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Decontamination of the Plum Brook Reactor Facility Hot Cells

Keith M. Peecook
NASA Glenn Research Center
Plum Brook Station
6100 Columbus Ave, Sandusky, OH 44870

ABSTRACT

The NASA Plum Brook Reactor Facility decommissioning project recently completed a major milestone with the successful decontamination of seven hot cells. The cells included thick concrete walls and leaded glass windows, manipulator arms, inter cell dividing walls, and roof slabs. There was also a significant amount of embedded conduit and piping that had to be cleaned and surveyed. Prior to work starting evaluation studies were performed to determine whether it was more cost effective to do this work using a full up removal approach (rip and ship) or to decontaminate the cells to below required clean up levels, leaving the bulk of the material in place. This paper looks at that decision process, how it was implemented, and the results of that effort including the huge volume of material that can now be used as fill during site restoration rather than being disposed of as LLRW.

INTRODUCTION

The National Aeronautics and Space Administration (NASA) operated the Plum Brook Reactor Facility (PBRF) from 1963 to 1973. The facility was principally used to experimentally determine the effect of radiation on various structural materials that were being considered for use in NASA's nuclear rocket program. The PBRF consisted of a 60 MW main reactor, a 100 kw mock up reactor, and a series of seven hot cells that were used to perform complete metallurgical analysis of post-irradiation test articles. Fig. 1 shows the front of the hot cells during the operating days, with the manipulator arms and leaded glass windows. Fig.2 shows the backside of the cells, with the cell doors open. Following shutdown in 1973 all fuel was removed from the site, and all equipment placed in Safe, Dry Storage. Various pieces of loose equipment, such as experiment support tooling and sample carts, were stored in the hot cells and the doors were closed.

In 1997 NASA made the decision to decommission the PBRF. Pre-decommissioning activities began with the 1999 submittal of the Decommissioning Plan to the Nuclear Regulatory Commission (NRC). Field work started with the removal of loose equipment, returning required plant infrastructure (such as cranes) to service, and putting procedures and staffing in place. The full on site effort began in 2002 with the NRC's approval of the Plan. Initial activities focused on the removal of all fixed equipment, including the successful dry segmentation of both the mock up and the main reactor, and the main reactor pressure vessel. A more complete look at the first few years of the PBRF decommissioning effort is available in Reference (1).


Fig. 1. Front of hot cells **Fig. 2. Rear of hot cells**

A DECISION POINT

In the spring of 2005 the focus of the project team shifted from the challenge of removing the reactors to the remaining balance of plant. While some level of planning for the remaining work had been performed, there was clearly a need for the project to do a more formal analysis and comparison of the options remaining to complete the decommissioning. Personnel from all the project team organizations (MWH Constructors Inc. (MWH) and its subcontractors, the US Army Corps of Engineers, and NASA) conducted an Engineering Study. The study looked at the cost, schedule, and technical issues and risks of four different options, ranging from decontaminating everything followed by Final Status Survey (FSS) (maximum labor, minimum waste) to a full up ‘Rip and Ship’, where all buildings and structures would be quickly removed down to the footer piers (minimum labor, maximum waste). It also looked at two options that were at some point between the two extremes.

While the initial study results indicated a potential cost advantage to the ‘Rip and Ship’ approach, several more immediate concerns came to light. First, no matter which option NASA selected, there were insufficient funds appropriated for the project to be able to complete it. Second, the margin between the options was not that large, especially when potential future increases in waste disposal rates were factored in. Finally, it was clear that several other key assumptions (particularly as to the viability and actual cost of decontaminating the various structures and embedded piping) could also easily sway the results in favor of the decontamination approach if they were slightly changed.

Given the lead time required in the federal appropriations process, NASA knew it had at least two years before new funding sufficient to complete the decommissioning could be secured. It was decided to adopt a lower intensity approach to the project (i.e. a decreased staff level) that would allow the existing funding to carry the project through that waiting period. The initial focus during that time would be to get some real world data so that the key assumptions could be replaced with site specific facts, to enable a better decision as to the path forward.

RISK REDUCTION ACTIVITIES

NASA termed its efforts during this period as being "Risk Reduction Activities". The potential risk in this case was to project schedule and budget from assumptions that were not well founded. The project focused on three key areas from the Engineering Study: (1) evaluating the viability of cleaning and surveying nearly 6 km (20,000 ft) of embedded piping; (2) performing additional characterization activities (including offsite in a 5.8 km (3.5 mile) stretch of Plum Brook); and (3) determining if a hot cell could be cost effectively decontaminated. For embedded pipe, it was proven feasible and cost effective to clean and survey embedded piping from 2 cm (3/4") to 60 cm (24"). Grouting of cleaned pipe is in fact currently underway with NRC approval of the survey results. In Plum Brook over 3,000 samples have shown that while levels are above background they represent no health risk to the public. At the NRC's suggestion, NASA is currently remodeling the dose to the public based on the knowledge gained through our sampling program. Any required cleanup will be based on Derived Concentration Guide Lines (DCGLs) developed for specific sections of the stream. The balance of this paper will focus on the final Risk Reduction Activity in the hot cells. Fig.3 shows the cutaway model of the Hot Lab with the seven hot cells.

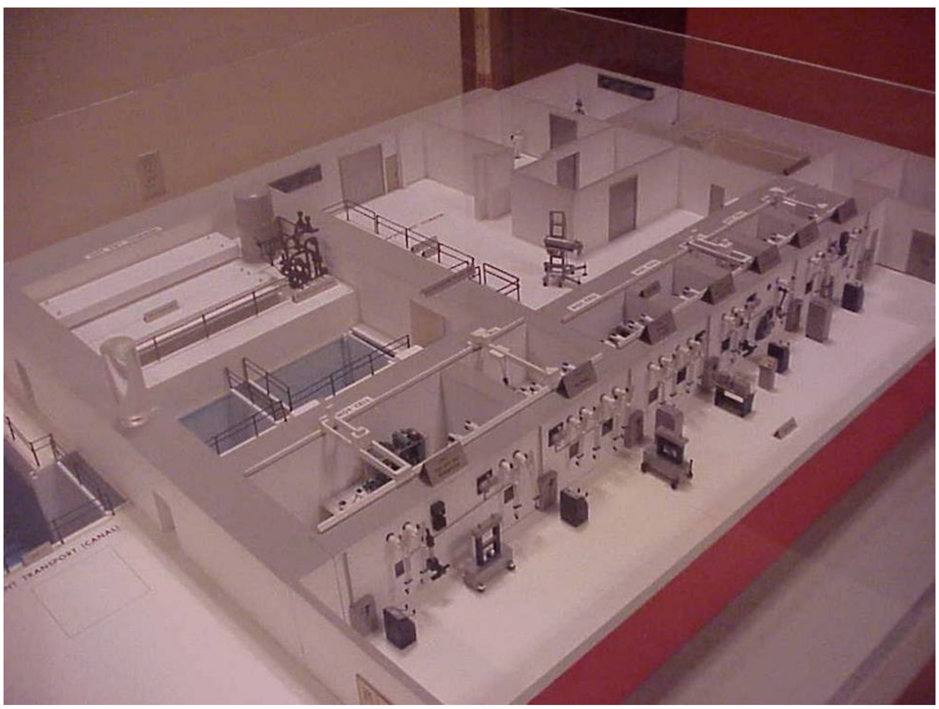

Fig. 3. Model of the PBRF Hot Lab Building showing Hot Cells #1-7

The cells had a total interior floor area of 77.3 m^2 (832 ft^2). The interior wall height was 4.7 m (15.5 ft), with a 7.5 mm (1/4") stainless steel liner extending across the floor and 2.7 m (9 ft) up the walls. The front walls of the cells were 1.2 m (4 ft) thick of high density concrete, with one or two leaded glass windows and associated manipulator arms per cell. The side and rear walls were 1.5 m (5ft) thick normal concrete. The roofs of the cells were composed of individual interlocking concrete slabs 0.6 m (2 ft) thick, and weighing up to 18,100 kg (40,000 lbs). There were inter-cell transfer doors, which were steel framed concrete panels that were used during operations to allow material to be passed between cells. Loose equipment associated with the cells, including the 1.5 m (5 ft) thick concrete rear doors, remaining pieces of test rigs, and analytical equipment had been removed earlier in the decommissioning. Despite the loose equipment removal, the cells still had a substantial inventory of fixed equipment, including the manipulator arms, leaded glass windows, stainless steel liners, and approximately 2,700 m (9,000 ft) of conduit and embedded piping.

The isotope mix in the cells consisted mostly of Cs-137, Sr-90, and tritium. Contamination levels ranged from 16,700 to 166,700 Bq/m^2 (10,000 to 100,000 dpm/100 cm^2) beta/gamma and 33.3 to 166.7 Bq/m^2 (20 to 100 dpm/100cm^2) alpha. Levels as high as 1.0E7 Bq/m^2 (6,000,000 dpm/100cm^2) beta/gamma and 6,667 Bq/m^2 (4,000 dpm/100 cm^2) alpha were found in areas such as on overhead crane rails and under the inter-cell transfer doors. Some conduit was found to be less than Minimum Detectable Activity, but other sections were contaminated to levels as high as 3.33E6 Bq/m^2 (2,000,000 dpm/100cm^2). General area dose rates in the cell varied form 0.002 to 0.1 mSv/hr (0.2 to 10 mrem/hr), with contact levels reaching 0.42 mSv/hr (42 mrem/hr).

NASA decided to answer the question of whether or not a hot cell could be cleaned to the Remedial Action Limit (RAL = 50% of the DCGL) was to decontaminate Hot Cell #1. The DCGL for structural surfaces was 57,340 Bq/m^2 (34,400 dpm/100 cm^2) beta/gamma, and the DCGL for embedded piping was 57,448 Bq/m^2 (38,341dpm/100 cm^2). Hot Cell #1 was the largest cell (nearly 40% of the entire hot cell surface area) and most highly contaminated. During the operating days it was where all irradiated experiments were initially cut up and prepared for further analysis. Since Hot Cell #1 levels were the highest anywhere in the plant the logic was if this cell could be cost effectively cleaned then so could all the rest of the cells as well as the entire balance of the PBRF.

CLEANING HOT CELL #1

At the time the Risk Reduction Activities began there were two companies on site under contract to NASA, each tasked with different portions of the decommissioning effort. MOTA Corporation (MOTA) was performing decontamination work on structural surfaces, while Babcock Services Incorporated (BSI) was working on cleaning and surveying embedded piping. For Hot Cell #1, MOTA was tasked with cleaning all the cell's interior surfaces while BSI was responsible for cleaning and surveying all the associated conduit, piping, and pneumatic transfer tubes.

The first step was to remove the manipulator arms and various other pieces of fixed equipment, as shown in Figs. 4, 5, and 6. The next step was to clean the accessible interior concrete walls of the cell and the underside of the roof plugs using hand scabblers and grinding wheels. Grossly contaminated areas were cleaned using a Brokk 180 with a hoe-ram attachment. The roof slabs were then removed using the installed overhead crane as shown in Figs 7 and. 8. The roof slabs were taken to a nearby location where the remaining surfaces were decontaminated to free release levels (no detectable activity).

Next the stainless steel liner was removed, followed by the two leaded glass windows (Figs. 9,10, and 11) and associated steel framing and lead shielding material (Figs 12, 13). Finally, all newly exposed surfaces were decontaminated, followed by a post remediation survey and spot clean up.

Figs. 4, 5, 6. – Worker removing manipulator arm – note arm is coated with lockdown to control loose contamination. Also note the hot cell stainless steel liner visible in the background. (Hardhat requirements in the cell were waived by the time work progressed to the point of Fig. 6).

Figs. 7, 8. Removal of hot cell roof slab using installed overhead crane.

Figs. 9, 10, 11. Workers size reducing hot cell leaded window slabs, shards disposed of in drums. The glass slabs often cracked as they were being slid carefully out of the frame, due to their extreme brittleness. Size reduction was very quick work.

Fig. 12, 13. Workers cut out the steel window frames after removing all lead shielding, including lead impregnated wool, lead bars, and lead shot.

BSI followed MOTA into the cell, and performed remediation and survey on 358 m (1176') of conduit. BSI used the same approach as had been successful in embedded piping throughout the plant. First, an ALARA first pass was made with the mechanical cleaning device (camera and tool pushed in one end of the conduit, HEPA vacuum pulling out debris on the other end). Then the survey probe was passed through the line to assess its status. Various mechanical abrasive tools such as flapper wheels and cylinder hones were evaluated first. Initial survey results following this cleaning approach were not promising, with slightly less than half the conduit being cleaned to below the RAL with a single pass, and only another third being cleaned with multiple passes. Grit blasting was chosen as the next cleaning approach, and it proved to be extremely successful. 93% of the conduit was below the RAL after a single pass, with the balance requiring an average of three passes to be cleaned. It even worked in some of the more stubborn spots, such as locations with corrosion on the conduit walls. While it was possible to clean conduit as small as .95 cm (3/8"), the surveying limit was 1.9 cm (3/4") due to the physical limit of the probe size. Smaller conduit was surveyed by core drilling out a representative sample sufficient to satisfy the project's FSS Plan.

The total effort to clean Hot Cell #1 took place over 10 month period (Oct 05 – June 06, and Aug 06 – Sep 06). The cost was approximately $800,000, including labor, management costs, and equipment purchases. The total cost compared fairly evenly with the original estimate to "Rip and Ship" the cell. Because the decontamination approach had been proven viable and because work could be performed within the limits of existing funding NASA decided to proceed with the decontamination of the remaining cells. NASA felt is was critical to keep meaningful work going within the fence while awaiting further appropriations, both to show good faith with the public and the regulators, and to reduce the eventual overall cost of the project.

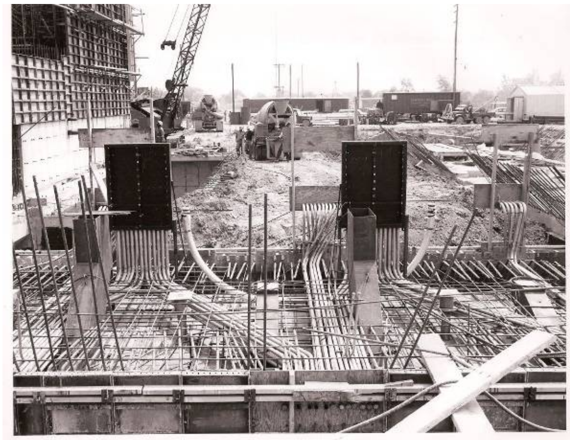

Fig. 14. Construction photo showing conduit in floor of Hot Cells #4 and #5. The bottom center of the photo shows the access location used for cleaning.

Fig. 15. Access hole to conduit in hot cell, located in the front wall of the hot cell directly beneath the former manipulator operator position. Ends of the conduit are plugged for isolation control when cleaning is not in progress.

Fig. 16. BSI worker feeds combination of camera and abrasive tool into conduit, while watching his progress on a television monitor.

HOT CELLS #2 - #7

Lessons learned from Hot Cell #1 were used to improve the efforts in the follow on cells, principally in the use of a sponge jet blaster for the bulk of the surface decontamination work, and grit blasting in the decontamination of the small bore embedded piping and conduit. As a result the pace of work in the later cells accelerated. As another example of the ‘learning curve’ it took nearly three days to cut out the first window frame in Hot Cell #1. By the last cell the job was down to 3 hours. A more detailed description of the decontamination activities performed by MOTA may be found in Reference (2).

BSI work expanded to cover a total of 2,296 m (7,532 ft) of conduit 9.5 – 5 cm (3.8” to 2”) in diameter, 196 m (644 ft) of penetrations 1.25 to 30.5 cm (1/2” to 12”) in diameter, and 273 m (896 ft) of embedded piping 5 cm to 25 cm (2” to 10”) in diameter. The total time for this effort was 26 weeks, at a cost of $675,000, or $246 per meter ($75.00 per ft). Production rates averaged 106 meters per week (348 ft per week), with peak rates of 137 meters per week (450 ft per week).

One embedded pipe challenge not been seen in Hot Cell #1 was the pneumatic transfer tubes, also know as the ‘bunny tubes’. They were made of 3” aluminum tubing embedded deep in the hot cell walls for shielding. Video survey revealed that several of the tubes had significant deformation which may possibly have occurred during initial installation. These damaged areas became locations where corrosion and contamination concentrated. In most cases several passes with aggressive grit blasting were successful, but in a handful of locations it was necessary to remove the problem areas by core boring 2/3 m (2 – 3 ft) through the hot cell wall.

The bulk of the hot cell work was successfully completed in May of 2007. The remaining effort required work in other areas around the cells be complete before hot cell work could go forward. These ‘mopping up’ actions are essentially complete. The total cost for MOTA and BSI to perform their decontamination activities to date is $3.98 M. The projected cost for performing FSS is $78 K (note that the survey of all pipes and conduits already performed covers FSS for those areas). Combined with an additional $100 K spent by NASA on equipment and supplies, the total cost for decontaminating and remediating the hot cells is $4.16 M. This is essentially equal to the original Engineering Study estimated cost for ‘Rip and Ship’ of $4.09 M.

SUCCESS WITH FREE RELEASE

The project experienced good results with its efforts to free release certain large components from the hot cells. The total estimate of concrete rubble that would have been generated by the “Rip and Ship” approach was 2,268,000 kg (5,000,000 lbs). For the hot cells, the bulk of the concrete is in the walls and floors. After these surfaces are released following FSS, they will be demolished and the concrete debris used as clean, hard fill in the many below grade voids that are to be brought to grade during site restoration. The result is no offsite disposal cost for these parts of the structure.

A significant amount of concrete in the form of the hot cell roof slabs and inter-cell transfer doors was not part of the fixed structure. The roof slabs, weighing up to 18,100 kg (40,000 lbs) as described above, were reinforced concrete covered with epoxy paint. According to former operating personnel these slabs had rarely been moved during the PBRF's operating days. Because surface contamination on the slabs was minimal and there was no indication of volumetric contamination issues, NASA decided to decontaminate the slabs to not just to the DCGLs, but to free release levels – meaning no detectable contamination above background. As stated above the cleaning was performed initially with hand tools (scabblers, grinders) but soon switched to the much more effective sponge jet blaster.

The inter cell transfer doors were seen as a stiffer challenge. The contamination levels on the doors (particularly along the side and bottom edges) were among the highest found anywhere in the cells. There was also the issue of contamination getting into the seams between the steel frame and the concrete. One by one the doors were removed and cleaned. While the sponge jet blaster worked fine on the overall surfaces there were occasional hot spots that required more aggressive cleaning with the more typical hand tools.

In the end, however, all of the inter cell transfer doors and roof slabs were successfully free released. As a result of this effort a total of 226,800 kg (500,000 lbs) of concrete and 45,400 kg (100,000 lbs) of steel were free released. (Fig. 17). Current plans are to use this material as back fill during site restoration.

Fig. 17. Hot cell roof slabs and inter-cell transfer doors after release from the site

Fig. 18. The view looking down into Hot Cells #3 - #7 with the roof slabs and transfer doors removed, and decontamination to the Remedial Action Limit (50% of the DCGL) complete. This area is ready for Final Status Survey.

REUSE CHALLENGES

The project was less successful in its efforts to dispose of the manipulator arms, the leaded glass hot cell windows, and the lead shot and shielding from around the windows by arranging for reuse by a new owner rather than disposal as waste.

Nine sets of ribbon drive manipulator arms were installed in the hot cells, and two additional smaller sets were in two hot caves located elsewhere in the PBRF. Several years ago NASA began attempting to find reuse opportunities for these arms as well as other legacy equipment. Since it seemed the most likely reuse would be at another test or research reactor, the word was put out through the Training Research and Test Reactor (TRTR) organization. While there was a fair amount of interest (especially for instrumentation spare parts from reactors with operating equipment of the same vintage as PBRF) these groups consistently had no funding. The standard response was they would be willing to take the manipulator arms (or other equipment) if it was decontaminated and delivered to their facility at NASA's expense. While this would have been good from an overall society point of view, helping academia and reducing waste volumes, the project could not justify the cost which would have been significantly higher than the cost of disposing of this material as LLRW.

The 12 hot cell windows were a similar story. The windows were 1.2 m (4' ft) thick, made up of individual slabs of glass that were 20 cm (8") thick. Mineral oil was used between the windows to keep air and moisture out. NASA and MWH, the prime decommissioning contractor at the time, spoke with several hot cell window companies about potential reuse of the glass. The ideal situation from NASA's point of view would be to have the windows removed for 'free', meaning a company could come in and remove the windows at no cost to the government, making back their labor cost on reselling the windows. Even if the cost to the government of supporting window removal was no more than the cost of disposing of the glass as mixed waste then it would have been acceptable. In fact, no satisfactory arrangements could be made, and the windows were removed for disposal.

As a side note the original intent was to remove the inner most window slab (the one exposed to the inside of the hot cell) for disposal as LLRW, and then to remove the middle and outer window slabs for disposal as normal construction debris. Two things kept that from happening. First, the window glass failed two individual TCLP tests meaning that, as a minimum, all the glass would have to be treated as lead waste. Second, when we had carefully removed a middle slab and attempted to survey it out it for free release we found hot spots on the glass. Upon spectrographic analysis of chips taken out of the windows these hot spots were found to be due to naturally occurring K-41 throughout the glass. A free release criterion of 'none detectable' above background presented a major stumbling block – every hot spot would require analysis to insure it was a naturally occurring isotope. Based on this it was determined that the most cost effective approach was to minimize labor costs by quickly removing the slabs (not worrying about getting them out intact), size reducing the glass and placing it into drums for disposal as mixed waste (See Figs 9, 10, and 11). A total of 30,545 kg (67,200 lbs) of leaded glass shards was generated.

The lead shielding from around the hot cell windows proved to be a final area where reuse or recycling has not been found to be economically viable from the narrow view of the project cost. There was a total of 7,000 kg (15,680 lbs) of lead shot and 714 kg (1,600 lbs) of lead bars removed from around the windows. This shot was drained out of the void space around the windows and into drums. The bars were then unbolted from the steel window frame. While it is to be expected based on their location inside the wall that the shot and bars would not be contaminated, surveying was not felt to be practical due to leads ability to self shield. Several organizations were contacted to determine the cost of recycling the lead, but it was consistently higher than the cost of disposal. The overall value to society of reuse or recycling did not weigh into the decision of how to dispose of the lead. The only consideration was the cost to the project. Based on this the lead was sent off for encapsulation and disposal as mixed waste.

LESSONS LEARNED

Given the right starting conditions, particularly the absence of volumetric contamination issues, it is possible to cost effectively decontaminate and perform Final Status Survey in an area as challenging as a hot cell. A solid characterization effort at the beginning of the decommissioning planning effort will be key to determining if this is true for a particular site.

The technology for cleaning and surveying even very small lines is field proven, NRC accepted, and readily available.

Efforts at waste minimization and reuse of contaminated material require significant proper planning, and likely rely on interfacing with outside organizations over which you have no control. Promises of how much something will cost sometimes fail to stand up when it comes time to negotiate a hard price.

Industry/ licensees interested in pursuing reuse may need to find a way to evaluate the total ‘societal cost’ of disposal of such items as contaminated lead. While the straight up monetary cost to the project may indicate disposal is the right option the ability to consider the replacement cost of the material (as for example the cost to the environment of mining and smelting new lead) might provide the rationale for more recycling and reuse of material from decommissioning sites.

CONCLUSIONS

The total expected cost to date of all work to decontaminate and perform FSS in the hot cells is $4.16 M. The original project estimate for the total removal and disposal as radioactive waste is $4.09 M. It is worth noting that this value is based on waste disposal rates in 2005, and those could certainly have ended up being higher due to the delay in available funding to perform the work. As a result, and considering the waste minimization that was accomplished, NASA believes that decontamination and Final Status Survey can be carried out as a viable alternative to ‘Rip and Ship’. This is an especially important consideration for projects that have limited year to year funding, as decontamination can go forward with however much or little staffing can be afforded, as opposed to the lump sum funding required to make ‘Rip and Ship’ economically advantageous. For PBRF in particular, if it worked in the hot cells, the most highly contaminated area remaining at the site, then the same approach should be the best way to go in all remaining areas.

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