved to remain in place.
7	All smoke detectors have been removed
8	All fire extinguishers have been removed
9	Radiological hazards have been evaluated and controls established considering: • Pre-work radiological surveys and historical information • Radiological monitoring protocols for dose, contamination, and airborne radioactivity documented in work governing documents • Contamination and airborne radioactivity controls are established
10	External Grout Conveyance installed and ready to deliver grout to Gallery interior (Work Package 2U-10-05481)

D.4 Example Checklist for Grout Placement

Step	**North Electric Gallery Grout Placement – 1st lift**
1	Verify equipment/supplies necessary has been staged
2	Verify work area boundaries (limited access/personnel exclusion control barriers, etc.) and signage have been established
3	Verify video system has been setup and tested per manufacturer's direction, IF used.
4	Verify internal flex hose delivery system is connected to external grout conveyance system.
5	Verify connection fittings are secure (bolted or pinned).
6	Verify flex hose is routed through the appropriate pipe chase into the northern electrical gallery
7	Verify all tools and equipment not being macro-encapsulated have been removed from gallery
8	Verify North Electrical Gallery is clear of all personnel
9	Verify bulkhead doors and/or ports to the north electric gallery are in place and there is no visible damage
10	Verify pump personnel are prepared to supply grout in accordance with work package 2U10-05489.
11	Deliver 140 cu. yds. Type A grout into North Electrical Gallery. Start Time: _____ Time Completed: _____
12	Verify personnel are clear of potential splatter and hose whip area for hose clean-out.
13	Purge grout conveyance hose with foam pig and air.
14	Return work package to field office
15	Design Engineer or designee shall record concrete temperature readings 2 times per day: Day of Pour Time: _____ Temperature: _____ Initial: _____ Date: _____ Time: _____ Temperature: _____ Initial: _____ Date: _____ Time: _____ Temperature: _____ Initial: _____ Date: _____ Time: _____ Temperature: _____ Initial: _____ Date: _____ Time: _____ Temperature: _____ Initial: _____

Appendix E – Above Grade ISD Hazard Category Evaluation

E.1 Purpose

The P- and R- Reactor ISD projects at SRS differ somewhat from those at Hanford and INL in that a significant amount of the facilities' superstructure remains above grade for the project end state. As a result, it was important to understand the consequences of an accident involving the above-ground structure.

The purpose of this Appendix is to describe the approach taken at SRS so that future projects that have a similar end state can consider its use for their projects. The information herein has been distilled from an extensive calculation conducted by the project engineers. The calculation itself is not included.

E. 2 Overview of Methodology

The approach used was to determine the Facility Hazard Category (FHC) of the ISD Reactor facility for the conditions of the facility after the completion end state. Prior to ISD the buildings contained enough dispersible radiological material for a FHC of "radiological." If it could be shown that enough removal, cleanout, stabilization and encapsulation had been conducted such that the amount of materials released under accident scenarios would be lower than the release quantity criteria of 40 CFR 302.4[7] for reporting, the facility could be categorized as "other industrial" (that is, not nuclear and not radiological). This would then minimize the degree of monitoring and inspection compared with a facility that would have an FHC of radiological.

The following steps were to determine the FHC:

Identify all material-at-risk (MAR).

1. Identify credible events for each MAR, and an airborne release fraction for each event.
2. For each MAR, determine the worst case airborne release fraction.
3. Calculate source term (ST, which is the fraction of MAR available for release/dispersion) for each constituent.
4. Compare STs to the applicable Reportable Quantities (RQs) from 40 CFR 302.4, and verify that no source term exceeds the applicable RQ
5. Perform a sum-of-the-fractions calculation, and verify that the sum-of-the fractions does not exceed unity (i.e., Σ(each source term)/applicable RQ < 1).
6. If the source term for each individual constituent is less than the applicable RQ and the sum-of-the-fractions is less than 1, then the ISD facility can be categorized as "other industrial." Otherwise, segments of the facility would remain categorized as radiological.

[7] 40 CFR 302.4, *Designation of Hazardous Substances*, is the federal regulation When there is a release of a reportable quantity of any extremely hazardous substance or CERCLA hazardous substance, the facility must make emergency release notification to the State Emergency Planning Committee and the Local Emergency Planning Committee.

E. 3 Events Leading to a Release

Events, which could result in a release, were categorized into four distinct categories; listed below:

External Impacts

- Collapse of the Building
- Collapse of Adjacent Structure
- Vehicle Crash
- Missiles (due to high winds, tornadoes, hurricanes, etc.)
- Aircraft Crash

Fire/Explosion in Adjacent Facility or Equipment

- Nearby Building and/or Equipment
- Aircraft Crash

Natural Phenomena Hazards (NPH)

- Earthquake
- Straight Wind/Tornado/Hurricane
- Temperature Extremes
- Snow/Flood
- Wild-land Fire

Fire in Building

E. 4 Results

In summary, there are three events that have a credible impact on the MAR: (1) an aircraft impact (no fire), (2) an aircraft crash with resultant fire, and (3) a building-wide fire. Of these three events, the one that by analysis would result in the greatest damage/release is the aircraft crash with resultant fire. This event has the ability to impact both the encapsulated/stabilized/capped sludge in the Disassembly Basin and Emergency Basin, the Filter Trailer in the Stack Area, and the transferable contamination in above grade spaces.

Without credit for segmentation or the nature of the process, the facility is categorized as an "other industrial" facility. The dispersible hazardous material inventory (both radiological and chemical) was found to be less than applicable RQs from 40 CFR 302.4. That is, the inventory of individual constituents was less than the applicable RQ and the "sum-of-the-fractions" was also less than 1. The sum-of-the-fractions calculation yielded a result of 0.812. Therefore, the facility, as a single segment, has an FHC of "other industrial."

It is noted that the Disassembly/Emergency Basins could be analytically segmented from the remaining above-grade Reactor Building. A separate cap covers the two basins, which lie outside the sealed above-grade Reactor Building. If treated as two different segments, then the sum-of-the-fractions for the Disassembly/Emergency Basin would be 0.425, while the sum-of-the-fractions for the remaining inventory would be 0.387. This is not necessary as the results show “other industrial” without credit for segmentation.

Because the FHC is "other industrial," there is no requirement to implement and/or maintain an Auditable Safety Analysis for the ISD project area.

Appendix F – Work Breakdown Structure

The purpose of this appendix is to provide an example of a Work Breakdown Structure (WBS), which is that used for the P Reactor project. This may serve as a starting point for future projects in creating their WBS. Table 11 indicates the SRS Site WBS levels above the project and Table 12 is the project-specific WBS.

Table 11 – P Reactor WBS to Level 8

WBS Level	WBS Index	WBS Title
1	01	SRS TOTAL SITE
2	0129	DOE EM SAVANNAH RIVER SITE
3	012932	AREA COMPLETION
4	01293250	ACP-ARRA
5	0129325005	STEEL CREEK WATERSHED AREA COMPLETION
6	012932500502	P-AREA COMPLETION
7	01293250050201	P-AREA FACILITIES DISPOSITION
8	0129325005020101	105-P DISPOSITION (INCLUDING 108-1P AND 108-2P)

Table 12 – P Reactor WBS below Level 8

WBS Level 9 Title	Level 10	WBS Level 10 Title
105-P (ISD) DECOMMISSIONING	010201	FY09 DECOMMISSIONING DESIGN
	01020197	FY09 ACTUALS DECOMMISSIONING DESIGN
105-P DECOMMISSIONING DESIGN	01020201	SEAL OPENINGS DESIGN
	01020202	ROOF WATER DRAINAGE DESIGN
BATCH PLANT OPERATIONS	01020301	OPERATE BATCH PLANT
	01020302	BATCH PLANT RAW MATERIALS
	010203099	BATCH PLANT OPS AND MATERIAL CLOSE-OUT
GROUT REACTOR BUILDING/REMOVE STACK	01020401	105-P STACK REMOVAL
	01020402	CORE HOLES
	01020403	GROUT OTHER AREAS 105-5
	01020404	GROUT -40 ELEVATION
	01020405	GROUT -20 ELEVATION
	01020406	SUBCONTRACT SUPPORT
	01020499	GROUT REACTOR BUILDING/REMOVE STACK CLOSE-OUT

WBS Level 9 Title	Level 10	WBS Level 10 Title
MODIFY SELECTED ROOF DRAINAGE	01020501	105-P CONSTRUCT ROOF DRAINAGE
	01020502	SUBCONTRACT SUPPORT
	01020503	MODIFY SELECTED ROOF DRAINAGE CLOSEOUT
SEAL REACTOR BUILDING	01020601	REMOVE FILTER COMPARTMENTS
	01020602	105-P PLENUM FINAL SEAL
	01020603	105-P SEAL OPENING ABOVE ZERO ELEVATION
	01020604	105-P SEAL OPENING AT ZERO ELEVATION
	01020605	REMOVE REMAINING EXTERIOR METAL
	01020606	SUBCONTRACT SUPPORT
	01020699	SEAL REACTOR BUILDING CLOSEOUT
GROUT REACTOR VESSEL/DISASSEMBLY BASIN STRUCTURE	01020701	GROUT REACTOR VESSEL
	01020702	GROUT DISASSEMBLY BASIN
105-P D&R DISASSEMBLY BASIN	01020801	105-P D&R DISASSEMBLY BASIN
DISASSEMBLY BASIN CAP	01020901	DISASSEMBLY BASIN CAP DESIGN
	01020902	DISASSEMBLY BASIN CAP DESIGN SUPPORT
	01020903	DISASSEMBLY BASIN CAP REMEDIATION
	01020904	DISASSEMBLY BASIN CAP REMEDIATION SUPPORT
SITE MOBILIZATION, IMPLEMENTATION, SUPPORT, DEMOBILIZATION	01021001	GENERAL AREA CLEANUP/HOUSEKEEPING
	01021002	BATCH PLANT INSTALLATION SUPPORT
	01021003	BATCH PLANT DE-MOB SUPPORT
	01021004	105-P DECOMMISSIONING SUPPORT
	01021005	105-P DECOM FIELD SUPPORT / WASTE
	01021006	105-P DECOMMISSIONING PROJECT SUPPORT
	01021099	MOB/DEMOB CLOSEOUT

Appendix G – Project Risk Management Example

G.1 Purpose

This appendix provides an example of a project risk management analysis for an ISD project. This example shows selected aspects of that used for the P Reactor project at SRS. The purpose here is to provide information for an ISD project regarding the method used, types of risks considered, and the results of the technical, schedule, and estimate risk assessment. The standard aspects of risk management methods and tools are only briefly addressed as each future project should have its own well established.

G.2 Project Risks Considered

The significant project risks in the P-Reactor risk assessment are identified here. Some of these are specific to ISD and others would apply to any decommissioning project. For purposes here, risks identified that were reported fall into two groups; the first is those that were closed and not included in the Technical and Programmatic (T&P) contingency calculation. These included:

- Batch plant will not be ready to support decommissioning
- Bids for 105-P stack removal is higher than planned
- Increase in number of core bores than planned
- Underestimated the grout needed to provide the disassembly basin cap
- Underestimated the grout needed to fill areas within 105-P
- P-105 Disassembly basin water evaporation
- Approved security plan is not adequate to cover the planned work
- An auditable safety analysis is not adequate
- Inadequate characterization of systems
- Plugging of grout lines during grout placement

The second group of risks is those used in the T&P calculation; these are listed in Table 13. In the table, “Residual Risk” refers to is the assessment after the risk handling strategy was implemented.

Table 13 – P Reactor Residual Risk

Risk Title	Statement of Risk	Residual Risk
Support from Specialty Resources to Perform Work	Specialty personnel (Industrial Hygienists and Rad Con Techs) will be required to support the P-Reactor Decommissioning. There is a risk that these Specialty personnel may not be available, resulting in an additional cost and schedule impacts.	Moderate

Risk Title	Statement of Risk	Residual Risk
Increase in Safety or Radiological Incidents	Area Completion plans to use subcontractors to execute a considerable amount of Decommissioning work scope. This work will be planned and executed following Site procedures. To support execution of Decommissioning scope, additional personnel with various levels of experience will be added to the Site workforce. The ARRA baseline includes training for all new personnel, and assumes that they will comply with Site work, safety, and radiological control procedures. There is a risk that due to the dramatic increase in Site activity and the large number of inexperienced workers, a safety and/or radiological incident may occur that affects the Area Completions' ability to complete Decommissioning scopes of work, resulting in the shutdown of one or more Decommissioning scopes of work, or the shutdown of the entire ARRA project until completion of the incident investigation.	Moderate
Reactor Vessel Grout Requirements	The reactor vessel is to be filled with grout. It has been determined that a specialty grout will be required to be used. There is a risk that with the new grout execution problems may be encountered in the field that were not anticipated (i.e. radiological, placement of grout, production of the grout, delivery to the field), resulting in impacts to the project cost and schedule.	Moderate
Higher Airborne Releases than Expected at Disassembly Basin	The above ground disassembly basin structure will be demolished. The structure has been characterized. There is a risk that some unexpected radiological contamination (airborne) may be encountered when demolition begins.	Low
Lack of Support Services from ISS	Site Services are required to provide support for various operations/processes. This support is in the form of trucking, heavy equipment, rigging, temp power/communications, etc. There is a risk that these particular site services cannot be provided to support the need, resulting in an additional cost impact to maintain schedule.	Low
Lack of Construction Craft Support	The project utilizes other construction craft to supplement Site forces. There is a risk that those construction support personnel will not be available because of outside influences when needed, resulting in cost and schedule impacts.	Low
External Supplied Equipment is not Available	Support equipment for all self-performed work will use equipment supplied by an external source. There is a risk that source will not be able to provide the equipment, resulting in additional cost and schedule impacts.	Low

Risk Title	Statement of Risk	Residual Risk
Receipt of Government Furnished Services and Information (GFSI)	During the performance of the P-Decommissioning project, GFSIs (such as CD2/CD3 approval, etc.) will be required to support the various work activities. There is a risk that the required/requested GFSIs will not be provided in a timely manner or at the level of detail necessary to perform the work scopes, resulting in schedule delays to the individual projects.	Low
Disassembly Basin Cap Design May Change	Grout will be used to provide the cap for the Disassembly Basin. The estimate indicates a specific amount of the grout based on the design of the Disassembly Basin. There is a risk that the basin cap design may change, resulting in additional cost and schedule impacts.	Low
Locomotives Availability	The rail line project has acquired an additional locomotive from Oak Ridge to use during Batch Plant operations. There is a risk that one or two of the locomotives in the locomotive fleet breakdown during the peak of the batch plant operations which would have a negative impact on the production of grout. The resulting impacts are to cost and schedule.	Low

G.3 Contingency Calculation

This Risk Analysis Report is a comprehensive evaluation of the technical and programmatic, schedule, and estimate risks and provides the basis for establishing the projects' cost and schedule contingencies to support the Estimate at Completion, i.e. to-go. The risks provide input to the three integrated techniques used to develop the forecasted project contingency analysis at completion.

The Technical and Programmatic Risk Assessment (T&PRA) addresses the technical and programmatic risks within the to-go scope of the project, but which have not been qualified nor included in the cost and schedule. Items included in a T&PRA include specific design issues, limited availability of certain equipment, availability of qualified personnel, grout requirements, safety, radiological conditions, etc. Programmatic risks are possible disruptions caused by resource issues, events, or actions that may or may not be within the activity manager's direct control. The technical and programmatic risks provide input to the three integrated techniques used to develop the total project contingency analysis, as follows:

- Technical and Programmatic Cost Contingency: Based on the above, a T&PRA cost contingency is calculated that addresses the impacts of these types of risks to the project scope. The programmatic/technical risks that are of significant concern to this sub-project considered the top three risks to the sub-project are:
  - Increase in Safety or Radiological Incidents
  - Reactor Vessel Grout Requirements
  - Locomotives Availability

The largest contributor to the contingency was the risk of an increase in safety or radiological incidents.

In addition to risks, one *opportunity* was implemented; namely, "explosives are allowed to be used for stack removal." It was stated that realization of this opportunity did not provide the cost savings that were anticipated.

- Schedule Contingency: Schedule contingency addresses issues to the to-go project schedule. Items addressed are schedule logic, activity durations, resource availability, and planned work processes, and schedule impacts from T&PRA risks. Schedule contingency yields an amount of time to be added to the schedule baseline and the associated additional cost to account for the extension of time.

Schedule contingency was developed for this project using a Monte Carlo technique with Primavera Risk Analysis software. Schedule impacts for contingency are developed with a Range of Durations analysis and a Probabilistic Branching modeling analysis. The Range of Durations analysis is developed using (Optimistic, Most Probable, and Pessimistic) duration impacts on each activity. The Project Team established specific duration ranges for key activities and default ranges for all others.

- Estimate Contingency: Estimate contingency addresses the risks associated with the information used to prepare the to-go cost estimate. This includes factors such as productivity rates, labor rates, material pricing, weather impacts, quantification accuracy and other technical scope (including T&PRA handling strategy(s) implementation), escalation factors, and planned work processes. Estimate contingency is limited to the project's current scope and schedule and bounded by the estimate bases, assumptions, exclusions, and inclusions. Estimate contingency varies depending on scope definition and complexity of the project.

An Estimate Contingency Monte Carlo simulation was performed using Crystal Ball Analysis software. The Monte Carlo simulation technique utilizes the probabilistic determination method and yields the probability of overruns or under runs to the total project cost at various levels of Estimate Contingency.

G.4 Results of the Technical and Programmatic Risk Assessment

The results of the Estimate at Completion contingency analysis, for P-Reactor Decommissioning are shown in Table 14. The project's T&PRA Cost Contingency, Schedule Contingency, and Estimate Contingency dollar impacts are addressed. The Schedule duration impact is also displayed. All contingencies are provided at the 50% and 80% confidence levels. The sum of the contingencies quantifies the total impact of probable risk to the detailed analysis reports for each of the risk techniques. All numbers in the table below are burdened.

Table 14 – P Reactor Contingency Results

Contingency Category	50% Confidence Level (Management Reserve)	80% Confidence Level	80% minus 50% (DOE Contingency Value)
T&PRA ($K*)	$1,391	$2,082	$691
Schedule ($K*)	$2,383	$3,483	$1,100
Estimate ($K*)	$2,129	$7,995	$5,866
Total ($K*)	$5,903	$13,560	$7,657
Estimate contingency as % of estimate to completion	4.1%	15.5%	11.4%
Schedule Contingency (days)	39	57	

Appendix H – Use of Three-Dimensional Modeling

Three-dimensional models (3-D) proved very useful for the P and R Reactor projects. The purpose of this Appendix is to show future projects how this approach can be used for planning, work management, and providing workers with a realistic view of work locations.

Uses included project planning such as for work sequence and grout line runs, engineering calculations such as space volumes, and for work planning by the contractor in determining the volume for lifts and communicating specific task locations to crafts. An example of the models' usefulness was for grout placement strategies because they can be used to either confirm or dismiss various placement approaches, which helps remove uncertainty in our planning.

Originally, SRS D&D managers had SRNL to use their rapid prototyping capabilities to create a scale model of one canal inside the R reactor complex to help them visualize placement of grout. The value of its use resulted in a decision to model the zero elevation and below grade areas of the R Reactor facility and subsequently the R reactor disassembly basin.

Rapid prototyping automates the translation of computer-aided-design (CAD) drawings into three-dimensional (3-D) models of the facility. The system used was a Stratasys Fused Deposition Modeling® in which plastic wire is fed to a nozzle, which is controlled by a computer that reads the CAD documents. The nozzle melts the plastic and extrudes it very precisely.

The entire underground portion of the R reactor complex was created in an 8 ft long, 4 ft wide (2.4 m x 1.2 m) model. The models include all of the reactor facilities' structural elements such as walls and stairwells and including every opening two inches in diameter or larger. The model of the major facilities is at a scale of 96:1; any smaller and the important details would be too small to see. The team also created a model of the reactor vessel itself at one-eighth scale. Again, the scale was chosen based on the size of important details.

The completed R reactor facility model is made up of about 142 pieces. Typically a piece can be produced in a day to produce the typical piece; larger pieces took as much as 160 hours. Much of the time invested in the project was to find and study historical prints and drawings to get the dimensions to produce the CAD model. The reactors were built in the early 1950s and shutdown in the 1960s. Retrieving all of the necessary information became the critical path effort in creating the 3-D models. Perspective on the size of the model can be seen in Figure 57, which shows the R reactor model with the leader of the model development team.

Figure 57 – R Reactor 3-D Model

Credit: Savannah River National Laboratories

Appendix I – Canyon Grouting Status Display

Keeping an up-to-date status of grouting progress is essential for managing operations and logistics for projects as massive as ISD. The purpose of this Appendix is to show a status display method that was developed at U Canyon that can be applied to other projects. To explain the method, view Figure 58, which shows a cross-section of the U Canyon.

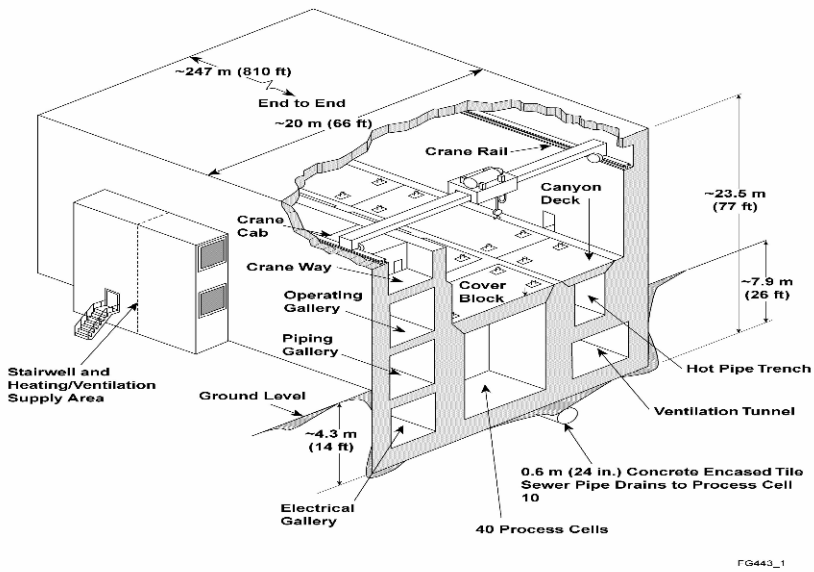
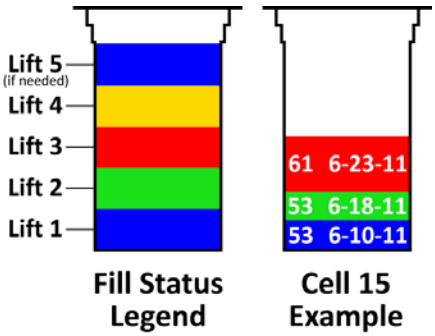


Figure 58 – U Canyon Cross Section

Figure 59 is a diagram that shows a limited part of the status display corresponding to locations along the length of the canyon. This portion shows eleven of the 40 canyon process cells and the portion of the adjacent electrical gallery corresponding to the same location. The display used by U Canyon project management (Figure 60) showed the entire length of the canyon for the cells, electrical gallery, ventilation tunnel, hot pipe trench, drain pipe, and pipe gallery, all of which were to be filled with grout. The entire diagram is several feet in length. Features of the display include the text information shown in the legend for each cell and for the entire canyon included:

- A visual depiction of the approximate elevation of the top of the lift. For example, Figure 59 shows the electrical gallery completely filled, grouted cells 8, 9, and 13 not grouted, and the other cells partially grouted. (For clarity, the text in each cell is not shown in this figure; however the Cell 15 example in the legend is how all cells were displayed.
- Color coding to indicate each lift in a vertical orientation. As shown in the legend, blue is first followed by green, red, and orange, after which the color coding continues with this sequence.
- Text on each lift indicates the date it was placed, its volume in cubic yards, and the entry hole in the cell or gallery through which it was poured.



Fill Legend

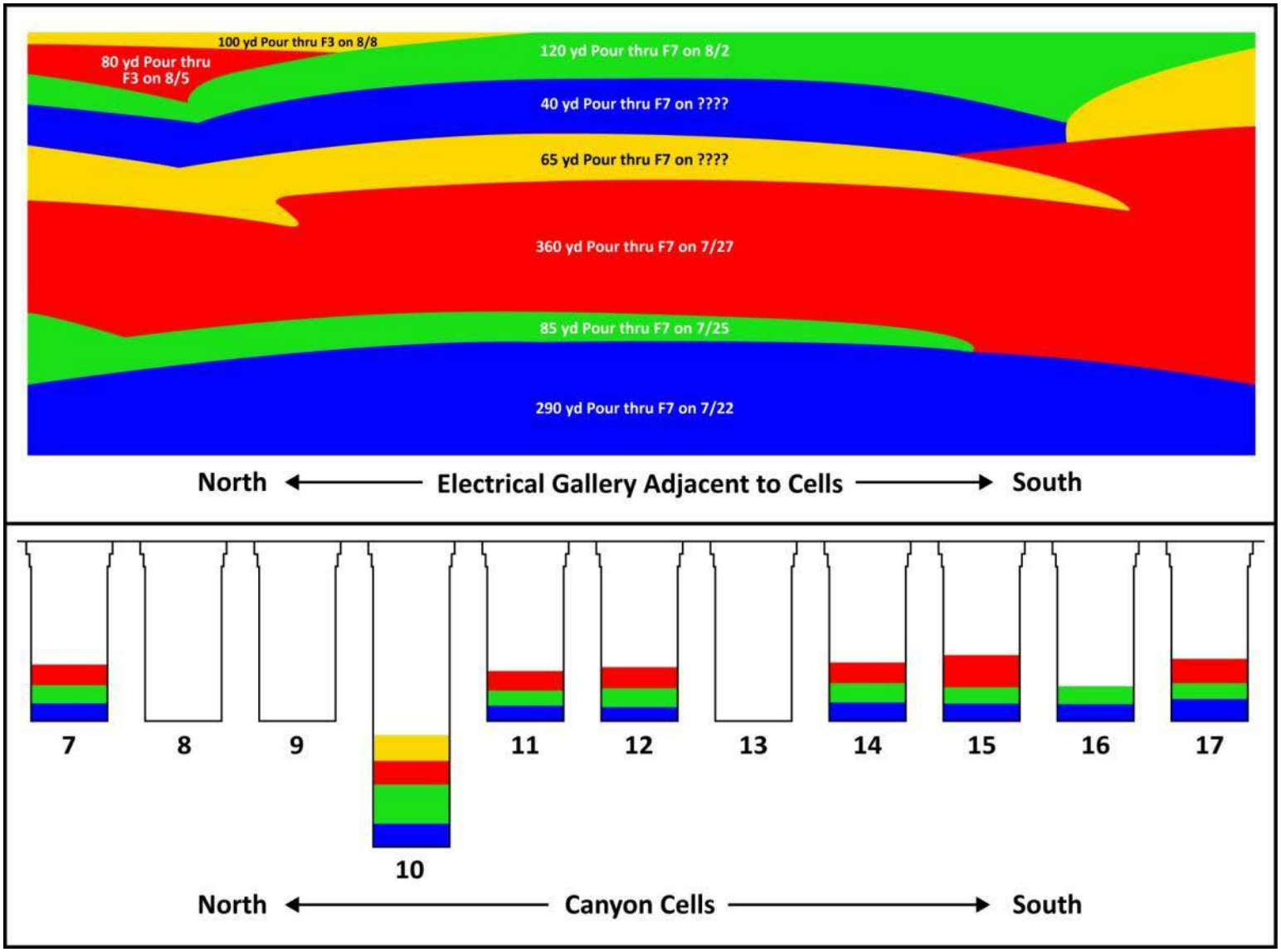


Figure 59 – Grouting Status Display Method at U Canyon

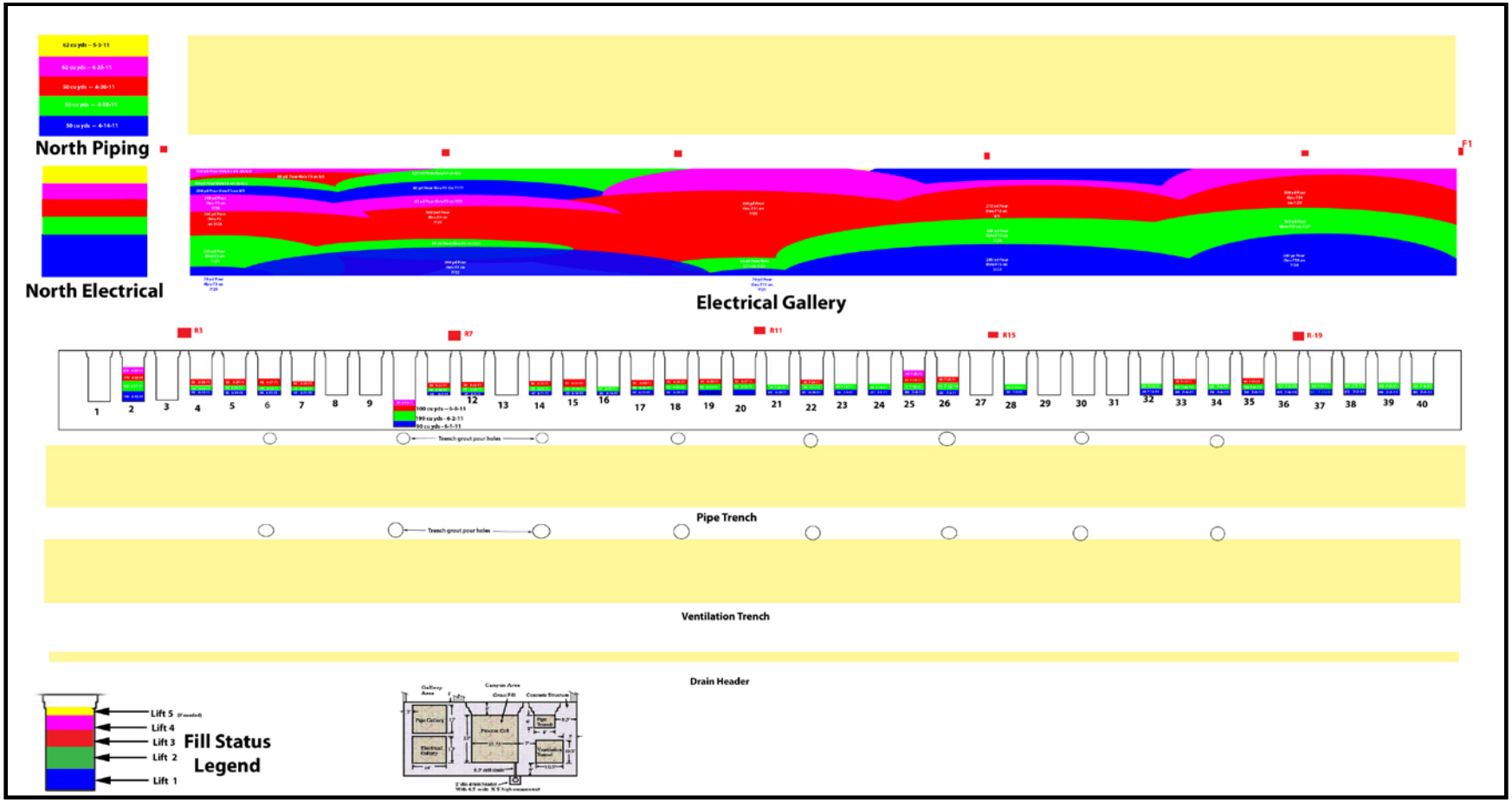


Figure 60 – Canyon Status Full Display