The Decontamination, Decommissioning, and Demolition of the Engineering Test Reactor at the Idaho Cleanup Project

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ABSTRACT

In September 2007, CH2M-WG Idaho completed the decontamination, decommissioning and demolition (D&D) of the Engineering Test Reactor (ETR) facility. The 50-year-old research reactor, located at the Idaho National Laboratory site, posed significant challenges involving regulations governing the demolition of a historical facility, the removal of a large amount of hazardous materials as well as issues associated with the removal and disposal of the 112-ton reactor vessel.

Prior to commencing full scale D&D, hazardous constituents were removed including cadmium, PCB oils and electrical components, lead, asbestos and mercury among others.

The reactor required isolation in order to be removed. Due to activated metal within the reactor vessel, dose rates in the core region were approximately 1100R/hr. Subsequent dose rates outside the vessel varied from 60mr to greater than 2R. Due to the dose rates, the project team decided to fill the reactor vessel with grout to a level above the core region and below the discharge to the canal.

To remove the reactor, access to the 17 mounting shoes was required. These shoes were encased in the high density concrete biological shield approximately 8 feet below grade. The project team used explosives to remove the biological shield. The demolition had to be controlled to prevent damaging the reactor vessel and to limit the seismic impact on a nearby operating reactor. Upon completion of the blast, the concrete was removed exposing the support shoes for the vessel.

The reactor building was then demolished to accommodate the twin gantry system used to lift the reactor vessel. In September, the reactor vessel was lifted and placed onto a multi-axle trailer for transport to an onsite disposal facility.

INTRODUCTION

Background

The ETR facility first became operational in 1957. At the time it entered service, it was the largest, most advanced nuclear fuels and materials test reactor in the United States at 175 megawatt thermal (MWth). After initial testing, the unit achieved full power operation in 1958. In 1972, a decision was made to have the ETR support the Department of Energy's (DOE) breeder reactor safety program. Conversion of the reactor for this purpose started in May 1973. The new assignment focused on safety programs relating to reactor fuel, core design, and operation for the liquid metal fast-breeder reactor program.

Initial deactivation of the ETR Complex was initiated in December 1981. The neutron startup source was removed. Radioactive water was drained from the ETR vessel, primary coolant system (PCS), water loop experiment piping and vessels, both canal sections, degassing tank and associated piping, and resin tanks. Other water systems were drained, including the secondary coolant water (including heat exchangers), utility water, the two demineralized water systems (low and high pressure), and water in heating and cooling units. The fuel in the ETR, as well as irradiated fuel in the ETR storage canal, was removed and shipped to the Idaho Nuclear Technology and Engineering Center for storage. After initial deactivation was completed in 1983, the ETR facility was left essentially dormant until D&D activities commenced in 2005.

Facility Description

The ETR reactor building (TRA-642) had four levels. The main hall, which comprised the above grade portions of the building, provided access to the uppermost section of the ETR vessel and the top of the ETR storage canal. The three underground levels were comprised of the console level and pipe tunnel, the basement with the experiment cubicles and a subpile room, and a lowermost level containing the control rod access room.

The ETR vessel was a multi-diameter, cylindrical vessel approximately 36 ft in height and 12 ft in diameter at the top, reducing down to 7 ft in diameter at the bottom. As stated above, all fuel had been removed from the ETR vessel. Major internal components that remained in the vessel included the control rod guide tubes, control rod sections, aluminum and beryllium reflector, grid plate, and four in-pile tubes. The vessel also contained miscellaneous fillers, adapters, and plugs. The ETR vessel with the internal components weighed approximately 82 tons.

Contaminants

Although the reactor had been defueled, it contained significant amounts of highly radioactive cobalt, strontium, and cesium. The ETR vessel also contained tritium and cadmium as well as irradiated beryllium. The facility contained nearly 1.5 million pounds of lead and vast amounts of asbestos-lined piping with a majority of it residing in the 17 experimental cubicles.

DEMOLITION APPROACH

Environmental Characterization and Documentation

The final disposition of the ETR vessel was of primary concern for two agencies, the Idaho Department of Environmental Quality (DEQ) and the U.S. Environmental Protection Agency (EPA). The final end state of the ETR facility as well as the final disposition of the ETR vessel was determined through the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Non Time Critical Removal Action (NTCRA) process. This process uses the Engineering Evaluation/Cost Analysis (EE/CA) to present alternatives and evaluate these alternatives and features input and oversight by the agencies and the public. The alternatives that are presented in the EE/CA are evaluated for protectiveness (risk) for the public, the worker, and the environment; technical feasibility; and cost. While cost and technical feasibility were important for selecting the alternatives for the final disposition of ETR, in the end, it was risk to the worker and protectiveness of public health that most influenced the selection of the final disposition of the reactor vessel.

During the EE/CA process, interfacing early and often with the agencies was key to determining the disposition of the ETR vessel. Biweekly status meetings and tours kept the agencies informed and allowed an atmosphere of trust to develop between the agencies and the project team. An excellent working rapport was established that allowed both sides to communicate concerns and issues in a timely manner and to resolve the issues without impacting project schedule and milestones.

One of the most important, and time and cost intensive issues, involved determining the radiological and chemical source term of the ETR vessel. This information was key for identifying the disposal path for the vessel. The ETR vessel was a research vessel that experimented with effects of neutron fluxes on materials. The information that was gained from these experiments was used to develop models of the influences. The models were further refined as more experimental data became available. As a result, modeling of the processes in a nuclear reactor has become an accepted method of characterizing radiological inventories in reactor vessels. The characterization of the ETR vessel employed the use of two models, the Origin II Code and the MCNP4C Codes. Using these modeling codes, an expert nuclear physicist on the project team determined isotopic concentrations of activated metals within the reactive core region of the vessel.

The radiological inventory in the vessel was used to determine the suitability for disposal at various waste disposal sites. Through the alternative analysis, all but two disposal sites were eliminated. Only the disposal area at the Nevada Test Site and the Idaho CERCLA Disposal Facility (ICDF) were considered viable alternatives because the ETR vessel did not exceed inventory or concentration limits specified in the Waste Acceptance Criteria (WAC) of these two facilities. Determining the concentrations of isotopes in the vessel components became crucial in determining whether the vessel met the WAC. To determine the concentrations, it was important to understand requirements and limitations to concentration averaging. The project team proposed and received concurrence from the agencies that the proper “waste package” for the purpose of concentration averaging was the entire reactor vessel. The walls of the vessel were both part of the waste and functioned as the package. Therefore, the concentrations of the ETR vessel (waste package) were determined by averaging the isotopic inventory in the vessel over the entire mass of the vessel internals and walls. The weight of the grout that was introduced into the vessel was not used as part of the mass of the waste package for the purpose of concentration averaging.

The agencies and the public were extremely interested in the ETR vessel from the transuranic waste classification aspect. Transuranic waste is defined as waste that contains more than 100 nanocuries per gram of transuranic isotopes. In addition, the waste acceptance criteria for the ICDF limited transuranic concentrations to less than 10 nanocuries per gram.

Generally, the characterization of the ETR vessel was determined by developing the inventories and determining concentrations of constituents by the project team, independent of any past characterization activities. In other words, to ensure accuracy, the project team developed its own source terms based on sampling and analysis data it generated. In the case of the transuranic inventory in the vessel, it was necessary to obtain a sample of the beryllium reflector that surrounded the active core. Beryllium ore when mined contains naturally occurring uranium (U 238) as an impurity. The neutron fluxes present during reactor operations activates (adds neutrons) to the U 238 nucleuses and converts these to transuranic isotopes. Transuranic isotopes are of concern for disposal due to their extremely long half-lives.

Sampling the beryllium reflector in the vessel required intense preparation. The ETR vessel was drained of coolant and sealed in 1982. With no coolant water in the vessel, radiation dose uptake by the sampling team was the primary concern. The beryllium reflector was 25 feet below the top opening of the ETR vessel. Many obstacles such as experiment tubes between the vessel opening and the beryllium sample location prevented direct access for the sampling effort.

The project team developed remote sampling techniques and tools. Cameras and monitors were used so samplers would not be directly exposed to radiation emanating from the reactor core. A mockup of the sampling activity, set up on the main floor of the ETR building and extended through a hole in the floor to the basement below, was used to simulate working in the vessel. The crew spent many hours practicing obtaining a sample.

Project management required a readiness review to ensure that activities could be performed safely. Even with all the planning and practice, it was the sample team’s ability and ingenuity that overcame unforeseen obstacles and successfully obtained a sample with far less than expected exposure to the workers. One unforeseen obstacle was the inability to remove the designated sample block in the reflector. The beryllium sample block was installed with the reflector and designed to be removed for analysis. The sample block and the reflector had expanded over the years – lodging the sample block in the reflector and making it inaccessible to remote tools. The crew designed a new remote tool similar to a gear puller to put counter force on the reflector while pulling up on the sample block. This allowed for a piece of the sample block to be broken free, enabling the project team to obtain a sample.

Analysis of the beryllium sample provided the modeler with the data necessary to model the total inventory of transuranic isotopes in the reflector. From the modeling, it was determined the transuranic concentration in the ETR vessel to be less than 2 nanocuries per gram - well below the ICDF WAC.

The transuranic data as well as the total radionuclide and non-radionuclide inventories were presented in the EE/CA. Although the project was able to demonstrate that the ICDF WAC had been met, regulatory agencies preferred to have the vessel size reduced for off-site shipment. The project was able to demonstrate that in addition to meeting the ICDF disposal criteria, size reducing and packaging this vessel posed significant safety risks to workers. Besides using the inventories for waste determination of the vessel it was also used in the human health and environmental risk assessments. Because the ETR vessel met the WAC, had the least risk for the public and the workers, and cost the least, the alternative for disposal of the ETR vessel at the ICDF was the selected alternative by the agencies and generally supported by the public.

The final end state of the ETR facility and disposition of the ETR vessel was documented in the CERCLA NTCRA Action Memorandum for Decommission the Engineering Test Reactor Complex under the Idaho Cleanup Project, January 2007 (DOE/ID-11303).

Radiological Characterization and Mitigation

From the start of ETR D&D, the project team desired to know the dose rates associated with the reactor vessel. This information was essential to ensure the appropriate controls could be put in place to protect the workers during D&D activities. In addition this information was critical in determining the proper characterization of the waste package. Direct radiation measurements of the external surfaces at that time were not possible since above grade portions of the vessel were enclosed within the removable biological shield (formed from ~6 ft thick high density concrete blocks), and the below grade regions were within the permanent biological shield where such a small gap between vessel and shield prevented the insertion of a detector probe. To perform the initial dose rate characterization, sets of thermoluminescent dosimetry (TLD) chips, spaced in 2 foot increments, were pushed through the rabbit tube (a vertical tube that extended from the upper portions of the vessel down through the vessel just outside of the beryllium and aluminum reflectors surrounding the core area to the grid plate). The TLD chips were removed and processed, and based on the exposure time of the chips, dose rates in the reactor interior were determined. The highest dose rate obtained was directly above the activated stainless steel grid plate and was 500R/hr.

As D&D progressed and previously inaccessible areas opened, additional dose rate characterization information was obtained. The following highlights some of the data obtained:

- During work activities in the Sub-pile room, project personnel were able to position TLD chips attached to a fish tape in the small annulus between the permanent biological shield and the lower portion of the vessel. The highest dose rate obtained during these measurements was 30 R/hr on the vessel exterior at an approximate elevation of just below the grid plate.

- When an access on the top of the reactor was opened to support the beryllium reflector sampling effort, dose rates were obtained from the top of the biological shield down, inside of the reactor to just above the core area. With the access open, the highest dose rate on the biological shield top was 150 mrem/hr. The dose rate over the open port was 1 R/hr and increased the farther the probe was inserted in the reactor to a maximum dose rate of 1120 R/hr just above the core.

- As the primary piping was removed from the facility, workers were able to obtain dose rates on the interior of the primary inlet and outlet piping from the location where it penetrated the biological shield to its attachment to the reactor. The dose rates in the piping interior of the outlet pipe ranged from 1.9 R/hr 12 ft from the reactor to 112 R/hr where it attached to the reactor. The dose rates on the inlet piping were as high as 3.6 R/hr.

- Workers were able to enter the space between the removable biological shield and the upper portion of the vessel (known as the nozzle trench). Average dose rate in this area was 10 mrem/hr, and the maximum contact dose rate on the vessel was 150 mrem/hr.

The above data is significant since it was known that work activities were planned in these areas to prepare the vessel for removal. Some of the remaining work activities that would place workers into these high dose locations are as follows:

- The reactor contained a lead shielding plug positioned over the discharge chute inside of the vessel. Removal of this plug would require workers to work in the 1 R/hr field in the open reactor port. Additionally, during the operational days of the reactor, when it was necessary to remove this plug, the reactor was full of water and the entire top of the reactor was removed. It was unknown if this plug could be removed through the 12 inch access port.

- The primary system inlet and outlet piping had to be separated from the vessel. Even if this was accomplished with the worker positioned 12 feet from the cut location, the worker would still be exposed to a 1.9 R/hr field.

- The reactor mounting shoes had to be separated from the biological shield. These shoes were at an elevation between the inlet and outlet piping and the dose rate in this location was estimated to be ~25 R/hr.

- There was several weeks worth of work to be performed in the nozzle trench. The 10 mrem/hr average dose rate would lead to a large cumulative dose being received.

Since many of the above tasks would be very difficult, if not impossible, to accomplish using long handled tools, a method to shield the dose was necessary. The most practical way to reduce the dose rate was to shield the radiation at its source. An analysis was performed to evaluate various grout densities for their shielding effectiveness, flow ability (i.e. ability to fill the void spaces around the core), and the grout contribution to the total weight of the lifted load when the reactor was removed. A final grout density of 1.5 g/cc was chosen. Calculations and modeling using this grout density determined a maximum contact dose rate with the reactor vessel of 500 mrem/hr.

The grout was more effective than anticipated. The dose rate at the primary outlet piping was reduced from 135 R/hr to 300 mrem/hr and the 300 mrem/hr was the highest measured dose rate on any of the vessel external surfaces. Inside the reactor at the grout fill line, the dose rate was reduced from 160 R/hr to 62 mrem/hr. Dose rates in the nozzle trench were reduced from the 150 mrem/hr contact dose rate to 1 mrem/hr. See Figure 1 for the pre- and post- grout dose rates.

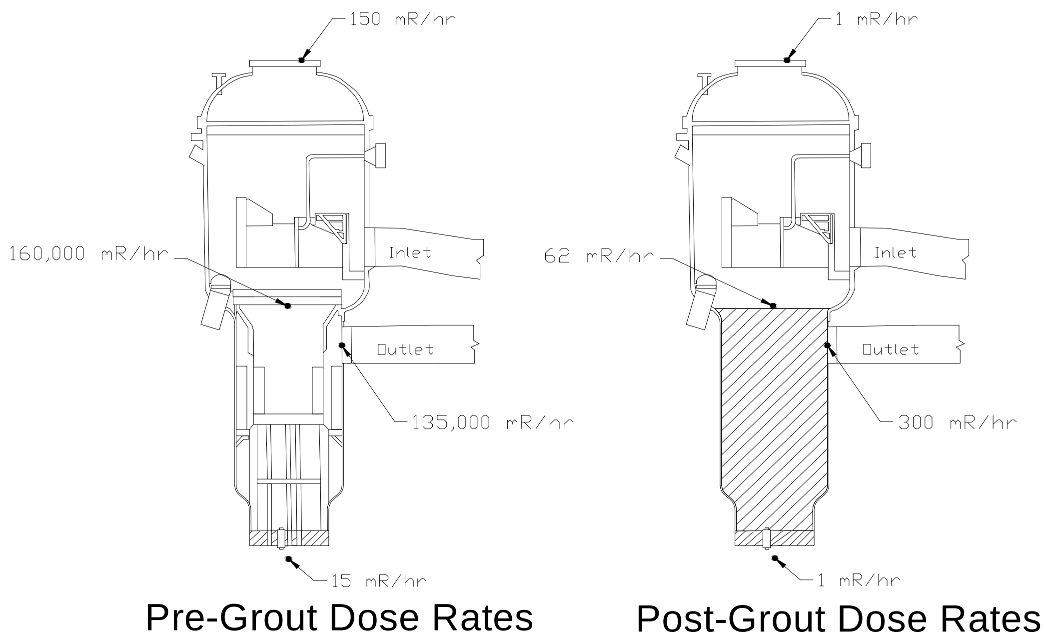

Figure 1. Vessel Dose Rates.

The dose savings from grouting the reactor were substantial. For example, preliminary dose estimates for the cutting of the primary piping from the vessel were as high as 15.62 R for the activity. The actual dose received by the workers who cut these pipes following grouting of the reactor was less than 400 mrem total for the entire activity.

Reactor Vessel Removal Preparations

To remove the reactor, access to the 17 reactor mounting shoes was required. These shoes were encased in the reactor fixed biological shield approximately 12 feet below grade. Several of the above grade biological shielding pieces could be removed to support reactor refueling and maintenance. These pieces averaging 50,000 pounds were removed and disposed of at the ICDF. The remainder of the biological shielding primarily below grade was constructed of approximately 6 feet of poured high density, reinforced magnetite concrete with ¾”carbon steel forms. Figure 2 is a cross section of the ETR reactor vessel model. Initially the method for removal involved using a large excavator with shear and hammer attachments and plasma cutting for the forms. This method, due to the concrete density (225 lbs/ft3) and the location and thickness of the forms, proved to be both highly hazardous and time consuming. The project decided to use explosives to remove the biological shield. A subcontractor was selected to drill into the primary shield and subsequently perform a controlled demolition of the shield to just above the shoes.

The demolition had to be controlled to prevent damaging the reactor vessel and to limit the seismic impact to the operational Advanced Test Reactor (ATR) and support facilities located adjacent to the ETR. Seismic impact had to be less than 0.25 in/sec peak particle velocity (PPV) as measured at three separate facilities. Two separate blasts were performed successfully with PPV readings all less than 0.114 in/sec PPV. Upon completion of the blast, the concrete was removed exposing the mounting shoes for the vessel.

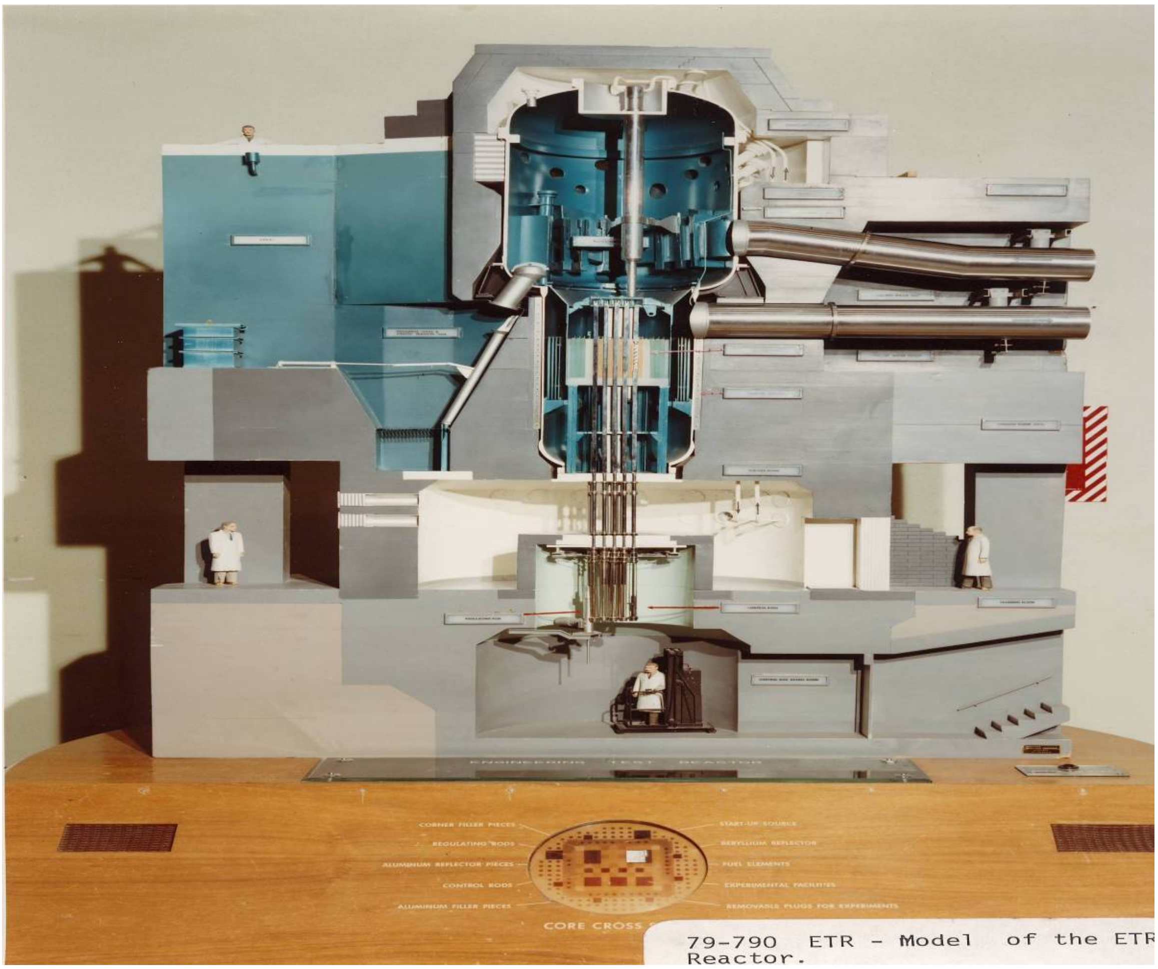

Figure 2. ETR model cross section.

Reactor Containment Facility Removal

In order to remove the reactor vessel using a twin gantry system, the reactor exterior containment facility had to be removed. The reactor containment facility (TRA-642) measured 90’ wide by 136’ long and 56’ high. Due to the size of the facility and its proximity to operating facilities supporting the ATR, the project decided to pull the facility over in a direction away from the operating facilities. Pulling the facility over, and the subsequent impact to the ground, had the potential to have a seismic impact on adjacent ATR support facilities. An independent study was generated which concluded that the impact to ATR and its support facilities would be less than 0.25 in/sec PPV as measured in the respective facilities. The first step to pulling the facility over was to isolate over 20 utilities supporting the facility. Exterior siding was then removed to expose the structural support members. The structural steel was then weakened to facilitate a controlled demolition of the building. When weakening of the facility was completed, the facility was pulled over using two Caterpillar D8 tractors and two articulated dump trucks (see Figure 3). Seismic readings were all less than 0.25 in/sec PPV as measured. Upon completion of the demolition of the facility, the debris was sized and disposed of at the ICDF.

Figure 3. Building TRA-642 pullover

Reactor Removal

The ETR reactor vessel estimated weight with the grout was approximately 112 tons. Additionally the vessel dimensions were 36' tall by 12' in diameter. Due to size and weight constraints of the reactor, a twin gantry system was chosen as the method to lift the vessel from its location and place it on a transport vehicle for disposal. This is a similar approach used to install the vessel in 1956 (see Figure 4). The reactor mounting shoes were attached to the lower biological shield with studs and nuts. The studs, which were anchored into the lower biological shield, were cut and removed thus freeing up the reactor vessel from its supports. The shoes then rested on the lower biological shield. The reactor was lifted with jacks from the shoe area approximately 20" to verify no interferences and then lowered and placed on its support shoes.

The twin gantry system was placed and leveled on the reactor floor and a haul road for the reactor was built/improved between ETR and the disposal facility. Due to the weight of the vessel and transport vehicle, 95 percent compaction was required on the haul road.

The project team commissioned and completed an independent self-assessment prior to lifting the vessel to evaluate readiness for this evolution.

Due to the age of the vessel and the uncertainty of the installed lifting fixtures, specialty lifting lugs were designed, fabricated and load tested for the reactor. Lifting lugs were installed on the top and bottom of the vessel. The top of the vessel was rigged to the gantry and lifted upwards. The second gantry tower was attached to the rigging on the bottom of the vessel and the vessel was rotated from a vertical position to a horizontal position. When the vessel was horizontal, it was traveled with the gantry system approximately 40 feet to clear the vessel from the reactor annulus area. A special purpose Goldhoffer multi-axle trailer with engineered cradles was driven under the vessel. The vessel was lowered onto the trailer and then secured with tie-downs. The vessel was transported to the ICDF approximately 2-3 miles. The gantry was re-assembled at the disposal facility and the vessel placed in its burial location. Prior to burial, the remainder of the void space inside the vessel was grouted for stabilization and to meet the ICDF WAC.

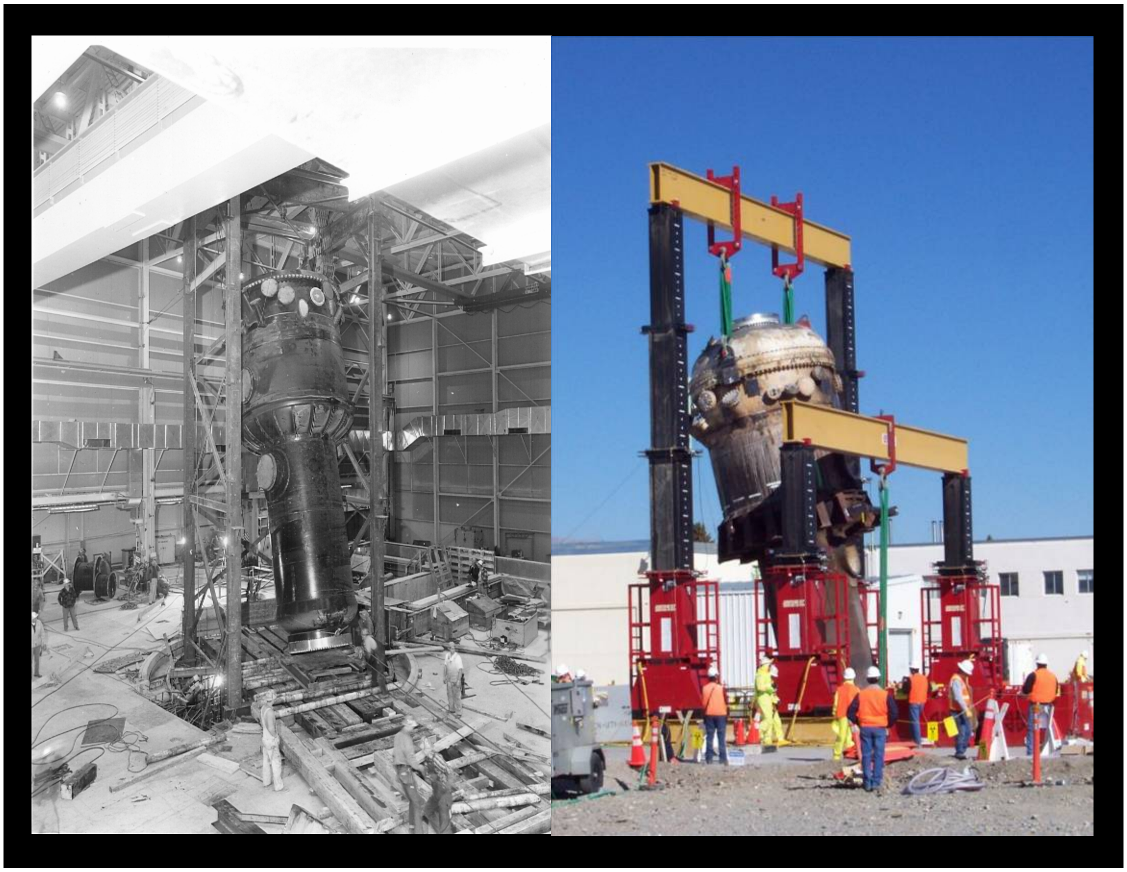

Figure 4. Installation and removal of the ETR vessel.

CONCLUSION

Demolition of the ETR facility was a significant success from many aspects. The Idaho Cleanup Project calls for the disposal of three reactors between May 2005 and September

2012; ETR was the first reactor completed under the CH2M-WG Idaho contract. CH2M-WG Idaho used a combination of innovative demolition techniques to protect workers and nearby operating facilities. Finally, the approval for onsite disposal set a precedent for the remaining reactors to be disposed of onsite, saving millions of dollars in disposal costs.

The following critical metrics were used to demonstrate the success of this demolition project:

- Outstanding safety record for the entire duration of the project
- Completion more than two years ahead of schedule and at a significant cost saving
- Cost performance index for the project was 2.36, which equates to 58 percent under cost as of October 2007
- Schedule performance index for the project was 1.51, which equates to 51 percent ahead of schedule as of October 2007

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