Experience from Fukushima 1F-3 Spent Fuel Removal System Project - 14573

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ABSTRACT

In March 2011, Japan experienced significant damage to the Fukushima Daiichi Nuclear Generation Station in the Fukushima prefecture of Japan. Following a series of preliminary engineering contracts and intermediate deliverables, Toshiba and Westinghouse Electric Company developed a Spent Fuel Removal System (SFRS) to remove debris and fuel from one of the most severely damaged spent fuel pools on site, Unit 3.

The contract scope for the project is the supply of a complete spent fuel removal system from conceptual design through integrated qualification testing. This scope also includes proof of principle testing for several technologies that may be used in support of the debris and fuel removal. Equipment from Westinghouse and Toshiba is remotely controlled and operated from approximately 2 km from the work area.

While similar to most traditional dismantling projects, this project is unique in the type of material handled by the system and environment exposure. Planning and project management were conducted by both companies over the course of one year prior to the award of the project contract. With the significant number of tooling and subsystems required for integration, the project team developed a technical solution that would combine commercially available equipment with first of a kind engineering in order to meet an accelerated schedule.

An international team from various engineering disciplines was assembled to participate in a global kick-off meeting to clarify team scope, communication norms and set common objective for both companies. After the development of the project kick-off, Toshiba and Westinghouse refined supplier and equipment specifications to create the flexibility needed to remove all fuel assemblies from the spent fuel pool and successfully transfer the assemblies to a storage area.

The first portion of this project was dedicated to preparation of specification development, equipment design, procurement of long lead equipment and project control development. While an accelerated project schedule was a priority, personal and nuclear safety were considered the primary focus of the project.

Following the engineering design and procurement stages of the project, a series of tests were conducted from an individual tool and subsystem level to qualify operation. In order to integrate all of these subsystems into the final SFRS, final assembly and integration testing was conducted to verify interfaces and operation of hydraulic, electrical and camera systems passing through thousands of feet in cables and hoses. The system is then transferred to Toshiba and its end user for implementation at the Fukushima Daiichi site.

This paper will describe the measures taken to ensure that complex system requirements can be met through commercially available products combined with international engineering experience. This paper will include experience and lessons learned from the Westinghouse project team.

INTRODUCTION

The Fukushima Daiichi Unit 3 reactor building was damaged by an explosion, initially caused by an earthquake-generated tsunami. A combination of concrete rubble, structural steel and refueling equipment was displaced into the spent fuel pool of the unit. As a result of this debris in the spent fuel pool, the chemistry of the water created a caustic environment which posed risk to the aluminum fuel racks designed to hold the spent fuel. In response to the damage sustained by the plant, Toshiba lead a team to develop a concept for removal of the debris and fuel from the spent fuel pool and solicit input from the international community regarding methods of removing these objects. In response to this request, Westinghouse mobilized an engineering team to assist in the development of this spent fuel removal system.

Unlike traditional dismantling projects, the environmental conditions drove the design and selection of equipment. After meetings with Toshiba, a characterization of the pool provided the necessary engineering inputs to select a tool list for developing a division of responsibility and work breakdown structure. This work breakdown structure was developed not only to clarify scope, but to ensure that each of the engineering work groups aligned to a similar reporting structure. This methodology allowed for real time tracking and management of a diverse and global team.

Following the development of the concept, Westinghouse identified technical leads throughout its Decontamination, Decommissioning and Remediation (DD&R) product group to create system components needed to complete the design concept. This team identified existing technology within the Westinghouse organization as well as technology from suppliers outside of the nuclear industry. With the support of internal and external engineering, the Westinghouse and Toshiba engineering teams were able to develop an integrated system through full scale mock-up testing replicating site conditions.

Each of these stages of the project supported the successful development and completion of equipment necessary to remove the debris and spent fuel from Fukushima Daiichi Unit 3.

SCOPE DEFINITION

Through work with Toshiba, Westinghouse developed a scope which would meet both the capabilities of the design team as well as the requirements of the final customer. A set of equipment was selected based on the following criteria:

1. Waste characterization of the spent fuel pool
2. Site operating conditions
3. Operational parameters based on Japanese codes and standards
4. Equipment with minimum operational experience standards

These areas helped bound the requirements of equipment so that engineers could make valid assumptions based on the little information known inside of the spent fuel pool at the start of the project. From the known materials at the Fukushima site, the engineering team could deduce a selection of debris that could be encountered in the spent fuel pool. This, couple with the sequence of removing fuel from the pool, allowed Westinghouse and Toshiba to generate the following tool list:

- Fuel Handling Machine – A gantry style crane used to position tooling and cameras in support of fuel removal
- Cask Crane – A second gantry style crane used to hoist a transfer vessel to transport fuel from the spent fuel pool to a storage facility
- Manipulators – A set of manipulators installed on the fuel handling machine used to support positioning of devices and segmentation of debris
- Debris Tools – Shears, grippers and grapples used to size reduce and package debris from the spent fuel pool
- Control Systems – Set of control systems to operate equipment from a minimum of 2 kilometers from the operational area of the fuel handling machine and crane
- Integral Television – Series of cameras located throughout the fuel handling machine and crane to support remote operations by users in the remote controlling room
- Fuel tooling – BWR specific fuel tools used to remove fuel (both intact and damaged) from the potentially damaged fuel storage racks
- Tool Exchange System – Provide a means of exchanging select tooling from the fuel handling machine and cask crane with no human intervention

With this base set of tooling, the project team set to begin planning the operational scenarios necessary to remove all fuel from the spent fuel pool. With the available time to deliver being the driving criteria of the project, the limited scope was created to perform necessary functions of the fuel removal while allowing the flexibility to create additional equipment based on as found conditions at site.

In addition to selecting the basic tool set needed for this work, the Westinghouse and Toshiba team developed basic facility requirements that would be needed in order to test the equipment. As the requirements at site were unique only to Japan, a testing facility specification was developed with the following in mind:

Figure 1: Fukushima 1F-3 Spent Fuel Removal System

- Remote operation – The facility was to allow for personal to test equipment using the remote systems designed for the project. Operators must be allowed to be isolated from the work performed by the equipment and witness only through cameras and electrical feedback devices
- Underwater testing – Since a majority of operations would be performed in the spent fuel pool, the facility was required to contain a pool capable of completely submerging equipment and a fuel assembly
- Full scale mock-up – From lessons learned of other decommissioning and dismantling projects, the proposed facility was required to provide full equipment testing on a one for one scale

As the equipment and basic testing parameters were determined, the project and technical teams began the task of sequencing the events to accommodate the site schedule. Managing cost and resources became a challenge as the projects spanned several countries and many major scopes of work.

PROJECT PLANNING

While the project was identified to require concurrent engineering and procurement, extensive planning was required to ensure that all of the site requirements were met through not individual equipment, but the system as a whole. To do this, the project team focused on the development of a consistent work breakdown structure (WBS) in order to organize the international teams. This WBS was broken down into sections that could be managed individually by separate engineering teams.

Table 1: Level 1 Work Breakdown Structure

WBS	Description
	Fukushima 1F-3 SFRS
IM-12-00XX-SFRS01	**Fukushima 1F-3 SFRS [Project Management]**
IM-12-00XX-SFRS02	**Fukushima 1F-3 SFRS [System Integration]**
IM-12-00XX-SFRS03	**Fukushima 1F-3 SFRS [FHM 1]**
IM-12-00XX-SFRS04	**Fukushima 1F-3 SFRS [FHM 2]**
IM-12-00XX-SFRS05	**Fukushima 1F-3 SFRS [Tool Positioning]**
IM-12-00XX-SFRS06	**Fukushima 1F-3 SFRS [Control and Support Systems]**
IM-12-00XX-SFRS07	**Fukushima 1F-3 SFRS [Debris Tools]**
IM-12-00XX-SFRS08	**Fukushima 1F-3 SFRS [Fuel Tools]**
IM-12-00XX-SFRS09	**Fukushima 1F-3 SFRS [Service Tools]**

Within each of the Level 1's of the WBS, a project manager was assigned to ensure timely completion of the work. Each Level 1 scope of work was further detailed by the associated project manager into work scope (or tool) followed by phase of work. This consistency allowed for a detailed project schedule that aligned to resource and cost estimates in order to appropriately staff the project to meet site requirements. Communicating this WBS early on in the project, with both the customer and design team, allowed for a consistent review process at a series of stage gates throughout the design and testing phases.

As the WBS provided scopes that could be broken down to individual teams, the integration and uniform testing of equipment proved to be more of a challenge. Since each team tested equipment at their home location, a detailed testing sequence was plan was needed to ensure that all teams understood the interfaces and the testing requirements of the project.

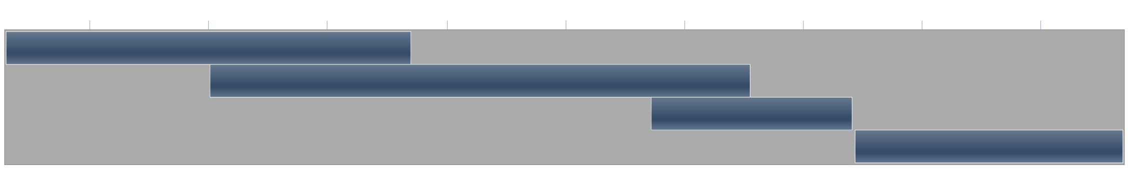

Figure 2: Project Schedule Overview

During all aspects of this design phase, Toshiba and Westinghouse identified participation milestones in which Toshiba would perform the role of participant, observer or approver. The development of these milestones supported the conclusion that the project team (Westinghouse and Toshiba) would collocate for the testing through integration of the equipment. Planning this collocation at the initial stages of the project created the first phase of turning over equipment to Toshiba prior to shipment of the system to Japan.

TEAM SELECTION

Through use of the Westinghouse Decommissioning and Remediation (D&R) business unit, a global team was assembled for a three (3) day project kick-off meeting. This meeting included members of Toshiba, Westinghouse and several suppliers in order to develop a cohesive team and reduce cultural barriers. Members travelled to the Westinghouse Cranberry Woods facility from the following areas:

- Tokyo, Japan
- Mannheim, Germany
- Chicago, Illinois, USA
- Richland, Washington, USA
- Charlotte, North Carolina, USA
- San Jose, California, USA

This diverse group reviewed the organizational structure of the project, reporting metrics and, most importantly, each group member’s role in completing the project. In addition to these areas, the team reviewed the organizational commitment to safety as well as the appropriate working environment in which to discuss any concerns related to the project or design of equipment. With these concepts in mind, project members were selected based on the following criteria:

- Tool development experience – For each major location, a technical lead with at least 10 years’ experience in field service or decommissioning was selected to support the location tooling development
- Travel availability – While it is common in the U.S. to travel to site for field service work for extended periods of time, this cultural difference was accounted for in the beginning of the project. Personnel were required to commit to a travel schedule demanding up to 75% travel time during the project
- Future availability – Following the delivery of equipment, personnel would be required to support the training and field installation of the project equipment. If resources were committed to other projects, they would not be available for the Fukushima 1F-3 effort.

Each major group was able to return to their home office to engage local resources and support the project. Holding the initial project kick-off meeting provided a unique opportunity for groups to develop a rapport and understand their working relationship before initiating the remaining members of the project.

SUPPLIER IDENTIFICATION/INTEGRATION

Although the project was deemed a first of a kind project due to the complexity of the integrated system, a series of critical suppliers were identified to provide commercial, off the shelf equipment that would be modified for this application. Suppliers were identified using three (3) main criteria:

1. Availability of existing equipment
2. Engineering resources available to support the project
3. Experience working with Westinghouse

The vendor selection process lead to several suppliers that became team members and integrated into the project staff. This coordination and attention to supplier resources and logistics provided a series of equipment that could only be provided on the project time line through successful supplier support. While Westinghouse maintained management oversight of the suppliers, direct discussions between suppliers, Westinghouse and Toshiba were held in order to minimize the turnaround time for comments and design changes. This area of the project became critical as it related to site specific quality requirements.

Figure 3: Integration Testing at Supplier Facility

Following receipt of supplier items, Westinghouse focused on the integration of equipment through use of a supplier facility. This facility provided a means to conduct full scale and underwater mock-up testing. The integration period required approximately 30% of the schedule duration in order to ensure that any project interfaces were tested without issue. It was during this time which Toshiba and Westinghouse engineers converged to the testing facility and supported testing exclusively through qualification. Collocating the engineering staff to perform integration did not reduce the equipment delivery schedule; however, it significantly decreased the cost of poor quality that typically arises from troubleshooting equipment failure. For the long term aspects of the project, this collocation also reduced the learning curve associated with operating remote equipment as the equipment is turned over to Toshiba and on-site operators for use at Fukushima.

CONCLUSIONS

As a result of identifying a clear scope with an organized and diverse team, the project was able to complete a large, complex integration of equipment in a relatively short amount of time. Early identification of capable suppliers with a uniform approach to managing scopes of work enabled the project management team to focus on the management of emergent issues instead of reinforcing project requirements to the design team.

Overall, Westinghouse identified several main factors for success on the project. These include:

- Customer commitment to provide necessary approvals and reviews in an expedited review cycle
- Revolving communication between the Westinghouse and Toshiba project teams throughout the project
- A global engineering group made up of experienced engineers, diverse cultural backgrounds and commitment to support the people of Japan on this project