Waste Solidification Building Project Y473
Lessons Learned Report
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APPROVALS

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Project Background Summary

Savannah River Site

The Waste Solidification Building is located within the F Area of the Savannah River Site (SRS). SRS occupies about 300 square miles (192,323 acres) on the upper Atlantic Coastal Plain of South Carolina and is located approximately 25 miles southeast of Augusta, Georgia; 22 miles south of Aiken, South Carolina; and 100 miles from the Atlantic Coast.

Waste Solidification Building

The mission of the Waste Solidification Building (WSB) is to process radioactive waste streams from the Mixed Oxide Fuel Fabrication Facility (MFFF) into the following waste forms: (1) a waste form that is suitable for shipment and disposal as transuranic (TRU) waste at the Waste Isolation Pilot Plant (WIPP), and (2) low-level waste (LLW) that is suitable for disposal at the Nevada National Security Site (NNSS). The WSB will be operational to support both the MFFF startup and operation.

The WSB is a 33,000 square foot reinforced concrete structure located near MFFF. It is a single story facility with the exception of the localized area surrounding the high activity waste (HAW) processing area, which is two stories. The second story provides elevated work areas to conduct operations and maintenance activities. Concrete process rooms are provided to process the waste streams in the building. The major pieces of process equipment are tanks, evaporators, and solidification equipment. Concrete is utilized to mitigate personnel exposure and to provide isolation from potential high alpha airborne exposure and direct dose field caused by the MFFF HAW stream. Enclosures adjacent to the process rooms provide worker protection to accommodate operations and maintenance activities. The shielding also serves as fire isolation barriers. The facility also houses the low-activity waste (LAW) processes, cold chemical feeds, storage, shipping areas, and balance of plant services. Secondary containment features such as dikes, sumps, and leak detection are provided for those areas with liquid waste spill potential.

The WSB processes the following separate waste streams in a batch process:

- One low-activity stream composed of the MFFF stripped uranium
- One high-activity stream composed of the MFFF high alpha stream

The waste streams enter the WSB via dedicated underground transfer lines from MFFF. The WSB has separate processing capabilities for the HAW and LAW streams as described below The WSB has the receipt capacity to accommodate MFFF operations during a planned WSB outage.

The MFFF high alpha stream is referred to as the HAW stream. The HAW may be evaporated to reduce the amount of TRU solid waste generation if necessary; however, the evaporator may be bypassed and the HAW transferred directly to the cementation process, depending on the concentration of the waste stream. The resulting overheads, if any, are transferred to the LAW stream for further treatment prior to transfer to the existing Effluent Treatment Plant (ETP). The resulting bottoms are neutralized and mixed with cementation materials to produce a solid form that is temporarily stored at the WSB site to solidify. The HAW drums are placed in a shielded transport unit to reduce worker exposure. The waste containers are loaded onto site vehicles for shipment to the SRS E- Area Waste Management Area Project (WMAP). After arrival in E-Area, the drums containing TRU waste are loaded into Transuranic Packaging and Transporter Model 2 (TRUPACT II) containers bound for WIPP.

Stripped uranium waste from MFFF feeds the LAW stream. The LAW is evaporated to reduce the amount of solid LLW generation. The resulting overheads are used as process dilution water or treated to allow for transfer to the existing ETP. The resulting bottoms are neutralized and mixed with cementation materials to produce a solid waste form. The final waste product is solidified in 55-gallon drums and temporarily stored on a separate covered concrete pad adjacent to the WSB, pending transfer to E-Area. Drums containing LLW are transferred to the NNSS.

The National Nuclear Security Administration (NNSA) directed that the WSB be placed in a modified lay-up mode to provide sufficient maintenance and protection to the facility to minimize undue equipment degradation. Based on this direction, only those systems that are required to be operational were commissioned. Equipment testing was limited to that necessary to demonstrate the ability to operate habitability support systems during layup. The remaining systems were placed in layup consistent with the facility layup plan developed by engineering. At the conclusion of startup testing, the WSB completed a Readiness to Operate Assessment to verify that the WSB Project met the core requirements necessary to satisfy the DOE Order 413.3B, “Program and Project Management for the Acquisition of Capital Assets” in preparation for Critical Decision (CD) -4 approval. WSB will remain in the modified lay-up status for an anticipated period of ten years. During this time, a limited Management and Operations (M&O) staff (operations, maintenance, and engineering) is assigned to the facility to operate key support systems, perform limited scope maintenance for system upkeep and repair, and to provide a small core of system knowledgeable personnel available to assist in the transition from a modified lay-up state to a facility that is ready to receive MFFF water transfers in the future.

The WSB is required to be operational in time to receive transfers during MFFF startup testing. It is anticipated that during MFFF Startup testing, the WSB will receive both non-radioactive liquid and chemical transfers. The WSB will not receive radioactive liquid transfers until the MFFF begins nuclear operations.

A phased approach to WSB nuclear operations is planned as follows:

- WSB placed in a modified lay-up state at the completion of equipment testing and CD-4 approval (complete)
- Startup Testing
- Non-radioactive water transfers during MFFF startup testing runs
- Chemical waste transfers during MFFF startup testing runs
- Savannah River Nuclear Solutions (SRNS) and NNSA Operational Readiness Review (ORR) to authorize WSB nuclear operations in accordance with DOE 0 425.1 D (or successor)
- Radioactive waste transfers upon authorization of MFFF facility operation

CD-4 approval was formally granted by NNSA on 7/31/2015.

Project Execution Summary

The WSB Project (Y473) required compliance with American Society of Mechanical Engineers Quality Assurance (NQA-1, 2000) and was managed in accordance with DOE Order 413.3 (Project and Program Management), using Earned Value Management System (EVMS) requirements.

Conceptual, preliminary and final design was performed by the prime SRS Management and Operations contractor. Fixed Price or Fixed Price Design/Build subcontracts were used by

SRNS to procure critical long lead (tanks, evaporators, glove boxes) and specialty engineered equipment (cementation system/enclosures). Early site subcontractors were used for the installation of electrical and underground utilities ahead of the general Construction subcontractor responsible for performing the process facility civil, mechanical, and electrical work scope. The general Construction subcontractor utilized sub-tier contractors for electrical, mechanical, and specialty work. The Construction subcontractor scope included material and equipment procurements and field engineering. Final construction, startup, and commissioning were performed by SRNS.

This report addresses lessons learned from the WSB project relative to design, procurement, construction, startup, and commissioning. The objective is to identify successes, issues encountered, opportunities for improvement, and recommendations for implementation on future projects.

Project Management Lessons Learned

- **Employee Orientation**
  The WSB staffing needs required the use of a significant number of staff augmentation subcontractors and other resources from elsewhere onsite. These personnel were not familiar with SRS and/or WSB Project procedures and processes. Organizations developed project specific orientation/ training packages in order to quickly orient personnel and minimize inefficiencies in the amount of time for subcontractors and reassigned onsite personnel to become familiar with WSB Project procedures and processes. Engineering developed an orientation checklist identifying key safety basis documents, desktop instructions, project policies and procedures, responsibility matrices, key specifications, location of network databases, etc. to facilitate each individual quick familiarization with the WSB project and how business was conducted. Completion of the process was documented via the Required Reading process. Projects should develop a plan for project familiarization and an orientation package. Task specific training should be provided for employees based upon the planned staffing curve.

- **Collocation of Project Team**
  The entire staff dedicated to WSB Project team including, engineering, construction, project management, project controls, startup, operations, maintenance, procurement, project owner, design authority and quality were collocated in adjacent space throughout the design construction, and startup phases of the Project. Collocation fostered teamwork and open communication. Support from the Design Authority Engineering function was further enhanced when they relocated to the immediate project site during the final construction and

startup, and commissioning phases. This enabled Engineering and Operations staff to be immediately available to jointly resolve emergent field issues.

The WSB Project was also staffed by matrixed design organizations, not assigned to or collocated with the WSB Team; e.g. fire protection, structural mechanics, piping stress analysis, procurement specification writers, and architectural designers. As a result of the associated communication logistics and competing priorities, the WSB Project faced cost, schedule, and design deliverable impacts. There was noticeably more timely support of the project by those functions which were collocated and dedicated to the WSB project. Early recognition and communication of these issues to senior management may have mitigated downstream project impacts.

- **Action Item Database**
  The Project developed and maintained a single real-time action item database to track technical issues. These issues were religiously reviewed and updated during the Project Team Plan of the Week (POW) meeting. The action item database helped the Project establish priorities, action ownership responsibilities, and resource planning. Any scope, cost, and schedule impacts were identified and reported to Project Management via change control (trends). During the latter project stages, this process facilitated timely completion of both the Construction subcontractor and SRNS construction activities. Issues were given high visibility during the Plan of the Day (POD) discussions to ensure timely follow-up and completion. On a weekly basis the status of these issues was provided to Management at the POW. Priorities were revisited and ownership and/or support resources were assigned as required to maintain the project schedule.

- **Early Involvement of System Engineering**
  The inclusion of the Systems Engineering Group as part of the WSB Project Team early in the Project aided in the development and continual maintenance of critical project documents that ensured technical baseline documents remained current. A strong Risk Management program was developed early through the guidance of Systems Engineering and their involvement in routine risk meetings ensured the Project Team maintained rigor and discipline in managing risks. Early in the project a project risk list was developed. Throughout the life of the project, the list was used as a management tool to track the closure/mitigation of risks previously identified and to identify, document, and evaluate newly emergent risks during the lifecycle of the project as issues evolved. This practice was effective in managing risks to ensure impacts to project cost and schedule were minimized The timely development of the System Design Description documents was a key element in

communicating design requirements to the design team. Also, the early development of the Functional Acceptance Criteria allowed the Startup group to initiate system test plan development in a timely manner to ensure the facility was not only designed to operate, but designed to be testable.

- **Match Subject Matter Experts to Processes**
  In the very early stages of the Project, the Technical Subject Matter Expert base for the Project Team was dominated by personnel with nuclear materials separation technology experience because the Waste Solidification Building was originally a part of the Plutonium Disposition and Conversion Facility (PDCF) Project and the PDCF Project utilized separation process technology. However, as the development of the WSB processing strategy matured, the evolving technology became more analogous to waste processing technology used elsewhere. As development continued, the shift in technology was recognized, and personnel were added to the project to bring this unique waste processing experience which allowed process changes to be made. This simplified the design and reduced project costs. In some cases however, the process design had become too mature to allow some changes and optimizations to be made without significant cost and schedule impact. Recognizing shifts in technical strategies early in projects allows matching the talents and experience of Subject Matter Experts to the technology being utilized so that timely application of these resources will ensure that the process technology employed is optimized throughout the design.

- **Good Utilization of Trends**
  The Project Team developed a robust change control process early in the design stage, even though not required, before the formal Project Baseline had been established. The Project Team executed a disciplined and rigorous approach to project execution, controlled through formal change review that allowed project decisions to be tracked and documented. A Project trend process was utilized early that ensured any and all proposed changes that impacted project cost, schedule and technical baseline were properly evaluated by the Project Team. Inclusion of the Federal Project Director in this process ensured that there was adequate and timely communication of project related issues, both technical and political in nature that could have significant impacts on the WSB Project. In some cases, trends were brought before the Project Team in the conceptual state, before detailed cost and schedule impacts had been developed. This allowed the Project Team to have early input into the issues before significant resources were expended. This approach was extremely valuable during external reviews in that it provided a solid, documented paper trail for the auditors to understand why certain decisions were made relative to the project technical baseline.

- **Critical Staffing, Marketplace Competition and Technical Expertise**
  The WSB Project was unique in that its technology required expertise in both cementation and chemical processes. Maintaining knowledgeable, cognizant engineering personnel from detailed design phase to support construction phase greatly reduced the time needed to approve/implement changes and resolve emergent issues during the procurement/ construction/testing phases. Large dividends are accomplished by employing and effectively implementing this strategy. Because the WSB Project was adequately staffed with critical Design Authority personnel, the quality of design inputs greatly influenced the ability to keep the project on track. However, due to outside market conditions and resource competition with other large onsite projects, the Project suffered high turnover rates. Obtaining and retaining high quality, experienced personnel was a constant challenge. This influenced design quality, schedule commitments, and costs. Market condition rate adjustments and the organization's commitment of required onsite resources provided to the project could have mitigated the impacts resulting from these issues.

- **Early and Ongoing Engagement of People (Site Experts, Regulators, and Oversight Personnel)**
  Early in the Design Phase, the WSB Project Team used previously accepted SRS practices as a guide in developing flow sheets, design requirements, and safety basis strategies. Example assumptions include; basing the conceptual cementation process on Saltstone, developing a justification to supply a safety related sprinkler system from a non-safety source similar to another facility on site, using the Defense Waste Processing Facility (DWPF) criterion for Hydrogen pipe explosions, and expecting soluble tributlyphosphate (TBP) levels in receipt waste streams. When the WSB Project began discussions with the cementation experts the advantages of an in-drum mixing concept over a mix and pump process became apparent. Subsequently, the development of the in-drum mixing concept was able to lag the rest of the project allowing for focus on nearer term design priorities. By engaging oversight groups early in the design process, the timely development of solutions alleviates rework. For example, Defense Nuclear Facilities Safety Board (DNFSB) standards and expectations for new projects are higher than existing projects. Beneficial discussions were held with the DNFSB regarding the fire water supply functional classification and changes to the hydrogen pipe explosion calculation input assumptions as a better understanding of the expected TBP levels became available. These discussions resulted in major design impacts to the project. Because they occurred sooner rather than later, the impact on the cost and schedule was minimized.

  The Project engaged personnel from the Environmental Compliance and Waste Management organization to support obtaining the permits required from the State of South Carolina. The organization had developed a strong working relationship with South Carolina Department of Health and Environmental Control (SCDHEC). Maintaining strong working relationship and good communication with Permitting Regulators SRNS enabled the Project to obtain required regulatory approval of a modified operating permit once NNSA made a decision to place the facility in an extended lay-up mode.

- **Active Engagement of NNSA Customer**
  The NNSA customer was an active member of the WSB Project team and participated in critical project related decisions so that there was a clear understanding of the issues and all potential solutions. This ensured that as issues evolved, there was a clear understanding of what the issues were and why they came about. When there were alternative solutions, the solution selected offered the best value to the Project in terms of cost and schedule impacts. Having an NNSA customer who was technically versed in the project details allowed for open discussion of various technical approaches so that there was a balance between changes that were required to ensure process functionality and changes that improved constructability or operability. The project always had clear direction as to what the Customer valued and what drivers from outside the Project might influence project direction. This was particularly significant with respect to issues that involved the DNFSB and the approach NNSA was willing to support. The timeliness of the feedback from the NNSA customer was critical, particularly as the Project Team approached key milestones and needed guidance to ensure that the Project deliverable met customer expectations.

- **Use of an Integrated Project Team**
  The WSB Project Team made a concerted effort to ensure that all positions at the Project Team table were filled early during project inception and that the positions were staffed with knowledgeable, experienced, dedicated and qualified individuals. As Project Team members were replaced, new team members were selected based on their previous experience from other major projects and/or process knowledge that was critical to the WSB process. The overall Project Team consistently maintained a very broad base of knowledge and experience that not only allowed members to apply their individual technical and project expertise, but ensured a diverse network of contacts throughout the Site and industry to ensure that evolving technical approaches were applied to process issues. Because of the breadth of the Project Team (construction, operations, startup, etc.), many lessons learned from previous projects and operating facilities were applied early on in the design and resulted in significant improvements in plant operability. As an example, recognizing that a continuous mixer for the cementation would require solid material storage and handling and be extremely difficult to operate and maintain, allowed the Project Team to change the technical approach to in-

drum mixing early on in the design phase so that the switch did not adversely affect project cost and schedule.

Formal, pragmatic use of Integrated Project Team (IPT) facilitated the identification of issues, provided focus/priority, identified impacts, assigned ownership, and identified actions/sequence necessary to resolve issues. A similar process (War Room Manager) was employed during the SRNS startup and testing phase with the same excellent results.

The project effectively used jointly staffed (Prime contractor/ Construction subcontractor) Critical Path Issue meetings to rapidly deal with the flow of information out of IPT meetings and to disposition the Construction subcontractor document submittals prior to formal issuance through the SRS document control system. Membership also included active NNSA customer involvement.

- **Contracting Strategy**
  The Construction Procurement Strategy for WSB included multiple smaller contracts for the site preparation, electrical power from the substation and the process sewer installation. The Balance of Plant (BOP) subcontract included all the structures, the installation of the process equipment and all the commodities for the facility. The project success was closely tied to the performance on the BOP subcontract scope.

  Large NQA-1 construction subcontracts performance often struggle at DOE sites due the complexities involved, limited experience on the subcontractor's part and difficulty in obtaining safety related material on time based on the current nuclear supply chain capability.

  Consider breaking the large contracts into smaller segments where practical or establishing performance phase gates within the contract to allow changes earlier in the process if subcontract is not meeting the project objectives. This will allow for changes in the strategy or subcontractors and provide the Project with more options to complete without adversely impacting the cost or schedule baselines.

- **Effective Use of an Acquisition Strategy**
  The acquisition strategy employed by the WSB project was the following multifaceted approach; Construction of the actual WSB facility and installation of internal systems was performed by a Construction subcontractor in accordance with an SRNS generated procurement Construction Specification Institute (CSI) format specification.

  Most equipment items were acquired by the Construction subcontractor based on requirements identified in the specification. Some of those items required design services from the Construction subcontractor and/or the subcontractor's sub-tier suppliers.

SRNS procured some major (long lead or specialty) equipment items (process tanks, motor control centers, cementation systems) and furnished these items as Government Furnished Equipment (GFE) to the Construction subcontractor for installation.

With regard to equipment acquisitions, it would be advantageous for a similar project to acquire a larger portion of critical/specialty equipment in parallel with establishing the Construction subcontract, particularly when the selection and acceptance of "or equal" equipment and the supplier's design documentation can significantly impact compliance with design and NQA-1 requirements. Also equipment changes can impact design and layouts due to trickle down effects of space requirements and utility connection configurations. This practice minimizes misunderstanding of equipment requirements and avoids multiple organizations handling engineering document submittals. Another positive is that this approach establishes a contractual relationship between the project and the supplier which may become significant if issues are identified during startup and commissioning. Additionally, establishing single points of contact with Engineering and each long lead/specialty equipment supplier for all technical correspondence proved to be beneficial during the procurement phase as well as during installation. Weekly teleconferences between SRNS and the suppliers involving the Project Owner and key technical and procurement personnel were also beneficial for the communication of technical issues, submittal status, and schedule progress.

- **Procurement of Safety Related Items and Materials**
  The Construction subcontractor was required to procure and install a significant number of safety related materials and items functionally classified as Safety Class (SC) or Safety Significant (SS) for the WSB project. Since there are only a very limited number of nuclear grade material suppliers in existence in today's industrial market place, the Construction subcontractor had to utilize commercial grade dedication (CGD) processes for safety related items. The Construction subcontractor relied on other entities having nuclear inexperience for assistance with activities such as acquiring safety related material/items, development of CGD plans, definition of critical characteristics, and requesting and obtaining the appropriate pedigree documentation for these material/items.

  Because safety related materials and items require cradle-to-grave monitoring, tracking, and documentation from receipt through installation and testing, it is recommended that project owners (SRNS) consider acquiring SS/SC materials/items for a project. If not, the project should require the subcontractor to regularly disclose (e.g., weekly) the status of where they are at in the acquisition process of SS/SC items (i.e., development of critical characteristics, CGD plans, inspection plans, document receipt, etc.) to ensure the acquisition of safety related materials is progressing as expected, documentation meets project requirements and the schedule does not get adversely impacted.

- **Lead Construction Subcontractor American Society of Mechanical Engineers Nuclear Quality Assurance (ASME NQA-1) Qualification**
  Subcontractors selected to perform work to NQA-1 should be previously qualified to NQA-1 with several years of demonstrated experience. The project contingency plans should be in place, in the event that potential bidders are not NQA-1 qualified. A significant amount of time and resources must be expended to develop and implement an NQA-1 quality assurance program. Not having the necessary programs and processes in place to meet NQA-1 requirements, can significantly impact the project schedule. It is not feasible to develop and implement a program while work is in progress. Requirements and expectations for engineering and quality record submittals by subcontractors need to be established and agreed upon during the early phases of construction. Document submittals without the proper formatting or submitted months after the work was performed, limit the ability to tie the record to the applicable system or equipment. Work packages associated with shop and field installation, including inspection and test records need to be contractually required for submission on a timely basis.

Technical Lessons Learned

- **Electronic Media**
  Electronic media was used effectively and efficiently during the WSB Design Phases. Access to information on the WSB servers, shared drives, and in the common comments database allowed continuous project team interactions and rapid resolutions of issues. The use of electronic media on the WSB Project proved to be very effective and efficient. Project information, drawings, and documents on the WSB shared drive allowed many team members to have access at the same time. The common WSB comment database allowed comments to be recorded and resolved in a proficient manner and provided excellent documentation. The use of electronic media during project phases will greatly increase the effectiveness and efficiency of a project.

- **Use of a Computerized Engineering Work Flow Process/Engineering Software**
  Utilize available technology, but enforce usage and ensure sufficient system capacity exists. Use of a computerized Engineering work flow process system for interfaces between engineering organizations (i.e. Design Authority, Design Agency, Fire Protection Engineering, Structural Analysis, etc.) simplifies the flow of information, provides real-time document status, reduces errors, allows for ease of tracking and trending, and eliminates transmittal of large amounts of paper.

- **Use of a 3-Dimensional Computer Assisted Design (3D CAD) System**
  If a project elects to employ the use of a 3-D CAD software program, all engineering disciplines (including fire protection, architectural and structural, etc.) need to participate in its use and maintain all updates in a timely manner. While there is an initial front end cost, there is a significant payoff during the lifecycle of the project as situations emerge where design changes are required.

  Sufficient 3D CAD hardware capacity must be available to effectively and efficiently utilize conflict/clash features of the system. Unless there is sufficient hardware capacity, when modeling a particular system or commodity, the CAD operator must inactivate other systems or commodities to achieve a reasonable response time from the CAD system. While inactivated the modeling software does not recognize physical conflicts or clashes between the system being modified and any of the inactivated commodities. The result is numerous unresolved physical interferences reside in the model until a formal “clash report” is run. There is rework associated with correcting the clashes after the fact. Also, projects should evaluate available computer network capabilities before implementing modeling activities to ensure network capabilities will support the additional workload associated with CAD model data transmittal.

- **Scheduling of 3D CAD Clash Reports**
  3D CAD Model conflict/clash reports must be run and issues resolved on a periodic basis. Typically fire protection systems are one of the last systems to have design completed. Waiting until the model is “complete” to run the reports is inefficient and potentially results in significant and/or numerous design changes and excessive adjustments to other system designs due to the “ripple effect” of correcting numerous conflicts in any given system. A ratio of modeling input to detecting and resolving clashes must be determined (considering the number of systems, model complexity, design space congestion, etc.) and scheduled as an element of the design execution.

  This is particularly important for fire suppression system design because unlike most systems for which piping only conveys a fluid from one point to another, fire protection system piping design also correctly positions the sprinkler heads functional performance and code compliance. This can be accomplished by utilizing Fire Protection discipline engineers to design sprinkler and standpipe systems (instead of just performing a review of the design) since they are more familiar with the various requirements of the codes than the average CAD designer.

The use of a computerized model of the WSB facility proved to be valuable during all project phases. The model was beneficial in early detection of interferences, determining space allocation, tracking quantity, and generating isometric drawings. The model also allowed continuous project team interactions and rapid resolution of conflicts. The 3D is a tool at the disposal of Engineering, however, when too much confidence is placed on the model to identify field conflicts, many interferences may not be identified until formal design reviews or during the construction phase of the project.

- **Timely Incorporation of Changes to Specifications and Design Documents/Streamline Low Risk Change Processes**
  Maintain up-to-date documents and utilize less formal design change processes when warranted. Supplier Deviation Disposition Requests (SDDRs) were effectively used as change documents to mitigate the cost of generating more formal design documents; however, incorporating SDDRs into specifications and contract drawings should be performed on a regular basis in order to enhance the manageability of changes and clarity of communications between designers and constructors. Consideration should be given to maintain real time, easily accessible electronic files for changes due to the significant volume that gets generated.

  Update original drawings frequently and when significant design change documents are processed and approved. This keeps design documents up-to-date on a real-time basis. Additionally, by doing so, the last change document that gets processed effectively results in As-Built drawings.

  The red-line process should be considered for items functionally classed as General Service (GS) items and for some functionally classed Safety Significant (SS) items. Sometimes formal design documents were utilized for low technical risk conditions. Implementing this can mitigate cost and schedule impacts. The red-line process should be considered for application to only those portions of a project's scope not associated with 3D Modeling, which requires rigorous configuration control.

- **Technology Development**
  The WSB Project Team analyzed the technology development needs and identified a need for a proof of concept testing of the cementation mixing process. The project developed an early specification and performed proof of mixing. This early proof of concept provided the necessary confidence in the process.

- **Use of Vendor Experience in Technology Development / Design**
  Based on operational experience and process knowledge, the Project Team made the decision during the early stages of design to change from a 'continuous mixer' approach for combining the radioactive waste material with the cement recipe to an 'in-drum' mixing approach. This process approach had been used successfully previously on Site, but the technical expertise for the in-drum mixing was no longer available. As a result, the Project Team made the decision to leverage industry experience with in-drum mixing to ensure that state-of-the-art technology was applied and to ensure that proven technology was utilized. Because there was not an 'off the shelf' system available for the in-drum mixing approach, the Project Team applied a phased procurement strategy to the cementation system to mitigate project risk for this critical, vendor supplied system. This approach included a preliminary design phase that required potential bidders to demonstrate their technical capabilities prior to contract award, a 'Proof of Concept' phase that required the selected vendor to demonstrate that their technical approach was reasonable and technically achievable, a detailed design phase that required the vendor to demonstrate that the final design approach was technically achievable, and fabrication and testing phase that required the vendor to perform an integrated system demonstration prior to shipment. This procurement approach mitigated the risk to the project that a key piece of process equipment that is vendor supplied would not be delivered on time, or would not meet the functional requirements of the design.

- **Engineered Equipment Supplier Support**
  Require equipment suppliers of unique and complex items (i.e., gloveboxes) to be contractually responsible for assembling equipment items at the site or provide technical support at the site during assembly. Any defects discovered after equipment installation should be corrected onsite by the supplier support personnel. The supplier support personnel should also perform an inventory of all delivered parts. Alternatively, the supplier must provide parts lists and explicit assembly and installation instructions for onsite installation.

- **Need Safety Basis Groups Engaged Early to Confirm Safety Requirements**
  The WSB project performed many activities in parallel in order to achieve the schedule. The design progression from preliminary to final occurred in parallel with validation of safety requirement assumptions. When there is not good coordination between activities worked in parallel, changes in assumptions and requirements can result in rework.

- **Schedule of the Consolidated Hazards Analysis**
  After the WSB fire protection system design was very near completion, the Consolidated Hazards Analysis (CHA) process determined that the safety basis must credit the sprinkler system with Safety Significant functions. This resulted in major changes to the fire protection system design, including adding two new fire areas. Since radiological facilities are now moving toward crediting fire protection systems (detection, suppression or both)

with safety functions and the CHA is design input for the fire protection system, it must be scheduled early enough to support the fire protection system design in order to avoid rework.

- **Schedule of the Fire Hazards Analysis**
  WSB, as a facility that processes radioactive materials, must meet the requirements of NFPA 801. A fire hazards analysis (FHA) must be performed for the facility per NFPA 801. The FHA becomes the primary design input for the fire protection systems and provided specific requirements to be included during design development based on past experiences from other facilities. When the WSB FHA was drafted, the fire protection system designs had already begun which caused design rework. Specific FHA issues, such as the lack of fire suppression in the High Activity and Cementation process areas and a Maximum Possible Fire Loss (MPFL) had to be addressed via specific design requirements. Since the FHA is design input for the fire protection system, it must be scheduled early to support the fire protection system design.

- **Use Bounding Basic Analysis Limits**
  The use of bounding versus "reasonably bounding" values in the safety analysis worked well for the WSB project. In developing accident scenarios and consequence the WSB Project in general used very conservative bounding values and then used the level of conservatism to justify classification of controls. This strategy avoided long discussion with reviewers on the validity or reasonableness of less conservative values. This philosophy is illustrated by the "fully engulfed facility" fire scenario. The WSB design input also included the capability to store six months of waste receipt. The "fully engulfed facility" fire scenario used nine months of maximum radio-nuclide composition for the material at risk. The resulting consequence (seven) was greater than the limit (five) required considering the application of Safety Class controls. As a result, the WSB Project team had no difficulty in justifying Safety Significant controls due to the conservative nature of the calculation.

- **Value Engineering Management**
  The WSB Project successfully applied Value Engineering throughout the project life cycle, using a graded approach, and documented the results as applicable in meeting minutes, project correspondence or formal study reports. The results of using Value Engineering methods have resulted in the selection of "best value" alternatives (lowest life-cycle cost without compromising safety, quality, etc. of the project) for design strategies, equipment selection and contract awards. Examples of where this approach was applied include:

    - Effluent disposal options
    - In-drum mixing strategy

- Steam supply options
- Evaporation options
- Cementation contractor evaluation criteria
- Glovebox evaluation criteria

- **Maintain In-House Technical Oversight and Approval of Major Equipment Item Specifications and Technical Decisions**
  The WSB design specified certain large equipment systems such as chiller systems, HVAC units, etc. to be procured as package units/skid systems. General specifications included; operational requirements, performance parameters, system capacities, acceptable manufacturers, etc. However, the lead mechanical Construction subcontractor procured the systems as individual equipment components and assembled them as a skid/package unit. In some cases, such as the chiller system, a third party provided the control software to make the individual equipment items perform as a unit. Difficulties encountered included; control systems that did not function as the facility design required, equipment drawings which were incomplete (e.g. did not show all instrumentation), there was no entity designated as the system "integrator" to ensure all of the pieces functioned as a complete unit or could even be operationally balanced, and there was no documentation describing how the system operated or how to operate the system. Operating manuals existed only for individual equipment items. These issues became very apparent during the commissioning phase of the project. The lesson learned is that the Project Team should maintain in-house control of the specification and procurement of large equipment systems intended to operate as package units. Doing so will ensure the project (and eventually the equipment owners) maintain control of how equipment is configured for subsequent startup, testing, and operation. It will also ensure appropriate documentation is provided for future commissioning, operation and maintenance of the systems.

- **Construction Subcontractor Field Engineering Support**
  If the project requires the construction subcontractor to provide robust field engineering services, the specification and bid solicitation documents must make this expectation explicitly clear. The expectation must be reinforced during pre-bid conferences, pre-award conferences and the capability must be confirmed prior to award. Bid/proposal evaluation must focus on this topic and ensure the subcontractor's proposed organization, procedures, management structure, etc. adequately address this requirement. Not meeting this requirement cannot be an option unless the prime contractor's engineering organization can provide the necessary resources and project assumes the scope for in-house performance.

- **Design for Contingency Space**
  Designers should plan for contingency space in mechanical and electrical equipment rooms and other areas to avoid congestion and significant cost and schedule impacts to projects if additional equipment must be added or design changes are required for other reasons. There were several locations in the facility where additional contingency space would have been beneficial in alleviating congestion. Electrical equipment room 103 is perfect example of why additional "spare" space is needed. During the construction phase, as final design details matured, it was determined that additional electrical panel boards were required. Fortunately there was adequate floor space available. The incremental cost for the contingency space during initial building layout pays big dividends in cost avoidance if it is later determined that additional space is needed.

- **Use of Conduit Versus Cable Trays**
  Projects should utilize cable tray systems where ever practical. This allows greater flexibility during detailed design phase and minimizes cost and schedule delays resulting from the inevitable changes that are required during the construction phase. However, because fire protection was a significant consideration, maximizing the use of conduit and minimizing the use of open cable trays was beneficial from a fire protection requirement point of view.

  Similar to cable trays, the use of field instrumentation rack arrangements, with spare space on each rack proved to be a very desirable design feature for the WSB Project. Greater flexibility for instrument type or location changes and economical installation options were realized during the construction phase as a result of having a space reserved for instrument placement and common routing of cabling.

- **Time and Motion Study**
  A Time and Motion Study for the WSB was developed by System Engineering with significant input from the Operations, Maintenance, and the Design Authority organizations. Operations assumptions input to the model for the anticipated operating steps and their associated times were based on knowledge gained from operating similar facilities on site. The early development of the Time and Motion Study allowed the Project Team to evaluate potential process changes and improvements, and to determine the resulting impacts to facility throughput. As a result, many design evolutions were able to be checked against the Time and Motion Model to ensure that changes did not have a negative impact on planned facility throughput. Additionally, the Time and Motion model served as the foundation for the Cementation System performance specification for procurement from an outside vendor. Cementation System performance is central to facility production.

- **Control Logic Diagram, System Software Design, and Piping & Instrument Diagram Integration**
  Due to three geographically and organizationally separate entities being involved in the design and development of interlocks and alarms for the WSB Process Control System, three distinct sets of design documents evolved which did not easily integrate with each other. There was no integrating function that kept the design in sync. The design organization which typically designs the field end of instrument control systems used Piping & Instrument Diagram (P&IDs) as their primary design document. The Process Control organization was primarily focused on control logic and used Control Logic Diagrams (CLDs). The vendor developing the software used internal, self-documenting features of the software program. This resulted in the startup/test seeing a different image on the operator computer screen than they expected to see based on P&IDs and CLDs. This issue is prevalent throughout industry. The Project Team developed a translation document that simplifies the integration of Piping and Instrumentation Diagrams, Control Logic Diagrams, software logic design and user screen images. The product was a spreadsheet that aligned each of the several thousand lines of features contained in the three design documents In effect, the spreadsheet showed; operate this switch, this logic gets applied, and this image will appear on the screen. This also included consistency checks between noun naming strategies within each of these design documents/tools. The document was used for startup/testing purposes, electronic procedure development, and for operator/system engineer training.

- **Baseline Documentation of Process Control Logic and Automated Functions**
  The increasing capability of process control systems has led to the automation of process controls and use of logic based or conditional limits on process parameters. It is important to carefully document these functions and limits in a manner which provides for testing, configuration management, and future modification and review. The WSB process control system utilizes automated actions (batch logic) to complete liquid transfers and other routine operations. These operations include conditional limits and logic based “interlocks” which prevent some operator actions during automated operations. The documentation of these process logic operations can become complex and difficult for testing, maintenance, and operations personnel to understand and request modifications. In addition, process control engineers can find it difficult to confirm that a desired operation meets the needs of the operations staff. The project developed a methodology to clearly document these automated actions, limits, and interlocks in controlled baseline documents. These documents provide the sequence, logic, basis, and a means of providing for requesting and implementing changes to these automated operations (procedures) in the future. The development of baseline documents which define and control batch operations is important to development and completion of system testing and the generation and future modification of facility operating procedures.

- **Use of Wireless Technology**
  Because of the state of the technology and cybersecurity issues at the time the WSB Project design began, wireless technology was not utilized on the project. However, as the capabilities in industry continue to develop, projects should consider increasing the use of wireless network type designs when project security profiles will allow. Dramatic reductions in costs result from ease of relocation, decreased material required for cable, conduit, and supports, and installation, testing and troubleshooting becomes much more streamlined.

Fire Protection and Life Safety Code Lessons Learned

- **Detector/Sprinkler Head Location Modeling Techniques**
  The WSB Project utilized a technique of modeling a zone around each smoke detector representing the areas into which a commodity was not permitted for National Fire Protection Association (NFPA) 13 compliance. The zone was represented by a "doughnut" around each detector which permitted modelers not familiar with fire codes to correctly place and modify detector locations. This technique avoids design rework due to noncompliant detector locations. While the WSB project did not use a similar methodology for fire suppression system design because the design was too far advanced, this methodology could have also been used for sprinkler head modeling work, since sprinklers have similar code requirements and restrictions necessary to avoid spray pattern interferences.

- **Fire Barrier Penetration Seal Design**
  Design for pipe and cable tray penetrations passing through fire barriers should be specifically reviewed to ensure that the final configuration of the commodities passing thru the penetration will match a standard Underwriter's Laboratory (UL) listed configuration. Deviations from standard configurations are costly and not well received by Authorities Having Jurisdiction because of the potential risk in deviating from a tested design.

- **Dual Fire Suppression System Capabilities**
  Providing a wet-pipe sprinkler system and a separate standpipe system was a great engineering/design feature. This allowed flexibility in meeting fire code requirements both in the design arena and during planned nuclear operations.

- **Use of Outside Expertise**
  Use of an independent agency (Southwest Research Institute) for evaluation of unique applications of listed features, including fire duct wrap, penetration seals (pen seals) and head

of wall seal, was very successful in documenting engineering evaluations and in satisfying reviews/audits from regulators and outside review groups.

- **General Facility Layout for Access, Egress and Exit**
  The layout of the exits and egress paths from anywhere in the facility was generally well designed and effectively achieved operational and emergency travel path requirements. However, additional consideration should have been given to provide access to areas above false ceilings for maintenance or other activities such as fire system testing. Scaffolding was used to provide both temporary access during testing, since other means were not included as part of the facility design. Future facility maintenance will require the time consuming erection of scaffolding, as well.

<u>Construction/Startup Lessons learned</u>

- **Early Site Preparation**
  A decision was made and implemented to establish a separate contract to perform early site construction work prior to awarding the main Construction subcontract. This enabled initial work on the project to progress at a rate commensurate with available funding and ensure all underground construction work was complete when the main Construction subcontract was established. Also, base mat rebar was procured prior to letting the main subcontract to ensure material would be on hand to support an early start of the main subcontract.

- **Lead Construction Subcontractor Worker Protection Plans (WPPs)**
  Subcontractors working on DOE Projects are required to have a Worker Protection Plan and implementing procedures. Many subcontractors have little or no experience in the development of these plans. Additionally, there are multiple layers of reviewers with opportunity to generate many comments. The time required to produce a fully approved WPP can be considerable

  Having the necessary WPP manual and implementing procedures in place at the time of award (or as part of the bid/proposal package) can substantially reduce the time between award and mobilization. Providing example, previously approved WPP's similar to the work scope contained in the bid/proposal documents can avoid extended development time and provide subcontractors a better understanding of site expectations.

  This reduces or eliminates potential delays in mobilization and the start of work due to a lengthy review/comment/approval cycle. Also, expectations/requirements better understood during bid/proposal preparation.

- **Retention of Construction Subcontractor Work Packages**
  Information that construction subcontractors include in work packages provide important historical information for project. It is also useful during the project startup and turnover phases of a project to facilitate record retrieval on installation of commodities. Projects should require submittal of work packages as a contract submittal. Additionally, the specification should be written to require early demonstration by the subcontractor of the ability to maintain traceability of turnover records and documentation to process systems/field components versus only making a tie to Turnover System. When specifying required time frames for submittal of records, clearly establish definition of phrases like "completion of work" and require up front agreement on the scope of work packages. Establish payment penalties for delays in document submittals. The submittal of bulk documentation at the end of the project can result in acceptance of less than expected document/record quality and place a significant burden on the project to review and comment on inadequate submittals during system turnovers.

- **Document/Record Submission**
  The exchange of records/submittals between the Construction subcontractor and the project should be well planned and coordinated. There were occasions when WSB Project work was delayed due to less than timely exchange of submittals. A majority of the records were not provided until the end of the project contract. This created a bow wave of submittals and reviews at a critical time during the project. Contract language should establish financial incentives which tie to timely completion and real-time submittal of quality inspection and testing records/documentation. Establish clear, specific requirements for record and documentation submittals as part of contract documents, including the timing, format, and content of submittals. Prior to issuance of the subcontract in alignment with Procurement practices, review prototypes and/or samples/examples of subcontractor submittals [e.g. equipment data sheets, equipment operating/maintenance manuals, in-storage maintenance records for long lead major equipment subcontractor procurements, integration process for skid type equipment procured from multiple manufacturers/suppliers (chillers, steam boiler, compressors, HVAC units, etc.), American Society of Mechanical Engineers ASME B31.3 records, and weld maps/methodology of tracking/documenting weld information]. This will ensure contract required submittals are adequate for project needs.

- **Effective Utilization of Vendor Technical Support Services**
  During Startup and Testing, technical issues were encountered when commissioning specialty systems and equipment. Once it was recognized that the problems being seen in the field posed challenges beyond the capabilities of onsite project personnel to quickly resolve,

decisions were made to expedite the use of authorized vendor technical support services. Examples include during the commissioning of a specialized Liebert process computer cooling system and during Fire System Testing when troubleshooting a synchronization issue with the fire alarm detection system. Use of technical experts with industry wide experience quickly identified and resolved the issues minimizing the cost and schedule impacts on project completion.

- **Effective Use of Greenfield Concept**
  The WSB Project was a "greenfield" project since it could not directly impact other facilities onsite and other facilities had not impact on project activities other than the normal utilities provided by the site infrastructure. The Project did not take full advantage of the cost, schedule, and scope benefits of being a greenfield activity. When appropriate, projects should be worked as greenfield to limit the application of Operations requirements until such time that they are programmatically required. This can significantly reduce the overall complexity in accomplishing work. Projects should also establish an objective and a program to utilize a team based approach for the development of Functional Acceptance Criteria which verifies the facility satisfies its design mission. Criteria should be established to ensure critical performance parameters are achieved. In addition, selection of Acceptance Criteria should consider the feasibility of testing and the methods required to achieve value. Many design parameters are based on extreme conditions and are difficult to create artificially during a test. Addition testing requirements should be documented, but should consider expanded gathering of data and engineering evaluation of performance following the test. This minimizes the potential to over-specify criteria beyond the minimum requirements which increases testing complexity and adds significant unnecessary cost and schedule demands on the project.

- **Use of the Construction Specification Institute Format**
  The WSB Project used the Construction Specification Institute's (CSI) format for specification development. Lack of familiarity with the CSI format by some specification section authors resulted in the lack of coordination between some sections.

  The CSI specification template was the basis for the WSB document. It organizes specifications relative to division of responsibilities between trades and uses specification sections to describe who performs the work. However in some instances, the division of work between trades overlapped. Examples of where the division of responsibility clarity was lacking included the responsibility for roof top gravity ventilators and its interface with the metal roofing system. The general Contractor subcontractor assumed that the metal siding/roofing subcontractor would perform this scope, and the metal siding/roofing subcontractor assumed that the roof gravity ventilation would be designed and installed by others. This resulted in vent mounting base and flashing materials that were incompatible with the metal roofing system. This scope should have also been included in the roofing manufacturer's section in order to ensure full coordination. Also, internal conduit smoke seals were included in the penetration seals specification section, however, the intent was to have the electrical subcontractor procure and install these internal seals in lieu of the penetration seals subcontractor. The result was that the electrical scope needed to be deleted from the penetration seals scope and added to the Raceways, Boxes, and Cable Trays electrical section to distinguish between divisions of responsibility. During the development of specifications, it is important to view the document through the eyes of the end user and ensure a clear understanding of the prescribed and implied division of responsibilities.

- **Fireproofing of Structural Steel**
  Valuable information was gained by the WSB Project regarding the Fireproofing of Steel. The roof assembly, including structural steel, was determined to require a 3 hour fire rating for the entire building. Use of concrete beams or precast concrete structural support systems in lieu of structural steel which required manually applied fireproofing may have averted many complications. Examples of complications associated with the application of fireproofing included, problematic mixing of materials, consistency challenges, equipment failures, pot life issues, and installation delays. Significant scaffolding logistics were required to facilitate spray-on application causing interference between trades. This was exacerbated by the fact that fireproofing took nearly two years to complete and the scaffold tied up space needed by other trades resulting in a work coordination challenge. Problems with overspray created significant cleanup operations. Proper installer/ inspector qualifications was a challenge for the subcontractor and the lack of a good mockup for quality assurance caused many non-compliant conditions that resulted in multiple repair cycles.

- **Penetration Seal Design, Installation and Inspection**
  WSB Project lessons were learned associated with the design and installation of penetration seals (pen seals). Multiple design, development, implementation and inspection issues were associated with the pen seals effort. Lessons learning include the following items.

  Pen seal design should be performed in-house since it is coordination intensive when considering interface with other building systems (piping, electrical, structural interferences, etc.) The coordination issues are likely best handled by the design agency rather than a third party consultant or installation subcontractor.

  It is important to have good design coordination between engineering design disciplines in order to minimize the number of penetrations. Early design should take into consideration the use of cast in place embedded sleeved pipes similar to conduit sleeves. Pen seals designers need to closely coordinate with other disciplines, particularly pipe designers, for placement of structural supports relative to penetrations, spacing of commodities, provisions for seismic and thermal movement, and piping configurations to avoid designs which will preclude the use of certain penetration seal types.

Finally to ensure adequate quality control, qualified engineering or specialized third party inspectors should be engaged to observe highly customized penetration seal installations.

- **Subject Matter Expert Concurrence**
  Life Safety issues need to be considered during all phases of a project. Life safety reviews that conducted late in the project which reveal code violations are expensive to correct. Review of life safety provisions should be part of the design process (e.g. walk through the 3D CAD model), then implement check points during construction. Examples of issues which surfaced because the appropriate Subject Matter Expert did not review design included, handrails and guards that did not meet the Life Safety Code, roof fall protection design that was determined to be inadequate late in the project cycle and initial design provided no clear egress path to two mezzanine access ladders. Subcontractor/vendor submittals that contain Life Safety implications also need timely review by Subject matter experts (e.g. prefabricated steel stairs).

This Waste Solidification Building (WSB) Project Y473 Lessons Learned Report incorporates previous lessons learned reports and documents developed during the life of the WSB Project. Specific reports referenced are; *Waste Solidification Building Project Y473 Procurement Lessons Learned* - V-PMP-F-00086, Rev 0 and *Waste Solidification Building Project Y473 Construction Lessons Learned* - V-PMP-F-00087, Rev 0.