U.S. DEPARTMENT OF ENERGY

Design and Commissioning Report

Revision 1

Office of the Chief of Nuclear Safety

Office of Environmental Management

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Abbreviations and Acronyms

A–E	Architect Engineer
AIB	Accident Investigation Board
AMWTP	Advanced Mixed Waste Treatment Project
AoA	Analysis of Alternatives
ASME	American Society of Mechanical Engineers
ASP	Alpha Strike Process
AVD	Attribute Verification Database
BNFL	British Nuclear Fuels, Limited
CAT	Construction Acceptance Testing
CE	Chief Executive for Project Management
CG&A	Calibration, Grooming and Alignment (Component Tests)
CLIN	Contract Line Item Numbers
CORR	Contractor Operational Readiness Review
CRA	Contractor Readiness Assessment
CRAD	Criteria Review and Approach Document
CRB	Commissioning Review Board
CSE	Cognizant System Engineer
CSS	Clarified Salt Solution
CSSX	Caustic Side Solvent Extraction
CVP	Certification and Verification Plan
DOE	Department of Energy
D&D	Deactivation and Decommissioning
DORR	DOE Operational Readiness Review
DSA	Documented Safety Analysis
DSS	Decontaminated Salt Solution
EM	Environmental Management
EMAB	Environmental Management Advisory Board
EP	Emergency Preparedness
EPA	Environmental Protection Agency
EPC	Engineering, Procurement, and Construction
ESAAB	Energy Systems Acquisition Advisory Board
ES&H	Environmental, Safety, and Health
ESHPOP	Environmental, Safety and Health Program Operating Plan

FAT	Factory Acceptance Testing
FDD	Facility Design Descriptions
FOAK	First of a Kind
FPD	Federal Project Director
FWEN	Foster Wheeler Environmental Corporation
GAO	Government Accountability Office
HTF	H Area Tank Farm
IAEA	International Atomic Energy Agency
IBR	Integrated Baseline Review
ISM	Integrated Safety Management
INL	Idaho National Laboratory
ISOT	Integrated System Operational Test
ISPD	Interim Salt Disposition Process
ISR	Integrated Simulant Run
IVS	Interim Ventilation System
IWR	Integrated Water Run
JONs	Judgments of Needs
JTG	Joint Test Group
KPP	Key Performance Parameter
LL	Lessons Learned
LMA	Line Management Assessment
LOI	Line of Inquiry
M&O	Management and Operating
MLLW	Mixed Low Level Waste
MSA	Management Self-Assessment
MST	Monosodium Titanate
NAS	National Academy of Sciences
NRC	Nuclear Regulatory Commission
O&M	Operation and Maintenance
OJT	On-the-Job Training
OPI	Office of Primary Interest
ORNL	Oak Ridge National Laboratory
ORR	Operational Readiness Review
PCC	Project Completion Criteria
PEP	Project Execution Plan

PJM	Pulse Jet Mixer
PMB	Performance Measurement Baseline
PME	Project Management Expert
PMRC	Project Management Risk Committee
POA	Plan of Action
PPS	Pioneer Plant Study
PTC	Parsons Technology Center
RAMI	Reliability, Accessibility, Maintainability, Inspectability
RAT	Readiness Assist Team
RCA	Readiness Certification Assurance
RCA	Root Cause Analysis
RCAPTS	Readiness Certification Assurance Process Tracking System
RFP	Request for Proposal
RP	Radiation Program
RPPM	Radiation Protection Program Manager
RR	Readiness Review
SAA	Startup Authorization Authority
SDD	System Design Description
SE	Strip Effluent
SL-PFB	Sludge Processing Facility Buildouts
SMP	Safety Management Program
SN	Supernate
SNR	Startup Notification Report
SOT	System Operational Test
SRNL	Savannah River National Laboratory
SRP	Standard Review Plan
SRS	Savannah River Site
SSC	Structures, Systems, and Components
SC&SS	Safety Class and Safety Significant
SWPF	Salt Waste Processing Facility
T&C	Testing and Commissioning
TPC	Total Project Cost
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level

TSA	Transuranic Storage Area
UPF	Uranium Processing Facility
TWPC	Transuranic Waste Processing Center
WIPP	Waste Isolation Pilot Plant
WVDP	West Valley Demonstration Project

Executive Summary

The Office of Environmental Management (EM) accomplishes a portion of its mission to disposition radioactive and hazardous wastes through use of pretreatment, treatment, and disposal facilities. Significant emphasis has been placed on the Operational Readiness Process for starting these costly and complex facilities. But less emphasis has been given to the overall commissioning process. The Readiness portion of Commissioning activities is focused on ensuring safe operations once such a facility begins operations, and the process is supported by significant published guidance, including associated Orders and Standards.

But for other Commissioning-related activities, DOE guidance has been marked by longstanding gaps. This report is directed to help fill these gaps.

Furthermore, there are four EM Standard Review Modules in this subject area in addition to applicable portions of DOE Order 413.3b, *Program and Project Management for the Acquisition of Capital Assets*. The Office of Project Management is currently developing additional guidance for Commissioning. For EM, such guidance will be welcome because, curiously, some DOE and contractor organizations have not recognized that success in Commissioning is highly dependent on design and construction parameters.

This report is a follow-on companion to the initial *EM Commissioning Experience Report*, issued in January 2015. That report examined seven EM facilities to glean applicable lessons learned. This report furthers the earlier effort by exploring more recent developments at these and other DOE/NNSA facilities. In addition, this report provides guidance in this area in the form of positive and negative lessons learned and recommendations for more effectively managing nuclear and chemically hazardous new builds, from Initial Design through Unrestricted Operations. Many of the desired practices and the timeline for commissioning activities identified in this report are based on the successes of both the Contractor and DOE during the startup of the Salt Waste Processing Facility (SWPF) at Savannah River Site (SRS).

1 Overview

1.1 Commissioning Requirements and Objectives

Commissioning of a building or plant is used to ensure that all process systems have been properly constructed, are operational, and are verified to perform according to the design intent and the user's operational needs. The main objective of commissioning is to confirm that the design intent of the components, the systems, and the plant as a whole are achieved. Experience has shown that a successful commissioning process takes considerable upfront planning at the design phase of the project to be successful. It is imperative that the design encompass operability and maintainability criteria that can be validated during commissioning in order to preclude facilities that are "maintenance nightmares" that are discovered during operations.

Although Department Order 413.3B (Reference 1) defines CD-4 as approval for start of operations, it does not specifically require a commissioning phase to ascertain operability. In August of 2016 the Deputy Secretary issued a memorandum, "Operational Release" Milestones for DOE Projects (Reference 2) requiring that each project conduct a startup risk analysis as part of CD-3 to identify where achieving full operational capability after construction completion might be delayed. The Operational Release Plan for such projects is in addition to the Transition to Operation Plans currently required to achieve CD-4. The Memo states that "Program Offices will provide quarterly progress updates, including lessons learned, to the PME and Project Management Risk Committee (PMRC) until full operational capability is attained." After completion of all commissioning and startup testing the appropriate Under Secretary will need to approve the project's Operational Release.

1.2 Nomenclature and Definitions

The primary terms used when discussing the transition from construction to operations are "commissioning" and "startup." These terms have had many differing meanings in the nuclear and non-nuclear industries, and in DOE Directives. Generally "commissioning" refers to the process of moving from construction to operations. The early portions of commissioning, however, begin in the design phase and run concurrent with construction. Commissioning ends at unrestricted operations. For a timeline of a DOE Nuclear Facility, see Figure 1 on page **Error! Bookmark not defined.**. "Startup" is used at DOE in the context of new nuclear hazard cat 1, 2, and 3 facilities. The following definitions, therefore, are used in this report:

Commissioning

Commissioning is defined as a systematic process for achieving, verifying, and documenting that the performance of the facility or system and its various components meet the design intent and the functional and operational needs of its owners, users, and occupants. Commissioning is a systematic process of ensuring that building and facility systems perform interactively. The process begins in the design phase by documenting the design intent. It continues through construction, acceptance testing, and the warranty period by actually verifying performance, operation and maintenance (O&M) documentation, and the training of operating personnel (Reference 3, DOE Guide 413.3-16A, Project Completion/Closeout Guide, October 2011).

Startup

First of a Kind facilities and Hazard Cat 1, 2, and 3 projects should use a subset of commissioning, often called Hot Commissioning, or sometimes Hot Functional Testing, involving initial operations of a process using expected feed materials [1] prior to unrestricted operations. For operation of Hazard Cat 1, 2, and 3 nuclear facilities, an approved Safety Basis is required, and would also apply for this period, to provide reasonable assurance that the nuclear facility can be operated in a manner to protect workers, the public, and the environment from the hazards present. A portion of the Contractor and DOE Operational Readiness Reviews (ORR) scope is a thorough review of the Startup Plan developed by the Contractor, which details how the startup activities will be conducted.

Because the term *startup testing for new capital facilities* is commonly used to mean any testing on the project after the construction acceptance tests (CAT) timeframe, this report will use the lowercase spelling *startup* to include all activities post-CAT timeframe. The uppercase, hyphenated spelling, *Startup*, commonly used in nuclear facility context, will mean Hot Commissioning.

Three additional terms with multiple meanings will be used here as follows:

[1] Startup authorization (permission to process material) is associated with the process in DOE O 425.1D, *Verification of Readiness to Start Up or Restart Nuclear Facilities,* to authorize radioactive material introduction. Startup authorization is often perceived as synonymous with CD-4; in actuality, CD-4 follows Startup authorization due to time needed for completion of documentation. Nuclear materials are not allowed in the facility pre-Startup. The Program Office must determine if hot commissioning (that is, introduction of radioactive material) and testing with radioactive inventory are, or are not, a condition of approving CD-4 per DOE O 413.3B. Historically, they have not been required.

- ***as-built drawings***. Drawings that are revised from the original set maintained current first by the construction contractor and then by the operating contractor. These drawings are cognizant of changes made in specifications and working drawings.
- ***Commissioning Plan.*** A document establishing commissioning strategies, sequence, schedule, and resources for the commissioning phase of the project. The Commissioning Plan is first developed early in a project with high-level information. As the project progresses, the plan is updated in more detail, including identification of system boundaries and capabilities.
- ***mechanical completion.*** A milestone in the construction phase of a project in which the facility reaches the condition that it has been built to code and specifications, and the systems and equipment are ready for turnover to Testing and Commissioning (T&C). The terms *ready for commissioning*, *physical completion*, and *mechanical completion* are often used interchangeably. In contrast, the tern *construction complete* has contractual connotations.

1.3 Interrelated Factors

There is a high correlation between complexity of design and the effort associated with commissioning. Too often on projects where this is not recognized, or where the project has not been planned and budgeted properly, significant problems and delays are encountered. Construction completion and CD-4 must not be confused with handover of “turn-key” operations. The past and present problems associated with commissioning of EM projects can be distilled into the interplay between three basic factors:

- a flawed design and/or construction
- problematic contract framework
- ineffective use of Federal technical capabilities

1.4 Timeline

The formality of the transfers of (also known as *turnovers*) and documentation for systems and areas between organizations during the process from start of construction to unrestricted operations is dependent on the structure of the contract and the number of different contractors involved. The flow-path direction, however, is the same: organizational jurisdiction transfers from Construction to an organization responsible for testing and commissioning (T&C) and ultimately to

Plant Operations groups. The turnovers must be based on a pre-defined set of testable systems and areas with known boundaries.

Testing and turnover activities are to be performed in accordance with an agreed-upon Commissioning Plan, and organizational jurisdiction transfers from Construction to T&C upon completion of construction, which normally coincides with the completion of initial component testing. Subsequently, organizational control transfers from T&C to Plant Ops, which normally coincides with the start of cold commissioning. Regulatory transition from 29 Code of Federal Regulations (CFR) 1926, *Safety and Health Regulations for Construction*, to 29 CFR 1910, *Occupational Safety and Health Standards*, can also occur at the end of Construction and start of T&C.

The significance of construction completion is that the primary focus changes from construction to commissioning. (See the definition of mechanical completion on page 3.) Commissioning plans should begin with CD-1, implementation should begin at approximately 80 percent construction completion, and performance of commissioning work should be fully in concert with the constructor before construction is complete. At that transition, while the lead is with the Commissioning engineer, the constructor remains in place for warranty/rework service; and the operations contractor team comes on board to be informed by the lessons learned in commissioning.

To help ensure that the project operates as specified for a defined life, various contract provisions for the constructor have been tried. A discussion of these provisions is beyond the scope of this document. A good practice, however, is to include contract provisions for the hot-commissioning period to demonstrate successful operations with actual material to be processed. Incorporation of a formalized, CD-5 type Approval of Operational Release would reinforce this assurance.

As seen in Figure 1, the commissioning process unfolds in distinct phases. In the paragraphs that follow, we will summarize the two busiest phases—Construction (Phase 2) and Cold Commissioning (Phase 3)—by explaining the “arrows” shown in the figure.

Phase 2: Construction

- ***Facility Acceptance Testing (FAT).*** During the Construction Phase, Factory Acceptance Testing of components is undertaken. It is important that the Commissioning Lead and Operation/Engineering not only observe the tests but also be involved in the selection of testing parameters. Extending the run times normally offered by the manufacturer has been found to be critical in identifying deficiencies.

- ***Construction Acceptance Testing (CAT).*** T&C and Plant Ops participation in CAT, and support of this testing, are also critical.

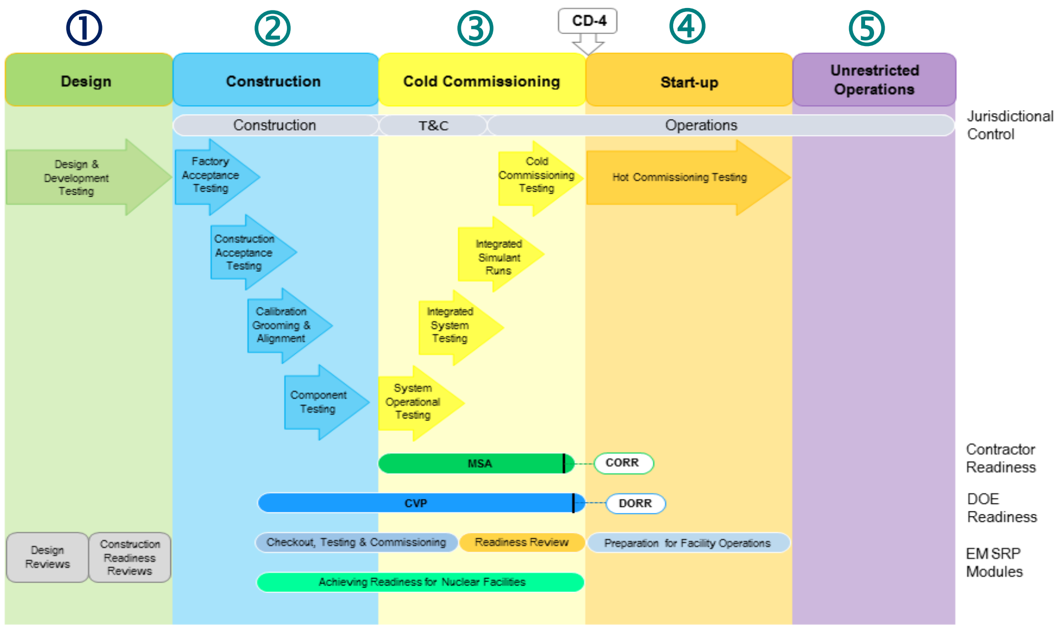

Figure 1. The Commissioning Timeline.

- ***Calibration, Grooming, and Alignment (CG&A) testing.*** As Construction progresses, jurisdictional control of completed Structures, Systems, and Components (SSCs) transfers to T&C. After construction is completed, a series of tests begins. Each test requires a more complex level of performance demonstration. The most basic level of testing—calibration, grooming, and alignment (CG&A)—includes the calibration checks of instrumentation and controls, functional checkout of control circuits, and initial component testing, such as bumping pumps to check for proper directional rotation. The CG&A phase should also emphasize the time commitment required by the steps needed to groom/systemize equipment. One such step is loop tuning to help ensure proper equipment prior to the more rigorous system testing.
- ***component testing.*** CG&A is followed by more comprehensive Component Testing to specifications for complex components.

Phase 3: Cold Commissioning

- ***system operational testing.*** The next step of testing, System Operational Testing, demonstrates the overall ability of plant systems to meet their intended performance and functional requirements.
- ***integrated system testing.*** Once the systems associated with a major unit operation have successfully completed tested, an Integrated System Operational Test (ISOT) is conducted to demonstrate the integrated operation and control of the multiple systems that are required to perform a major unit operation in the plant.
- ***integrated simulant runs.*** After the ISOT has been completed, the Integrated Simulant Runs (ISRs) portion of testing begins. In this testing, the Plant operates as a complete unit for the first time; but the plant uses only a simple simulant, preferably water, unless, for some reason, the process cannot be tested with water. If water is used, this portion of testing is referred to as *Integrated Water Runs* (*IWRs*), which is a subset of the ISRs.
- ***cold commission testing.*** Upon successful completion of the ISR, jurisdictional control of the plant process systems is typically transferred to the Plant Operations group, and Cold Commissioning commences. During ISRs, some planned tests that require the use of density-adjusted fluids to collect data are more easily performed after completion of the ISR and before the start of cold commissioning. Cold commissioning tests require the introduction of a non-radioactive waste simulant and the normal contingent of non-radioactive chemicals, sometimes referred to as "cold chemicals." Process verification testing will be performed at full-scale operations with actual plant equipment, using the non-radioactive waste simulant and the normal contingent of cold chemicals. Cold Commissioning tests have three primary objectives: train staff, demonstrate the design capacity for the process systems, and determine the facility operating characteristics under routine and off-normal operating conditions.

In summary, the objectives of the major steps of the commissioning process are as follows:

- ***Calibration, Grooming and Alignment*****—**component level verification, (for example, nameplate on valves and pumps), setup, and tuning of instruments —for example, calibration checks) and bumping pumps to verify directional setup
- ***System Operational Testing*****—**confirmation of testable system attributes
- ***Integrated System Operational Tests*****—**confirmation of Integrated System Performance requirements

- ***Integrated Simulant/Water Runs***—confirmation of plant performance requirements, using simple simulant/water and process chemicals, and confirmation of operators' basic familiarity with plant operation as a whole
- ***Cold Commissioning with Chemical Simulant***—chemical processing confirmation, using non-radioactive simulant for parameter estimations, including estimations of efficiency, design capacity, performance, and staff proficiency
- ***Hot Commissioning***—confirmation of processing, using radioactive (or hazardous) feed.

Oversight activities from both the Contractor (Management Self-Assessment (MSA), Contractor Operational Readiness Review (CORR)), DOE (Certification and Verification Plan (CVP), and DOE Operational Readiness Review (DORR)) are also overlaid, as is the timing of the applicable EM Standard Review Plan Modules.

1.5 Commissioning Planning

1.5.1 DOE Commissioning Guide

Section 4.0 of DOE G 413.3-16A (2015) (Reference 1) contains information on the Commissioning Process from a DOE perspective. Some of this information is based on the Portland Energy Conservation's *Model Commissioning Plan and Guide Specification*. The applicable sections are reproduced here, changing their nomenclature from *Commissioning Plan* to *Commissioning Guide* to prevent confusion with the Contractor's Commissioning Plan discussed in section 1.5.2.

1.5.1.1 Activity

For nuclear facilities, post–CD-1, develop a Checkout, Testing, and Commissioning Plan that identifies subtasks, systems, and equipment in preparation for acceptance and turnover of the SSCs at CD-4. The commissioning plan ensures that the equipment, systems, and facilities, including high-performance sustainable building systems, perform as designed and are optimized for greatest energy efficiency, resource conservation, and occupant satisfaction. The Commissioning Plan includes checkout and testing criteria required for initial operations.

1.5.1.2 Discussion

Commissioning is defined as a systematic process for achieving, verifying, and documenting that the performance of the facility or system and its various components meets the design intent and the functional and operational needs of the owners, users, and occupants. Commissioning is a systematic process of ensuring that building/facility systems perform interactively. It begins in the design phase by documenting the design intent. It continues through construction, acceptance, and the warranty period with actual verification of performance, O&M documentation, and training of operating personnel.

Commissioning, including checkout and testing, is performed to demonstrate that SSC and structures, systems, and equipment (SSE) meet or surpass previously established project requirements. The Key Performance Parameters (KPPs) and Project Completion Criteria (PCC) should be defined or referenced in the Project Execution Plan (PEP). Commissioning and the resulting transition to operations are best achieved by taking three measures:

- Conducting early project planning, organization, and preparation for transition
- Systematically performing required inspections and testing
- Providing adequate documentation of testing and transition activities

If testing and commissioning are required for project transition and closeout, a commissioning authority should be designated as a member of the IPT at CD-1. If the IPT believes that commissioning is required for project transition and closeout, the Commissioning Authority is responsible for testing and commissioning. The commissioning authority approves the commissioning plan. If testing and commissioning costs are considered significant enough to influence alternative analysis, a commissioning authority should be designated at CD-0 to be part of the gap-analysis or alternatives-analysis process.

1.5.1.3 Objective

During the Design phase, the commissioning guide specifications have four objectives:

1. Ensure that the design team applies commissioning concepts to the design. For example, ensure that clear and complete design intent documentation is developed, clear and concise process system and integrated system performance test requirements and acceptance criteria are specified, defined, and conveyed for inclusion in the construction documents, and commissioning-focused design reviews are conducted.
2. Ensure that the design team prepares commissioning specifications and specific forms or data sheets for documenting construction inspections and checks.
3. Ensure that the commissioning authority develops a commissioning plan for inclusion in the construction documents.

4. Ensure that verifiable operability and maintainability design requirements are addressed along with appropriate testing requirements for all phases of facility life, including T&C (for example, flush and sample connections).

When the foregoing objectives are met during the design phase, four goals can be achieved:

1. Commissioning work can be accurately bid.
2. The commissioning process can be effectively executed by the contractor.
3. Contractors or the DOE user/operating organization can understand how to efficiently execute the commissioning process.
4. There is a systematic, efficient, and accountable method to accomplish the commissioning objectives.

The commissioning objectives are met by using a systematic and accountable method, including four measures:

1. Ensure that applicable equipment and systems are installed properly and receive an adequate operational checkout by installing contractors.
2. Verify and document proper performance of equipment and systems.
3. Ensure that O&M documentation left on site is complete.
4. Ensure that the owner's operating personnel are adequately trained.

1.5.1.4 Commissioning Scope Description

The scope description provides a suggested outline (and checklist) for use in preparing a commissioning plan. As the plan is developed, it should be tailored for the various types of DOE project scope, complexity, and associated project risks. The Commissioning Plan scope should be under configuration control.

1.5.1.5 Commissioning Planning

The Commissioning Guide is composed of four documents, or "parts":

1. Part I. Commissioning Requirements Design Phase
2. Part II. Commissioning Guide Design Phase
3. Part III. Commissioning Guide Specifications
4. Part IV. Commissioning Guide Construction Phase

A brief description of each part follows.

1.5.1.5.1 Part I. Commissioning Requirements in Contracts – Design Phase

During this part, the requirements are defined for use in subsequent contract documents. Included are the responsibilities for each member of the design team and for all participants during the construction phase. If a bid for an Architect Engineer (A–E) firm is to be implemented, this document should be included in the request for proposal (RFP).

1.5.1.5.2 Part II. Commissioning Guide – Design Phase

This document describes the commissioning activities that occur during the Design phase. It provides details of responsibilities called out in Part I for the architect, design engineers, commissioning manager, construction manager, project manager, and Federal Project Director (FPD). The plan describes the duties of the design team and commissioning authority in developing the site-specific commissioning specifications.

1.5.1.5.3 Part III. Commissioning Guide Specifications

The commissioning guide specifications contain recommended language that describes both the requirements and the processes to incorporate commissioning into construction specifications. All divisions and sections that relate to commissioning should include language ensuring that the contractors or the DOE user/operating organization staff are clearly informed regarding their commissioning responsibilities. An explanation of the commissioning process is also provided. In addition, pre-functional checklists and sample functional tests are included for many common types of equipment and systems. Few systems and components lend themselves to a pre-functional checklist or generic type of testing. Most new facilities include unique, one-of-a-kind process systems that require a dedicated test team to validate them and put them into service.

1.5.1.5.4 Part IV. Commissioning Guide – Construction Phase

The commissioning plan is developed in draft form for the specific project during the design phase. The plan provides direction for the development of commissioning specifications by the design team. During the construction phase, the plan provides direction for the commissioning tasks during construction. The plan focuses on providing support to the specifications. It provides forms for application of the commissioning process.

1.5.1.5.5 Requirements Maturation

The programmatic, system, functional, and technical requirements are initially established in the Systems Requirement Documents and the Conceptual Design Report prior to CD-1. In subsequent revisions (that is, conceptual to preliminary to final design documents), the requirements are updated, ultimately residing in the Facility Design Descriptions (FDDs) and System Design Descriptions (SDDs).

These documents are maintained by the system engineers and are a good calibration check on the content of the Commissioning Guide. Historically, the first draft of the SDDs and FDDs are completed by the engineering staff without input from operations or maintenance. Including this perspective at this early stage can avoid "maintenance nightmares" or difficult-to-access equipment that requires manipulation in hard-to-reach locations and resulting modifications later.

1.5.2 Contractor's Commissioning Plan

This section is based on the commissioning process and commissioning plan used at the Salt Waste Processing Facility (SWPF) (Reference 4), the American Institute of Chemical Engineers, and four EM Standard Review Plan (SRP) Modules:

1. Checkout, Testing and Commissioning (Reference 5)
2. Readiness Review (Reference 6)
3. Preparation for Facility Operations (Reference 7)
4. Achieving Readiness for Nuclear Facilities (Reference 8)

Successful completion by the construction and operations contractors of the Commissioning Plan elements provides a supporting basis for the contractor readiness activities. One milestone of the Commissioning Plan is the providing of a detailed plan for testing and acceptance of facility systems and equipment. This test and acceptance plan clearly defines the basis for attaining initial operating capability, full operating capability, and project closeout. It describes in detail the major processes and programs and explains how the Project meets applicable contractual and regulatory requirements.

As the Commissioning Plan addresses test objectives and criteria, it provides a summary-level description of what each program element accomplishes, how it will be implemented, and how the individual elements will be integrated together.

The recommended EM review criteria for use by Federal reviewers are contained in the SRP Module on Checkout, Testing, and Commissioning. That module examines the following areas.

General Requirements and Overview

This area of the review is intended to address the overall commissioning process. It identifies the commissioning authority, lays out responsibilities, outlines the budget, defines the format and content of the commissioning plan, and defines commissioning schedules. Some of these elements are addressed in greater detail in other review areas. However, the goal of this area is to ensure that these elements have been integrated into a successful commissioning plan (document) and process.

System Turnover Process

This area of the review is intended to capture the elements required to evaluate the adequacy of the formal process to transfer responsibility for equipment and systems from the construction forces to testing & commissioning and then to the facility operating staff. It assesses the process to ensure that requirements of DOE Orders and industry standards are incorporated into a consistent, cost-effective, and rigorous process for placing new, modified, or restarted Structures, Systems, and Components (SSCs) into service. This review also evaluates the adequacy of acceptance and systems testing to ensure that the equipment/systems meet the design criteria and project objectives.

Quality Assurance

This review area verifies that Quality Assurance (QA) requirements are identified and implemented for the commissioning process. It also addresses QA performed during testing and acceptance to ensure that the final product meets the design and safety basis criteria.

Plant Staffing

This review area focuses on the overall plant's staffing and hiring plan. A detailed plan is necessary for the project to ensure that the correct mix of qualified personnel is hired for the various project phases. This review area is limited to the selection and hiring personnel; it does not address the training or qualification of personnel to the site and project procedures.

Training and Qualification

The purpose of this review area is to ensure that the personnel hired in accordance with the plant staffing plan are pre-trained and pre-qualified to perform their assigned duties. This review area also addresses the adequacy of the overall training and qualification process for the transition and initial operation phases.

Procedure Development and Verification

This review area focuses on the adequacy of procedures for operation and maintenance of the facility, both during the transition phase and in the operations mode. Procedures are required for normal, off-normal, and emergency operations.

Emergency Preparedness (EP)

This review area focuses on the adequacy of the EP program and procedures to ensure the safety of the workers, the public, and the environment during an off-normal event. The EP review is limited to the transition program; the operational readiness review will ensure that the program is sufficient for facility operations.

Maintenance Implementation

This review area addresses the adequacy of the project maintenance program and procedures necessary to maintain the facility operational once full operations are achieved. It includes the calibration program, the surveillance program, the preventive maintenance program, and the associated work control and recall processes necessary to effectively implement and perform maintenance activities.

Safety Basis Implementation

The purpose of this review area is to ensure that the approved safety basis and associated controls have been adequately implemented for the operations. Successful implementation of the safety basis documents and controls will encompass many other areas addressed in this process. The associated areas include the implementation of controls in operating procedures and training of personnel to the safety basis and controls.

Safety Management Program (SMP)

As the project transitions from construction to operations, the SMPs will also transition from those of construction-related and construction-focused programs to SMPs identified and committed to in the safety basis documents. This review area will ensure that the SMPs are adequate as implemented.

Most commissioning plans will address the following elements:

- Testing and Commissioning Program
- Commissioning Organization
- Readiness Plan
- Startup Plan
- Transition to Hot Operations Plan
- Cognizant System Engineering (CSE) Program
- Radiation Protection Program
- Maintenance Program
- Training and Qualification Program

- Conduct of Operations
- Environmental, Safety and Health Program (ES&H)
- Emergency Preparedness
- Nuclear Safety, including Safety Basis approval and implementation
- Quality Assurance Program
- Fire Protection Program
- Waste Management Program

The first five programs are discussed in detail in this report; so are the CSE and Radiation Programs, to the extent that they bear on a successful commissioning effort. For detailed information on the remaining programs, Reference 4 (*Salt Waste Processing Facility (SWPF) System Turnover from Construction to Commissioning*, 2014) can be examined.

An effective organizational structure must be in place to implement the Commissioning Program. A Commissioning Program relies primarily on a Testing and Commissioning (T&C) group and a Plant Operations group, supported by Engineering and ES&H. Most of commissioning work will be performed initially by the T&C group with support from the Plant Operations group, and later by the Plant Operations group with support from the T&C group. In order for an accurate staffing plan to be developed, the activities to be performed to commission and operate the facility need to have been completed to a sufficient level of resolution. The staffing structure needs to be built for flexibility, however, to account for the unforeseen challenges that will arise as commissioning activities progress. Commissioning work will also be supported by other organizations; historical experience has found that a Joint Test Group (JTG) and the Commissioning Review Board (CRB) have been very effective in managing different aspects of the commissioning process (References 9 and 10).The functions and roles of these two groups are discussed below.

1.5.2.1 Testing and Commissioning Group (T&C)

This group will accept the turnover of systems from Construction; test the components, systems, and integrated systems; and then turnover of the plant to the Plant Ops group or a similar organization. The Testing and Commissioning group personnel will need to be qualified to perform their function.

A Test Engineer Qualification Program that complies with the requirements cited in American Society of Mechanical Engineers (ASME) NQA-1, *Quality Assur-*

ance Requirements for Nuclear Facility Application, Appendix 2A-1, *Non-mandatory Guidance for the Qualification of Inspection and Test Personnel*, is recommended.

Experience has shown that different levels (usually three) of Test Engineers should be developed, together with requirements for qualification at each level; and the functions and activities that each level is authorized to perform should be defined. This will result in a more effective T&C organization because some types of equipment are more complex and sophisticated than others. The T&C Manager will normally qualify the Test Engineering Manager, and the Test Engineering Manager will normally qualify the Lead Test Engineers, after evaluating the individual's education, experience, and training. Lead Test Engineer and Test Engineer qualifications should be reevaluated periodically.

1.5.2.2 Plant Operations Group

This group consists of personnel from Operations, Maintenance, Training, and, if applicable, Laboratories. During the Project's testing phase, Plant Operations supports the T&C group in conducting the test program. When the tests are completed, the Plant Operations group accepts the handover of the plant from the Testing and Commissioning group. Plant Operations conducts Cold Commissioning testing and proficiency activities, readiness review activities, hot commissioning testing, and—eventually—unrestricted operations.

1.5.2.3 Joint Test Group (JTG) and Commissioning Review Board (CRB)

The Commissioning Review Board is an organization composed of senior representatives from various functional organizations. Often it will include a DOE representative, in some cases serving as a nonvoting or ex-officio member. The CRB is responsible for the review, approval, and assessment of testing programs; plans, procedures, and results of testing, and other testing documents in support of the testing and commissioning efforts.

The Joint Test Group is a working-level group that functions as a technical resource to the Project. Membership is composed of representatives from T&C; Operations; QA; Engineering; ESH; and, often, DOE. The JTG is responsible for performing thorough, detailed reviews of testing documentation, including test plans, procedures, deficiencies, and results. The JTG forwards needed approvals to the CRB. Typical functions of a JTG include approving test procedures; reviewing and approving results of test reports, including assuring resolution of test deficiency reports; and serving as the authority that approves whether test objectives were met.

1.5.2.4 Testing and Commissioning Program

Experience has shown that a successful commissioning process takes considerable upfront planning at the design phase of the project to be successful.

A nuclear facility shall be proven acceptable to start hot commissioning through a previous series of tests performed in distinct phases. Testing shall commence with Functional Acceptance Tests (FATs) and Construction Acceptance Tests (CATs), discussed further below, carried out during the Construction phase, followed by simple component-level tests, progressing through system-level and integrated system-level tests, and finally performance-based testing. Each test phase is designed to progressively verify the functions of the components and systems within the facility, resulting in a plant ready for transitioning into Hot Commissioning.

The Testing and Commissioning staff must segregate the facility into a number of testable systems, plant areas, or both. The testable systems are defined as systems, or a cross-grouping of systems, that provide a functionally testable entity that can be isolated from other systems. The plant areas, by contrast, represent specific buildings or areas within a building. These systems/areas form the basis for determining the scope of each turnover system, from Construction to Commissioning and Testing, and they are used to develop the turnover system boundaries. Fluid-systems turnover occurs at completion of system hydrostatic testing.

When a project is in the construction phase, a room-by-room approach has typically been used for buildout. But when a project is in the testing phase, a system-by system approach is needed for releasing systems for test.

Note that if construction by systems was used originally—as opposed to construction-by-area tracking—it may have resulted in higher construction cost but lower testing and commissioning costs, and there would not be a need to pivot to a systems identification process. However, typical construction progress identification by area will likely continue in the future, followed then by systems testing. As a result, there will continue to be a need to be able to track the systems for testing and turnover, even though construction tracking may be conducted by area.

An Earned Value Management System, or EVMS, makes use of construction-by-area reporting, so many projects will continue to need to pivot. The sooner the project can pivot to systems identification, the better. The *Chemical and Commissioning Handbook* (Reference 11) recommends that the pivot occur at 80 percent construction complete. But as noted above, if it can be accomplished sooner, so much the better.

To accomplish this pivot more effectively, SWPF came up with a scheduling transfer plan and an integrated database with multiple data identifiers to transfer a schedule of 15,000 activities from a "room by room" approach to a 71-activity "system by system" approach needed for testing. (SWPF also kept a welding database containing Quality Control Inspection Report records that were very useful.) This database allows records to be organized and readily accessible, and it gave the project the capability to perform turnovers efficiently and improved the work package closure process.

Planned physical boundaries of the turnover systems have been defined on "system scoping" piping and instrumentation diagrams, electrical single-line drawings, HVAC flow diagrams, and other applicable design documents. These drawings show the physical interface where the mechanical, electrical, control, and support-system boundaries occur.

Additionally, commodity lists—lists of manual valves, specialty items, instruments, equipment, cables, pipe lines, and HVAC equipment—electronically linked to the configuration managed technical baseline databases have been developed, where each entity is tagged to the appropriate system identifier, creating a direct link between components and the system in which they are scoped. The system scoping drawings and the commodity lists define both the system turnover boundaries and the scope of equipment and components contained within the system. These boundaries should be clearly defined during the formal turnover process. Labeling of systems should be accomplished using DOE-STD-1044-93, *Guide to Good Practices for Equipment and Piping Labeling* (U.S. Department of Energy, 1998) (Reference 12).

The sequencing of testing should initially be based on selecting systems that are required to support the major process systems. The testing of these support systems is intended to be performed early in the schedule so that they are operational and available to support the testing of the more complex systems. This approach provides three benefits:

- Testing can be performed simultaneously on multiple components within a system.
- Testing can be performed simultaneously on multiple systems within the plant.
- Since these systems tend to be less complex than process systems, design deficiencies and component deficiencies can be identified early during overall component and system testing, thereby providing the greatest chance of not impacting schedule in future process testing.

Some of the support systems are equipment or skids supplied by different vendors, together with their associated technical support supplied for initial startup. This coordination effort impact on T&C staff resources must be accounted for and planned for, although efficient planning can start this support system effort in parallel with later-timed construction activities.

1.5.2.5 Approval of Test Results

Upon completion of a test, the Test Engineer should prepare a test package composed of the completed procedure, attachments, and a test report summary. A good practice is to have the test package peer-reviewed by another Test Engineer for completeness before it is submitted for final review and approval by the JTG, or in some cases submitted for approval by the CRB.

If the peer review determines that the test results did not meet the relevant requirements, one of the following disposition paths should be followed:

- ***Use As-Is.*** The determination has been made that the test deficiency will not impact operations or Quality Compliance or ES&H requirements. A written justification for the use-as-is disposition will be prepared and approved by Engineering and retained. This area is a concern for contracts that do not have adequate protection from constructors who have no future liability for lax acceptance of defective components. This is addressed later in this report.
- ***Rework and Retest.*** The determination has been made that the test deficiency can be resolved by reworking the equipment and returning it to its original design condition. The affected portions of the test will then be reperformed.
- ***Perform a Design Change.*** A determination has been made that the test results indicate that a design change is appropriate to address the test deficiency. The design change process will be entered.

Attribute Verification Database. The Engineering group, in consultation with various manufacturers and the Nuclear Safety Group, should determine and document test requirements and acceptance criteria for design, performance, functionality, and safety at the component level, system level, and process level. Some variant of an Attribute Verification Database (AVD) has been shown to be desirable to maintain control over testing and regulatory requirements. Such a database will likely be maintained by Engineering, with the Cognizant System Engineer (CSE) serving as the point of contact. The AVD should be used to identify and track significant and measureable test requirements. Design output documents, including specifications, data sheets, drawings, basis-of-design documents, and safety basis documentation, are input to the AVD. They are also incorporated into the contract and upper-tier contract deliverables that identify component-level and system-level features that must be validated through testing. Upon test requirement identification, the requirement is entered into the AVD and tagged to a specific component or piece of equipment, or to a specific system. For requirements that must be validated by a test, once the test is completed and all test results are approved, the identification of the document(s) providing objective evidence that the requirement has been satisfied needs to be entered into the database.

1.5.3 Factory Acceptance Testing (FAT)

The Factory Acceptance Testing of selected components usually conforms to the respective Vendor Inspection Program. Usually, the FAT includes a check of completeness, a verification against contractual requirements, quality assurance requirements, a proof of functionality, and final inspection. Safety Significant & Safety Class (SSC) components, and other critical components, should be factory-acceptance-tested to ensure the integrity of the design through procurement. Among items that the commissioning team must verify, four are often overlooked:

- suitability of the equipment to travel
- degree of cleanliness
- preservation medium
- temporary hydro-related gaskets removed with service gaskets installed

As part of the FAT, consideration should be given to including requirements for Environmental Qualification testing for safety-class and safety-significant components, as required by DOE O 420.1D.

1.5.4 Construction Acceptance Tests (CATs)

The overall conduct and objectives for the CATs need to be developed and approved by Engineering. CATs are performed by the organizational element performing the construction—that is, CATs for subcontracted work will be performed by the subcontractor—before a system is turned over to T&C. CAT requirements for self-performed work are specified in Inspection Test Plans prepared by Engineering. These requirements will be translated into CAT procedures where required by specification, or translated into detailed work instructions.

CAT requirements for subcontracted work are specified in engineering specifications referenced or contained in applicable procurement documentation. Subcontractors who are responsible for performing CATs will develop CAT procedures where required by the specification, or detailed work instruction that must be reviewed by T&C and approved by Engineering prior to conducting the CAT. T&C, Engineering, or both should witness the conduct of selected subcontracted and self-performed CATs.

The process for turning over completed systems from Construction to T&C is administratively controlled by a procedure that

- Defines interface responsibilities,
- Provides for the identification and tracking of open items and deficiencies,
- Provides for a formalized acceptance of the turned over system,
- Provides clear guidelines for marking jurisdictional boundaries, and
- Establishes a turn-back process for construction rework, as needed.

The turn-back process for construction rework is a formalized process that establishes the required controls and responsibilities for the turn-back of SSCs to Construction after jurisdictional control has been assumed by T&C. Under the turn-back process, control of the system (or partial system) is formally transferred back to Construction, and T&C is not responsible for performing the testing or maintenance on the system while the system is back with construction.

After completion of the rework and acceptance by T&C, control of the system is transferred back to T&C.

Typically, the turn-back process is not used for small jobs whose work could be performed by plant maintenance personnel or construction craft forces working under the T&C work control process. Rather, it is used for larger jobs, such as completion of significant open items, implementation of design modifications, or correction of significant latent deficiencies identified during testing.

1.5.5 Calibration, Grooming and Alignment Component Tests (CG&A)

CG&A is the first sequence of startup testing that occurs after a system has been turned over from Construction to T&C. This is an extensive testing phase that will continue almost through the full duration of the startup testing phase. The objective of this basic level of testing is to test individual components, place them into service, and continue until all components within a system are readied for service and the system can undergo SOT.

Since the same types of components are found in multiple systems, a uniform testing standard and cost-minimization approach is realized through the use of “generic" test procedures that will be developed for testing the same types of components across multiple systems. Any component that is not tested during CG&A component testing will be tested during SOT, ISOT, or both.

"Generic" test procedures are typically used to test components such as the following:

- pumps and motors
- valves, by operator type: manual, motor, pneumatic
- instrumentation, by type

During this phase of testing, much of the testing of devices connected to a Process Control System occurs:

- Instrument and control field devices are configured on the control system, calibrated, and checked for proper operation.
- Solid-state devices, such as variable-frequency drives and overcurrent-protection devices, are programmed.
- Control-circuit functional tests are performed to verify proper sequencing of operations and interlock functions.
- Field devices are placed into service.

During the CG&A phase, mechanical and electrical equipment may undergo initial operation and testing to verify conformance with product specifications. CG&A also includes the initial startup and testing of packaged systems (air compressors, chilled-water units, and so on), where specifications require the vendor to perform the work, and material-handling equipment, where specifications require the vendor to test the equipment and place it into service. T&C is responsible for reviewing and approving vendor test procedures and final test reports and for witnessing these tests, as appropriate.

During the CG&A phase, maintenance procedures for instrument calibration checks and surveillance checks are finalized and validated. This phase of testing also provides a significant opportunity to conduct on-the-job training (OJT) for the Plant O&M staff by having them participate in and observe these activities.

1.5.6 Component Testing

Component-Level Test Procedures are written for testing specific types of equipment, such as pumps, motors, valves, and can be generic (where applicable) or component-specific. These procedures include Component Test Data Sheets, upon which test results will be recorded. The approved Component Test Data Sheets are retained as quality-controlled records.

It is important to note that new hardware and software will be needed to be powered up and available prior to the first loop testing. In conjunction with loop testing, the T&C group will devise test procedures to check alarms, interlocks, and then proceed to devise shutdown test procedures.

1.5.7 System Operational Tests (SOT)

System Operational Tests will demonstrate that each system performs as designed and that all performance, functional, and safety design attributes are met. SOTs are conducted by Test Engineers, with support from plant operators and maintenance personnel. These tests will use the most current facility-level or plant-level operating procedures, when required. This will not only provide on-the-job training opportunities for the Plant Operations staff but also verification and validation of plant operating procedures. To that objective, the test should use and validate the normal plant operating procedures for system startup, normal operations, and shutdown, and testers should provide feedback for improvements. Usually, water is used as the test fluid.

SOT and ISOT procedures are limited-use procedures developed with the intent of providing documented, objective evidence that the SSCs are correctly installed and capable of performing their intended functional, performance, and safety design functions. SOT and ISOT procedures serve five purposes:

- They provide step-by-step instructions, including hold points for performing test activities.
- They provide data sheets for recording data.
- They identify prerequisites.
- They provide the post-test restoration activities.
- They identify the acceptance criteria that must be used to evaluate the test.

SOT/ISOT test procedures are reviewed and recommended for approval by the JTG. Typically, SOT/ISOT test procedures are validated by walking down the procedure before they are executed in the field. After the JTG review, test plans and procedures are normally submitted to the CRB for final review and approval.

1.5.8 Integrated System Operational Tests (ISOT)

After the systems have been operationally tested, ISOTs will be conducted. ISOTs will demonstrate integrated operation and control of multiple systems or subsystems that are required to perform integrated process operations in the plant. Control, safety, and plant protection features, as well as full throughput (usually with water), will be demonstrated.

ISOTs are conducted by Test Engineers with support from plant operators and maintenance personnel. To the extent possible, these tests use facility-level or plant-level operating procedures. In this way, they provide additional on-the-job training opportunities for Operators and enable plant operating procedures to be verified and validated. These tests also verify that all integrated system alignment and grooming have been completed to ensure that systems and processes will function as designed.

ISOTS are the last activity that must be successfully completed before the Integrated Simulant Runs can begin.

1.5.9 Integrated Simulant Runs (ISR)

After ISOT is completed, integrated unit operations are tested with simulant to demonstrate the plant's overall readiness to proceed to Cold Commissioning. As noted in section 1.4 (<sally>heading</sally>Timeline), most processes can be tested with water, but if for some reason water cannot be used, a simple simulant is used instead.

During ISR testing, each unit process is operated to demonstrate functionality with simulant, and the plant is operated with all processes integrated, in a mode as close as possible to full production mode that simulant will allow. This testing also demonstrates successful operation of the plant's integrated control system. Upon successful completion of simulant runs, operational jurisdiction of the plant transitions to the Operations group.

During an SOT/ISOT/ISR conducted with simulant as the test fluid, some testable attributes identified in the AVD cannot be demonstrated. This is because density-adjusted fluids are required for proper equipment function during certain processes—for example, the Caustic Side Solvent Extraction process. It is desirable to have these testable attributes validated prior to starting Cold Commissioning; indeed, during the latter portion of their ISR, SWPF staff included a phase for testing with Process chemicals.

maintenance trials. Maintenance trials on selected SSCs are conducted prior to Cold Commissioning. The criteria for selecting these SSCs should be based on importance to facility, which includes Safety SSCs. Another criterion for maintenance trials is the inclusion of remotely maintained equipment.

The maintenance trials should be integrated into the system testing schedule to minimize both disruption of the operational test program and retesting after maintenance.

1.5.10 Cold Commissioning

Cold commissioning under the purview of the Operations group can begin upon successful completion of the ISR.

Cold Commissioning has three main objectives:

- Operate plant systems at design flow rates, temperatures, and pressures with the chosen simulant and actual process chemicals to verify that the process meets specifications.
- Identify and make modifications to equipment and processes/procedures before the facility goes hot, especially in regard to maintenance acts.
- Provide OJT for operation, maintenance, and training staff.

Testing during Cold Commissioning should be designed to verify that the objectives of Process Verification, Design Capacity Performance, and Environmental Performance can be achieved. Plans and procedures for controlling and conducting these tests should be developed, both to control the test activities and to ensure that all required data is collected. In addition, approved plant operating procedures should be used to operate the plant during these tests. This testing may entail construction or use of temporary test systems, structures, or analytical facilities whose use needs to undergo a USQ-like process. Both normal and abnormal conditions should be factored into the testing.

1.6 Cognizant System Engineer (CSE Program)

The Cognizant System Engineer (CSE) Plan should be finalized in early construction. It should address how the CSEs will participate in Construction verification and system turnover to T&C. It also should address how the CSEs will continue to participate in testing, commissioning, maintenance, and periodic operability assessments. The CSE is the technical authority on the assigned system. The CSE Program is initiated in Construction ramping to full implementation before Startup Authorization is received, although the sooner it is fully implemented, the better; ideally, it should be implemented during Cold Commissioning. The CSEs themselves can be utilized as field engineers during construction, transitioning to testing engineers, and eventually to CSEs. This evolution is desired and could be taken advantage of in the overall Staffing Plan.

The CSE Program is composed of four elements:

- Identify which SSCs are included in the scope of the Program.
- Address Configuration Management requirements associated with the SSCs in the Program.

- Define the CSEs' qualifications, training, roles, and responsibilities.
- Define CSE support for Engineering, Operations, and Maintenance.

1.7 Radiation Program (RP)

The Radiation Protection Program for all DOE nuclear facilities must conform to the applicable subparts of 10 CFR 835, *Occupational Radiation Protection*.

During the Design and Construction phases, the Radiation Protection Program Manager (RPPM) should be present to ensure that the program incorporates rad protection design features that affect personnel exposure, rad waste generation, and contamination control.

Prior to the start of Cold Commissioning, the RPPM should have completed an RPP Manual, the implementing procedures, and an ALARA analysis. The Rad Protection Staff should be finishing training. At SWPF, for example, a Radiological Engineer, Health Physicist, and Radiation Protection Supervisor are staffed approximately nine months prior to Cold Commissioning. Here is what they do:

- During the first three months, these individuals are trained and qualified on the SWPF RPP, Final Design/Operational ALARA Analysis, and implementing procedures. In conjunction with the training, they help verify facility-installed equipment. They also acquire field instrumentation, count-room equipment, and associated supplies.
- About six months prior to Cold Commissioning, the Lead Radiation Protection Technicians (RPTs) and RPTs are staffed.
- During the months leading up to Cold Commissioning, these individuals are also trained on the RPP, Final Design/Operational ALARA Analysis, and implementing procedures.
- During Cold Commissioning, the RP staff supports facility operations and maintenance, progressively ramping up mock radiological controls until the facility is in a full mock rad mode of operation.

Upon successful completion of the Readiness Reviews, the RP staff prepares for the introduction of radioactive material with reduced activity feed. This allows Operations and Maintenance staffs to become familiar with actual rad conditions. It also confirms that shielding is adequate. This metered approach allows a phased step-up and time sequencing of higher-concentration feeds to be introduced.

1.8 Readiness

The area of Operational Readiness has been a significant focus area of the Department since the early 1990s. For this reason, numerous DOE directives are available. The so-called Readiness Order, DOE O 425.1x, *Startup and Restart of Nuclear Facilities,* establishes the requirements for readiness verification for nuclear facilities, activities, and operations. The order discusses the approach to conducting readiness reviews, including both Contractor and Federal Operational Readiness Reviews and Readiness Assessments.

Guidance is provided by three additional DOE orders:

- DOE-STD-3006-2010, *Planning and Conduct of Operational Readiness Reviews (ORRs)*
- DOE-HDBK-3012-2015, *Guide to Good Practices for Readiness Reviews, Team Leader's Guide*
- DOE O 226.1A, *Implementation of Department of Energy Oversight Policy*

In addition, five Federal documents provide both requirements and guidance:

- DOE O 413.3B, *Program and Project Management for Acquisition of Capital Assets*
- *DOE Acquisition Regulation (DEAR)*, 48 CFR 970.5223-1
- DOE O 414.1D, *Quality Assurance*
- DOE P 450.4, *Safety Management System Pol*icy
- DOE-STD-1189, *Integration of Safety into the Design Process*

Aspects of Readiness that are not depicted on the timeline of Figure 1 include the submittals of the Startup Notification Report (SNR), and the Plan of Action (POA) for both the contractor and DOE. Additionally, during the time period, other reviews, such as those for MSA, ISMS, and IVR, are ongoing, and the scope of the Readiness Reviews (RRs)—either the Operational Readiness Review (ORR) or the Readiness Assessments (RAs)—must be cognizant of and integrated with these other reviews and credited, as appropriate.

DOE Order 425.1D, section 4.d (1) (b) states that the POA may reference a timely, independent review that addressed a core requirement in a technically satisfactory manner, to justify *not* performing an evaluation of a core requirement or portion thereof. The Project should align the ISMS verification reviews and the planned IVR so that the POA can credit these independent reviews and thereby reduce the scope of the associated Core Requirements.

Under DOE Order 425.1, the SNR is required to identify known nuclear startups/restarts at least 12 months prior to the planned date on which actual operations are to start. The SNR identifies each item and specifies whether an RA or ORR will be required to confirm readiness to commence or resume operations. A startup or restart cannot be placed in the SNR until the required Review Level Determinations have been completed and approved. If a startup or restart requires either an RA or an ORR but has not been included in the SNR, a delay can result because the review cannot start until DOE and Startup Authorization Authority (SAA) approvals of the review level are obtained.

After initial input, the SNR may be updated each quarter to reflect items such as date changes, funding holds, or contact changes. Any major scope change that can affect the approved review level must be resubmitted for formal DOE approval.

About four to six months prior to the start of the Contractor Operational Readiness Review, the Contractor POA must be submitted to the SAA. Earlier submission is encouraged to allow effective coordination and review of activities that may occur before the onsite CORR review, such as EP drills. The POA must clearly discuss the physical and geographic scope of the CORR and clearly describe the SSCs, individual processes, and programs that are within the scope of the CORR, using the safety basis as the starting point for this discussion.

Additionally, in the current version of the Order, *Verification of Readiness to Start up or Restart Nuclear Facilities*, DOE O 425.1D Chg. 1, Attachment 1, 2.d.(5) and 2.e.(6) state that prior to starting the CORR, contractor line management must have issued a formal written Readiness to Proceed Memorandum *certifying* that the facility is ready for startup or restart. Line management must also *verify* that the preparations for startup or restart have been completed. *Certify* means that contractor line management has officially attested to or authoritatively confirmed compliance with specified requirements or standards. *Verify* means that line management has substantiated or confirmed with evidence that specific requirements are met.

1.9 Startup Plan

As required by DOE O 425.1D, Chg. 1, Core Requirement 11, following SAA approval, a nuclear facility can commence operations according to the provisions of the Startup Plan. The Startup Plan identifies three kinds of activities:

- actions to be taken from the time of DOE ORR completion until DOE approval to begin operations

- activities to be completed after DOE approval to begin operations up to the point of introducing radioactive material
- the sequence of activities to be completed as part of initial introduction of radioactive material. This entails a specified sequence of deliberate operations and oversight identified, with particular emphasis on compliance with the limitations and compensatory measures specified in the plan to achieve safe, unrestricted operations.

The Startup Plan details implementation of site, management, and facility activities necessary to achieve full operations. It also details specific responsibilities of management observers. The plan addresses those areas that could not be demonstrated for the ORRs due to their radioactive nature. It spells out compensatory measures and increased management oversight expectations, final equipment testing to be completed during hot commissioning, and procedures for implementing hot commissioning.

The plan should address the following concerns:

1. ***Identification of facility management observers necessary for initial operations oversight***
   a. List the management personnel assigned to conduct initial operational evaluations of the graded operations testing, including summary-level duties, responsibilities, and shift staffing requirements. Specific duties and responsibilities should be listed in the remaining sections of the plan. Include recordkeeping expectations and the specific qualifications required of each individual.
2. ***Equipment operability***
   a. Identify and describe the integrated tests planned and required to confirm operability of equipment during initial operations. Include the purpose and a summary of the testing acceptance criteria.
   b. List management responsibilities for approving the commencement of testing and management observer oversight of test performance. Include management approval requirements for key events or progression to the next phase of testing.
   c. Provide a summary-level schedule that clearly illustrates the systematic approach to full operations.
3. ***Procedure viability***
   a. Identify and describe the mechanism for verifying the viability of procedures during actual performance, including requirements for man-

agement observer participation in the first-time execution of procedures. Among other topics, the primary first-time execution procedures are expected to

i. Specify how to conduct laboratory sampling and analysis activities.
ii. Summarize the process for procedure changes resulting from the identification of inadequacies in the field. Include any provisions for increased procedure revision support during the initial execution of procedures.

4. ***Operator Performance***
   a. Identify and describe the mechanism for real-time, in-plant management observer evaluations of operator performance to verify the adequacy of operator training.
   b. Identify and describe the established mechanism for remediating any identified weaknesses.

1.10 Transition to Hot Operations

In Project space, DOE O 413.3B (Reference 1) includes a requirement for a Transition to Operations Plan. By contrast, in Readiness space, DOE O 425.1D includes a requirement for a Startup Plan. The EM Standard Review Plan Modules (References 7 and 6) discuss each plan, respectively.

The objective of Hot Commissioning testing is to demonstrate that the facility is ready to commence unrestricted Hot Operations, with all products and secondary wastes produced in accordance with the requirements. Hot Commissioning activities may be performed either in sequence or in parallel. Milestones include shielding adequacy, achievement of process capacity, and meeting of environmental and regulatory criteria. During this period, management observation and oversight individuals must ensure that the requirements found in the Startup Plan are adhered to. They also must ensure that first-use protocols are being appropriately applied.

First Use controls and checklists. The First Use controls and checklists are used during Startup, beginning with the first time the Operating Procedures are used to introduce or generate hazardous materials. The overarching objective of the checklists is to ensure that certain prerequisites and tasks have been completed prior to initiating first-use operations. On these checklists, hold points are highlighted to ensure that the appropriate disciplines have reviewed the proposed test or operation and concur with its execution. If a procedure or process is not self-contained on the checklist, the checklist should direct the user to the full procedure or process when the user must respond to upset conditions or unforeseen circumstances encountered during execution.

using reduced-activity feeds. For the initial Hot Commissioning runs, it is often a good idea to use a feed with reduced activity level. Such a feed will limit the risks associated with system upsets during this time period. It could also confirm that radiation shielding is adequate. Since a reduced-activity feed will contain radioactive contaminants, it will allow the Commissioning and Operations staffs to gain familiarity with actual conditions and allow for phased step-up and time sequencing of higher-concentration feeds to be introduced.

Specific milestones include the following activities:

- ***Qualify*** O&M staff under radioactive operating conditions.
- ***Continually verify*** procedures used for operational and industrial safety.
- ***Evaluate*** operating procedures under radioactive feed conditions.
- ***Evaluate*** maintenance procedures with radioactive material and maintenance personnel working under radiation exposure conditions.
- ***Verify*** operational radiation dose rates in accordance with previously developed shielding analysis, and, if necessary, use the resulting data to modify operating and maintenance procedures.
- ***Verify*** the accuracy of process instrumentation and analytical procedures, using radioactive material.
- ***Evaluate*** radiochemistry and sampling techniques and accuracy.
- ***Perform*** State and/or EPA Environmental testing and Permitting processes, using radioactive material.

2 Overall Results

A few common themes are evident across all DOE projects. Specific recommendations are contained in section 2.1, but we can safely make three generalizations:

1. ***The general formula for achieving operational status within a reasonable budgetary envelope and schedule*** is to fit existing technology into the Project requirements—that is, minimize risk on high-value items by using proven technology or commercially available equipment. If existing technology is not available, then the general formula for failure is to undertake first-of-a-kind (FOAK) efforts without full-scale testing of critical components.
2. ***The general formula for failure*** includes incentivizing the constructor to build as cheaply as possible without any specifications or "skin in the game" for longer-term operations.
3. ***The general formula for success*** is to design for optimized lifecycle costs implemented via contract specifications and end states.

The listing of recommendations in section 2.1 has been condensed from the discussions that follow in section 2.2. Recommendations are based on interpretative observations by the writer, Bill Weaver; they do not convey official positions of EM. Ideally, the analysis would have yielded hard-and-fast rules, complete with absolute lists of dos and don'ts for commissioning activities. But between the subjective nature of the data, a lack of availability of personnel involved in historical decisions, and missing data points, an absolute list would have been inappropriate and invalid.

Nevertheless, the discussions and recommendations presented here can be reasonably incorporated into successful or detrimental practices for future facility commissioning efforts. Moreover, the underlying causes of all EM facilities that have had difficulties can be traced to one or more items on the lists presented in this report.

Furthermore, the 2016 Operational Release Milestone Memorandum [2] from the Deputy Secretary highlights the welcome shift in emphasis from construction complete to operational ready. This report takes that emphasis one step further to an operational life perspective, because a facility could get through commissioning to operational ready and yet still be ill-equipped to be run economically for the life of the project.

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[2] Elizabeth Sherwood-Randall, "Operational Release" Milestone for DOE Projects, August 11, 2016, https://energy.gov/sites/prod/files/2016/08/f33/EXEC-2016-002322_signeddoc.pdf

2.1 List of Recommended Practices

1. Perform an independent, defensible analysis of alternatives (AoA), not an analysis to justify the chosen selection. Also perform a follow-on AoA when a significant performance baseline deviation occurs or if new technologies or solutions become available.
2. Avoid FOAK projects and technologies to the extent possible. If they cannot be avoided, Recommendations 3 and 4 are required.
3. Gather data for determining the correlation between scale testing and prior operating experience to identify past problems in scale-up assumptions and situations or conditions where use may not be justified.
4. Perform full-scale testing on critical components that do not have operational experience or where scale-up is not justified. Perform sufficient analysis to ascertain what parameters are needed before the Test Facility is designed in order to obtain the data that is really needed. An often-overlooked benefit from full-scale testing is the identification of any manufacturing limitations of the full-scale (and never-built-before) components.
5. Construct and use a Pilot Plant for design decisions. Retain the Pilot Plant for use even after design is completed. Consider procuring a simulator and using it for operational training and other insights.
6. Overdesign the project with additional margin from the beginning to account for regulatory and operational uncertainties. Additional upfront costs for larger-capacity tanks, concrete, and steel will pay dividends in design stability and acceptability for a relatively small cost.
7. Extend runtimes beyond the lengths normally considered adequate during Vendor Testing for continuous operating equipment to detect additional issues and reveal design problems that a shorter-duration FAT might miss. As part of the FAT scope, ensure that equipment is properly packaged for shipment.
8. Raise the importance of and allocation of resources to the Technology Readiness Assessment (TRA) process.
9. After design is complete, do not reduce the footprint to save on budget. Do not shorten the commissioning schedule and reduce the scope for the objective of completing ORRs in order to exit the Total Project Cost (TPC) funding regime.
10. For critical components that have a large impact on schedule, heightened due diligence on suppliers is necessary. Onsite audits of suppliers of critical items, no matter how many sub-tiers below the contractor they may

fall, should be considered. Sole reliance on documentation reviews of suppliers is to be avoided, and care must be taken to ensure that certifications achieved by suppliers are still applicable to their present-day operations. Contract clauses requiring the use of the low bidder are to be avoided.

11. Make use of technical Federal groups that are available to support initial project design and selection. If Federal technical capability is unavailable, then hire, fund, and formalize in the contract an owner's agent with associated operations staff to represent the long-term operations-and-maintenance perspective during design, construction, commissioning, and testing. By including this perspective at this early stage, you can avoid "maintenance nightmares" or difficult-to-access equipment that will require manipulation and resulting modifications later. Have an effective Lessons Learned (LL) program for language and terms from past contracts.
12. Perform an Integrated Baseline Review or equivalent reviews at Contract award and at each CD gate thereafter.
13. Structure construction projects as FAR performance-based contracts that include Contract Line Item Numbers (CLINs). Incentives should be structured with life cycle (through completion of Decontamination and Decommissioning / D&D) costs in mind, including specifications that include Reliability, Accessibility, Maintainability, and Inspectability (RAMI) requirements, flow-proving indicators, and material-selection considerations. Intermediate milestones must be selected so as to not to misdirect effort toward completing milestones at the expense of overall schedule objectives. The selection of past construction milestones has resulted in defeating optimization of T&C schedules.
14. Develop processes and controls to ensure that the Design and the Documented Safety Analysis (DSA) are in sync. Time the Implementation of the DSA for successful Operation.
15. Testing & Commissioning Process Recommendations:
    a. ***Staffing.*** Organizational structure must be determined early.
        1. Make use of a JTG and a CRB or their equivalents.
        2. Maintain consistency and availability of the engineering and operations staff from construction through early operations. Keep a sizable construction force on through commissioning, because they are the people most familiar with facility.

3. Ensure early involvement of operations and maintenance personnel with system design; startup activities and procedures; validation activities; cold runs; and hot testing. Not only will these personnel provide what is needed from an operations and maintenance perspective, but also their combination of experience and established working relationships will support successful problem resolution when it occurs and will facilitate the overall commissioning and operations startup.
4. Ensure that verifiable design criteria are developed for operability, maintainability, and testing.
5. Use CSEs to support systems startup testing.

b. ***Test Logic.*** Executing testing without well-understood test logic and system parameters will cause test failures and delays.

1. Avoid an expert-based testing approach.
2. Use an integrated, proceduralized timeline process, such as the process discussed in sections 1.5.5 through 1.5.10, whose first step is "grooming" component items—that is, simple tests to verify continuity, rotation, and alignment criteria.
3. Categorize testing into major subgroupings. Four subgrouping are often used: Utilities and Instrument Control Panels; Process Systems; HVAC and Cooling Water Systems; and Miscellaneous.
4. Make sure that control system functionality is available. Control system functionality prior to the start of the test program is a practice that improves testing, operations, training, and schedule efficiencies.
5. Perform "mock system turnovers" to strengthen the turnover process, using lessons learned.

c. Supporting Requirements

1. Make sure that configuration management systems are fully established before system and facility turnover. Make sure that as-built drawings are under configuration control.
2. Use an attribute database to support system turnovers, preferably one that is hot-linked to evidentiary documents. Ensure that Nuclear Safety input is included in the database and that information from testing flows back to the DSA.
3. Make sure that Document Control is designed for use with commissioning in mind. Historically, problems have been experienced

when systems and rules were very restrictive and non-commissioning-friendly.

4. Perform maintenance trials for essential equipment and for remotely maintained equipment. Implement a preservation maintenance program and for those components that have been in a warehouse for long periods. Perform bench testing before installing such a component in the facility. Bench-test components going into tight spots. Cover or seal installed components to protect them as much as possible from construction damage.

d. ***Readiness*** (for large facilities)

1. Make use of a Readiness Assist Team (RAT) and Readiness Certification Assurance Board (RCAB) or their equivalents.

2. Make use of a Readiness Certification Assurance Process Tracking System (RCAPTS)-type software system or equivalent.

3. Multiple smaller-sized serial Contractor Management Self Assessments (MSAs) are a desirable option.

4. Be familiar with Readiness Lessons Learned maintained by the Office of Primary Interest (OPI) for the Readiness Order, currently AU-31.

e. Preparation for Rad Ops

1. Introduction of hot feed requires a measured or step-wise approach to full rad ops to verify proper system and instrument response.

2. When procuring and controlling surrogates or other supplies that will be used for testing, use the same quality-assurance program that is used when you procure and control equipment components.

3. Implement a Mock RA Plan before Rad Ops begin.

4. Shoot video of maintenance acts in future Rad areas for later improvement. For example, stand in different positions or put in scribe marks now to see better when dressed out.

2.2 Historical Contributing Causes

This section consists of detailed discussions correlated with the recommendations of section 2.1 organized by recommendation in generally ascending order (Recommendations 1 through 15).

Historically, many AoAs have not been of the quality or independence required of an analysis of such importance. The responsible program office is required to conduct an AoA that is independent of the contractor organization responsible for managing the construction or constructing the capital asset project. The AoA is to be conducted for projects with an estimated Total Project Cost (TPC) greater than or equal to the minor construction threshold prior to the approval of CD-1. The AoA may also be conducted—but in many cases, has *not* been—when a performance baseline deviation occurs or if new technologies or solutions become available. The AoA should accord with best practices published by the Government Accountability Office (GAO). Refer to GAO-15-37, DOE, and NNSA Project Management: *Analysis of Alternatives Could Be Improved by Incorporating Best Practices*. For projects with an estimated TPC below $50 million, the AoA should be commensurate with the project cost and complexity. Historically, the scope for inclusion of alternatives has been lacking, and once new direction is taken in the chosen alternative, an updated AoA has not been performed. Poor AoAs—and other contributing causes, for the failed projects normally contain multiple contributing causes—include the following three examples:

- ***Waste Treatment Plant (ORP, Richland).*** Many of the contributing causes that the Recommendations listed in section 2.1 address have been experienced at WTP. Although many Analysis of Alternatives (Recommendation 1)-type reviews were conducted, the Project continued on with a variant of the British Nuclear Fuel Limited (BNFL) FOAK (Recommendation 2) design with multiple single-point failures (Recommendation 13).

  WTP is considered here as a FOAK because some equipment—for example, pulse jet mixers—had never been operated at this scale before without full-scale prototype testing (Recommendations 3 and 4).

  Subsequently, the invariable money-saving changes are introduced—for example, to reduce the footprint (Recommendation 9)—despite a lack of technical input (Recommendation 11).There was not an appreciation of the impact of the change on functionality. The reduction of the footprint caused many tanks to grow taller and skinnier from their original fat, squatty profile, resulting in less-effective mixing and leading to safety and regulatory issues (Recommendation 6). Indeed, this desire to reduce the footprint to save on construction costs (Recommendation 9) is seen as a common theme throughout the DOE/NNSA complex; the latest example is the Uranium Processing Facility (UPF) at Oak Ridge, where the footprint was frozen for budgetary reasons before the design was completed, a decision that eventually resulted in too little space for the required equipment. It is exactly the opposite course of action to take (Recommendation 6).

- ***Integrated Waste Treatment Facility (IWTU).*** DOE management terminated processing high-level waste at Idaho in 2000, when 8.1 million gallons of a total of 9.0 million gallons had been processed to that date. They undertook to build a new facility to process the remainder and embarked on a FOAK (Recommendation 2): two fluidized beds in series without full-scale testing of critical components (Recommendations 3 and 4). As a result, the facility, after achieving CD-4, was used as a test platform to gather needed information, for it was incapable of operating. Though it was not completely ready to operate, the facility was advanced to CD-4 because of budgetary and political drivers (Recommendations 6 and 9).
- ***U-233 Down-blend (Oak Ridge 3019).*** The original AoA was performed for U-233 down-blending when the mission included medical isotope generation. The facility requirements changed along with the mission change. But a new AoA was not performed to verify that the best alternative for the reduced-scoped mission was the one being pursued (Recommendation 1). Transporting the material to an existing facility (that is, the HB line at SRS) was dismissed as “too expensive” with only scoping analyses; and because of a lack of technical input of the disposal requirements at the waste site (Recommendation 11), and non-consideration for use at other DOE facilities, the project proceeded with the chosen option.

  However, when the cost of the project kept escalating and eventually started to exceed $1 billion ($1\times10^9$), an evaluation of other alternatives was performed; and a subsequent Analysis of Alternatives identified viable and cost-effective disposition paths, including a combination of direct disposal, transferring wanted material to other DOE sites, and down-blending in an unused but capable building (Bldg. 2026). DOE/EA-1488, *Final Environmental Assessment for the U-233 Disposition Medical Isotope Production and Bldg.3019 Complex Shutdown at Oak Ridge National Laboratory (ORNL)*, December 2004, included an alternatives analysis, but only for the original mission: processing of U-233 for safe, long-term economical storage and increasing the availability of medical isotopes.

There is a need to put more upfront effort into AoAs, then have a hold point for a truly independent review of the AoAs (Recommendation 1). Moreover, because the original timeline usually includes a long time lag, there needs to be a reevaluation of other alternatives that may have developed in the intervening time period, analogous to the need for a true-up of the selected contract. In the past, some alternatives have been dismissed because the project was needed “right away” when in actuality, schedule slippage is measured in decades. Finally, when the mission changes, a completely new AoA is called for (Recommendation 1).

Furthermore, AoAs in the past have not been cognizant of many of the Safety aspects of the alternatives. In many cases, the details associated with safety lag too far behind the design (Recommendation 14). Additionally, historically the AoAs are process-oriented; accordingly, the details associated with supporting systems are often overlooked, and in some cases—such as the UPF—it was found that the building footprint could not even accommodate the supporting systems (namely, the HVAC) of the preferred or selected design, leading to huge cost overruns.

Design and construction of first-of-a-kind facilities should consider the use of full-scale prototype testing (Recommendation 4) or pilot-scale testing (Recommendation 5) of all critical parameters. If no full-scale prototype is utilized, a thorough and deliberate testing protocol needs to be established as part of the design phase so that design, scaling assumptions, and critical parameters can be verified as part of a comprehensive testing program during procurement, construction, and commissioning (Recommendation 3). If a pilot-scale facility is utilized (Recommendation 5), it should be retained during startup and production operations to allow process refinements coincident with production operations (Recommendation 5). Larger facilities, whose design is predicated on the operational experience accumulated at smaller operating facilities, still need to investigate scale-up (Recommendation 3). This area is in need of further data gathering from DOE and other facilities to identify where problems exist in scale-up assumptions.

Furthermore, analysis must be performed prior to a Test Facility being designed to ensure that the needed data can be obtained from the testing. This analysis will eliminate the need to rework the Test Facility at a later date.

Full-scale mock ups have revealed unanticipated issues. For example, at the SWPF, the main Monosodium Titanate (MST) crossflow filter design was found to be defective in the initial testing phase, and the Caustic Side Solvent Extraction (CSSX) piping size (2-inch) was found to be inappropriate.

Conversely, a lack of full-scale testing masks problems with assumptions with scale-up, such as problems with the Pulse Jet Mixer (PJMs) at WTP, where successful operation of small PJMs did not scale (Recommendation 3) to successful operation at WTP size, and this reliance on an incorrect scale-up assumption has resulted in significant technical and nuclear safety issues at WTP (Recommendation 6).

The SWPF project is an example of a successful integration of testing and design. The contract included a robust Technology Development Test Program in which Parsons constructing full-scale test systems for both the CSSX and the Alpha Strike Process (ASP) and conducted extensive testing of these processes. Initial testing of these SWPF processes was conducted in Pasco, WA and Barnwell, SC, respectively and identified significant design issues with both the process piping size in the CSSX system and the manufacturer's crossflow filter design in the ASP process. As a result of that initial testing, the crossflow filter internals were completely redesigned by the manufacturer and functioned successfully during all future testing, and the CSSX interconnect piping design was changed from 2-inch to 3-inch to eliminate flow imbalances during processing.

Both design issues would have had significant impact on facility startup had they not been identified and corrected as a result of full-scale testing. As this testing progressed, the need for additional testing of both the CSSX and ASP system was identified, and Parsons leased an industrial building in Aiken, SC and built the Parsons Technology Center (PTC). The center has operated since 2008 as the central testing facility for SWPF. The follow-on testing approved by DOE included extended duration performance testing of the CSSX system with crossflow filtration in place. It also included testing to confirm that marginal performance of the Decontaminated Salt Solution and to confirm that the Strip Effluent Coalescers during the Barnwell CSSX test campaign had been corrected through a design modification to both coalescers. This testing was successful in confirming the foregoing design changes, and full design flow decontamination factors for the CSSX process surpassed contract requirements by several orders of magnitude.

Other, previously planned testing was likewise conducted at PTC, including extended sleeve-valve operability and maintainability testing that identified wear issues with these valves—issues that were corrected through design changes by the manufacturer. End-of-life cycle testing conducted at PTC on a redesigned valve confirmed that all wear issues had been corrected.

A second previously planned test conducted at PTC was a full-scale functional test of the Barium Decay Tank, a unique tank designed to allow short-lived barium to decay before the liquid moved through the final stage of the process. This testing demonstrated that the design did not function as required, and as a result the tank was completely redesigned.

Air Pulse Agitator mix testing previously performed at both Pasco, WA and another location in Aiken, SC for two different-size vessels was repeated at PTC, both to test a new strontium and actinide extractant (Modified MST) and to confirm for the DNFSB (Recommendation 6) that there were no open mixing issues for SWPF. This testing was successful, resulting in a DNFSB letter closing their mixing tank concerns.

Prototype testing provides throughput data for decision making earlier in the project life. For example, full-scale cold CSSX testing of solvent demonstrated that throughput capacity was greater than baseline (9.4 Mgal/yr. vs 7.3 Mgal/yr.), even greater (12 Mgal/yr.) with next-generation solvent, and greater still (up to 15+ Mgal/yr.) with high-molarity salt feed. Learning this early in the project left time to examine options for capitalizing on the data.

Benefits of testing in a full-scale testing facility include completion of technology and process maturation before relying on use. But there is an additional benefit that is often overlooked: identification of any manufacturing limitations of the full-scale (and never-built-before) components (Recommendation 4).

Use of a full-scale, full-process prototype facility is invaluable to ensure a successful production facility design. It also streamlines and reduces technical issues during the transfer from construction to operations, startup testing, and the ramp-up to full processing capacity. If no full-scale prototype is used, a thorough and deliberate testing protocol should be used to verify design and scaling assumptions as part of commissioning (Recommendation 3).

Retaining a pilot-scale facility during startup and production operations allows process refinements to occur coincident with production operations (Recommendation 5). Technology development facilities can continue to provide valuable information even after construction and startup. Retaining a pilot-scale facility during startup and initial production operations allows process refinements to occur coincident with production operations.

All EM projects exist in a complex environment that includes political, regulatory, and stakeholder aspects. As the project schedule becomes extended, these aspects become more important. Stakeholder involvement should be obtained early in the project, before research, design, and construction decisions are made. Design decisions are the responsibility of the facility designers, but the designers need to be aware of the political climate; and if that means adding design features only to appease regulators, then that is an option they need to consider. Even if the features are not technically warranted, adding them may be the path of least resistance. Stakeholders need to buy in to the approach to safety, including decisions about where design features are needed, where safety SSCs are needed, and which areas can be addressed through administrative controls. The earlier they buy in, the better. Community participation is beneficial to facilitate project success, and efforts should be made to engage the community throughout the process.

One option for dealing with regulatory issues is to overdesign for added margin to accommodate technical uncertainty, regulatory changes, or regulatory change "ratchets" later in the project (Recommendation 6). Indeed, in the nuclear industry, adding safety margin to account for uncertainties has a long and storied history, starting with the Manhattan Project. The engineers overdesigned the Hanford B Reactor over the objections of the nuclear physicists, who insisted that the extra 500 tubes were unnecessary and that the margin would never be used. But during the first few hours of operation, xenon gas poisoning of the transmutation process was discovered, preventing continued operation. The B-Reactor was started with the originally designed 1,500-tube cylindrical geometry, and the effect of xenon poisoning caused the reactor to shut down. The correction was made by adding more nuclear fuel in the 500 peripheral tubes (that is, the margin) to the originally designed core. This added neutron source overcame the xenon poisoning, and operations were able to continue.

The reasons for regulatory driven changes could be new requirements or newly updated adverse information, such as more restrictive seismic data. Some up-front examples that have been used to account for potential down-the-road seismic impacts include digging up soil under the proposed facility footprint and filling with concrete/grouting (for example, UPF and CMRR), although the benefit of such an action depends highly on the local geology. It could improve seismic stability for some facilities, but it could worsen stability for others. Another example in seismic space is adding thickness to the basemat (at SWPF), a move that satisfied regulatory concerns for mitigation of any impacts of surface settlement due to potential "soft zone" collapse at depth in soil column. Although subsequent data indicated that the extra thickness was not needed, the decision was a smart, sound cost/benefit choice at the time.

Another design choice, the decision to overbuild space, has been shown to be beneficial as opposed to scrimping and leaving as little as possible margin over what is thought to be adequate. H-234 at SRS included additional space for no known reason during design. Within two years from start of operation, the additional space was completely utilized.

By contrast, UPF could not fit the process equipment into the building structure. Even a cursory review of the UPF history illustrates multiple missteps, with a need for multiple recommendations (Recommendations 2, 3, 4, 5, and 6).The facility was a FOAK, with no full-scale testing or pilot plant. Yet instead of overdesigning for margin, the facility was *under*designed as the footprint was frozen because of initial cost concerns (Recommendation 9) before design was completed. It later found to be severely undersized. These issues were in addition to the fact that the TRAs were not comprehensive (Recommendation 8), and as a result, questionable TRLs were assigned.

Another choice in the design area for added margin is fire-protection-coated steel. With the possibility of derating the structural steel in the facility by 25 to 30 percent if fire coating is unsuccessful, the option of adding margin to the steel—that is, increasing the size of steel members to begin with (Recommendation 6)—should be considered. This margin would provide a measure of fire response in lieu of fire protection coatings and additives.

Factory Acceptance Testing is performed on the vendor's premises with the objective of identifying problems before equipment is shipped and installed. Thorough and detailed vendor tests of components and subsystems performed at the vendor facility can identify issues, which can then be solved at the vendor facility, or can result in system design changes prior to installation. This approach avoids startup delays by avoiding rework of installed equipment in the facility. Testing includes a check of completeness, a verification against contractual requirements, quality assurance requirements, a proof of functionality, and a final inspection .SSCs, along with other critical components, should be factory-acceptance-tested to ensure the integrity of the design through procurement.

Some of the more important lessons learned have included that extending runtimes over what is normally considered adequate during Vendor Testing for continuous operating equipment is important. The longer runtimes allow detection of additional issues and reveal design problems that a shorter-duration FAT could miss (Recommendation 7).

Additionally, delays have resulted from not having all vendor documents and test records from the FAT complete and available onsite before system and facility turnover.

A corollary observation to FAT is that some successful projects have set up welding operations in local shops with "live-in help" from the project. One such success story occurred at the DUF6 project. On the Portsmouth and Paducah DUF6 Conversion Project, the prime contractor awarded to a local shop a contract to fabricate and supply all welded large-bore process piping for both the Piketon and Paducah sites. The award included welding of special materials (Monel, Inconel, and stainless steel) that require extensive fabrication experience and well-established quality and welding programs. DOE PPPO, as part of their vendor oversight program in association with the DUF6 Contractor, provided initial and early support to help establish the level of performance and documentation needed to supply safety-significant (containment) piping systems. PPPO support included the following measures:

- Welding engineer oversight and support to establish equipment setup and welder qualification program
- Subject Matter Experts to help develop special processes, such as material control and segregation, the use of filler metal, and welding rod control
- SME support to ensure the establishment of QA to ensure that documentation necessary to meet code requirements is prepared and verified
- Onsite presence of a welding engineer, SMEs, and a weld inspector during the welder qualifications and initial weld productions for each metal type
- Onsite presence of an oversight welding inspector (Level II) for approximately six months to confirm programs implementation

The local shop was very supportive of the time and effort extended by the DOE team. The shop owners invested in new equipment and expanded their facility to produce facilities process piping for both sites. The involvement of DOE ensured delivery and installation of compliant welded piping on the DUF6 Conversion Project. A similar model can be considered on future projects, where applicable.

TRA reviews. Technology Readiness Assessments and associated Technology Maturation Plans are used as a project management tool to reduce the technical and cost risks associated with the introduction of new technologies. Unlike the readiness review area discussed in section 1.8, which has a multitude of guidance documents, and substantial resources dedicated to the process, the TRA reviews are underappreciated and underfunded. The level of significance and allocation of resources to the TRA process needs to increase in order to improve quality and usefulness (Recommendation 8).

The TRA model evaluates technology maturity, using the Technology Readiness Level (TRL) scale. Where technological readiness is a significant concern, TRAs should be considered for alternatives under consideration. Major system projects, or first-of-a-kind engineering endeavors, must be assessed prior to each CD, using a TRA. Before that CD can be approved, the project or endeavor should achieve the following minimum TRL scores for each critical technology item or system, as determined by an independent review team outside of the project team:

- CD-1: TRL 4
- CD-2: TRL 7

The higher the TRL at CD-2, the lower the risk to the project. The Project Management Expert (PME) must provide justification to the Energy Systems Acquisition Advisory Board (ESAAB), if pursuing a TRL less than 7 at CD-2. The board, in turn, will notify the Chief Executive for Project Management (CE).

For Major System Projects where new critical technologies are being deployed, the TRA shall be conducted and the associated Technology Maturation Plan developed prior to CD-2. On those projects where a significant critical technology element modification occurs subsequent to CD-2, conduct another TRA prior to CD-3. It is strongly encouraged for use by the PME even for projects with a TPC less than $750 million. (For additional information, see DOE G 413.3-4A.) The major setbacks at many projects, including WTP, IWP, and UPF, can be traced, in part, to their less-than-adequate TRA efforts (Recommendation 8).

budget pressures and political pressures. Budget and political drivers are as much a risk to completion of a successful commission effort on an EM facility as any other factor. Budget pressures first affect cutbacks in design, reducing capability, capacity, or footprint size. As discussed earlier, WTP made change that saved a few dollars by reducing footprint costs. But in doing so, they unknowingly (due to lack of technical awareness) (Recommendation 11) caused huge increases in downstream cost because of inadequate mixing in the same-capacity—but taller and skinner, and therefore less effective at mixing—tanks to fit in the reduced footprint, resulting in regulatory (Recommendation 6) concerns.

The constant pressure to show progress to Congress to attenuate threats to reduce funding makes for an environment that is conducive to rush through startup and commissioning. Additionally, these cost concerns pressure some projects to start with less “margin” and lower costs up front to get Congressional money to start the project. Once the project is underway, they inevitably run out of funds and either go back for more money or declare operational ready (CD-4) when not ready, as the IWTU experience demonstrates. One motivation for declaring readiness is that once out of project space, the post–CD-4 funding comes out of operational instead of TPC funds (Recommendation 9).

schedule pressure. The turnover/acceptance process is always under schedule pressure to shorten and take the project operational. Some people in DOE upper management (Recommendation 11) reason, “After all, the plant is now constructed, so what are we waiting for?” or “We’re out of commissioning space,” or “We need to make up for lost ground.” So the commissioning schedule is always under pressure. When combined with a FOAK project, which requires more commissioning time, not less, the outcome is failure—which is all the more reason not to use a FOAK approach (Recommendation 2).

Lessons Learned. Historically, there has not been an effective Lessons Learned process associated with newbuild nuclear facilities throughout the DOE complex, or even within the smaller EM organization. In an effort to address this issue, DOE O 413.3b states that

> Lessons Learned and best practices should be captured throughout the continuum of a project. Within ninety days of CD-3 approval, up-front project planning and design lessons learned shall be submitted to PM. Likewise, project execution and facility startup lessons learned shall be submitted within ninety days of CD-4 approval. Lessons learned reporting allows the exchange of information among DOE users in the context of project management. Refer to DOE G 413.3-11 for more information.

An example of a comprehensive lessons-learned study in this area is the Rand Report (References 13 through 18).The Rand Corporation Pioneer Plant Study (PSS) research began in 1978 under a contract with DOE's predecessor organization. The study sought to better understand the reasons for inaccurate estimates of capital costs and performance difficulties for first-of-a-kind process plants. The initial studies took information from 44 chemical plants characterized by more than 900 data items from projects performed in the 1970s. This information was then categorized into a database and analyzed.

A major conclusion of the Rand Report was that the schedules for most new-start, first-of-a-kind facilities are widely optimistic, leaving little time for rework and repairs. Even when there appears to be no real change in design details, there are changes that could make a difference. For example, the same equipment, when installed and used in a completely dissimilar facility, may not respond the way the historical data would suggest.

The report stated that technological innovation can be particularly troublesome when coupled with either a lack of experience by the firm with building similar plants or an inability to rely on experience from previous units. It is not just the use of new technology that is important: it is also the degree of technical advance attempted. Plants involving two or more new process steps typically experience shorter, less-costly startups than those involving three or more new steps. It is often not until startup that serious design problems are recognized. Corrections then are usually costly and time-consuming.

The report found "that many firms fail to learn effectively from past experience or to communicate adequately across and within corporation organizations." This is true at EM. In fact, the Rand Reports results were all but forgotten. The report states that there was no structured method to learn from project design mistakes (and successes) that were prevalent at DOE 35 years ago. Why did WTP go with the unproven-at-scale BNFL design over the tried-and-true canyon design? These poor decisions were not documented, and the responsible parties are no longer available to explain what their thought process was at the time to enrich a lessons-learned program now.

Additionally, the DOE complex has an added layer of insulation against true lessons-learned sharing: Different contractors are not eager to share any competitive advantage gained by lessons they have learned.

the problem with the lowest bidder. Subcontracting to NQA-1 vendors is of paramount importance. Lessons learned in this area highlight this importance. The low-cost bidder is not necessarily the best bidder; indeed, they may be the lowest bidder because they don't understand all the intricacies of suppling NQA-1 components.

For example: The large SWPF tanks were subcontracted out to an NQA-1-qualified vendor whose bid was substantially below the next-lowest bidder. At one time, this low cost vendor had been NQA-1 proficient. But over time, between turnover and failing to maintain its procedures and other support activities, they ceased to be as proficient. This was not recognized until it was too late. Therefore, due diligence on subcontractors for NQA-1 or other critical component must be stepped up. There is little solace in having a win in legal space for lack of performance to contract when the schedule slippage and associated costs due to unavailability of said components are bleeding the project. For critical components that have a large impact on schedule, heightened due diligence on suppliers is necessary, and contract clauses requiring the use of the low bidder are to be avoided (Recommendation 10).

DOE Design Authority. The EM organizational structure in the past lacked the technical and engineering resources to either effectively review and influence the design function from an owner's perspective or act in a Design Authority capacity for a complex process (Recommendation 11).With the EM reorganization of late 2016, EM HQ now possesses a technical capability to assist in design decisions. Additionally, there have been a few successes in the field with DOE acting as the Design Authority. Design Authority (for nuclear facilities only) is defined in DOE 413.3b (2016) as

> The engineer designated by the PME to be responsible for establishing the design requirements and ensuring that design output documentation appropriately and accurately reflect the design basis. The Design Authority is responsible for design control and ultimate technical adequacy of the design process. These responsibilities

> are applicable whether the process is conducted fully in-house, partially contracted to outside organizations, or fully contracted to outside organizations. The Design Authority may delegate design work, but not its responsibilities.

The Design Authority function is distinct from the Design Agency function. The Design Agency function is the responsibility of only the Engineering, Procurement, and Construction (EPC) contractor. The Design Agency implements the Design by transforming it to a product (usually a physical product, but it could be software). The Design Agency prepares design documents, maintains the design basis, and controls configuration. During facility design, the DOE Design Authority conducts in-process reviews and design document reviews to confirm that the facility design complies with design input and code requirements. During construction, the DOE Design Authority reviews construction submittals (for example equipment, material, operating and maintenance manuals, welding information, design of specific systems, and relief valve calculations); material, operating, and maintenance manuals; welding information; and proposed design changes to confirm that the facility construction meets design requirements. The DOE Design Authority is responsible for reviewing the Safety Basis and other technical baseline documents that define the design basis and safety functions. The DOE Design Authority ensures that design acceptance criteria and procurement specification are consistent with the project design safety basis, safety functions, and applicable codes and standards .It has been the practice at DOE facilities that have DOE itself as the initial Design Authority, to transfer this authority to the EPC Contractor sometime late in the construction phase.

The DOE Design Authority has the overall authority to ensure that the design and as built configuration and materials meet design specifications and requirements. DOE was the DA at SWPF, which was an unqualified success. Additionally, at SRS the DOE did Direct Manage the nearby GWSB-2, achieving an estimated savings of 22 percent from the price that the contractor had bid. While DOE DA and Direct Managed projects are the most cost-effective model, this model works only with the requisite personnel expertise, which is often hard to find. SWPF had the requisite DOE resources, but other projects should carefully weigh whether DOE possesses these resources at project inception and will be able to maintain them through the life of the project. Historically, the SRS has had the widest application of differing Design Authority models, including the following four:

1. ***DWPF (SRS)***
    a. Owner: DuPont, Westinghouse Savannah River Company (WSRC)
    b. Design: Bechtel National

   c. Construction: Bechtel National and Morrison Knudsen
   d. Design Authority: DuPont, WSRC

2. ***3-H Evaporator (SRS)***
   a. Owner: WSRS
   b. Design: Ebasco
   c. Construction: Bechtel Savannah River
   d. Design Authority: WSRC

3. ***Tritium Extraction Facility (SRS)***
   a. Owner: WSRS
   b. Design: Bechtel Savannah River
   c. Construction: Bechtel Savannah River
   d. Design Authority: WSRC

4. ***K Area Materials Storage(KAMS)***
   a. Owner: WSRS
   b. Design: Bechtel Savannah River
   c. Construction: Bechtel Savannah River
   d. Design Authority: WSRC

The projects in the foregoing list were organized with a strong design authority group that enjoyed organizational independence from the design agent. These four projects are judged as positive benchmarks; for example, the KAMS project was noted as an Honorable Mention for Acquisition Project of the Year among DOE projects in 2003. At a specified point—for example, construction complete, completion of cold testing, CD-4, or completion of hot testing—the DA transfers from DOE to Contractor control. The contractor need not be the constructor/limited-time operator but could be the long-term operator or the site M&O, if different from the constructor /limited time operator. The important criterion for the DA that must be satisfied is *independence*.

Another option, which has not yet been pursued at any EM facility, would be for DOE to retain the DA throughout the life of the project. This would entail a concurrent increase in staffing because the amount of review and approval during operations exceeds what DOE resources could cover.

performance-based FAR contracts. In a performance-based FAR contract, DOE is directing the contractor, in essence, to complete the project by their own means and they will be paid based on results. With the prevalence of such contracts, there appears to be little room for DOE to act as the Design Authority in the foreseeable future. Additionally, since Federal in-house capability is normally not available for Design Authority or not available to represent the operations perspective, the “owner’s rep” model should be pursued by the DOE acquisition and procurement group. In other words, DOE needs to hire an owner’s agent to represent the long-term O&M perspective during design, construction, commissioning, and testing (Recommendation 11). Projects need to have the requirement to fund the backbone of an operating organization (responsible for commissioning and operations) early in the project. Projects also need to have a defined minimum level of resources committed in the contract (CLINs) for Operations at the various project stages (conceptual, design, and construction).

An example of an owner’s rep currently in place is the rep at the WTP project:

> The Owner’s Representative serves in an advisory capacity to the WTP FPD and supports the oversight of BNI’s performance of work, deploying a broad range of specific expert technical and capital project resources, to support oversight and assessment of key project milestones related to completing the design, nuclear safety basis, system testing, and commissioning of the WTP. The Owner’s Representative will be used as a primary resource to assist the WTP FPD in expediting completion of the WTP design and commissioning, mitigate technical and programmatic risks, and identifying approaches and strategies to minimize cost and schedule to complete the project. In addition, they will perform walk-downs of selected systems, review system turnover, review system testing procedures and testing results, and review operational testing and testing reports. In accordance with the National Defense Authorization Act for Fiscal Year 2016, Sec. 4446 the Owner’s Representative (referred to as Owner’s Agent in the Act) will have specific oversight responsibilities with respect to safety basis development and management, which includes reporting to the Secretary and Congress on a periodic basis…

Integrated Baseline Reviews. The value of effective reviews cannot be overestimated; timely and effective reviews can put a project back on course before damage becomes significant. An Integrated Baseline Review (IBR), though not widely used to date, has been shown to be highly effective (Recommendation 12). GAO’s *Assessment Guide Best Practices for Developing and Managing Capital Program Costs*, GAO-09-35P, March 2009, provides guidance for conduct of IBRs. In that guide, a reference is made to DOD’s *The Program Manager’s Guide to the Integrated Baseline Review Process*, which states that preparation should begin as soon as practical after determining the need for an IBR.

An IBR is required under three conditions: when required by policy, when required in the contract, or where the project carries an obvious degree of complexity. The policy includes use of an EVM system. When the project uses an EVM, an IBR is required to verify the technical content and realism of the related performance budgets, resources, and schedules. This requirement could come as soon as award timeframe. DOE O 413.3B requires an EVM system for all projects over $20 million. SWPFO recommends also performing an IBR periodically—for example, at CD gates, before major modification, and while performing Performance Measurement Baseline (PMB)—and with a joint Fed/Contractor composite team.

To concentrate on whether or not the project was adequately prepared for success, SWPF used an Integrated Baseline Review (rather than the EM Construction Project Review) that focused more on testing and commission than on scheduling details. The facility's first IBR was a cooperative effort between the Contractor and DOE that resulted in good project acceptance. The team was composed of independent experts, project personnel (Contractor and DOE Project personnel), corporate reachback personnel, and DOE SMEs. The resulting report added fidelity to the schedule, identified items for the risk register, identified problem areas, and spelled out a resolution path, included the hiring of specific personnel.

Here are some of the findings identified in SWPF's Integrated Baseline Review:

- Engineering activities were identified as LOE but needed discrete activities for proper understanding and scheduling.
- Work package closure activities were underestimated and under-resourced.
- Some activities, such as SOTs, were not recognized as heterogeneous in terms of effort and schedule and need more granularity to properly resource schedule.
- There were not enough QA personnel to support activities to keep from significant schedule slip.

The first IBR performed at SWPF was estimated to yield $26 million in savings … at a cost of only $1 million.

lack of "skin in the game." EM construction projects consists of one entity that constructs and operates for a short period—usually a year—followed by other entities that operate over the life of the project. Fundamentally, this construct possess drawbacks to economical life-cycle costs because the constructor contractor does not have "skin in the game" for the lifecycle of the project. Unless specifications are well-thought-out and contracts are incentivized toward the lifecycle, the constructor will optimize profits by construction parameters 3 without regard to easy,

[3] For example, welded systems are more expensive to build than flanged systems, and the number of bends and tight spots is not a concern.

long-term maintainability (some existing EM facilities were designed as “maintenance nightmares”) or the need to select materials that resist erosion and corrosion.

Another consideration, less obvious but also important, is that of a laxer QA regimen, allowing “defects” to be dispositioned rather than reworked if the constructor is also the long-term operator. This writer detected one such example [4], in which a “passed” defect may have caused future problems after the initial operation period.

One option to address lack of skin in the game would be to have turn-key projects for the life cycle of the project (that is, the old DOE model). However, return to this model is unlikely in the foreseeable future, and therefore it will not be discussed further. Perhaps the best builder (constructor) is not the best operator, so the turn-key concept may indeed not be optimal. A contract with tight specifications and appropriate incentives, used in conjunction with an owner’s rep to provide input and perspective from an operations viewpoint, appears to be the best path forward (Recommendations 11 and 13).

integrating contracting with project management. In its acquisition, procurement, and supply-chain management section, EA’s DOE Best Practices website describes success in the integration of contracting and project management from EM’s Oak Ridge Office, making this recommendation:

> New Construction projects should be structured as a FAR performance-based contract, which dictates end state, not specifications with a structure that includes Contract Line Item Numbers (CLINs) with priced options that can be scoped in as needed. The CLIN structure allows easier “off ramp” if performance is substandard and incentivizes the contractor with more than fee. Additionally use of a prioritized buy-back list maximizes efficiency, utilization, and stewardship.

For these multiple-contractor projects, the contracts need to include clauses that clearly define turnovers, full operability completion milestones, and which contractor will be responsible for what at each stage. Contract schedule milestones tied to performance can be designed to eliminate or minimize the overlap of the design, procurement, and construction project phases.

[4] After approximately 5 years of initial operation, a condenser portion of one of a number of identical heat exchanger experienced a failure that allowed a leak from the shell side into the process stream, resulting in failure and required replacement of this and other identical heat exchangers. The condensers had received improper repair heat treatment by the manufacturer. A nonconformity report was originally issued by the manufacturer shortly after the deficient treatment on the Heat Exchangers was performed that documents the details associated with the issue. Although the exact cause of the failure is still being analyzed, the process of acceptance needs improvement. The constructor (specifically, one of the partners of the contractor construction consortium) had no operational involvement with the operation of the facility and accepted the heat exchangers “as is” during construction, and therefore would not suffer any consequences from the deficient heat exchangers during operation.

Contract incentives used to date on some large EM projects could be improved. Reliance on some milestones (that is, construction complete) has been shown to not be an optimal way to get through to operations in the most cost effective manner. SWPF experience indicates that incentives for achieving "construction complete" resulted in work toward that milestone at the expense of optimizing work flows to get to CD-4. Incentivizing milestones have to be carefully constructed, or resources will be misallocated. In commissioning optimization, decision makers should never lose sight of two important principles:

- Make use of a backward approach.
- Do not prioritize a system that, once completed, will add no immediate value but rather will remain unused for a substantial period while it awaits the completion of other systems (Recommendation 13).

Contract interface specifications could make use of RAMI goals and specification; material specifications based on lifecycle costs, not construction costs; and design for both flow-proving and decommissioning aspects (Recommendation 13). When members of a commissioning team find a contract confusing, it's usually because the contract's writing suffers from three problems:

- poorly defined scope
- insufficient detail
- badly worded descriptions

From the contract's perspective, a well-operating Lessons Learned program should be able to identify this confusion and other significant issues.

Additionally, as is the case with all business decisions, the corresponding entities to the contract cannot be a "shell corporation" or an LLC without financial wherewithal, that can go bankrupt (for example, Foster Wheeler at TWPC) or threaten to walk away from project if things don't go their way. This should also be a consideration of the Contractor when reviewing subcontractors, along with the level of confidence in the NQA-1 qualifications of the subcontractors (Recommendation 10).

Documented Safety Analysis. Historically, problems have existed with keeping the design and the safety basis in sync. The new requirements contained in STD 1104-2017 help ensure that the design is consistent with the Documented Safety Analysis (DSA), which is not the case with STD 1189.

Although not required by DOE O 425.1x, documented safety analysis implementation (DSA) prior to CD-4 has shown to be a desired practice as opposed to waiting till DOE Approval To Operate (ATO) for DSA implementation to begin. There is a fine balance, though: If DSA is implemented too early, it can cause problems by restricting needed activities, especially activities that are allowed only in various modes (Recommendation 14). De-confliction of controls caused by the DSA, which are derived from an operational perspective, with T&C activities has been shown to be time-consuming and schedule-unfriendly, and this impact must be considered before implementing the DSA. This is a subset of the larger issue: Document Control must be designed with enough flexibility for use during T&C.

Experience has shown that a successful commissioning process takes considerable upfront planning at the design phase of the project to be successful. A successful ORR does not necessarily equate to physical plant success. For example, WVDP had extensive full-scale prototype experience and a subsequent successful plant commissioning, but it struggled with the ORR due to procedures and training. In contrast, the IWTU had very a successful ORR but struggled to commission the physical plant.

establishing control-system functionality. One of the most important milestones for testing efficiency is achievement of the control system functionality prior to the start of the test program (Recommendation 15).This practice is highly recommended because it improves testing, operations, training, and schedule efficiencies. The objective should be to test the plant in as real a manner as possible. This necessitates control system functionality at the beginning of the test program: Without the use of the control system, testing would have to rely on temporary test rigs and systems. The use of the control system in testing allows familiarity for operations and maintenance personnel and ensures that the software used during the test is current and kept up-to-date.

Establishing control system functionality at the start of the test program is a notable practice, identified at SWPF, that provided improved testing, operations, training, and schedule efficiencies. SWPF followed the preferred testing sequencing:

1. Install Basic Control System Software
2. Complete Instrument Addressing
3. Complete Instrument Control Panel Testing
4. Perform Instrument CG&A
5. Perform System Test

simulants. Not only do the simulant properties need to be as close as possible to the real material: The simulant requires the same care and focus as the real material. Simulants or other supplies for testing require the same QA focus as equipment components (Recommendation 15). For example at ARP/MCU, temperature changes in manufactured simulant during transport resulted in precipitation of material when introduced into the installed process for testing. The precipitation of material created problems, which then had to be addressed during system testing. Establishing temperature limits and controls as part of the procurement and manufacturing process would have minimized or prevented this issue and its associated impacts during startup testing.

maintaining spares. Spares and Preservation management is an area requiring realistic schedules to be effective. Preservation maintenance is an important function at EM new-builds: By the time the facility is ready for commissioning, the equipment is old but never-used, and in some cases already obsolete, so having adequate spares is paramount to success.

The determination of a spares policy needs also to have RAMI input. Rolls Royce (previously KPMG) has developed software to identify and find obsolete equipment and spares. Their software is available for purchase. WTP is currently using them to help deal with obsolescence at the Project.

ensuring preservation. Preservation is also a critical item, and decisions such as how best to protect equipment (for example, by covering or sealing to protect against damage from construction), whether to rework damaged equipment or replace it, and whether to delay the project's completion by installing select pieces (such as actuators on valve positioners) later, need to be integrated with construction and T&C planning. Bench-testing components that are going into tight spots is also recommended (Recommendation 15). One area of Commissioning—Readiness—has had a good lessons-learned program that has been effectively communicated across the DOE complex.

Successful achievement of operational readiness starts with a well-thought-out and developed plan—that is, a schedule that has been integrated-resource-loaded and logic-linked. Planning for operational readiness involves understanding the true scope of what is to be accomplished—for example, design, procurement, installation, testing, maintenance, procedures (operational and support), safety documentation, training, and readiness confirmation—along with determining the applicable set of management requirement.

readiness review teams and boards. Successful contractor organizational structures for achieving readiness have included the use of a Readiness Assistance Team (RAT) and a Readiness Certification Assurance Board (RCAB). Such teams and boards have been found to be effective at validating the line-management readiness progress and help the Readiness Coordinator and staff prepare certifications, such as Ready to Proceed (Recommendation 15). Successful boards have about five members, independent of line and functional managers reporting directly to the Program Manager, with responsibilities for review of readiness criteria, Plan of Action (POA) core requirements, assignments, prerequisites, and associate documentation. Reviews of the objective evidence to provide confidence to support startup are often carried out by board members.

Successful DOE organizational structures incorporate assured (if not dedicated, then committed matrixed) SME support for use in the Certification and Verification Plan throughout the life cycle of the project.

Plan of Action prerequisites. The approach taken by many successful projects has been to meet performance-based criteria that are clearly mapped to DOE O 425.1D core requirements in order to establish that readiness has been achieved. These criteria need to be shown in the project schedule and logically linked to the predecessor activities that will provide the evidence that the criteria have been met. The successor activity should be the "certification" by the RCAP that operational readiness has been accomplished. By capturing the performance criteria in this manner, the POA prerequisites can also be mapped to the performance criteria, thus providing a higher level of confidence that the prerequisites are fully met.

Similarly, the Safety Management Program implementation activities, including SMP-specific training and the Integrated Safety Management (ISM) verification Phase-1 and Phase-2 reviews, should be captured in the project schedule.

The prerequisites must define measurable actions or deliverables for each specific core requirement that is to be reviewed during the readiness reviews. The prerequisites must provide significant detail and be fully measurable in order to permit contractor line management to track, and DOE to verify, each prerequisite to completion. Prior ORR experience has shown that it is important for the project to clearly develop and agree to a prerequisite definition list or list of deliverables that demonstrate completion for each of the prerequisite.

Additionally, the prerequisite section of both the contractor and DOE POAs should refer to specific items, such as a project management plan, a readiness self-assessment plan, a compliance assessment program, and safety documentation, such as the DSA and TSRs, and should not avoid the use of wording within the prerequisite that is not a measurable action or deliverable. The CRADs associated with implementation of DOE 425.1x are rife with subjective terms such as "sufficient, adequate, satisfactory, effectively" unaccompanied by additional qualifiers. The EM Standard Review Plan Module, *Achieving Readiness for Nuclear Facilities* (U.S. Department of Energy Office of Environmental Management, 2017), provides guidance in this area by adding performance-based expectations for a successful outcome in achieving readiness. It identifies the critical parameters of a particular element that must be demonstrated for the facility's operator to declare itself ready to operate and obtain DOE approval to startup. When the important performance-based parameters that are crucial to a successful operating plant are identified, the subjectivity of the review process outlined in DOE O 425.1x is reduced, and operating organizations gain a clear understanding of the expectations.

Meeting the expectations that the startup or restart is ready for operation requires a systematic approach to showing that

- a set of defined requirements has been met,
- there is evidence to support that fact, and
- the evidence has been verified to meet the defined requirements.

DOE has copyrighted a web-based software system called the Readiness Certification Process Assurance Tracking System (RCAPTS). Developed by the Y-12 National Security Complex, RCAPTS provides the structure to facilitate and capture the results to support certification and verification of operational readiness.

DOE's readiness software. As implemented at Y-12, The Readiness Certification Assurance (RCA) process, provides a framework for ensuring that line management—for example, Production/Operations, Engineering, Maintenance, and ES&H—accomplish their tasks necessary for attaining operational readiness with high-quality deliverables. The RCA process is designed to assign responsibility and obtain agreement on who owns a requirement and what are the expectations (that is, performance criteria), and to thereby instill accountability across various organizations for the declaration of readiness to operate a nuclear facility and validating the accuracy of the declaration. As part of the RCA process, the RCAPTS software replaces paper-based administrative tasks performed by responsible managers and readiness personnel. RCAPTS is used from a project's early planning stages to the point of operational readiness certification. It supports the identification of tasks needed to produce the evidence documentation for validating requirements prior to the formal readiness certification required by DOE Order 425.1x.The RCAPTS software system allows information to be simultaneously shared between performers, Readiness Assurance personnel, senior management, oversight groups, and startup authorities, saving time and avoiding missteps.

A key element for the successful completions of the RCA process is the development of documentation and other deliverables that are of high quality and meet procedural expectations. Ensuring that a high level of quality is achieved will support an efficient readiness confirmation process. To this end, the Readiness Leader makes use of the RAT to help the project team ensure that applicable requirements (that is, performance criteria) are met with adequate assurance of quality and that performance can be demonstrated without problems. As project deliverables are completed or put into final draft form, a member of the Readiness Assist Team will review the documentation, or will observe how personnel are using technical procedures, to validate that requirements are met and expectations (defined in RCAPTS) are accomplished. In the RAT approach, problems or concerns are provided to the person responsible for the particular document. While these are tracked, they are not documented as formal findings.

Completion of the RCAPTS confirmation prepares operations and support organizations for safe and compliant operations. At the same time, it allows the completion of a successful Readiness review. Once the RCA process has been completed, operational readiness can be certified.

Management Self-Assessments. A critical step in achieving readiness is the quality and timing of the Contractor’s Management Self-Assessment (MSA).The more comprehensive the MSAs, the more easily the readiness reviews proceed. A modified MSA process that uses greater coverage and rigor contributes directly to a more successful ORR process. For example, SWPF used a unique approach to MSAs. In fact, they used three bite-sized MSAs in series (Recommendation 15):

- ***MSA-1, Ready to Test.*** This MSA verified readiness to commence the startup testing program. The verification review included testing program processes and procedures, the availability of qualified personnel, and the availability and readiness of facilities and equipment to support testing activities. At the conclusion of MSA-1, SWPF transitioned from 29 CFR 1926, *Safety and Health Regulations for Construction*, to 29 CFR 1910 *Occupational Safety and Health Standards Based Programs*, and transitioned the SWPF work control processes from construction processes to operational facility processes.
- ***MSA-2, Ready to Operate with Chemicals***. This MSA will verify readiness to safely operate with process chemicals and caustic waste simulant introduced into the facility. Phase one Integrated Safety Management System (ISMS) verification for operational activities will also be performed. At the conclusion of MSA-2, and with the Project Manager’s approval, the non-radioactive waste simulant and process chemicals, including CSSX solvent, are introduced into the plant. Additionally, plant jurisdictional control changes from the Commissioning and Testing organization to Operations.

- ***MSA-3, Ready to Operate.*** The final MSA focuses on and verifies that the SWPF is ready in all respects to safely and compliantly operate as prescribed in DOE O 425.1D, Chg 1, *Verification of Readiness to start up or Restart Nuclear Facilities*, and DOE-STD-3006-2010, *Planning and Conducting Readiness Review*. That is, the plant would promptly start nuclear operations if there were no requirements for ORRs because it is truly ready to operate. The SWPF Phase-two ISMS verification occurs prior to or coincident with MSA-3. Additionally, SWPF performs an Implementation Verification Review (IVR) of the safety basis prior to making the formal declaration of implementation. The IVR is an independent review of the readiness to declare implementation of the safety basis and is performed coincident with MSA-3. Their approach was to perform the IVR as a readiness review using DOE-STD-3006-2010, *Planning and Conducting Readiness Reviews*, as a guide. After the successful completion of the IVR, implementation of the DSA is declared. At the successful conclusion of MSA-3, the Project Manager issues the Declaration of Readiness memorandum and asks the CORR to commence in accordance with DOE O 425.1x.

In addition to contractor preparations, a deliberate and methodical DOE process of certification and verification is effective in assuring contractor performance and readiness (Reference 6) for start of the CORR. A CORR must be a robust activity supported by operational evolutions and drills to confirm the readiness of all equipment, personnel, and procedures. The time required to recover from a failed CORR is far greater than the preparation time required to ensure a successful DORR. Ensuring that the contractor is completely ready before the ORR process is begun facilitates ORR success. Time pressures are significant as the ORR nears, but taking extra time to ensure readiness is still preferable to experiencing significantly more extra time and embarrassment for corrections during an ORR or after a failed ORR.

All the DOE certification and verification activities, along with an independent assessment of the performance of the contractor's ORR, form the basis for DOE to agree to proceed with the DOE ORR.

As the project evolves, so must the contractor's project execution plan and DOE's need to be cognizant of the shifts in skill sets and experience needed from both DOE and contractor staff.

3 Scope

The review included detailed information from ten facilities:

- IWTU at Idaho
- DUF6 at Portsmouth, OH and Paducah, KY
- West Valley Demonstration Project Vitrification Facility (WVDP) at West Valley, NY
- ARP/MCU at Savannah River with some input from SWPF
- Advanced Mixed Waste Treatment Project (AMWTP) at Idaho
- Transuranic Waste Processing Center (TWPC) at Oak Ridge, TN
- WIPP at Carlsbad, NM
- WTP at Richland, WA
- NNSA facilities
- DOE and non-DOE facilities of the Rand Report

3.1 Guidance Documents

3.1.1 DOE-wide Guidance

DOE guidance for commissioning comes from two primary areas: facility construction and nuclear safety. The primary references are listed below, though several supplemental references can be found from those listed.

- DOE Order 413.3B, *Program and Project Management for Acquisition of Capital Assets.* This reference addresses commissioning as the natural follow-on to the design and construction of a new or modified capital asset. Primarily it provides requirements, though supporting guides provide commissioning guidance, and PM is in the process of generating commissioning guidance.
- DOE Order 425.1D, *Startup and Restart of Nuclear Facilities.* This reference addresses the requirements and process for external review of readiness prior to authorization for operation (CD-4).
- DOE-STD-3006-2010, *Planning and Conduct of Operational Readiness Reviews.* This reference provides a comprehensive “How To” guide for conducting an Operational Readiness Review(ORR)as required by DOE Order425.1D.

- DOE-HDBK-3012-2015, *Guide to Good Practices for Operational Readiness Reviews*, Team Leader's Guide.

3.1.2 EM Guidance

The most relevant, applicable, and useful guidance for commissioning was developed for the Standard Review Plans, by CNS, in four modules [5]. These four modules were developed to support improved project management and facility operation execution within EM:

1. Standard Review Plan, 2nd Edition, March 2010, *Checkout, Testing, and Commissioning Plan Review Module*
2. Standard Review Plan, 2nd Edition, March 2010, *Readiness Review Module*
3. Standard Review Plan, 2nd Edition, August 2013, *Preparation for Facility Operations Module*
4. Standard Review Plan (Draft), February 2017, *Achieving Readiness for Nuclear Facilities*

3.1.3 DOE Lessons Learned Database

The DOE Corporate Lessons Learned (LL) database, managed by AU, is a web-based LL tool designed to facilitate the sharing of information in a consistent and timely manner among HQ elements and contractor and subcontractor entities. The DOE LL application provides a mechanism for communicating experiences throughout management and across functional areas. It is used to identify lessons for improving performance, for planning, and for correcting hazardous conditions.

The LL items below, listed from the most recent to the least recent, have particular relevance to EM commissioning.

- PMLL-2011, ARRA-OR-BJCEMWMF-0102, 8/2/2013, *Requirement for Pre-shipment Material Inspection at Supplier's Facility*. This LL describes delays in the construction schedule that occurred because the Supplier defects were not detected in time. For suppliers of major equipment that are not listed on Approved Suppliers list, conduct a pre-shipment material inspection at the Supplier's facility in order to detect and correct any non-conforming conditions before the equipment is delivered to the site.

[5] The entire EM SRP and individual Review Modules can be accessed on the EM website at https://energy.gov/em/standard-review-plans

- PMLL-2013-Other-07/11/13, *Commissioning of Line Item Construction Projects.* This LL tabulates lessons learned from commissioning projects. A dozen common lessons were learned from all projects:
  1. Prototype testing correlates with design and construction success.
  2. Pilot or full-scale correlates with commissioning success.
  3. Vendor inspections and QA records were critical for all projects.
  4. Early and extensive involvement of process operators correlates with commissioning success.
  5. MSA approach for ORR success should be extended over a longer period, not merely reviewed shortly before the ORR.
  6. Undertaking separate ORRs—one by the Contractor, the other by DOE—is more difficult, but it is necessary for complex facilities.
  7. Commissioning is a major component of the facility lifecycle.
  8. Commissioning rigor correlates with operations success.
  9. ORR is only one component of a comprehensive commissioning effort.
  10. There is an institutional knowledge gap for commissioning.
  11. Extensive information on ORR successes and failures.
  12. Limited information is available for the balance of commissioning.
- LL13-0020, 7/9/2013, *Elevated Radiation Levels during Accelerator Startup*. This LL describes how a particular hazard—radiation fields—can manifest in unexpected ways during the startup of a new facility.
- PMLL-2011-SC-PNNL-PSC-0003, 2/21/2011, *Managers Adapt Readiness to New Business Needs at PNNL.* This LL describes a programmatic approach to apply principles of readiness to an expanded population of business applications.
- PMLL-2010-LLNL-NIF-0005, 4/27/2010, *Extrapolation and Scalability Are Not Always Accurate Techniques.* This LL describes the difficulty of extrapolation and scale-up for complex, first-of-a-kind facilities. Several compensatory approaches are offered to reduce the inherent risks of scale-up.
- PMLL-2009-PX-EDSU-0001, 4/24/2010, *A Checkout, Testing, and Commissioning Plan Ensures Optimum Performance of Equipment, Systems, and Facilities.* This LL describes the benefits of a comprehensive checkout, testing, and commissioning plan.

- PMLL-2009-Y12-HEUMF-0001, 3/30/2010, *Contractor Readiness Certification Assurance Process and Site Level Federal Oversight is an Effective Tool for Achieving Project Readiness*. This LL describes in detail a process to ensure achievement of overall facility readiness in advance of the ORR.
- RPP-WTP-LL-09-0404, 12/8/2009, *GREEN – Startup Testing*. This LL describes important actions for planning and conducting startup testing activities.
- RPP-WTP-LL-08-053, 5/23/2008, *BLUE – Storage and Preservation Maintenance of Equipment and Components during Construction*. This LL describes actions to ensure the preservation of equipment and supplies procured during construction for later use in construction, testing, commissioning, or operations.
- 2008-SSO-SNL-10260-01, 2/11/2008, *BLUE – Experience needed for startup of Hazard Category 2 nuclear facility*. This LL describes the skills, techniques, and management attention required for successful commissioning of Hazard Category 2 facilities.
- 2006-SSO-SNL-10326-11, 9/25/2006, *Importance of Requirements Review*. This LL describes the necessity for comprehensive review of requirements with stakeholder and regulator input in advance of readiness activities.
- 2004-RL-HNF-0033, 8/10/2004, *Successfully Completing a Readiness Review*. This LL describes techniques and actions to ensure readiness review success.
- 2004-RL-HNF-0030, 7/22/2004, *Readiness for Sludge Water System Startup*. This LL describes problems and deficiencies that caused initial ORR failure and suggests actions to ensure first-time ORR success.
- 2004-RL-HNF-0001, 1/13/2004, *Successful Readiness for Startup of TRU Retrieval Project*. This LL describes techniques and approaches used that resulted in a successful Readiness Assessment.
- 2002-RL-HNF-0066, 12/4/2002, *Significant Changes after MSA Can Adversely Affect ORR Results*. This LL describes the problems resulting from making process changes after completion of the contractor's MSA. It includes actions needed to preclude the problems.
- 2002-RL-HNF-0010, 2/26/2002, *Common Readiness Review Issues*. This LL describes a summary-level outline of actions to prepare for a successful readiness review.

- 1999-RL-HNF-0041, 10/27/1999, *Highly Successful Activity Based Startup Review*. This LL describes a graded approach to DOE Order 425.1D compliance, using an Activity Based Startup Review.
- L-1998-DOE-ID-98-001, 2/17/1998, *Lessons Learned from Operational Readiness Reviews at INEEL*. This LL describes an overview of key techniques and actions for successful ORRs gathered from multiple Idaho National Engineering and Environmental Laboratory experiences.

3.1.4 International Atomic Energy Agency (IAEA) Guidance

The IAEA has over a dozen guides addressing safety of nuclear facilities through their full facility lifecycle. The guides are broadly written to be widely applicable to the international user community. Thus, they are not specifically applicable to DOE/NNSA facilities. However, the potential benefit of the IAEA guidance is that it addresses the nuclear and radiological hazards to the worker, the public, and the environment. The strong safety focus with a defense-in-depth philosophy is consistent with DOE guidance for nuclear facilities.

Three guidance documents apply most directly:

- IAEA Safety Guide No. NS-G-4.1, *Commissioning of Research Reactors, 2006*
- IAEA Safety Guide No. NS-G-2.9, *Commissioning for Nuclear Power Plants*, 2003
- IAEA Specific Safety Requirements No. SSR-2/2, *Safety of Nuclear Power Plants: Commissioning and Operation*, 2011

3.1.5 U.S. Environmental Protection Agency (EPA) Guidance

Two EPA guidance documents are directed at new-facility commissioning:

- *EPA Building Commissioning Guidelines*, January 2009
- *General Commissioning Requirements*, EPA, December 2007

EPA guidance is directed toward standard office or industrial facilities and thus is not ideally applicable to DOE/NNSA facilities. However, the potential benefit of the EPA guidance is that it presents commissioning as a holistic, integrated activity, which has elements throughout the facility lifecycle, from pre-design through ongoing operations. This holistic perspective is consistent with DOE guidance and is useful as an introductory primer on the integrated nature of commissioning activities.

3.1.6 U.S. Nuclear Regulatory Commission (NRC) Guidance

The NRC has an extensive body of regulation and guidance applicable to nuclear reactors, nuclear fuel cycle, and nuclear fuel storage facilities. Most EM-mission facilities, although nuclear, are not similar to nuclear facilities regulated by the NRC; thus the NRC guidance related to commissioning is less applicable to EM facilities than are the DOE and EM references. Additionally, NRC guidance may have been of more use to EM at its start in the early 1990s, when minimal internal guidance existed. More than two decades later, with dozens of facilities commissioned, both large and small, EM has collected commissioning guidance that more specifically apply to its mission. The few EM facilities that may be regulated by NRC should investigate appropriate commissioning guidance and resources from the NRC website at http://www.nrc.gov/reading-rm/doc-collections/.

3.1.7 Independent Review Guidance

Many EM projects have benefitted from independent external reviews from expert panels such as panels from the National Academy of Sciences (NAS), or from national or local stakeholder-based organizations, such as the Environmental Management Advisory Board (EMAB). Typically, these reviews focus on the specific facility undergoing the review. But sometimes they have included recommendations related to commissioning activities.

3.2 Structured Interviews

The literature search described above revealed some good sources for commissioning guidance and lessons learned. However, it also revealed a significant gap in reports or lessons learned related to commissioning and startup. Most of the information discovered either was directed at lessons from the facility design and construction (a requirement of DOE Order 413.3B) or was significantly condensed and summarized.

To address the dearth of commissioning experience information for EM facilities, a structured interview process was developed for the initial EM commissioning Experience Report. The process used a structured interview, using consistent Lines of Inquiry (LOIs), to gather the commissioning experience from knowledgeable participants from the original facility commissioning. Interviewees could be DOE or contractor; often they included both.

This approach gathered mostly subjective and anecdotal information, but the consistent LOIs and interview format allowed even the subjective information to be compared and analyzed. Additionally, the interview process provided access to some objective data and reports, which had not been otherwise discovered through normal search mechanisms. In each Experience Report, the interviewees for the investigated facility are listed in Appendix 5.3.

LOIs used for the interviews included the following:

- Scope and description of facility and mission, including design capacity and limitations, and commissioning requirements (per DOE Order 425.1D and DOE Order 413.3B)
- Description of laboratory-scale testing and scope/purpose of test(s) and summary of conclusions germane to facility construction and operation
- Description of pilot facility testing with scale, and scope/purpose of test(s) and summary of conclusions germane to facility construction and operation
- Description of any full-scale prototype testing and scope/purpose of test(s) and summary of conclusions germane to facility construction and operation
- Rationale for use of other facility operations in lieu of laboratory, pilot, or full-scale prototype testing
- Rationale for ability to use surrogate material to demonstrate facility operations
- Planning and preparation for turning components, subsystems, and systems over from construction to testing, including turn-back criteria
- Planning and preparation for turning subsystems and systems over from testing to operations, including CSE involvement
- Scheduled and actual time for non-radioactive (“cold”) testing to achieve TRL 7 (See DOE Guide 413.3-4A, *Technology Readiness Assessment Guide*.)
- Planning and preparations for MSA and ORR
- Scheduled and actual time from first ORR to DOE Order 425.1D startup authorization
- Scheduled and actual time for radioactive (“hot”) testing to achieve TRL 8
- Scheduled and actual time from first operational runs to planned production runs to achieve TRL 9
- Documented and/or anecdotal lessons learned from commissioning experience

3.3 Data Analysis

The final step in the process of evaluating commissioning experience was analysis of the collected information. Individual facility information, summarized in section 3.4 for each facility reviewed, was discussed and contrasted with the other facilities to identify apparent tendencies. These apparent tendencies could either be positive, suggesting a successful practice, or negative, suggesting a detrimental practice. The suggested practices were then compared against the documentation from the literature search to ensure consistency or identify any conflicts. Where conflicts were identified, additional discussion was needed to develop a better understanding of the conflict, and, if appropriate, to develop a reasonable basis which recognized unique circumstances for the EM facility.

3.4 Facility Summaries

3.4.1 IWTU – Idaho

The IWTU was originally named the sodium-bearing waste (SBW) treatment facility. It was identified by mission need as a facility to complete the processing of sodium-bearing liquid tank waste. Most of the SBW had been treated by calcining in other facilities that operated from 1963 to 1999, when processing was halted by DOE because of concerns about air permit non-compliance .During preliminary IWTU design, EM decided to expand the mission to include possible, future reconfiguration of the facility to treat the calcine waste created by the earlier calcining process. This “integration” of mission needs in a single physical structure led to the IWTU name change. Provisions were also made for storage of the treated SBW containers until a suitable disposal facility was approved.

3.4.1.1 Mission and Scope

The project’s mission was to design, build, and commission a facility to treat 900,000 gallons of radioactive liquid waste (sodium-bearing waste or SBW) stored in the Idaho Tank Farm Facility. The facility would be required to accommodate reconfiguration for Hot Isostatic Pressing equipment to be used to process the inventory of calcine waste stored in 11 nearby bin sets.

3.4.1.2 Design and Construction

The fundamental treatment process selection for the SBW was determined through the contract acquisition process. Vitrification was most commonly used for high-level radioactive-liquid tank wastes. However, the SBW was much less radioactive, having characteristics more similar to transuranic (TRU) waste. Steam reforming was an emerging process which had been successful in commercial use for other radioactive waste streams. The steam reforming technology was viewed as less expensive to build and operate, and it was the technology proposed by the winning contractor. Steam reforming uses a high-temperature fluidized bed to react steam with the SBW to create the treated waste.

Early laboratory-scale research on steam reforming for EM waste streams was conducted at the Hazen Research facility in Colorado. This research expanded to construction of a 1/10-scale pilot plant at the Hazen Research facility. Extensive testing was performed in the pilot plant over several years to verify design parameters and performance.

The Hazen pilot plant research was generally successful; however, several key design issues were not sufficiently evaluated. One key design element was the decision to use coal and coke as the heat and carbon source in the IWTU, while the Hazen pilot plant was heated by propane. Lack of design and operating information on this substantial difference contributed to a major upset during IWTU startup.

Another key design element was the configuration of the fluidizing gas rails. The rail designs were modified and evaluated by modeling efforts but were not verified in the pilot plant. The rails, too, proved to be inadequate and required a full-scale mockup and testing to achieve an acceptable design and process parameter data.

A full-scale prototype, originally proposed for the IWTU, was canceled to save cost and time. Proceeding without a full-scale prototype was believed to be technically valid because the IWTU design was informed by substantial Hazen pilot plant testing, and the operating experience from a commercial steam reforming facility, which had been successfully operating to treat radioactive waste in Erwin, TN. Like the Hazen pilot plant, the Erwin commercial facility had some key differences from the as-built IWTU. Most significantly, the Erwin facility had a single fluidizing vessel while the IWTU had two vessels operating in series.

The IWTU design was significantly impacted by the decision to include provisions for reconfiguring the facility to process calcine waste. The higher levels of radioactivity in the calcine waste drove the facility to a more conservative design to accommodate seismic events. In practical terms, this decision required a substantial increase in the number of structural members, cross-bracing, pipe bracing, and concrete reinforcing. These changes, in turn, caused secondary impacts to piping layouts and equipment placement.

However, the impact of the design change went beyond the direct changes. The multiplicative impact of the changes put the design team behind schedule, while construction proceeded to maintain the project schedule. Consequently, the design was always behind the construction need, causing increased rework in the field. A clear example occurred in 2007, when design was reported to be 90 percent complete yet there were no isometric drawings of the piping layouts, an element that would normally be present by 60 percent design. Additionally, some design issues did not receive adequate analysis; instead, an understanding of the design unknowns was deferred into construction or commissioning.

The construction process was impacted by delayed and incomplete designs as described above. Additionally, the IWTU required 8.5 miles of process piping, most using specialty materials that required expert welding techniques for nuclear facilities (Nuclear Quality Assurance or NQA-1). During construction, it was determined that welders with expert skills and competent in NQA-1 procedures were extremely scarce. Training and other compensatory measures were partially helpful, but the IWTU construction still experienced significant delays from pipe and hanger weld rework.

3.4.1.3 Commissioning Experience

Key components for the IWTU underwent testing at the vendor locations and receipt inspections consistent with the QA Plan. Some vendor testing for valves and valve actuators showed that more repetitions, or test cycles, were required to truly demonstrate the acceptability of the equipment.

Turnover of the facility from construction to operations was generally organized by larger geographic sections. Testing followed the typical progression from individual components, to subsystems, to full systems, to integrated systems. A particularly valuable technique, adopted from the DUF6 commissioning experience, was called *grooming*. The grooming technique involved simple checks on individual equipment items for continuity, proper rotation direction, proper alignment, and other criteria that were simple to verify. This was all done informally, outside of a formal test plan, while corrections could be made quickly and easily. Operations staff had some involvement in the turnover process, but their involvement was somewhat limited by other demands for procedure development and training.

Following turnover, the subsystem and system tests were conducted. Testing required approximately twice as long as planned. In part, this was due to design issues, which did not appear until system testing. Also, because of the DSA hazards, the startup testing was modified to ensure that the greatest risks were considered. Carryover of hydrocarbons presented risk of an internal system fire in the Granular Activated Carbon (GAC) vessels used to remove mercury from the off-gas stream. Cold testing was modified by using superheated nitrogen or air to heat the system for integrated system testing. Following authorization to operate the system, the hydrocarbon sources (coal and coke),which represented one of the greater risks, would be used to heat the system to full operating temperature and pressure, but with surrogate—nonradiological—waste. Following the cold test, the system would be tested with radiological waste (hot testing) and would then ramp up to production operations.

The MSA process of the contractor self-assessment program was modified to increase confidence in the outcome. An independent group was used, and the MSA was started four months in advance of the scheduled Contractor ORR (CORR). Rather than sampling various systems and procedures, the MSA team performed a 100 percent review of all aspects of the IWTU operation. Many corrections and process improvements were inherent in this kind of MSA.

However, the extended, very comprehensive MSA was credited with facilitating successful ORRs. The CORR and DOE ORR (DORR), which followed, were completed within a month, with minimal issues.

Following authorization for operations, the cold (non-radiological) testing was begun with heated nitrogen. As system temperature continued to be increased by the addition of coal, a system overpressure event occurred. The overpressure resulted in the automatic shutdown of the system and damage to some system components. An investigation revealed that multiple system design issues and operational errors caused the event. About 18 months were spent to analyze, repair, and modify the IWTU to recover from the upset during startup. In essence, the as-built IWTU was being used as the full-scale prototype through the cold-testing evolutions. In hindsight, the time and expense saved by the decision to eliminate a full-scale prototype in the design phase was more than offset by time and expense incurred by analysis and testing during the commissioning phase.

IWTU non-radiological testing restarted in November 2014, under Test Instruction 102 (TI-102), which ran through January 10, 2015, and processed 62,000 gallons of surrogate waste (simulant). Problems encountered in June 2012 were not experienced during TI-102, thanks to physical and operational changes made to the facility. In response to new challenges encountered during TI-102 (accumulation of wall scale “Bark” in the primary treatment vessel, unacceptable hold up of filtered particulate in the Off Gas Filter), additional modifications were implemented in the facility.

Simulant testing was resumed in July of 2015, but soon after heat-up it was discovered that the Process Gas Filter was not functioning properly; the process was shut down to evaluate and correct the condition. Simulant testing was again restarted on November 7, 2015 and ran through December 16, 2015 under Technical

Procedure 8023 (TPR-8023); approximately 8,000 gallons of simulant were processed during this campaign. Overall, the plant ran well. However, the process repeatedly encountered unfavorable bed behavior as it progressed from its alumina startup bed to the carbonate product bed. Analysis and testing continue as the facility tunes the process flow sheet and operating parameters.

3.4.1.4 Key Learning

1. The pilot-scale testing was insufficient to provide adequate information for final design.
2. Some issues that had been identified in pilot-scale testing were not sufficiently addressed in the design. The decision to forgo full-scale prototype testing for this first-of-a-kind facility exacerbated the problem of insufficient design and inadequate understanding of operating parameters.
3. The impact from changing the mission to incorporate follow-on processing of calcine, which resulted in stricter seismic design criteria, was significantly underestimated. The design impacts manifested in a ripple effect that continued throughout construction and into commissioning. A design change during preliminary design that impacts fundamental criteria can never be considered minor.
4. The modified MSA process, which used greater coverage and rigor, contributed directly to a more successful ORR process.
5. Operational startup testing, even after successful ORRs, must maintain a perspective of testing rather than operations. A "bias for surprises" must be maintained until full operational performance is demonstrated, especially if no full-scale prototype was used in the design process.

3.4.1.5 IWTU Update

The Auger/Grinder, which is a critical single-point vulnerability component at IWTU, experienced binding and ceased to operate during cold commissioning activities. Subsequent efforts to recover from this failure were unsuccessful.

The root cause was that the design of the grinder blades, and possibly the auger flights, was not effective in clearing the buildup of material in the Auger/Grinder. The built-up material may even have been generated by the grinding of bed material while it was held up in the Auger/Grinder.

An analysis revealed six contributing causes:

1. Failure to validate the Thor Treatment Technologies design when responsibility was transferred to CWI.

2. CWI elected not to perform a formal design review for either the Revision 0 or the Revision 1 design. The rigor, peer review, and documentation of a formal design review are basic engineering tools intended to reduce risk. Without these tools, there was a much greater level of risk.
3. CWI elected not to perform representative testing of either the Revision 0 or Revision 1 design. Testing occurred but was not representative of the conditions encountered in the DMR. Representative testing could have revealed the design flaws that were the root cause of failure.
4. CWI elected not to respond to a failure that occurred during testing of the Revision 1 design. A jamming failure did, in fact, occur and was documented during this testing; however, the failure was rationalized and discounted. Subsequent interviews revealed that the failed test was, in fact, similar to the failure in the DMR and in part predicted that event.
5. CWI elected not to perform a root cause analysis for the Revision 0 failure. A root cause analysis of the initial, failed design would have identified effective improvements to the existing design.
6. Formation of a hard, consolidated cementlike substance in the Auger/Grinder as a result of a potential chemistry process or a powder compaction process was not understood.

Testing with simulated waste at IWTU over the 2012–2106 timeframe has resulted in equipment failures and upset conditions that have delayed the processing of SBW. Therefore, the Contractor has developed a four-phase approach to identify and resolve the remaining IWTU technical issues. This approach is a systematic mechanistic approach underpinned by scientific principles and is based on a systematic progression of activities that use the results from the previous phase to develop the next phase:

- Phase 1 involves chemistry and fluidization studies and bench-scale tests to establish process-control strategies for pilot and large-scale testing in Phase 2 and to identify potential plant modifications. These studies and tests are critical to understanding the chemical reactions and fluid-mechanic conditions occurring in the Denitration and Mineralization Reformer (DMR), IWTU's main reaction vessel. It is not anticipated that conducting further simulant tests in the IWTU will be required until Phase 2, both because of the need to first establish operating strategies and set control boundaries through small-scale testing and engineering analyses in Phase 1, and because the issues with the auger-grinder and ring header equipment need to be resolved before the IWTU can be operated again.

- Phase 2 involves pilot plant testing at Hazen and performing additional simulant testing in the IWTU facility.
- Phase 3 confirms sustained simulant operations in the IWTU.
- Phase 4 moves to radiological operations to process the SBW.

The bottom line is that IWTU is post–CD-4 but not yet in hot operations. Instead, the facility is operating post–CD-4 as a test platform as staff members gather needed information that should have been obtained during the design phase.

3.4.2 DUF6 – Portsmouth and Paducah

The DUF6 project was established to provide the capability to process tens of thousands of cylinders of DUF6 to nonreactive uranium oxide for disposal. Considering the location of the waste cylinders and other factors, the decision was made to construct two virtually identical DUF6 plants: one at the Portsmouth, OH site, and the other at the Paducah, KY site. Differing state regulations, local seismic conditions, and capacity requirements caused the plants to not be completely identical, thus increasing costs. However, the plants were sufficiently similar that phased commissioning allowed lessons from the first startup at Portsmouth to facilitate the second startup at Paducah.

3.4.2.1 Mission and Scope

The project's mission was to design, build, and operate two facilities to convert DUF6 currently stored in steel cylinders for beneficial reuse or disposal. Facilities operate in a modified batch manner, using multiple autoclaves to heat the DUF6 cylinders to drive off the DUF6 as a gas, then reacting the gas in a fluidized bed vessel (three at Portsmouth, four at Paducah). Finally, the reacted uranium oxide waste product is placed into the original cylinders for offsite disposal.

3.4.2.2 Design and Construction

The DUF6 design was based on a proprietary fluidized bed process to convert the DUF6 to depleted uranium oxide. No laboratory, pilot-scale, or full-scale testing was done. Instead, the design was based on experience from similar conversion equipment in use at the Richland, WA site. However, the Richland unit was about one-quarter the size of the DUF6 fluidized bed vessel, and it operated as a single vessel. The DUF6 facility support systems in Paducah—the site with four reactor vessels—experienced a scale-up factor of 16. Also, the Richland unit operated in a pure batch mode, while the DUF6 design was a modified batch concept. To mitigate the technology deployment and design concerns, the subject matter expert

(SME) who actually held the patent for the proprietary process was hired as part of the DUF6 contract. This mitigation was partially successful to address design and construction issues. But it failed to provide the suite of test data that would normally be used to inform the design and development of operations procedures.

Construction of the facilities was delayed by the unavailability of some equipment and by management of subcontracts and vendors. Also, the lowest-price contractor received the work and, as the project progressed, it appeared that the contractor had significantly underestimated the cost. The construction challenges complicated the commissioning process, as original contract scope was intended to include five years of operation. But because of the construction delays, the operations portion of the contract was deleted, and the contract only provided for the startup testing activities to verify system performance.

3.4.2.3 Experience

Turnover of DUF6 occurred mostly by system, with component testing completed by the construction trades. The remaining grooming, subsystem, system, and integrated system tests were performed by the Test Group within operations. The turnover process was planned for 6 months and required twice as much time—12 months—for Portsmouth. Weaknesses in the test procedures and instructions accounted for much of this delay, compounded by the “expert-based” design basis. The Paducah facility was able to benefit from the Portsmouth lessons. As a result, it required only eight months of turnover and testing versus the six-month plan. The cold (non-radiological) testing was also complicated by lack of any valid surrogates to use for DUF6. System test focused on the non-radiological hazards in the facility, which dominated the DSA. These greater DSA risks included hydrofluoric acid (HF), supercritical steam, and hydrogen gas, all operating at elevated pressure.

The MSA was organized by functional area at Portsmouth. This approach did not work. Moreover, the MSA that had been planned to take one month ended up taking three months. Adjustments in the MSA approach were made to a system approach; and just as they had benefitted from lessons learned from the turnover process, the Paducah site staff benefitted from the Portsmouth lessons and completed their MSA in the scheduled one month. Portsmouth also provided the learning curve for Paducah in completion of the CORR and DORR.

The hot testing was planned for nine months. Since no adequate DUF6 surrogate was available, the concept was to test each individual autoclave and fluidized-bed reactor vessel, then increase to multiple parallel processing in a deliberate and stepwise manner. A backflow incident at the Portsmouth facility during hot startup shifted the focus of testing to the non-radiological DSA hazards. The cold tests were essentially redone to verify all of the supporting facility systems.

A major contributor to the testing challenges was that the design SME was directing most of the test activities and protocols. Revising the testing to a procedure-based system, rather than one that was expert-based, ultimately led to successful start of production operations. The ramp-up from first production run to full production was planned for 12 months. After 12 months, each vessel had run successfully, achieving an overall availability of 84 percent. Full production capacity of 95 percent with parallel operations in all conversion vessels took another year to achieve.

3.4.2.4 Key Learnings

1. The testing sequence with supporting logic and system parameters must be well-understood, using detailed test instructions and procedures to execute the testing. Use of an expert-based testing approach should be avoided, no matter the skill and experience of the SME.
2. The technique of "grooming" component items through simple tests to verify continuity, rotation, alignment, and other fundamental criteria was very successful, and it facilitated completion of the formal test procedures.
3. The DOE process of certification and verification was very deliberate and methodical. The approach was generally effective in ensuring contractor performance and readiness.
4. The contract was awarded for a bid price that was lower than the established project baseline, so the project baseline was reduced to align with the contract in accordance with EM policy. When it was determined the contractor had underbid the project and needed more funding to complete the work, the project baseline had already been reduced to align. This reduction in scope made it more difficult to acquire the needed funds.

3.4.3 West Valley Demonstration Project (WVDP) – West Valley

The WVDP was the first major treatment facility built under the newly created EM. The facility at West Valley was constructed and operated for nuclear fuel reprocessing by a commercial organization .Oversight responsibility and liability were shared by DOE and the State of New York, though the DOE had the larger share at 90 percent. After cessation of fuel reprocessing activities in the late 1980s, approximately 600,000 gallons of caustic, high-level liquid waste (HLW) and some lesser amount of acidic waste required treatment for storage and disposal. The WVDP name makes clear that this capital project was intended to serve as a demonstration of HLW vitrification technology. Accordingly, it would serve as a springboard for construction of full-production vitrification facilities, such as the Defense Waste Processing Facility (DWPF) in operation at the Savannah River Site (SRS) in South Carolina and the WTP under construction at Hanford, Washington. The importance of EM achieving a successful demonstration was paramount, and so the WVDP was structured to use a very deliberate testing approach, culminating with a full-scale vitrification test facility to inform the design, construction, and operations.

3.4.3.1 Mission and Scope

The project's mission was to design, build, and operate a facility to treat 600,000 gallons of HLW from commercial processing of spent nuclear fuel.

3.4.3.2 Design and Construction

Initial vitrification test work was done at laboratory scale by Pacific Northwest National Laboratory and Catholic University of America. The lab-scale vitrification testing progressed to pilot-scale vitrification testing in a 1/12-scale "mini-melter." Finally, a full-scale vitrification test facility was constructed. The test facility was operated "cold" (non-radiological) for five years, with a wide range of surrogate feed materials. The same operators who would run the WVDP operated the test facility. More than half of the $552 million capital cost of the WVDP was committed to the technology development and cold testing. While this sum represented an extraordinary commitment of funds for pilot and full-scale testing, the results were positive. The design for the WVDP was refined by applying data from the test facility, and even after "hot" (radiological) startup, the test system continued to provide data for operational improvements.

3.4.3.3 Commissioning Experience

Commissioning proceeded very smoothly on the basis of the five years of operational experience in the test facility. Equipment was turned over from construction to operations in large groups in a virtually seamless process. Testing activities were completed according to the approved testing and QA Plan, with minimal difficulties.

The ORR process provided the biggest challenge. The CORR was mostly a document and "paper review," without many operational evolutions or drills. As one of the first major EM nuclear facilities to undergo an ORR, the WVDP received intensive DOE oversight. The contractor was unaccustomed to this degree of scrutiny, and their preparation proved to be insufficient. The contractor failed the first DORR, then took more than four months to recover and prepare properly. Overall, the ORR process planned for 1 month and required 18 months to complete. Authorization for radiological operations was finally granted in June 1996, and the operations that followed were very successful, again owing to the experience from the five-year test-facility operation. After a few months of hot testing, the facility quickly ramped up to full production and operated for a successful six-year campaign.

3.4.3.4 Key Learnings

1. The CORR must be a robust activity supported by operational evolutions and drills to confirm the readiness of all equipment, personnel, and procedures. The time required to recover from a failed DORR is far greater than the preparation time required to ensure a successful DORR.
2. The full-scale, full-process prototype facility was invaluable to ensuring a successful production facility design. It also streamlined and reduced technical issues during the transfer from construction to operations, the startup testing, and the ramp-up to full processing capacity.
3. Retaining the 1/12-scale mini-melter during startup and production operations allowed process refinements to accrue coincident with production operations. The technology development facilities continued to provide valuable information, even after construction and startup.

3.4.4 ARP/MCU – Savannah River

The Radioactive Liquid Tank Waste Stabilization and Disposition Project is an ongoing project to provide for the treatment and permanent disposal of liquid radioactive waste currently stored at SRS, as well as radioactive waste from planned nuclear material stabilization activities. The SWPF is a line-item project within the broader Stabilization and Disposition Project. The purpose of the SWPF is to pre-treat salt waste, resulting in a highly radioactive fraction to be sent to the DWPF for vitrification and low-level waste products to be sent for treatment and final disposal at SRS's Saltstone Facility. To meet waste disposal objectives prior to SWPF operation, some existing SRS facilities were modified and the ARP/MCU was constructed to pre-treat salt waste for a three-year interim period.

The waste is treated in the following sequence of steps:

1. The ARP decontaminates salt solution via sorption of strontium-90 (Sr-90), actinide radionuclides, and entrained sludge solids in the salt solution onto mono-sodium titanate (MST). followed by filtration.

2. The actinide, Sr-90, and MST-laden sludge waste stream are transferred to DWPF for vitrification, and the remaining, clarified-salt solution is transferred to the MCU process.
3. The MCU process extracts Cesium-137 (Cs-137) from the clarified-salt solution, using Caustic Side Solvent Extraction (CSSX) chemistry. The CSSX technology uses multicomponent organic solvent and centrifugal contactors to extract Cs-137 from salt waste.
4. Coalescers and decanters process the decontaminated salt solution and strip effluent solutions, both to allow recovery and reuse of the organic solvent and to limit the quantity of solvent transferred to the downstream facilities.
5. The low-Cs-137, low-actinide decontaminated salt solution (DSS) from the MCU is subsequently transferred to Tank 50 for feed to the Saltstone Production Facility. The strip effluent (SE) solution of cesium nitrate from the CSSX process is transferred to the DWPF for vitrification.

The ARP/MCU process was constructed and permitted initially for a three-year service period reached in 2012, to bridge the crucial period before the startup of the SWPF. The original goals of the ARP/MCU process were to treat salt solution prior to the start of SWPF, and, importantly, to provide operational experience and lessons learned for the SWPF project. With the delay of SWPF, however, ARP/MCU has been enhanced and improved to provide a longer-term option for salt disposition.

3.4.4.1 Mission and Scope

The project's mission was to design, build, and operate a 1/10-scale pilot facility to process salt-tank waste and provide operating experience for the SWPF. These activities were managed under three subprojects, collectively referred to as the Interim Salt Disposition Process (ISDP):

- The ***ARP – Capacity Enhancements (ARP-CE) project*** modified the 241-96H and 512-S facilities.
- The ***MCU project*** built a new facility in the H Area Tank Farm (HTF).
- The ***Waste Transfer Lines project*** modified the waste transfer system between ISDP facilities and the receipt tanks for ISDP in DWPF.

Pre-treatment of the salt waste solution requires two basic steps to meet Saltstone Waste Acceptance Criteria:

- Reduction of the concentrations of Sr-90, actinides, and entrained sludge solids in the salt solution, using a MST sorption treatment followed by filtration
- Reduction of the Cs-137 content of the clarified salt solution (CSS) processed through the first step, using a CSSX process

The source tank for all of the salt solution feed to be pre-treated in this fashion is Tank 49, a 1.3-million-gallon Type IIIA waste tank on the HTF east hill. Salt solution feed is transferred from Tank 49 to 241-96H. In 241-96H, MST is added, and the material is agitated, then held to allow MST adsorption prior to transfer. This material is transferred to 512-S, where the insoluble solids are filtered out and transferred to DWPF. Cs-laden CSS is sent to the MCU. Decontaminated Salt Solution (DSS) is sent from MCU to Tank 50, which is the feed tank for the Saltstone Facility. The high-Cs content stream produced in MCU is sent to DWPF.

3.4.4.2 Design and Construction

ARP/MCU was developed as a pilot plant in order to demonstrate the process chemical theory and technology required to reach the mission goal, providing operating experience of the ARP and CSSX technology with real waste. Additionally, the ARP/MCU provides interim salt-processing capability to create tank space and support H Area Tank Farm, DWPF and High Contamination Area operations. The general design for this pilot plant followed a modular approach, using skid-mounted equipment assembled in the ARP/MCU project.

The ARP/MCU project was itself a pilot plant, so no pilot-scale testing was done. However, the ARP/MCU design was based on significant laboratory-scale testing. Savannah River National Laboratory (SRNL) conducted laboratory-scale Extraction Scrub Strip testing on real waste. SRNL also conducted laboratory bench-scale testing with two Curium contactors, using real waste, and conducted MST tests with both simulant and real waste.

Prior to installation, the contactor assembly, composed of 18 contactors, was fully tested at the manufacturer. That testing included a 120-hour durability test and a mass transfer test, using non-radioactive simulant provided from a mocked-up cold-feed facility. These tests were repeated, and the results were validated with the actual installed assembly prior to radioactive operations.

Construction started in 2004 and was completed in 2006.The modular design and the use of skid-mounted equipment facilitated the construction process. The Project received authorization for operation in March 2008. The Project was completed on schedule and below cost at a Total Project Cost of $161 million, with an end-of-project cost variance of +$26 million.

3.4.4.3 Commissioning Experience

Since Tank Farm operations were ongoing, operations staff were available throughout the Project and additional operators were not required. Moreover, all support systems were in place, and they had logged many years of operational experience. As systems were completed, they were turned over from construction to operations and then to the startup organization to undergo system tests.

Testing of equipment for commissioning began at the contractor facility prior to installation with hydraulic and mass transfer tests. After installation, the startup testing of ARP and MCU followed a specific sequence of component testing, system tests, individual unit operation tests, and finally integrated unit operation tests. The component testing and system testing were performed by test personnel, who were assisted by operations personnel. Simulant material—material similar to real waste but without radionuclides—was used to perform facility testing. By testing systems with simulant, staff could conduct full process testing to determine whether system hydraulics behaved in accordance with system design and whether process parameters met design requirements. Also, facility operations were validated during proficiency runs, giving operators firsthand experience with system operations.

The startup test procedures were developed in parallel with the ARP/MCU startup testing. In some instances, draft versions of operating procedures were used to support system alignments and system operations, thus validating the operating procedures during startup testing. The system turnover and testing were completed in five months—about one month quicker than planned. When the system testing was completed, and proper turnover to operations was completed, systems were declared operational.

The review for operational readiness process was also facilitated by the experience of the operations staff. The MSA was completed in less than six weeks, with no major issues. The CORR was completed in two weeks, quickly followed by the DORR, which was completed in less than two weeks. Authorization for hot operations followed in one week, and the ARP/MCU facility ramped up to full production in less than one month.

3.4.4.4 Key Learnings

1. Operations personnel were involved with MCU, starting with system design, startup activities, and procedures validation activities and continuing through cold runs and finally hot operations. Early involvement of the operating staff was essential to ARP/MCU operation startup success.
2. Extensive vendor tests of components and subsystems were performed at the vendor facility. Testing issues identified at the vendor facility resulted

in system design changes prior to the equipment's installation in the ARP/MCU facility. This approach avoided startup delays by avoiding re-work of installed equipment in the facility.

3. ARP/MCU was designed as an interim process for a three-year operating life. However, delays in SWPF operations have extended MCU operations beyond the three years; MCU operation began in 2008 and was still processing in 2013. Several design changes have been implemented to extend its operating life. However, these changes would have been more cost-effective if they had been included within the original design.
4. Temperature changes in the manufactured simulant during transport resulted in precipitation of material when the simulant was introduced into the installed process for testing. The precipitation of material created problems, which then had to be addressed during system testing. Establishing temperature limits and controls as part of the procurement/manufacturing process would have minimized or prevented this issue and associated impacts during startup testing.

While the replacement facility for ARP/MCU, the SWPF, is still undergoing commissioning, it has already yielded some successful lessons learned. The SWPF project is an example of a successful integration of testing and design. The contract included a robust Technology Development Test Program in which Parsons constructed full-scale test systems for both the Caustic Side Solvent Extraction (CSSX) and the Alpha Strike Process (ASP) and conducted extensive testing of these processes. Initial testing of these SWPF processes was conducted in Pasco, WA and Barnwell, SC, respectively and identified significant design issues with both the process piping size in the CSSX system and the manufacturer's crossflow filter design in the ASP process. As a result of that initial testing, two design issues were resolved:

- The crossflow filter internals were completely redesigned by the manufacturer and functioned successfully during all future testing.
- The CSSX interconnect piping diameter was changed from 2-inch to 3-inch in the CSSX design to eliminate flow imbalances during processing.

Both of these design issues would have had significant impact on facility startup had they not been identified and corrected as a result of full-scale testing.

As this testing progressed, the need for additional testing of both the CSSX and ASP system was identified, and Parsons leased an industrial building in Aiken, SC and built the Parsons Technology Center (PTC). The center has operated since 2008, as the central testing facility for SWPF. The follow-on testing approved by

DOE included extended duration performance testing of the CSSX System, with crossflow filtration in place and testing to confirm that marginal performance of the Decontaminated Salt Solution and Strip Effluent Coalescers during the Barnwell CSSX test campaign had been corrected through a design modification to both coalescers. This testing was successful in confirming all the design changes discussed above. For the CSSX process, full-design-flow decontamination factors surpassed contract requirements by several orders of magnitude.

Other, previously planned testing was also conducted at PTC. That testing included extended sleeve-valve operability and maintainability testing that identified wear issues with these valves, issues that were then corrected through design changes by the manufacturer. End-of-life-cycle testing conducted at PTC on a redesigned valve confirmed that all wear issues had been corrected.

A second, previously planned test conducted at PTC was a full-scale functional test of the Barium Decay Tank, a unique tank designed to allow short-lived barium to decay before the liquid moved through the final stage of the process. That testing demonstrated that the design did not function as required. As a result, the Barium Decay tank was completely redesigned.

Air Pulse Agitator mix testing, previously performed at both Pasco, WA and another location in Aiken for two different-size vessels, was repeated at PTC to test a new strontium and actinide extractant (Modified MST) and to confirm for the DNFSB that there were no open mixing issues for SWPF. That testing was successful, resulting in a DNFSB letter closing their mixing tank concerns.

Additionally, prototype testing provides throughput data for decision making earlier in the project life. For example, by conducting full-scale cold CSSX testing of solvent, PTC staff demonstrated that throughput capacity was greater than baseline (9.4 megagallons vs 7.3 megagallons per year), even greater (12 Mgal/yr.) with next-generation solvent, and greater still (up to 15+ Mgal/yr.) with high-molarity salt feed. Learning this early in the project left time to examine options for capitalizing on the data.

3.4.5 AMWTP – Idaho

The Advanced Mixed Waste Treatment Project (AMWTP) was initiated as a privatized contract for DOE-Idaho; the contractor selected was British Nuclear Fuels, Limited (BNFL).The contract required BNFL to fund the project using their own money, then recover their capital cost and earn profit indexed to the number of cubic meters of transuranic legacy waste they would ship for disposal. The contract rate structure incorporated cost recovery based on the first 25,000 cubic meters of waste at the Transuranic Storage Area (TSA), remaining waste at the TSA, other Idaho National Laboratory (INL) waste, and offsite waste. In calendar year 2005, the contract with BNFL was ended, and the existing Management and Operating (M&O) contractor at INL was issued a modification to operate the AMWTP.

3.4.5.1 Mission and Scope

The AMWTP mission was to design, build, and operate under a privatization contract a facility to characterize, sort, size reduce, and package for disposal TRU legacy waste.

The AMWTP scope is to manage drum and box waste that requires further treatment (for example, removal of prohibit articles, pressurized containers, liquids, and waste segregation) prior to final characterization, packaging, certification, and shipment to the WIPP for disposal.

3.4.5.2 Design and Construction

The AMWTP concept was based on similar operations in service at the Sellafield facility in the United Kingdom. since the UK operations were well-established, no laboratory, pilot, or full-scale testing was conducted to inform the design process. Design and testing information essentially consisted of using similar equipment and waste-processing methodology from facilities in the UK and/or other industries. The exception to this was the remote box handling and sorting equipment using Brokk floor-mounted manipulators. A full-scale mockup of the Brokk manipulator was constructed for operator training. The mockup is still supporting operations.

Since the plant was based on BNFL's familiarity with the process and equipment, its design and construction proceeded with minimal disruption. The as-constructed AWMTP houses a box-opening gantry saw, two box lines for sorting waste, a box shredder, two drum assay machines, and a Supercompactor.

The legacy TRU is treated in the following sequence of activities:

1. Waste sent to the AMWTP is transported to different areas within the facility by an intricate system of conveyors. All waste handling is controlled remotely. The two waste-treatment boxlines contain Brokk floor-mounted manipulators, PaR Overhead Power manipulators, and manual master–slave manipulators.
2. In the boxlines, the waste is sorted and size-reduced, then packaged in "silver drums" for processing through the supercompactor.

3. The emptied boxes (metal, fiber-reinforced polymer and plywood) are sent to the shredder.
4. All silver drums are processed through one of the two assay machines to determine their fissile content prior to supercompaction.
5. The supercompacted drums (that is, pucks) are then loaded into 100-gallon puck drums.
6. The 100-puck drums are transported out of the facility for final assay and packaging for disposal at WIPP.

3.4.5.3 Commissioning Experience

Commissioning activities proceeded smoothly because of BNFL's experience with the equipment in the UK. The System Commissioning and Operability Testing process was specified in the BNFL contract, with the testing plan and testing results submitted to DOE-Idaho for approval. To the extent practical, components and systems were tested at the manufacturer's facility—that is, during Factory Acceptance Testing—prior to being installed in the facility. The AMWTP underwent construction testing and acceptance by system. The activities within the treatment facility were divided in systems. Because systems were completed individually, they were turned over from construction to operations for testing and commissioning. Ultimately, a 380-item punch list of turnover items was completed by the Operations and Testing group because that group was judged to be more familiar with the system requirements than the constructors.

When the individual components were successfully commissioned, they would be tested and commissioned with their respective upstream or downstream system. Finally, surrogate materials (boxes and drums) were processed through the complete operation to test and confirm functionally and automatic operations. Surrogate material usage for testing varied based on the system being tested. For example, assay machines were tested using a source drum. The Supercompactor was tested with drums containing wood and metal components.

The AMWTP did not involve significant chemistry challenges that surrogate materials needed to replicate or simulate. The biggest challenge was fine-tuning the automated system, the drum conveyors, the assay feed stock, and the machine-to-machine communications between the automated systems.

The AMWTP was essentially commissioned in three phases, each ending in an ORR:

1. The first ORR evaluated BNFL's ability to safely manage the TRU and mixed low-level waste inventory, referred to as "Waste Stewardship."

2. The second ORR evaluated the safety management systems, waste storage, retrieval, characterization, packaging, and shipment.
3. The third ORR was focused entirely on the treatment facility.

Schedules for key turnover, testing, and commissioning events therefore proceeded within their phase, with some overlaps between phases, as shown with completion dates in sections 3.4.5.4 through 3.4.5.6.

3.4.5.4 Waste Stewardship (Phase 1)

- DOE Line Management Assessment (LMA) – May 2001
- DOE ORR – June 2001
- BNFL authorization granted – 2001

3.4.5.5 Retrieval and Waste Characterization Operations (Phase2)

- Approval of Commission System and Operability Plan – January 2002
- Commission System and Operability Plan Test Results Comments – February 2003
- Approval Commission System and Operability Plan Test Results – August 2003
- DOE LMA – October 2002 to January 2003
- Contractor ORR – January 2003
- DOE ORR – February 2003 (Industrial Hygiene program in question – ORR continued)
- BNFL authorization granted (restricted operations) – March/April 2003
- DOE Startup Plan (augmented oversight) – March 2003
- BNFL authorization granted (unrestricted operations) – November 2003

3.4.5.6 Treatment Facility (Phase 3)

- Approval of Commission System and Operability Plan – November 2002
- Approval Commission System and Operability Plan Test Result – 2003
- DOE LMA – July 2004
- DOE ORR – August 2004 (Note: ORR report issued November 2004)
- BNFL Authorization (treatment facility operations) – 2004

During the treatment facility ORR process, the regulatory basis for operations became an issue. As a “privatization contract,” the BNFL contract did not include all the DOE Orders. A subset of DOE Orders was selected for the contract, and revisions to the Orders did not always result in contract modification. The end product of this approach was a document called the *Environmental, Safety and Health Program Operating Plan* (ESHPOP). he ESHOP was regularly reviewed and approved by DOE-Idaho. However, members of the ORR teams were not familiar with this approach and judged the rigor of documentation for many environmental, safety, and health (ES&H) controls to be lacking. BNFL managers were not familiar with the DOE Orders. Accordingly, they based their approach on comparable, but not identical, ES&H systems. Ultimately, BNFL was compelled to meet established DOE requirements, but not without considerable turbulence and expense.

The plant's startup was further complicated by WIPP certification. A WIPP audit was required, followed by ultimate authorization from WIPP to allow treatment of TRU waste. The WIPP audit would not be scheduled and conducted until the treatment facility was authorized to operate on the basis of the results of the DOE ORR. Thus, there was a gap of about six months when the AMWTP was authorized to operate, but could not process TRU waste for disposal—its mission. Most of this time was used for cold testing of the facility and additional surrogate testing and fine tuning. To BNFL, this extended period of operation with surrogates was frustrating. But the extension yielded one beneficial result: after WIPP certification, the AMWTP quickly ramped up to full production operations.

3.4.5.7 Key Learnings

1. The commissioning group and operators were integrated as a contributing part of the BNFL team from start of design, through construction and commissioning, to operations. Some designers had operated the UK facilities upon which AMWTP was modeled and hence were very knowledgeable and experienced. As a result of this approach, design and construction efforts were effective, and turnover to commissioning and operations was mostly seamless.
2. Contractor documentation and procedures were weak because of the wide latitude allowed by the privatization contract and the contractor's lack of familiarity with DOE Orders. Ultimately, the required standard was met by "augmented oversight" from DOE. But this approach proved to be difficult and inefficient.
3. The privatization contract approach, while positive for both the BNFL and the DOE in concept, was very difficult to administer. The contractor was incentivized to meet minimum requirements, while the DOE continually pushed the contractor to do better than "good enough." This tension caused inefficiencies and turbulence, especially during the ORR process.

Ultimately it led DOE to reassign the operations portion of the contract to the M&O Contractor.

3.4.6 Transuranic Waste Processing Center (TWPC) – Oak Ridge

The TWPC was initiated as a privatized contract for DOE-Oak Ridge, and the contractor selected was Foster Wheeler Environmental Corporation (FWEN). The contract required FWEN to fund the project using its own money, then recover the capital cost and earn a profit indexed to the amount of TRU waste treated and packaged for disposal during operation of the TWPC facility. FWEN was awarded the contract in August 1998. FWEN designed and built the TWPC and began the first treatment campaign in January 2004. Operation of the facility was transferred to EnergX in 2007, then to the subsequent operator, Wastren Advantage, Inc., in 2009.

3.4.6.1 Mission and Scope

The project's mission was to design, build, and operate under a privatization contract a facility to characterize, treat, and package for disposal liquid and solid TRU legacy waste. Initial inventory of waste, mostly from Oak Ridge National Laboratory, included 2,000 cubic meters of sludge tank waste, 429,000 gallons of supernate (SN), 1,500 cubic meters of contact-handled (CH) TRU debris waste, and 500 cubic meters of remote-handled (RH) TRU waste.

3.4.6.2 Design and Construction

The TWPC facility was conceptualized as a collection of proven technologies assembled within the TWPC facility, each technology designed and intended to process a specific waste stream. The sludge waste was to be "washed" with process water, and the soluble species were to be treated as supernate waste. The suspended solids were to be dried and the dry product placed into what were then 72-B canisters. But because of the delay in WIPP receiving RH TRU waste and additional process development, a stabilization and solidification process, using cement, fly ash, and slag as binding materials, was planned for sludge wastes. The project was ultimately renamed the Sludge Processing Facility Buildouts (SL-PFB) project. It is currently undergoing CD-1 reauthorization.

An Evaporator combined with a Vacuum Dryer was used for the liquid SN generating a stabilized LLW. A sorting and packaging area was planned for CH and RH TRU Legacy debris waste, with an expectation that only about half the waste would be TRU and the other half would be low-level waste.

Approximately one year after CH Operations commenced, a Macro-Encapsulation process was added to treat mixed low-level waste (MLLW) identified during the TRU certification process. All equipment and systems were considered "proven technology" because they had been used in similar or near-identical waste processing at other facilities. Given this perspective, there was no laboratory or pilot-scale testing. Pre-qualification of equipment vendors and substantial full-scale component testing at the vendor locations and post-installation were used to verify equipment capability.

The overall concept of multiple treatment modules installed in a host facility allowed design and construction to proceed in parallel. For example, the tanks, SN Evaporator, SN Dryer, and associated subsystems for processing SN mostly on the first floor of the facility were installed before the CH, RH, and sludge equipment was installed on the second and third floor. The approach was generally successful; vendor equipment experienced only a few problems, and those problems arose only because engineering design information was delayed.

3.4.6.3 Commissioning Experience

The commissioning effort began as specific major equipment items or subsystems were completed. Turnover from construction to operations was generally seamless because the operators were considerably involved in component testing. Operators became involved with the systems approximately eight months before construction was complete. A three-phase testing plan was established to verify treatment system operation, starting with benign material (such as water), followed by surrogate waste, and finally by limited quantities of actual waste. The second phase with surrogate wastes was significantly extended from a planned duration of about 2 months to an actual duration of almost 12 months. But this extended time allowed the operators to increase their proficiency and confidence with the treatment systems. Engineering remained available for consulting throughout the testing and commissioning, even extending into early operations. Their availability proved to be very positive in support of the commissioning effort.

The readiness review process was also planned in three steps: an MSA, CORR, and DORR. The initial CORR was stopped before completion when it became apparent that the contractor was not ready. After about two months of additional preparation, the Contractor successfully completed their ORR; this CORR was followed by a successful DORR. The overall MSA/CORR/DORR process was planned for three to four months. It actually required five to six months.

After authorization was given, the TWPC began hot operations in the facility very quickly. The use of proven equipment technology and extensive surrogate testing allowed hot operations to begin with high confidence. Ramp-up of processing to full design capacity followed a "crawl–walk–run" philosophy to ensure that systems were well-understood and operating as expected before staff would proceed to the next step. Even with this deliberate approach, the ramp-up was accomplished in about three months.

3.4.6.4 Key Learnings

1. Early acquisition and training of process operators are very beneficial to a successful turnover and commissioning process. Operators should be engaged before construction is complete and should be actively involved in construction turnover and testing. The operators should then move from testing into processing operations.
2. Ensure that the Contractor is completely ready before the ORR process is begun. As the ORR nears, time pressures become more significant. But taking extra time to ensure readiness is still preferable to experiencing significantly more extra time—and embarrassment—for corrections during an ORR or after a failed ORR.
3. Maintaining the consistency and availability of the engineering and operations staff from construction through early operations was very positive and helpful. The combination of experience and established working relationships supported successful problem resolution when it occurred. It also facilitated the overall commissioning and operations ramp-up.

3.4.7 Waste Isolation Pilot Plant (WIPP) – Carlsbad

The WIPP facility was the culmination of a four-decade effort to provide a repository for defense transuranic waste. Original investigation work begun in the 1950s was intended to support disposal of high-level radioactive waste from both defense and commercial (nuclear power) sources. However, regulatory and political concerns limited the focus to address only defense sources, TRU waste. Even with this reduced scope, the WIPP would be a first-of-a-kind deep geologic disposal facility for radioactive waste. As such, it experienced significant technical, political, legislative, and stakeholder challenges. While this report focuses on the technical facility commissioning, the other aspects cannot be ignored. After the facility was constructed, the political and legislative challenges required an additional ten years to resolve, creating a total commissioning timeline that was extended, complicated, and unique in EM experience.

3.4.7.1 Mission and Scope

The project's mission was to design, build, and commission a geologic repository with associated surface facilities to provide a way to dispose of TRU wastes safely and permanently.

3.4.7.2 Design and Construction

Earliest laboratory-scale testing of TRU waste disposal in geologic salt formations began in Lyons, KS, by the NAS in the 1950s. For the next 30 years, government and industry continued research, including pilot-scale excavations to determine performance of the salt formation. Information was also gathered from the German Morsleben repository. The experience gained by the NAS researchers allowed there to be knowledgeable peer reviewers for the WIPP project as it was developed. Moreover, independent peer review by NAS helped support the technical and scientific reasoning for the disposal of CH TRU and for the eventual disposal of RH TRU in a salt environment at WIPP. Their reports were provided to Congress and other stakeholders to verify that WIPP was safe for the community and the environment.

It should be noted that, although this report mentions full-scale testing at the WIPP facility from the programmatic sense, the entirety of the WIPP, as indicated by its name, is a "pilot" for deep geologic disposal of radioactive waste. Beginning in the early 1980s, some full-scale excavations were created in the North Area of the WIPP site in New Mexico. These tests generally focused on heat generation and thermal testing of the salt formation response. Pilot-scale heat tests also continued at Lyons, KS into the 1990s.

Construction of the WIPP excavation proceeded using well-established mining equipment and techniques. Salt is one of the safer and easier geologic structures to mine. As a result, the excavation proceeded relatively quickly, with no major difficulties. The Mine Safety Administration was directly involved in overseeing the excavation aspects of the overall project.

The WIPP received unprecedented interest and involvement across a wide range of disciplines. This involvement spanned multiple decades. Overall management of the research, design, and construction by DOE and its predecessor agencies was a significant challenge because of the extended time period and the complexity of the mission.

3.4.7.3 Commissioning Experience

Turnover of WIPP facilities from construction to operations was organized by geographic area within the mine. To facilitate the turnover effort, Operations staff were hired and trained many months in advance of turnover. However, the turnover planned for 6 months required almost 18 months to complete. Operators were skilled Nuclear Engineers, many with Nuclear Navy experience. But they were not familiar with operations in a mine. Conflicting perspectives between mine safety issues and nuclear safety issues confounded the turnover process. These conflicts further manifested in the development of operational procedures that took almost three years to complete.

Legislative and regulatory requirements required almost a decade to resolve (1989 to 1999). Beyond the obvious cost of holding a facility in "standby" and the lost-use opportunity costs, tangible disposal capacity was lost. Excavated salt rooms slowly collapse (creep), which is part of what makes them desirable for TRU waste disposal, but desirable only after waste is emplaced. During the ten-year delay, three panels with 780 boreholes each were lost due to creep.

Once the legislative and regulatory path was clear, the external scrutiny of the facility readiness was intense. The internal review (now called a Management System Assessment) was planned to require two months, followed by the two-month CORR and a one-month DORR. Each of these efforts was conducted rigorously and thoroughly, completing successfully close to the planned schedule. But once authorization to accept TRU waste for disposal was granted, the WIPP still continued to be constrained by external political concerns. Additionally, WIPP operated only when receiving TRU shipments from generator sites around the country. Integration of requirements for generator shipments with WIPP receipt was poorly understood at first, further impairing the ramp-up to full disposal capacity. Initial waste receipts were limited to CH TRU. It took another seven years of careful planning and demonstrated performance to begin accepting RH TRU waste.

It is important to note that, despite the many interested stakeholders attempting to derail or delay the WIPP, the local community was very supportive. Strong community support existed from the beginning for citing WIPP in Carlsbad, NM, and this local support was considered one of the critical elements of success for creating the WIPP radioactive disposal facility.

3.4.7.4 Key Learnings

1. DOE needs to actively manage the facility and the contractors from the earliest stages, including early research, design, and construction. Technical and scientific aspects of disposal, such as disposal site performance assessments, are critical to success. However, DOE must also manage the complex political, regulatory, and stakeholder aspects of the project. That management becomes even more important as the project schedule becomes extended.
2. The local community needs to be your facility's strongest advocates. Community participation is essential and community members—both residents and business owners—should be actively engaged throughout the process.

3. Good communication of the program mission and goals is essential. Be sensitive to the political aspects of radioactive waste disposal. Be prepared to explain in simple terms what the facility is doing, why it is safe for the community and environment, and how it is of benefit to the country. Using the same simple, straightforward talking points for everyone ensures consistency and clarity of the message. It is also useful to apply the same clear and simple approach with regulators, to the extent possible.
4. Ensure that the skill sets and experience of both contractor staff and DOE overseers evolve in accordance with the project needs. Skills need to shift in recognition of requirements and the essential evolution of the facility throughout its lifecycle, from concept to decommissioning.

3.5 Impact of 2014 Events

Some of the decisions that caused problems are cross-referenced below to specific recommendations of section 2.1 that were violated.

On February 5th, 2014, the WIPP facility experienced a significant fire on a salt-hauling vehicle in its Underground while 86 workers were in the mine. The fire developed quickly; it involved one of the tires of the vehicle and its hydraulic and fuel payloads. Worker evacuation was complicated by deficiencies in the emergency announcement systems, ineffective training on mandatory respiratory escape equipment, and inappropriate corrective actions taken on the surface with the ventilation systems in the mine. Nevertheless, all 86 workers escaped. The mine was shut down and an Accident Investigation Board (AIB) was commissioned. The Board found numerous systemic deficiencies in the Safety Management Programs at WIPP and issued a report detailing multiple Judgments of Needs (JONs), which were necessary before operations could restart.

While the AIB was still conducting its review, on Feb 14th, 2014 a waste drum experienced an exothermic reaction within, causing an active waste emplacement panel to release its contents into the mine. The mine was unoccupied at the time, so no one was contaminated within the mine itself. However, a number of workers on the surface were contaminated while investigating the causes of the event. The mine ventilation system is configured such that the exhaust air is monitored by a Continuous Air Monitor (CAM). The CAM is designed to reroute all the mine exhaust ventilation to two banks of HEPA filters on the surface. The CAM also secures the normal running ventilation fans, reducing the airflow in the mine from as high as 425,000 cubic feet per minute (cfm) to 60,000 cfm. It was later discovered that dampers in the above-ground ventilation system that rerouted the air had been built in such a way that the butterfly assembly would allow nearly 1,000 cfm of flow to pass through the damper even when the damper was in the completely closed position. This unsuspected airflow was a contributing cause of the contamination to the workers.

A second AIB was commissioned and conducted a review of the radiological release. The cause of the exothermic reaction was the mixing of an organic liquid absorbent (kitty litter) and the nitrated salts in the offending drum at the generator site.

Following isolation of the drums, the prime contractor embarked on a recovery mission to reclaim portions of the mine that had been contaminated and to catch up on ground-control activities, which had not been conducted for almost nine months.

This recovery was greatly complicated by three unanticipated issues:

- The significantly reduced airflow in the mine affected the ability to run the mining equipment necessary to install bolts in the roof. In the past, as many as four bolting machines could be run simultaneously. Now, only two bolters, sometimes only one, had enough airflow in the immediate area to properly carry away the diesel emissions.
- The crews operating the bolters now had to perform work in contamination areas. As salt is mined, it releases fine dust and contaminants entrained in the salt matrix, making it necessary for the workers to wear respiratory protection. None of the bolting crews had ever worn respiratory protection; very few were even qualified as rad workers. Radiological survey equipment was in short supply, and the expertise to use it was not available at WIPP. So radiological technicians from all over the country had to be brought into Carlsbad.
- The WIPP DSA was determined to be deficient and would be required to be reissued to comply with the new 3009-2014 Standard for DSAs, the first of its kind in the DOE Complex.

As part of the recovery effort, plans were formulated for a new, permanent ventilation system capable of running at pre-event airflow rates, all through HEPA filtration. But the new ventilation system would require a significant capital project and would take years before it would come to fruition. Hence, plans were made for an Interim Ventilation System (IVS) that would double the HEPA-filtered flowrate. The IVS was slated to be installed in March 2016.

Problems with the procurement and design of the Interim Ventilation System plagued the project from its beginning:

- The prime contractor did not perform its own inspections; it relied on its subcontractor for onsite quality assurance of the vendor's work (Recommendation 10).
- The system was built with wrong types of materials.
- Commercial-grade dedications had to be conducted on many of the components to ensure their suitability for installation. The documented evidence that the dedications were adequate was not completed, even after the installation of the components had been completed.
- Finally, the initial ductwork fabricated for the new system was transported to the WIPP site on a truck without a proper strongback, resulting in damage that required repairs (Reference 19), further delaying the installation (Recommendation 7).

During the IVS installation, the subcontractor was cited for a number of hoisting and rigging violations. After installation of the IVS was complete, a Contractor Readiness Assessment (CRA) was conducted by a Line Management Assessment, accompanied by a DOE shadow team. The CRA Team concluded that the Contractor was not ready to start the IVS (Recommendation 15d3) system because they had implemented the new DSA just prior to the CRA for the IVS, and all the procedures and training for the IVS were still written to the old DSA version (Recommendation 14). DOE directed the Contractor to conduct an MSA to ensure that they had prepared properly to start the IVS. DOE then required that a Federal Readiness Assessment (FRA) be conducted.

NWP passed the FRA, but these delays pushed out the startup of the IVS by six months, to September 2016.

Meanwhile, the Contractor began its MSA for waste emplacement in August 2016, followed by its CORR in October. The reviews revealed many issues. Of special note was the fact that both reviews concluded that the Contractor had not taken as much time providing the workforce with sufficient run time on the new procedures and practices to demonstrate anything but just passing performance. Also, the physical plant was not ready to start waste emplacement at the start of either review. A significant number of items were carried into the CORR on the manageable list of items because the plant was not physically ready to support waste emplacement. Among these items were three key pieces of equipment or facility:

- the only waste transporter capable of carrying the waste payloads in the mine, which still needed a compliant fire-suppression system installed

- the roof of the room where waste emplacement would commence, which needed bolting to keep a roof fall from occurring
- the floor of the room where waste emplacement would occur, which needed leveling to allow vehicles transporting waste to travel without the danger of dropping the payload

While these activities were occurring, WIPP experienced progressively deteriorating mine ground conditions. In the WIPP underground in the south sections of the mine, two roof falls occurred. The roof falls happened in access drifts to two of the closed waste-emplacement panels. The Contractor could not conduct roof bolting in these areas because of competing resources for recovery activities. So access to these areas was prohibited. Furthermore, Mine Safety and Health Administration inspectors deemed other areas to be too dangerous to enter.

The DORR began in November 2016, two weeks before Thanksgiving. Because of the long holiday break, the DORR reviewers had to split their time at WIPP into two periods: before the break, and after. This discontinuity placed a strain on the DORR team.

The team determined that WIPP staff was ready to begin waste emplacement as long as they corrected the findings determined in the review. There were 21 Findings. The scope of the review was broad, but all the same, 21 Findings represented an unprecedented number. While validating the closure of the Findings, CBFO determined the floor of the room where waste would be emplaced was still not level enough to support safe waste emplacement. Accordingly, the CBFO delayed the initial emplacement until January 4, 2017. On that day—1,064 days after the fire in the salt haul truck—the WIPP facility finally emplaced two payloads of drums into Panel 7 of the WIPP underground.

Key WIPP Restart Takeaways

1. Facility conditions changed significantly since the issuance of the AI's Judgments of Need (JONs), to the point that some were obsolete and were diverting attention to what was actually required for restart.
2. Some of the resources sent to support WIPP were not technically aligned with the needs of an active mine that conducts Nuclear Operations (Recommendation 11).
3. The Contractor staff focused their attention on passing the CORR and the DORR, not on preparing to operate (Recommendation 15d4).
4. The physical plant was not actually ready to start any of the readiness activities when they were commenced.

5. The Contractor tried to conduct two major readiness activities in parallel: the implementation of the new DSA and the IVS CRA. This parallel approach proved unsuccessful.
6. The MSA and the CORR determined that although all of the plant procedures had been written and were in place, the operators had been given too little time to become proficient in them, leading both parties to recommend soak time prior to moving on to the next step in the readiness process. Readiness is not achieved with a procedure in place. It is achieved when a procedure or a process is understood by the workers who must conduct it. Workers must be given the time necessary to become proficient in the procedures and processes they will be conducting (Recommendation 15a3).
7. In the face of schedule pressure to restart waste emplacement, the WIPP contractor prioritized all things necessary to support waste emplacement over other concerns, including a concern for life safety. This misplaced prioritization was the result of setting unrealistic goals with little or no contingency to account for failures.

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