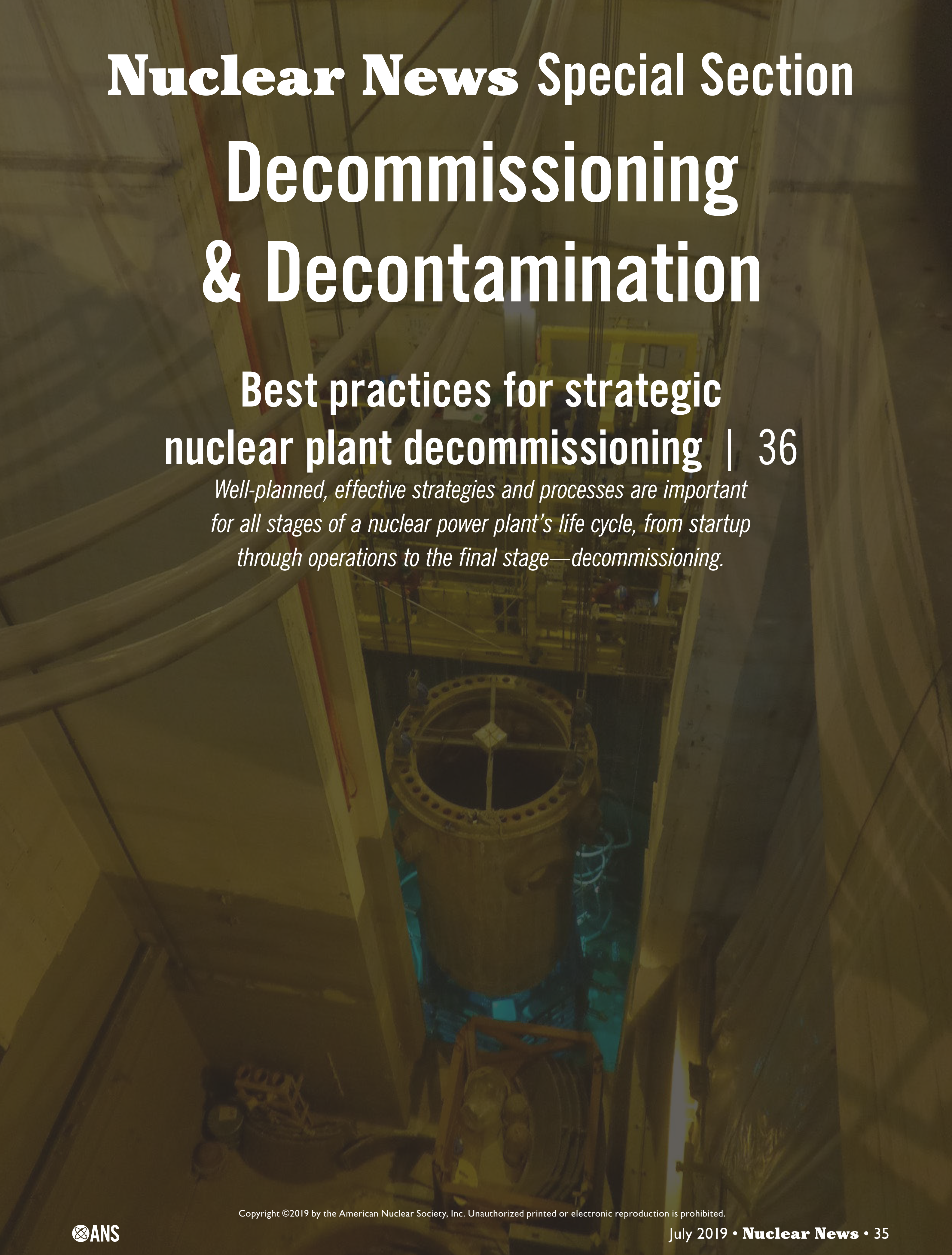

Nuclear News Special Section

Decommissioning & Decontamination

Best practices for strategic nuclear plant decommissioning | 36

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Best practices for strategic nuclear plant decommissioning

Well-planned, effective strategies and processes are important for all stages of a nuclear power plant's life cycle, from startup through operations to the final stage—decommissioning.

By Joseph Boucau and Keith Mahosky

Decommissioning and decontamination needs have risen globally due to recent decisions by some countries to phase out nuclear power, the natural life cycle of plants, and plant closures based on economic factors. This has been most significantly realized in Europe, with about 90 reactors being shut down for various reasons (e.g., damage, political or economic decision). In North America, the number of plant shutdowns is growing, with approximately 8 percent of the operating U.S. commercial fleet—based on 104 reactors in 2012—shutting down between 2013 and 2019, and approximately 13 percent of those remaining in operation slated to retire by 2025. In Canada, 10—approximately half—of the reactors will be shut down by 2025. The trend extends to Asia as well, in Japan, South Korea, and Taiwan.

Westinghouse leverages its knowledge, based on more than 30 years of experience in decommissioning and waste processing, to assist utilities in the last stage of the life cycle of a nuclear power plant. The purpose of this article is to discuss best practices for strategically planning nuclear power plant decommissioning, with an emphasis on the following:

- Establishing a decommissioning plan and strategy.
- Optimizing decommissioning planning and minimizing the volume of waste and the associated processing costs.
- Planning technical strategies that make the best use of plant space when conducting decommissioning and dismantling work.
- Using 3-D modeling to optimize the decommissioning strategy.
- Conducting a full-system chemical decontamination of the primary circuits at the beginning of the project to facilitate subsequent dismantling activities with hands-on tooling and to reduce waste disposal costs.
- Using dedicated waste processing systems to further reduce waste volume, especially for highly radioactive elements.
- Deploying mobile waste treatment equipment for decommissioning and further reuse in other plants—both operating plants and those undergoing decommissioning.

In order to optimize cost and schedule, it is vital to establish a detailed decommissioning plan and strategy. Decommissioning planning and strategy constitute the foundation of the entire decommissioning program and should typically begin two to three years before plant shutdown. There are many inputs to the overall decommissioning plan, including, as the first layer of that foundation, the correct plant data. It is necessary to work closely with plant personnel to ensure that the right plant data can be obtained.

Westinghouse led the detailed decommissioning plan at the José Cabrera plant in Spain, working closely with plant personnel. The planning process included performing "optioneering" studies for defining the optimum dismantling scenario. Optioneering allows creative engineering solutions to be formed at the generative stage in conjunction with utility partners. It is an iterative process during which various options are evaluated using engineering techniques that take plant data and other input information into consideration. This allows the team to find the best path forward through the series of complex activities that must occur for a nuclear power plant decommissioning.

Plant characterization

One of the most important inputs for decommissioning planning is the radiological and environmental characterization of the plant. The preparation of accurate radiological and hazardous material inventory facilitates selecting the most appropriate technical solutions, reducing costs, providing a baseline against which decommissioning progress can be measured by plant managers and regulators alike, and helping the entire project to remain on schedule.

Generally, characterization activities begin while the plant is still operating, continue during the period often referred to as the transition phase—the time between ceasing operation and beginning decommissioning strategy implementa-

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tion—and further continue during the dismantling stage, according to the specific plant and regulatory requirements. Characterization data must be collected to determine the type and extent of contaminants before decontamination or dismantling begins, as this information is imperative to planning those activities, including from an "as low as reasonably achievable" (ALARA) perspective. The scope of the characterization activities includes not only the nuclear installation but also areas of the site that could have been radiologically or environmentally contaminated during the plant's operational lifetime.

Radiological characterization of activated and contaminated components throughout the plant is essential for planning the appropriate and optimum dismantling approaches and identifying the necessary waste streams that are needed to formulate waste management strategies. The reactor vessel internals, second only to the spent fuel, have the highest activity levels and need to be adequately characterized in order to develop and fully optimize the segmentation and packaging plans.

Accurate waste characterization allows the main objective of the reactor vessel internals segmentation and packaging plan to be realized. That objective is to determine the strategy for separating the highly activated components, called Greater-than-Class-C waste (GTCC), from the less activated material, called Class A, B, or C, so that all components can be disposed of in the most cost-effective manner.

Different countries have different regulations concerning how the various classes of waste must be handled. In the United States, GTCC waste cannot be shipped off-site, so it must be packaged such that it can be dry-stored in an independent spent fuel storage installation. Waste classified as Class A, B, or C can be shipped to an off-site disposal site, depending on space availability. Several of the U.S. plants dismantled to date have repackaged the Class A, B, and C component segments back into the (Class A) reactor vessel, in accordance with the Nuclear Regulatory Commission's concentration averaging guidance, and have shipped the entire assembly to the disposal site. Decisions like these are driven by many factors, such as disposal costs, transportation logistics, and licensing fees, among others. Since disposal methods have a significant impact on the reactor vessel internals segmentation and packaging plan, they must be considered early in the planning phase, and this consideration begins with accurate waste characterization data.

Referring again to the José Cabrera nuclear power plant decommissioning project as an example, neutron flux calculations were made and benchmarked against the vessel surveillance capsule measurements to characterize the reactor internals, reactor vessel, vessel insulation, and the concrete biological shield. Before beginning the segmentation portion of the project, these calibrations were checked and the theoretical model calibrated by measuring radiation on the upper and lower reactor vessel internals with high-level gamma probes. During the segmentation, underwater characterization of each cut piece was performed using a gamma probe (with weights and dose rates measured at three points) to check individual waste acceptance. Once the waste baskets were loaded, each loaded basket was then also characterized with a gamma probe spider, which consists of gamma probes positioned at eight points (each face and corner) of the cubic-shaped container, to verify average dose acceptance before grouting. The waste containers were then transported to the appropriate depository, depending on the activity concentration.

Planning technical strategies

Many factors play a role in determining the best technical strategies for dismantling a given plant. Among them is assessing and planning the most effective use of the available plant space for dismantling activities so that each can be scheduled and performed as efficiently as possible. This includes determining whether work can be conducted in sequence or in parallel and the sequence of each activity. The radiological characterization of the plant and decisions concerning the decontamination of primary components will influence how the plant space can be manipulated for parallel work, shielding, and movement, as well as the tools and personnel required.

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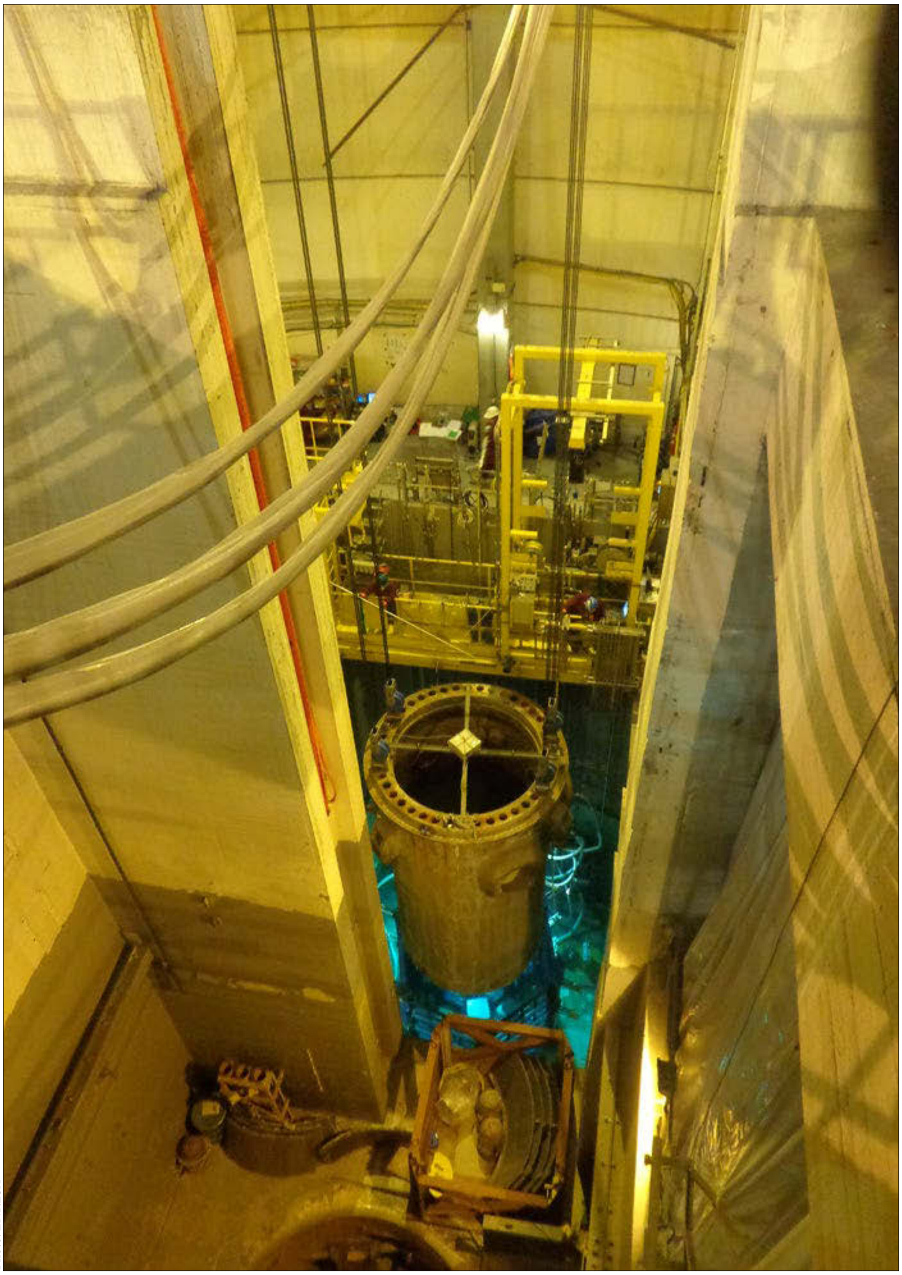


Photo: ENRESA

Demolition of the wall separating the reactor cavity and the spent fuel pool at José Cabrera.

Certain strategies are generally recognized in plant decommissioning. In terms of plant dismantling sequence, site and preliminary reactor characterization should be performed while the plant is still operating. Confirmatory dose profiling should be performed on the reactor vessel and reactor vessel internals immediately after defueling. It is generally recommended that one of the first activities to be performed after defueling is a full-system chemical decontamination of the primary circuit to enable lower dose and easier and faster dismantling activities in the controlled area. Once the chemical decontamination is complete, steps to remove the reactor internals and the reactor pressure vessel are expected to be part of the critical path of the project.

Due to the rather severe radiological conditions of the reactor internals, it is prudent to segment them underwater so that the water can continue to be used as a radiation shield. To facilitate this activity, the support systems for managing and cleaning the water in the reactor service and internals storage pools will need either to remain operational or to be replaced by temporary substitutes. It is therefore recommended that the reactor internals be removed as early as possible in the project to reduce the site radiological inventory and general area dose rates and to release water management systems and their associated power supplies for decommissioning. This minimizes the cost of maintaining these systems or substitutes and that of their operators during the period between the end of fuel handling and internals segmentation. There is also the potential advantage of removing the overwhelming majority of the site radiological inventory (fuel and activated components). The reduction in site radiological inventory offered by removing the fuel, followed by early removal of the internals, will significantly decrease the total radiological hazard present on-site. Depending on the applicable regulatory regime, significantly reducing the radiation on-site may lead to a reduction in the nuclear security and safety measures required, with resulting cost savings.

Based on this generally recognized approach, reactor dismantling is the first major activity to be carried out inside the reactor building. Reactor dismantling should be performed following the pre-decommissioning decontamination of the primary systems to reduce worker dose exposure incurred during the dismantling tasks, as well as the amount of project radiological controls.

Once the internals have been removed, work can continue on other tasks inside the reactor building in parallel with work in other areas of the site, such as the turbine building, so that as other systems are made redundant by progress in the reactor building, they can be released for decommissioning. After the removal of discrete contaminated systems and components, additional surface decontamination can be performed in accordance with the decommissioning strategy as framed by regulations to support normal (open-air) plant demolition.

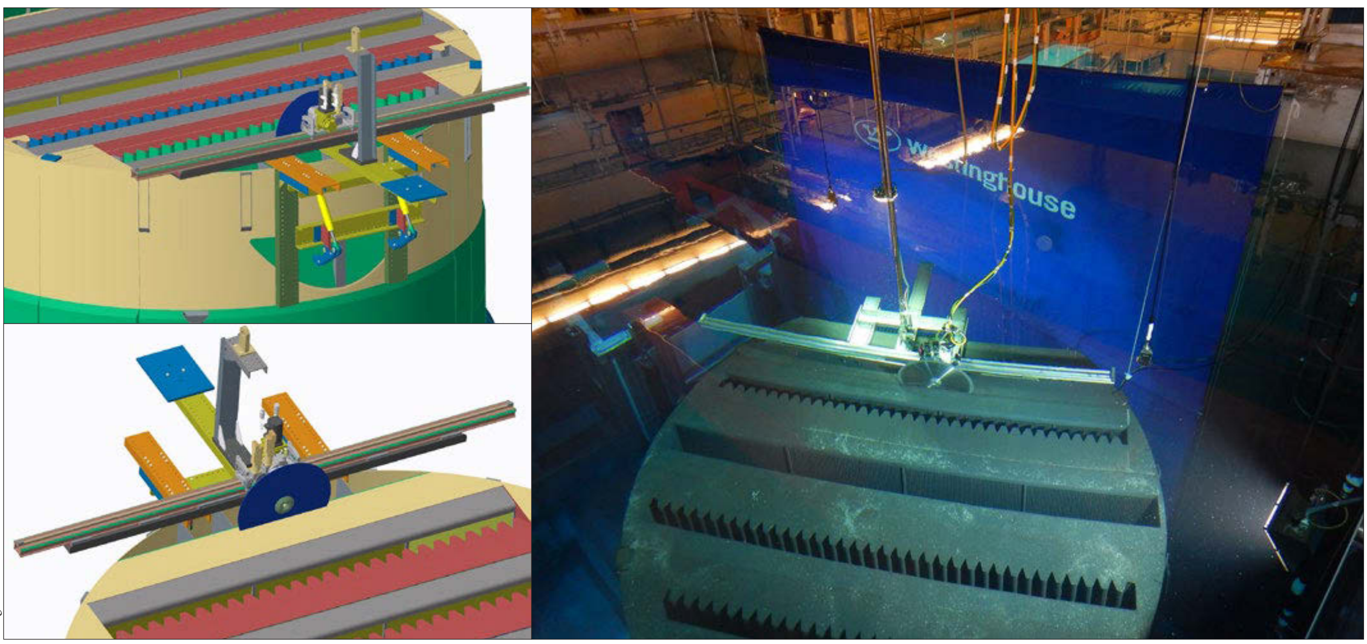
In some cases, certain critical infrastructures do not exist or are not suitable for the plant dismantling, and the decommissioning strategy is crucial for avoiding problems later. At José Cabrera, a number of activities had to be performed before the actual cutting activities could begin. For example, because the water in the reactor cavity was not deep enough to provide shielding during segmentation work, the wall between the reactor cavity and the spent fuel pool was cut to provide access to the deeper spent fuel pool. The pre-segmentation work also included securing the spent fuel pool's integrity (leak tightness), characterizing the internals, retrieving the spent fuel racks, installing a new working bridge, and cleaning the pool's floor and water.

This strategic decision constituted a substantial reactor building design change, and detailed structural analyses were performed to demonstrate that the wall demolition was safe. This civil modification allowed the reactor vessel to be transferred to the spent fuel pool area in one piece via the new connection created between the spent fuel pool and the reactor cavity.

Use of 3-D modeling

Detailed planning is essential to a successful project, and 3-D models help complete this task. 3-D modeling for the main areas of the plant using laser scanning to help visualize the entire plant configuration has become common.

In the special case of reactor dismantling activities, 3-D models help determine the precise logistics of component placement and movement in the reactor cavity as part of the reactor vessel internals segmentation and packaging plan. This is an important part of planning, since moving, measuring, and packaging these highly radioactive pieces are conducted remotely from a working bridge with tooling and cameras, and the reactor cavity is typically very congested once the internals components are out of the reactor vessel in various stages of segmentation.



Images: Barsebäck

3-D modeling helped determine how to cut the Barsebäck-2 plant steam dryer.

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. Many factors drive the resultant plan, including which waste containers must be used, container logistics, the costs of disposal methods, and local transportation requirements. Each of these factors should be considered early in the planning phase, with the use of 3-D modeling to accurately plan all of the steps.

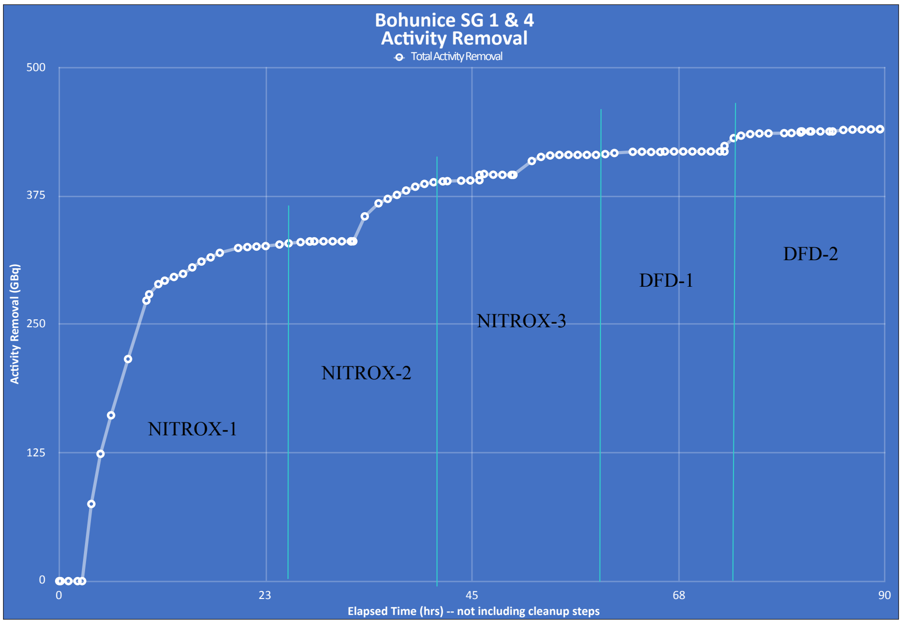
For the Barsebäck (Sweden) reactor internals segmentation, the first year of the project was dedicated to engineering studies, design work, and manufacturing of equipment needed to perform the work. Detailed 3-D modeling was the basis for the tooling design and provided invaluable support in determining the optimum strategy for component cutting and disposal in waste containers, taking into account the radiological and packaging constraints.

Primary circuit decontamination

Pre-dismantling chemical decontamination of the primary circuit (steam generators, reactor coolant pumps, pressurizer, and connecting piping) of a nuclear power plant with aggressive chemicals, such as those available through the Electric Power Research Institute's Decontamination for Decommissioning (DFD) process, offers some significant advantages:

- Removes activity from the primary circuit components for easier packaging.
- Reduces dose rates for workers around piping and components.
- Simplifies access to the installations, making it possible to use hands-on techniques for dismantling rather than the more expensive use of robotics or manipulators.
- Minimizes the potential for spreading contamination during decommissioning activities.
- Reduces the cost of disposal.

To illustrate the effectiveness and benefits of a full-system chemical decontamination of the primary circuit, the example of the work done at the Bohunice V1 (Slovakia) nuclear power plant is provided.



Bohunice V1 activity removed (Unit 2, Loops 1 and 4).

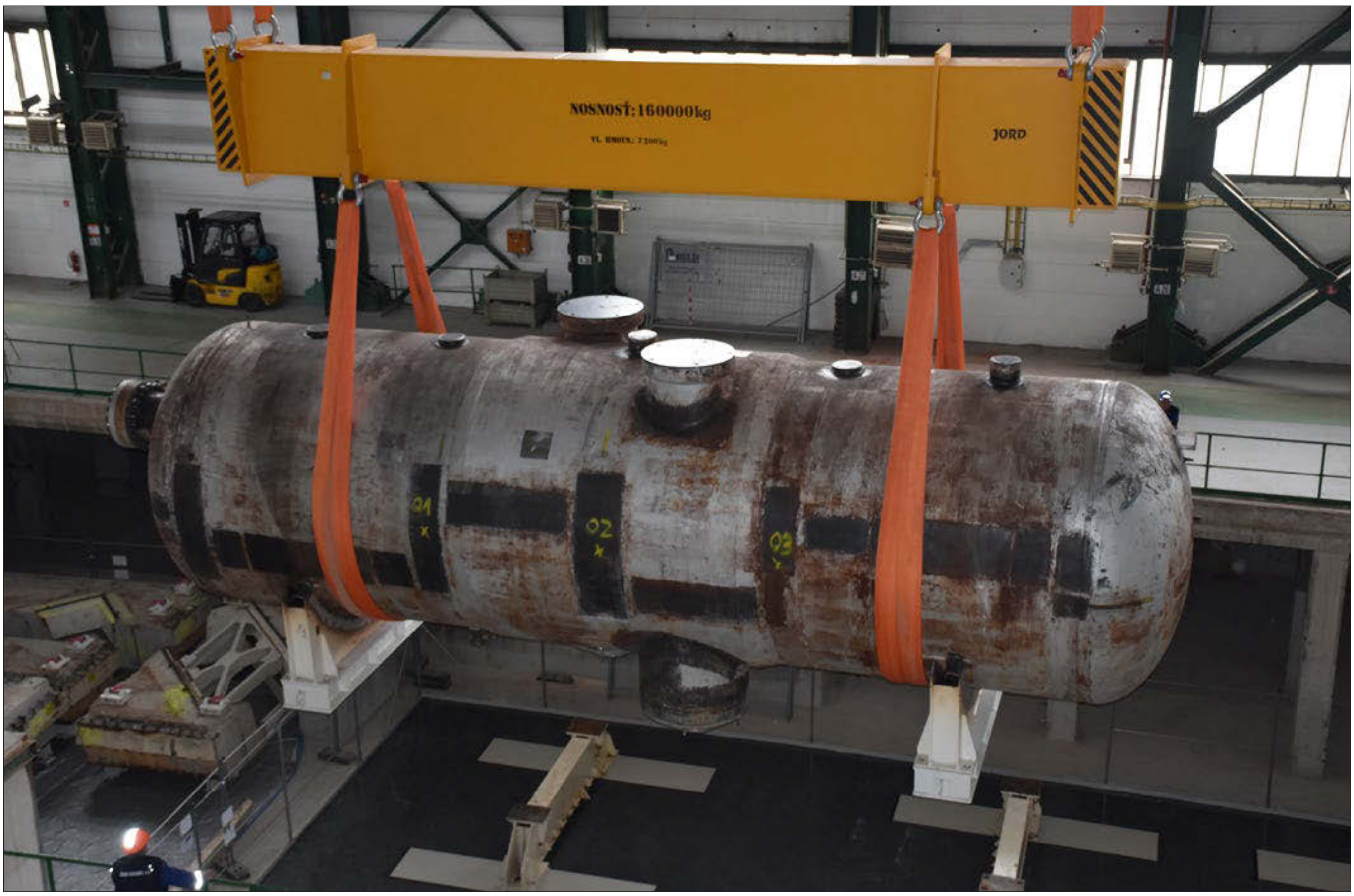


Photo: JAVYS

Bohunice V1 dry cutting workshop in turbine building.

Bohunice V1 is a VVER-440 design with two units, six loops per unit. The chemical decontamination was performed two loops at a time, with the reactor core bypassed. The pressurizer and pressurizer relief tank (bubble tank) were decontaminated as well, in a separate application.

The activity removal of Bohunice V1 Unit 2 Loops 1 and 4 is illustrated at left. Loops 1 and 4 were successfully decontaminated as planned, with three cycles of NITROX-E for removing the oxide layer and two cycles of DFD chemicals for removing the residual contamination located in the surface micro-cracks. The final decontamination factor (DF) was 55.7 (98.2 percent activity removal). Dose rates were measured at several points prior to the start of the decontamination and at the end of each process cycle, to allow for DF calculation, which measures the progress and effectiveness of the chemical decontamination.

Including the full-system chemical decontamination of the primary circuits in the decommissioning plan for Bohunice V1 Units 1 and 2 significantly simplified the decommissioning strategy, since hands-on equipment for dismantling the reactor coolant loops could be used. Being able to dismantle the reactor coolant loops by hand further improved the optimization strategies for the schedule and on-site work efficiency, including taking advantage of the large space available in the turbine building. This space was used to configure and build a dry cutting workshop in which all 12 steam generators from the two units could be segmented. Due to the chemical decontamination, the steam generators are currently being dismantled without any extra shielding or protection.

Reducing waste volume

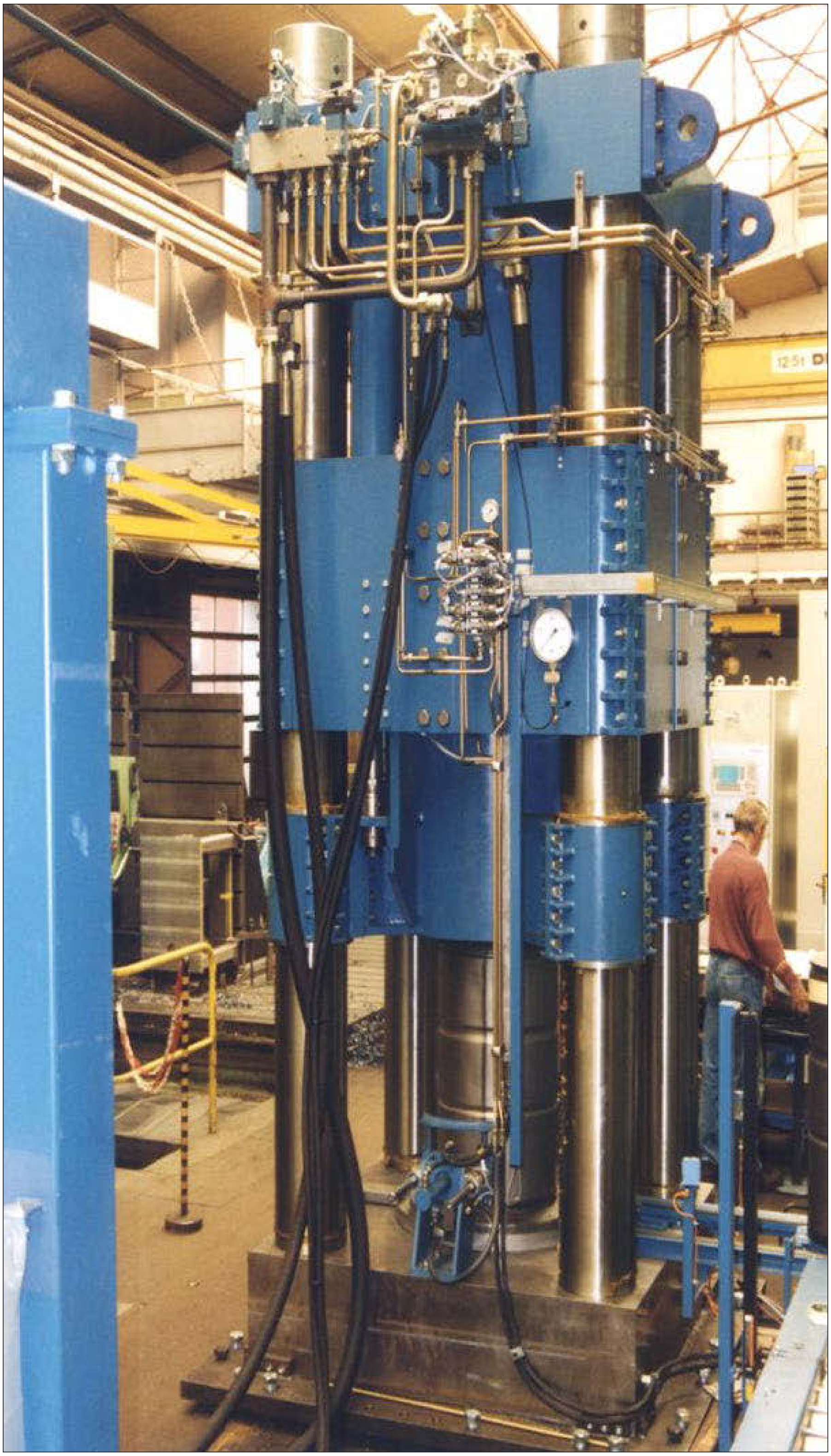
The management of radioactive waste from decommissioning is an important step in the overall decommissioning process. The main goal at this stage is to generate conditioned waste in packages that are qualified for interim storage, pending final disposal. An important secondary goal is to reduce the volume and, as possible, the waste class, and therefore the disposal costs, either by decontamination or by other specific treatment processes.

Various options are available to reduce the volume of radioactive waste, depending on the waste type:

- Thermal treatment, including incineration, pyrohydrolysis, and plasma for organic material and plasma heating for mixed waste.
- Melting metals into compact disposal shapes.
- Compacting solid waste materials, including metals, glass, plastics, small equipment and tools, filters, compactable trash, wood, pipes, sludge, asphalt, and insulation.

Compaction is a mechanical volume-reduction process by which waste material is compressed in a disposal drum. Volume reduction achieved during compaction is a function of void space in the waste package, the force applied by the press, the bulk density of the material, and its spring-back characteristics. Super compactors are capable of compacting traditionally marginal-compactable waste. Such super compactors can achieve a volume reduction factor of 2 to 4 for marginal-compactable waste, and a volume reduction factor of 6 to 7 for usual-compactable waste. The advantages of compaction processes include the following:

- Compaction is a proven process used in the nuclear industry throughout the world.
- Compaction systems are simple and



Super Compactor with 2,000-ton operating force.

tend to be reliable and trouble free.

- Waste compaction is relatively inexpensive.
- The process is simple to operate.
- The increased waste density promotes self-shielding.

Mobile waste treatment

In recent years, mobile waste treatment systems have been increasingly deployed for processing various types of radioactive waste. These mobile waste treatment systems encompass any radioactive waste processing system or component designed to be transportable, rather than permanently installed. They offer flexibility in the selection and application of the optimum technology for a specific waste stream by bringing the process to where the waste is generated, with the additional benefit that equipment can be shared among multiple generating sites.

The use of mobile systems is driven by a variety of factors, such as avoiding off-site waste transport by bringing processing technology to the point of waste generation, providing opportunities to manage waste in various campaigns in the case of multiple facilities that generate similar waste streams, and easing on-site installation of more advanced techniques and processes.

There are specific circumstances under which mobile systems have clear advantages, such as when dealing with non-routine, problematic waste with a smaller volume that requires a case-specific solution using a combination of techniques; accident and incident situations, when systems need to be deployed in an emergency; and decommissioning situations, where building new permanent nuclear facilities, such as a waste processing facility, is to be avoided.

One example of such a mobile system is the Westinghouse Mobile Solidification System (MOSS), which is a complete, remotely controlled system for cement solidification of liquid radioactive waste. The system is compactly installed in a framework the size of a standard 20-foot transport container. MOSS immobilizes various kinds of waste—such as ion exchange resins, sludge, and evaporator concentrate—in standard 200- or 400-liter drums. Together with the container, the separate control module can be transported from one site to another for different tasks. This system was developed to meet customer and authority requirements in various applications for nuclear power plants, research centers, waste disposal sites, and other nuclear facilities. Incorporating lessons learned from the most recent cementation projects, the MOSS system has been improved with enhanced features.

Another example of mobile waste reduction systems is the mobile super compactor, which is integrated in a semitrailer with the ventilation system and the hydraulic and electrical components. To be compliant with local road traffic regulations and not exceed the maximum permissible transport height, the Westinghouse Mobile Super Compactor's height can be adjusted. To protect the system from damaging environmental impacts, particularly when being transported, the Mobile Super Compactor is enclosed by a protective hood. It can be handled like an International Organization for Standardization (ISO) container. The connection to the semitrailer is performed by standard ISO locking fixtures, as usually used for standard containers.

Planning is key

Conducting a plant decommissioning is an expensive and complex undertaking with many nuclear security and safety requirements to be considered. Understanding the plant's characterization, plant data, the regulatory requirements of the country in which the plant is located, and waste transportation and storage constraints requires careful planning that is best started two to three years prior to plant shutdown. This allows time for formulating a decommissioning plan that is safer for workers and efficient in terms of schedule and cost. As with other activities in the nuclear industry, the whole decommissioning program must be planned and conducted in a safe, efficient, and effective manner. Fortunately, several techniques as described in this article are available so that plant owners can feel secure in completing this step toward full site remediation. NN

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