Best practices for preparing vessel internals segmentation projects

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ABSTRACT

Westinghouse has been involved in reactor internals segmentation activities in the U.S. and Europe for 30 years. Westinghouse completed in 2015 the segmentation of the reactor vessel and reactor vessel internals at the José Cabrera nuclear power plant in Spain and a similar project is on-going at Chooz A in France. For all reactor dismantling projects, it is essential that all activities are thoroughly planned and discussed upfront together with the customer.

Detailed planning is crucial for achieving a successful project. One key activity in the preparation phase is the "Segmentation and Packaging Plan" that documents the sequential steps required to segment, separate, and package each individual component, based on an activation analysis and component characterization study.

Detailed procedures and specialized rigging equipment have to be developed to provide safeguards for preventing certain identified risks.

The preparatory work can include some plant civil structure modifications for making the segmentation work easier and safer.

Some original plant equipment is sometimes not suitable enough and need to be replaced.

Before going to the site, testing and qualification are performed on full scale mock-ups in a specially designed pool for segmentation purposes. The mockup testing is an important step in order to verify the function of the equipment and minimize risk on site.

This paper is describing the typical activities needed for preparing the reactor internals segmentation activities using under water mechanical cutting techniques. It provides experiences and lessons learned that Westinghouse has collected from its recent projects and that will be applied for the new awarded projects.

Optimum reactor dismantling sequence

Removal of the reactor internals and the reactor pressure vessel is usually on the critical path of the nuclear power plant decommissioning program. It is also expected to belong to the most difficult activities. Due to the severe radiological conditions of the reactor internals, these must be segmented underwater. In order to support this activity, the systems that support the management and cleaning of the water in the reactor cavity and internals storage pools need to remain operational. It is therefore recommended that the reactor internals are removed as early as possible in the plant dismantling sequence, so that these water systems and their associated support systems can be released for decommissioning. This minimizes the costs of maintaining these systems in operation after permanent plant shutdown.

Moreover, after spent fuel, reactor internals constitute the next significant contributor to the radiological inventory of the site. Therefore, the spent fuel removal and the early removal of the reactor internals significantly reduce the total site radiological hazard. Depending on the regulatory requirements applicable at this decommissioning stage, this may allow a reduction in the nuclear safety measures that must be maintained and that eventually leads to additional cost savings.

Based on the above, it is therefore recommended that the reactor internals segmentation is the first major dismantling activity to be carried out inside the reactor building. It should be performed after the chemical decontamination of the primary system in order to minimize doses to the personnel during the dismantling activities.

This principle of dismantling the reactor and its internals at the early stage of the plant dismantling program will be applied in Sweden (Barsebäck 1-2) and in Germany (Philippsburg 1 and Neckarwestheim 1). It could not be applied for the José Cabrera plant since the turbine building needed to be first transformed into a facility for grouting the segmented reactor internals before shipment to the El Cabril Low and Intermediate Level Waste repository.

Segmentation and packaging plan

Detailed planning is essential to a successful project, and typically a "Segmentation and Packaging Plan" is prepared to document the effort. The usual method is to start at the end of the process, by evaluating handling of the containers, the waste disposal requirements, what type and size of containers are available for the different disposal options and working backwards to select a cutting method and finally the cut geometry required. 3-D models help complete those tasks as well as for determining the logistics of component placement and movement in the reactor cavity, which is typically very congested when all the internals are out of the reactor vessel in various stages of segmentation.

The main objective of the segmentation and packaging plan is to determine the strategy for separating the components so that they can be disposed of in the most cost effective manner. Such strategy can be driven by many factors such as waste container selection, disposal costs, transportation requirements, etc., but must be considered early in the planning phase.

Once the preliminary packaging plan is developed, the primary cutting methodology can be determined (e.g. Plasma Arc Cutting, Abrasive Water Jet Cutting, mechanical cutting). All cutting processes typically generate varying degrees of secondary waste. This waste must also be properly controlled, collected and packaged for disposal. The methodology and equipment for this effort is specific to the cutting process.

For the José Cabrera reactor internals segmentation, the first year of the project was dedicated to engineering studies, design work and manufacturing of equipment needed to perform the work. Detailed 3-D modeling has been the basis for tooling design and provided invaluable support in determining the optimum strategy for component cutting and disposal in waste containers, taking account of the radiological and packaging constraints. Fig.1 shows an example of a 3-D model that helped determine how to cut the lower internals at the Chooz A plant.

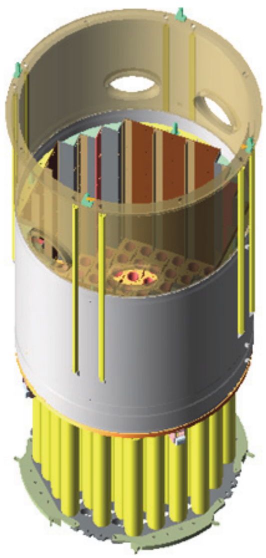

Fig.1. 3-D model of Chooz A lower internals

Preparatory activities

The preparatory work can include some plant civil structure modifications for making the segmentation work easier and safer.

At José Cabrera, a number of activities had to be performed before the actual cutting activities could start: e.g. cutting of the wall between the reactor cavity and the spent fuel pool, securing the pool integrity, characterizing the internals, retrieval of spent fuel racks, installing a new working bridge and cleaning of the pool floor and water.

Cutting of the wall between the reactor cavity and the spent fuel pool was necessary to provide access to a deeper pool and led to better water shielding for the operators. That constituted a substantial design change and detailed structural analyses had to be performed to demonstrate that this demolition was safe. Moreover, this civil modification proved to be useful for the next reactor vessel segmentation project, facilitating the transfer of the vessel in one piece to the spent fuel pool area. Fig.2 shows the wall cutting with a diamond wire.

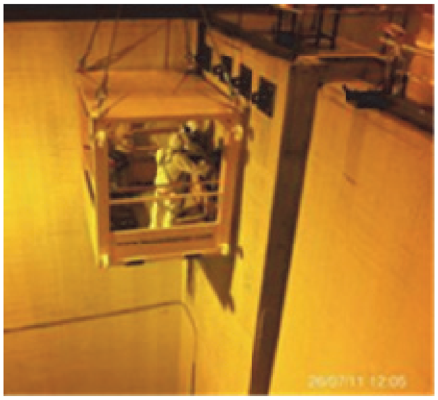

Fig.2. Demolition of the spent fuel pool separation wall

The sealing of the pool walls was a challenging task as the initial leakage was substantial and coming from all over the pool area. The floor of the reactor pool was therefore reinforced with a 15 cm thick concrete layer whereas leakages in the wall were sealed by injecting sealant into all identified cavities and the whole surface was then painted with an impermeable paint. The leakages in the spent fuel pool steel liner had to be sealed under water because highly irradiated operational waste was stored in that pool which prevented draining of it. This operation was performed using divers.

In Chooz A, the entrance to the reactor cave has been enlarged to allow access to some heavy equipment, like the future reactor vessel stand that will be sealing the reactor pit after removal of the vessel (see Fig.3.). Other significant civil work modifications occurred for allowing the installation of a hot cell for the future drying and characterization of the cut internals and final container loading. To achieve that, a previous steam generator pit has been sealed with a concrete slab to create the necessary space for installing the hot cell. Another steam generator pit has been also sealed for installing the future dry cutting workshop. Other significant works had to be performed for bringing new electrical cabinets and installing new ventilation ducts.

Fig.3. Installation of new ventilation ducts

At José Cabrera, a new working bridge has been installed in the spent fuel pool). The existing spent fuel pool bridge led to some concerns about the adequacy of its load capacity (2 tons) and the fact that it should have been removed to raise water level higher during the Lower Internals transfer, have compelled Westinghouse to decide its replacement by a new bridge, with higher capacity, and placed at a height compatible with the maximum water level. This new arrangement had the additional benefit of placing the access to the bridge at the floor level, simplifying the access of personal and equipment to it. The same replacement will occur at Chooz A.

Risk mitigation

Another key element of the segmentation and packaging plan is the material handling plan. Many of the pieces that will be cut and packaged need to be rigged and manipulated to get them into their respective disposal container. Since many of these pieces could potentially produce a lethal dose of radiation if they were inadvertently raised out of the water, safeguards must be in place to prevent any possibility of this occurring. Another risk is if one of the cut pieces were dropped, damage to the reactor cavity liner or other critical equipment could result. Detailed procedures and specialized rigging equipment have been developed to provide these safeguards.

To mitigate the possible risks due to uncontrolled drop of heavy pieces and resulting damages to the Stainless Steel liner of the pool floor, Westinghouse steel protection plates are always installed to cover all exposed floor areas. The plates have a typical thickness of 6 mm. For the José Cabrera reactor vessel internals and reactor vessel segmentation projects, protection plates have been installed at the bottom of the spent fuel pool and in addition, two contingency pumps have been foreseen to address the residual leakage risk.

Removal of operational waste

At José Cabrera, before installing the new working bridge, the spent fuel racks had to be removed from the spent fuel pool. However, some operational waste was still stored in rack cells and needed to be segmented and packages first. A number of operational waste such as RCCA's, primary sources, secondary sources were cut with shearing tools and positioned into special designed canisters that was later put into the Multi-Purpose Canisters along with the other high activated waste.

At Chooz A, the operational waste was stored in the vessel in the previous core region. It included dummy fuel, Zircaloy control rod followers, neutron source rods, MOX bottom pieces, control rods, adaptors. Fig.4 shows the Chooz A operational waste inventory stored in the reactor vessel.

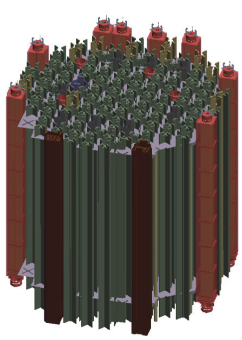

Fig. 4. Chooz A operational waste inventory

Qualification

A qualification is usually performed in the Westinghouse test facility located in Västerås where 1:1 scale mockups of chosen parts of the internals are manufactured (see Fig.5). The mockup testing is an important step in order to verify the function of the equipment and minimize risk during segmentation work on site. When the qualification is approved by the customer, all equipment is then transported to site with a high confidence of a successful implementation.

Fig. 5. Qualification of segmentation equipment

Licensing aspects

Before starting any activities on site, it is important to demonstrate that the proposed reactor dismantling process is safe and approved by the local Safety Authority. The format and content of the required licensing documentation can differ from country to country but in all cases, a licensing support is provided to the plant owner or the responsible company for plant decommissioning.

The following documents, provided for the José Cabrera reactor dismantling project, are usually requested:

- Final Segmentation & Packaging Plan which contains a description of the proposed disassembly and cutting technologies, proposed mock-up testing program, equipment layout, connections to existing plant systems, as well as the required plant modifications.
- Safety Analysis Report, which identifies both nuclear and conventional risks associated with the performance of the Segmentation & Packaging Plan,
- ALARA Report.
- Radwaste Evaluation Report, which includes the estimation, by waste type, of the expected volume and total and specific activity for the solid wastes, both primary and secondary, expected to be produced as result of the segmentation project, as well as the corresponding packaging strategy.

Conclusion

It is important to well prepare the dismantling of a reactor vessel and its internals in advance. Such a project is not limited to the pure segmentation activities. A detailed study of the optimum dismantling scenario must be done upfront, considering the available plant systems and infrastructure. Especially for old plants, significant plant modifications need sometimes to be considered for completing the reactor dismantling, including civil work modifications, new water filtration system, new power supply, new HVAC system, …Specific waste management constraints may also require installation of dedicated characterization and handling equipment before final container loading.

Those lessons learned will be useful for the four more major reactor internals segmentation projects that have been recently awarded in Sweden (Barsebäck 1-2) and in Germany (Philippsburg 1 and Neckarwestheim 1).