AN OVERVIEW OF THE NASA PLUM BROOK REACTOR FACILITY DECOMMISSIONING - FACILITIES

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ABSTRACT

The National Aeronautics and Space Administration (NASA) is nearing the successful completion of its $230 Million (US), 12 year effort to decommission the Plum Brook Reactor Facility (PBRF). This paper will examine the challenges and solutions involved in the segmentation and removal of the reactor and its internals, and the decontamination of the hot cells.

1. BACKGROUND

The NASA Glenn Research Center's PBRF is located near Sandusky, Ohio. It is halfway between Toledo and Cleveland, five kilometers south of Lake Erie. There are two US Nuclear Regulatory Commission (NRC) licensed reactors on site. The main reactor was a 60 MW pressurized water reactor and the Mock-Up Reactor (MUR) was a 100 kW swimming pool type. Both were used to perform neutron exposure testing on materials in support of the nuclear rocket program.

Figure 1. The NASA Plum Brook Reactor Facility – circa 1987

Construction started in 1958, with initial criticality in 1961. Full power operations began in 1963. The plant ran for 10 years, accumulating 98,000 MW days of run time. In 1973 it was shut down, all fuel was shipped offsite, and the balance of plant was placed in Safe, Dry Storage. Pre-decommissioning began in 1999, and full decommissioning started in 2002 with the NRC's approval of the NASA PBRF Decommissioning Plan. NASA expects to submit its License Termination Request (LTR) for both reactors to the NRC in early 2012.

1.1 Shutdown Conditions

When the PBRF was shutdown, great care was taken to place the plant in standby in such a way that would minimize dose rates during the shutdown period, and allow an eventual restart of the facility. Plant personnel were divided into teams based on systems to be secured; PBRF went from operating to safe shutdown in six months. All teams kept meticulous records of what they did and the condition they left the equipment in. These records proved invaluable in planning decommissioning work – as an example, the fact that there were notes showing the laboratory hoods had been cleaned out meant the project didn't have to worry about picric acid when disassembling the hoods.

All fuel, spent and new, was returned to the supplier. The 8 m deep Quadrant and Canal (Q&C) system was drained and washed down using fire hoses. This system had connected the reactor and hot cells, and contained the spent fuel racks and the Mock-Up Reactor (MUR). During operations it allowed the safe underwater movement of experiments and fuel.

All piping systems were drained, and all water was disposed of prior to the shutdown of the water processing system. The Reactor Pressure Vessel (RPV) was placed under a dry nitrogen purge to prevent corrosion of the reactor internals. The nitrogen exhaust was equipped with a real time monitor to watch for a surge in tritium – this would have indicated whether one of the highly irradiated beryllium reflector plates inside the vessel had fractured.

The hot cells were used for storing everything that was portable, contaminated, and expected to be needed following the expected facility restart. They were packed with a mixture of machine tools, pieces of experiments, and miscellaneous support equipment.

1.2 Project Goals and Approach

Concentration Guideline Levels (DCGLs), the clean up levels that tell us when we are done with decontamination, were developed using a pair of models. For residual soil contamination RESRAD Version 6.0 was used. This model has been formally accepted by the NRC for analysis of residential farmer scenarios. The dose model selected for analyzing residual building surface contamination, RESRAD-Build Version 3.22, is widely used in analyzing building reuse scenarios. These two site-specific models include all pathways and exposure modes included in the NRC generic screening.

The approach used has been to decontaminate the site to the DCGLs, and then to perform Final Status Survey (FSS) to demonstrate and document this was done. The Decommissioning Plan is written so as to allow NASA to demolish the structures either before or after License Termination. Buildings are to be demolished to one meter below grade, and the resulting hole is to be filled with Clean, Hard Fill. The final one meter will be backfilled with topsoil.

There are two other goals that have guided the decisions made by the project. The first, as directed by NASA Headquarters, was that everything would be done to protect the safety of the public, the workers, and the environment. Second, where it made fiscal sense, work would be done so as to minimize the need to use offsite landfill space to dispose of waste.

2. REACTOR SEGMENTATION

An early technical challenge was determining the best approach for removing and disposing of the reactor vessel and the core internals. This hardware represented the largest source term, and some of the greatest unknowns. The overall vessel was 12 m tall, and 3 m in diameter. The top of the vessel was at grade level, and the core was 7 m below grade. The vessel walls were 2.5 cm to 7.5 cm thick, and were made of carbon steel with a stainless steel lining welded in place. The vessel was surrounded by a high density concrete bio-shield, and then by four, 8 m deep quadrants, three of which were purposely flooded during operation to provide shielding for moving irradiated experiments out of the reactor into the canal system, which provided a safe path to the Hot Cells, spent fuel storage, and the Mock Up Reactor (MUR). The dry quadrant held a large polyethylene block structure used for thermalizing a 1 m diameter beam of neutrons. As a result the bio-shield was asymmetrical, ranging from 0.6 m to 2.6 m in thickness. The control rod drives were located under the core, and were located in a sub-pile room 18 m below grade.

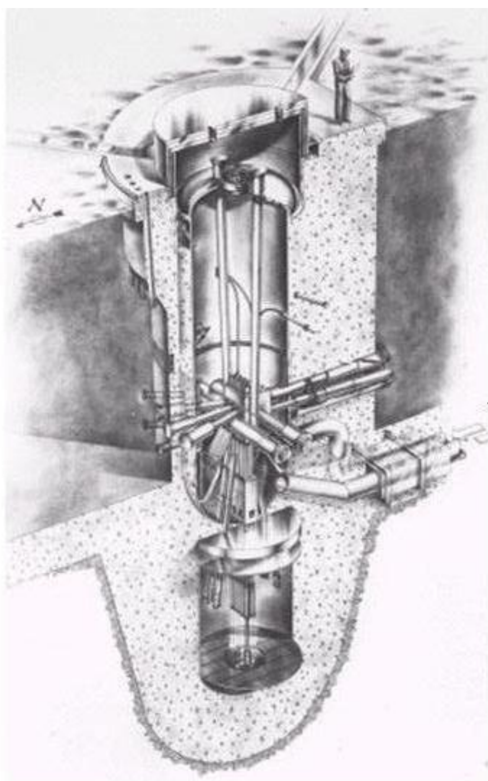

Figure 2. Cut away view of the main reactor

2.1 Reactor Internals

In the late 1980's dosimeters had been lowered into the vessel to capture in-core dose levels. These results were coupled with an activation analysis, which considered core construction materials, reactor run times, and known flux levels. The resulting analysis indicated that the core and vessel contained over 1.1×10^{15} Bq of activity. In addition there were concerns regarding the physical condition of the beryllium reflector plates located around the core box. While the absence of a tritium release in the dry nitrogen vent indicated that the plates had not fractured during shutdown, there was still the fear that the high levels of neutron exposure had left them very brittle. The assumption was that if the plates were broken during segmentation the result would be a large release of tritium which would be very difficult to contain. Additional analysis indicated that just opening the vessel to the atmosphere could result in a release as the tritium rapidly exchanged with hydrogen in the water vapor.

The project examined two options for core removal, either segmentation or grouting followed by intact removal. Analysis showed a number of technical challenges and risks with intact removal involving transport and shielding. These risks, coupled with the absence of significant cost or dose savings, lead to the decision to go with segmentation.

The next decision was whether to perform segmentation dry or wet. The thirty years that had passed since shutdown made this decision easy; there were no water processing or clean up systems in place, and the seals around the control rods in the bottom of the vessel were assumed to be no longer watertight. On the other hand it was felt that 30 years of radioactive decay would have lowered dose rates from the core to levels that could be handled safely unshielded by water. It was decided to proceed dry.

Dose rates at the top of the open reactor vessel were 11.0 mSv/hr. The original plan was to remove and dispose of the three, 18 metric ton, nested shrapnel shields from above the vessel and then to remove the pressure vessel head. A shielded work platform was to be installed across the top of the open tank from which workers would access the core. Unfortunately, an adequate dose analysis of the work platform was not performed during the planning phase. When it was done, just prior to installation of the work platform, dose rates were estimated at 0.5 mSv/hr. NASA judged these levels as being too high to meet ALARA, and worked to develop an alternate approach.

The solution was to make use of the original shrapnel shields. The shields were 20 cm thick carbon steel, and nested together on top of the vessel. A 2.5 m hole was cut in the top of each shield for access. With the shields in place, the general area dose rates were cut to 20 μSv/hr. A 25 cm hole cut in the side of the shield was connected to a HEPA ventilation unit to insure no airborne activity escaped during segmentation.

Workers from Wachs Technical Services (Wachs) then performed the disassembly of the reactor internals using standard tooling (wrenches, screwdrivers, etc) mounted on the end of 8 m poles. They manipulated these poles from behind the shields using 90 degree reach rods. The poles were suspended from jib cranes attached to the shrapnel shield outer wall. The workers were able to see what they were working on through the use of multiple in-tank cameras that they viewed on monitors, as shown in Figures 3 and 4.

To address the concerns with the tritium in the cadmium reflector plates Wachs designed a pole-mounted, spring-loaded, clamping mechanism. The mechanisms were custom built for each plate, and were planned to be disposable. The assembly was held open with air pressure and lowered into place around a beryllium plate. With the air pressure released, the clamping mechanism gently closed around the plate, securely holding it while the plate was unbolted from the core box. The plate and mechanism was then raised out of the reactor and placed directly into a shipping container, where the entire assembly was disconnected from the pole. The containers were then filled with an epoxy material that served as a shock absorber during shipping, contained any released tritium, and provided significant shielding.

Figures 3 and 4. Workers using remote viewing and long reach tools

The key to making this seemingly complex approach successful was that the workers were able to train and proof test all of the tooling and procedures in advance by disassembling the MUR. This swimming pool type reactor was physically identical to the main reactor, but the much lower power level it had operated at resulted in negligible dose rates. The highest on-contact dose for the MUR was 0.02 mSv/hr and the general area was background. A plywood silhouette was constructed to simulate the visual blockage created by the aforementioned shrapnel shields. Segmentation workers were able to 'test drive' tooling and handling techniques remotely while other workers were right on top of the action, as seen in Figure 5. They were able to see immediately why a particular tool or approach was not working, make the correction, and test it out. They also worked out optimum camera positioning. Once a step was mastered on the MUR it was executed on the main reactor.

Figure 5. Workers on the Mock Up Reactor

2.2 Segmenting the Vessel

Once the internals were gone it was time to deal with the vessel. The low dose rates that remained following the removal of the internals meant workers could now safely work within the tank. The approach used was to cut up the vessel into manageable pieces from the inside, while leaving the bio-shield in place.

The first step was to spray the entire interior surface with "lock down" (essentially, white paint) to fix any loose contamination in place. Next, a scaffolding arrangement was installed that allowed access to one meter sections of the vessel at a time. A milling machine track was tack welded to the tank wall in a vertical orientation, and several passes of the mill were used to cut through the tank wall, as shown in Figure 6. A number of vertical cuts were made at each elevation – the exact location driven by the location of vessel penetrations and keeping the size of the resulting pieces manageable. This typically resulted in four to five cuts per level.

Figure 6. Segmenting the vessel with a milling machine

The track was then tack welded to the tank wall horizontally, and one by one the pieces for each layer were removed. Prior to cutting a piece, it was secured by overhead cables so that workers or tooling would not be put at risk when it came free. As each layer of tank wall was removed, the scaffolding floor was lowered, and the process was repeated.

One issue that arose at this point is worth noting. Between the vessel outer wall and concrete bioshield there was a 2.5 cm layer of asbestos. The asbestos was remediated as each cut 'broke through' the metal and again as each piece was actually removed from the wall and the asbestos material behind it was exposed. The entire work area was remediated prior to relocating the mill and starting the next cut. This wasn't technically challenging, but was a time consuming, repetitive evolution.

2.4 Results

Segmentation was successfully completed in just over a year. The activation analysis proved to be quite conservative. Between the reactor internals and the tank walls a total of 36 metric tons of steel and aluminum were removed, with a cumulative activity level of 3.7×10^{14}Bq. The single highest dose item removed was a section of control rod; it was 16 mSv/hr on contact. The total dose for performing the work was 127 mSv. This is 20% of the projected dose had the "work platform approach" been used.

3.0 HOT CELLS

The PBRF had a full metallurgical laboratory that performed post-irradiation testing and analysis of materials specimens housed in a series of seven interconnected hot cells. The first, largest cell was licensed to contain 5.55×10^{16} Bq of activity at a time. The cells covered a total area of 77.3 m^2 with an interior height of 4.7 m. The front walls of the cells were 1.2 m thick and made of high density concrete. Each cell had an operating station that included a leaded glass window and manipulator arms. Figures 7 and 8 show the front and back side of the hot cells during reactor operations.

The side and rear walls of the cells were 1.5 m thick of normal concrete. The roof was composed of individual concrete slabs 0.6 m thick, and weighing up to 18,100 kg. Each cell had several hundred meters of conduit and piping. All cells were interconnected by a series of intercell transfer doors as well as a 7.5 cm diameter pneumatic tube system. Drain lines and ventilation ducting passed out through the floor to the Hot Pipe Tunnel that ran under the cells,

Figures 7 and 8. Front and back of hot cells during operations

from there to the Waste Handling Building. Entry could be made to the cells through the use of door plugs in the rear of each cell. Each cell also had a stainless steel liner that went half way up the walls. These liners had been added several years after reactor operations began due to the inability of the operators to sufficiently clean the original concrete floor and walls.

3.1 Entry and Clean Out

When the plant shut down the hot cells were used to store contaminated loose equipment. One of the earliest tasks in the project was to enter the cells and retrieve enough data to characterize and dispose of the loose equipment. In many cases identifying the equipment, and what it might contain, was a matter of detective work, since much of it was unique test apparatus. Some answers were available from the logs of the Shut Down teams, but in many cases it meant working our way by telephone through the network of retirees who still remembered what the equipment was, and what it was used for. Once the loose equipment was removed, characterization of the cell surfaces and fixed equipment was conducted.

Contamination in the cells consisted of Cs-137 (53%), Sr-90 (33%), H-3 (11%), Co-60 (3%) and trace amounts of Eu-154. Contamination levels in the cells ranged from 16,700 Bq/m^2 beta/gamma and 33.3 to 166.7 Bq/m^2 alpha. In a few areas, such as on top of crane rails and under inter-cell transfer doors levels as high as $1.0x10^7$ Bq/m^2 beta/gamma and 6,667 Bq/m^2 alpha were found. General area dose rates varied from 0.002 to 0.1 mSv/hr, with contact readings reaching 0.42 mSv/hr.

With these results, further clean up of the hot cells was temporarily halted while higher source term areas were taken care of. By 2005, when the cells were ready to be dealt with again, the project had developed competing ideas for how to handle them.

3.2 D&D vs "Rip & Ship"

In 2005 attention turned again to the cells, and developing the proper approach to handling them. There was a strong push from the contractor team to adopt a "Rip and Ship" approach. Simply put, this means bringing in the biggest "yellow gear" that will fit, knocking everything down, packaging it all up, and shipping it for disposal. All that is left to perform Final Status Survey (FSS) on is the hole in the ground. This approach minimizes labor and management costs while maximizing waste volumes and disposal costs. It works well when there is an inexpensive waste site nearby, as is the case for many U.S. Department of Energy sites.

NASA felt that given the relatively clean condition of the cells it made more sense to perform D&D, that is, to decontaminate the cells to the site's DCGL. This would be followed by FSS to demonstrate and document the levels that were being left behind. Finally the remaining structures would be demolished, with concrete within the volumetric DCGL remaining on site for use as backfill. A team of government and contractor personnel studied the two options, and determined little difference in the end cost. The biggest unknown was what the offsite disposal costs would be for the estimated 2,268,000 kg of contaminated concrete. Obviously small variations in the unit cost could drive the choice either way.

Still convinced that the D&D approach would prove best, and concerned with meeting its goal of minimizing offsite waste, NASA proceeded with a "risk reduction" effort to perform decontamination of Hot Cell #1. In this case, the risk in question was to project cost and schedule, not safety. Hot Cell #1 was the largest cell, representing nearly 40% of the total cell area, and it had the highest contamination levels. It was concluded that if Cell #1 could be cleaned in a safe, cost effective manner, then so could all the other cells.

The end result of the risk reduction effort was a clear victory for D&D. Hot Cell #1 was in fact decontaminated for US $1M less than the studies' estimated cost for 'rip and ship'. In addition to the cost savings, if all cells could be cleaned then it would avoid generating 2.3 million kg of radioactive waste. The decision was made to perform D&D on the balance of the cells. As with the first cell the clean up included the interior of the cells (MOTA Corporation) and is described in the following sections. Cell D&D also included the cleaning and surveying of the embedded conduit, piping, and pneumatic transfer tubes (Babcock Services Incorporated). This work is described in detail in Reference [1], and is not included in this paper.

3.3 Hot Cell Clean Up

Since loose equipment had previously been removed, the first step was to remove the fixed equipment, including the manipulator arms, control panels, conduit, storage racks, etc. This equipment was coated with the same lock down material used in the reactor vessel to fix loose surface contamination in place. It was then size reduced and placed in IP-1shipping containers for disposal. Once the equipment was removed the stainless steel liners were taken out. This proved to be more of a challenge than expected due to the extremely thorough job that had been done tack welding the liners to the extensive reinforcing bars in the cell walls. The Brokk® demolition robot turned out to be best tool for peeling the liners out.

The next step was the removal of the hot cell windows. NASA had contacted several current hot cell window vendors in an attempt to find someone to reuse the glass. In all cases the cost to NASA to meet the vendor's requirements for accepting the glass (including cleaning and delivery) was greater than the cost of simply disposing of the material. (The same thing happened when NASA attempted to give away the manipulator arms.) In addition, when 'free release' of a slab of glass was tried it was found that due to the combination of the lead in the glass and a naturally occurring potassium isotope it was problematic to achieve the site's free release standard of 'none detectable above background.'

The decision was made to dispose of the windows. Given the high lead content of the windows a Toxicity Characteristic Leaching Procedure (TCLP) was conducted; the window failed, meaning they had to go out as "mixed waste." Each 1.3 m thick window was actually made up of multiple layers of .25 m thick glass. Size reduction was simply a matter of attaching a rope to a glass slab and pulling the rope from outside the cell. The window would fall to the floor and shatter, resulting in chunks as seen in Figure 9. Where necessary, the chunks were further sized reduce with a sledge hammer, and the glass was then shoveled into 55-gallon drums which were sent off site for macro encapsulation. Once the glass was gone, workers removed the steel window frame using cutting torches, as shown in Figure 10. This work had to proceed with caution, as there were typically 7,000 kg of lead wool and lead shot packed in around each frame that had to be removed first.

Figures 9 and 10. Removal of hot cell window glass and frame

The removal and decontamination of the 20-ton concrete roof slabs came next. These were able to be decontaminated and free released using sponge-jet blasting. This is similar to sand blasting using small sponges embedded with abrasive material in place of blast grit. Figure 11 shows a worker performing sponge-jet blasting. The chief advantage is that after use the

Figure 11. Sponge Jet blasting

sponge media and debris are easily separated using a vacuum cleaner. The heavier debris drops out, but the light sponge is carried along to a different hopper. This way, the "sponge media" can be recycled up to a dozen times before it wears out. The result is a significant savings in waste volume. With the roof gone, the concrete intercell transfer doors were next. High levels of embedded contamination made it impractical to clean these "blocks," and they were disposed of. All walls were cleaned via sponge jet blasting, leaving a surface to clear of paint and contamination to survey. Floors were cleaned using a Marcrist Floor Shaver, seen in Figure 12. When used with an attached HEPA unit it was unnecessary for workers to use respirators, even in situations where there was asbestos. Figure 13 shows the cells ready for FSS.

Figure 12. Marcrist Floor Shaver

Figure 13. Decontaminated hot cells, with roof and intercell doors removed

4.0 SUMMARY

The decommissioning program at the NASA Plum Brook Reactor Facility was most successful when experienced D&D contractors were able to apply pre-existing technologies and methods in innovative and creative ways. Two different technical challenges were resolved in ways that may be of direct use to other sites, but more importantly it shows the importance and payoff of having the licensee and the contractor work together to identify the best options for the project. In this way NASA was able to meet its goals of protecting the safety of the public, the workers, and the environment, while minimizing the volume of waste produced that required offsite disposal.

REFERENCES

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