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REACTOR D&D AT ARGONNE NATIONAL LABORATORY - LESSONS LEARNED

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ABSTRACT

This paper focuses on the lessons learned during the decontamination and decommissioning (D&D) of two reactors at Argonne National Laboratory-East (ANL-E). The Experimental Boiling Water Reactor (EBWR) was a 100 MW(t), 5 MW(e) proof-of-concept facility. The Janus Reactor was a 200 kW(t) reactor located at the Biological Irradiation Facility and was used to study the effects of neutron radiation on animals.

I. INTRODUCTION

ANL-E has been accomplishing nuclear reactor D&D since 1986. The D&D of the EBWR was completed in December 1995. The D&D of the Janus Reactor was completed in October 1997. It is not unusual during projects of these magnitudes to encounter unforeseen problems, to increase knowledge through new experiences and to make noteworthy discoveries. This paper discusses experiences gained and discoveries made during the last four years for the purpose of providing lessons learned to those involved in similar work. Incorporation of important lessons learned into the planning and execution of future reactor D&D projects may improve worker safety, eliminate unnecessary project costs and enhance schedule completion.

II. RADIOLOGICAL UPTAKE

The EBWR facility ceased operations in 1967. Three characterizations of the facility were conducted between 1986 and 1992. Co^{60} was the only isotope detected.

Exit bioassay results for two D&D personnel indicated a minor uptake of tritium. All project personnel submitted bioassay samples, and the subsequent report of uptakes of tritium and Pu^{241}/Am^{241} by three D&D technicians resulted in an immediate work stoppage at the project.

A. Results of Incident Investigation

Bioassay results indicated that seven workers had detectable uptakes of Am^{241} and minor uptakes of Co^{60}, Cs^{137}, Sr^{90} and tritium. Gamma and alpha spectroscopy of nearly three hundred air sample filters provided dates of elevated airborne particulate contamination. The presence of alpha on the air samples was not detectable at the job site. A matrix was developed to correlate the people who were exposed with the dates of elevated airborne and the work in progress. Six of the seven affected workers were involved with plasma arc operations in or above the fuel pool. The uptake probably occurred over a five-month period, with the greatest uptake in individuals working the longest with plasma arc cutting operations. Workers had been taken out of respiratory protection based on air sample results derived during the initial stages of the work. It is believed that radioactive particles, transported by the smoke and fumes rising from the fuel pool, were inhaled by the workers, causing the uptake.

Analysis of the corrosion layer present on the surfaces of the core internals revealed the presence of trace amounts of Am^{241} and other fission and corrosion products. It is important to note that the corrosion layer was rusty in color and extremely difficult to remove. A file was the only tool that could produce a sample of the material. Smears of the surfaces before the project started revealed only Co^{60} in quantities less than 6000 disintegrations per minute (dpm). It appears that the corrosion layer formed over time and was very successful in locking in the activity present on the surface of the core at shutdown. This corrosion layer had twenty million times as much Co^{60} present as Am^{241}. Speculation remains as to how an Am^{241} uptake was possible in the presence of such large quantities of Co^{60} without detecting Co^{60} during air sampling. Speculation also remains as to the source of the americium. Some believe it may have been a product of a Pu^{241} foil documented as lost in the EBWR facility during experiments run in 1967.

Approximately half of the Pu^{241} would have decayed into Am^{241}; however, no trace of Pu^{241} was ever found. Another scenario is that undetectable microscopic cracks may have allowed the release of transuranics over the lifetime of EBWR. Two of the personnel received approximately 3 mSv (300 mrem) from the uptake of Am^{241}. It is estimated that the remaining personnel received between 500-600 μSv (50-60 mrem) from the uptake of Am^{241}.

B. Lessons Learned

1. ***Monitor to detect radionuclides reasonably expected based on past operations, even if they are not found during characterization.*** During the D&D of a radiological facility, and especially an experimental facility, radionuclides which were not expected may be encountered. It is necessary to periodically perform full gamma and alpha spectroscopy of air samples to detect radionuclides which may be present, even if they were not detected during the initial characterization.

2. ***Thorough knowledge of historic operations is a key factor in quality characterization, especially at experimental facilities.*** The lack of detailed documentation on EBWR reactor operations significantly impeded the characterization and subsequent D&D activities performed at this facility. The lack of detailed drawings resulted in conservative assumptions being made in the cost estimate, waste volumes, activity durations, and personnel exposures. The lack of accurate operational records resulted in an incomplete characterization of the facility, which may have contributed to the Am^{241} uptake.

3. ***Establish personal protective equipment (PPE) levels conservatively.*** By conservatively choosing PPE levels, initial uptakes to unknown radionuclides may be reduced or avoided. Once it has been shown a particular task will not expose workers to unexpected uptake, the PPE levels can be reduced.

4. ***Expand use of scheduled bioassay.*** Should all other sampling methods fail, bioassay is the most sensitive way of conclusively determining the presence and level of an internal uptake. Greater frequency ensures a more accurate assessment of internal uptake and an earlier indication of a problem. Monthly bioassay is recommended as confirmation of routine air sample results.

5. ***Ensure bioassay data reaches key managers in a timely fashion.*** Bioassay data must be reported to line managers in a timely fashion in order to take appropriate corrective actions. This will ensure workers do not continue to receive an unexpected uptake after the initial exposure.

6. ***Use of better quality air monitoring and dosimetry equipment is desirable and cost effective.*** The benefit of using quality air monitoring and dosimetry equipment far outweighs its added expense. Quality air monitoring will provide an accurate historical record of unexpected uptakes and airborne radioactivity. Quality dosimetry equipment will provide a quick warning system if radiation levels increase unexpectedly.

7. ***If investigation committees are to be utilized, they should be preselected, trained and dedicated to the investigation function.*** An *ad hoc* investigative committee was formed after the Am^{241} incident occurred, requiring individuals to interrupt their normal schedules to become familiar with the specific issues at hand. It is suggested that an investigative committee, trained in formal investigative techniques, be formed at the beginning of a D&D project. This will allow greater freedom in choosing individuals with backgrounds appropriate to the potential hazards, and allow committee members greater flexibility to become familiar with a specific D&D project and to adjust their schedules as required. By ensuring that the investigation committee fully understands the issues at hand and is dedicated to the D&D project, recovery from an incident will proceed in a timely fashion and will incur minimal additional expense.

8. ***Improvement in recovery procedure roles is desirable.*** The precise role and function of the investigative committee should be detailed in formal procedures. Included in these procedures should be the limits of authority held by the investigative committee. The procedures should delineate to what extent the committee can use project funds and direct project management. If an unexpected event does occur and the investigation committee is activated, all parties must have a clear understanding of the overall goals, functions, authority and responsibilities held by each person. This is essential to avoid confusion and to ensure that a clear course of action is taken which is targeted toward determining the cause of the unexpected event and methods needed to prevent a reoccurrence. Recovery from the incident will thus proceed in a quick and timely fashion and incur minimal additional expense.

9. ***"Surge" analytic capability is needed for sample analysis.*** In a recovery situation, quick analysis turnaround time is essential to minimize cost. Ideally, an on-site laboratory dedicated to the project would be available. If not, a laboratory which can provide quick turnaround analysis is essential.

10. ***Clear consensus is needed on balancing internal exposure against other health and cost variables.*** Anticipated internal exposures should be calculated using a 50-year Committed Effective Dose Equivalent (CEDE). The CEDE should then be added to the anticipated external exposure to develop the Total Effective Dose Equivalent

(TEDE). The ALARA philosophy requires that for a given task the TEDE be as low as reasonably achievable. Currently, the internal dose may be viewed as more harmful than direct exposure. The result may be a lower CEDE but a higher overall TEDE, which is against ALARA philosophy and which may incur a higher cost. The bias against internal dose should be corrected to maintain ALARA philosophy.

11. Entry and exit bioassay data was extremely valuable. Bioassay data was extremely important in determining the areas of greatest uptake. By correlating bioassay data, air sampling data and RWP sign-ins, the locations of greatest uptake and the personnel involved were identified, and the specific tasks which released the airborne radionuclides and their pathways of exposure were pinpointed. This data was then used to reconstruct the event and to prevent or mitigate further occurrences.

12. Archiving air samples was key to dose assessment and event reconstruction. An air sample was taken daily by the contractor and, depending on the tasks being performed, sometimes multiple air samples may have been taken. By using the information from the air samples and bioassay data, event reconstruction and accurate dose assessments could be determined.

13. Excellent record keeping helped to understand and reconstruct events. All contractor air samples and area surveys were accurately filed and archived during the project. This facilitated the review of these records while reconstructing the incident.

III. RIGGING FAILURE DURING CORE ASSEMBLY LIFT

The EBWR core assembly consisted of the core shroud, upper and lower control rod guide structures, fuel element frames and the core support plate. This assembly weighed approximately 6000 pounds (2724 kg). During the removal from the reactor vessel, the assembly became wedged near the top of the vessel opening and two of the four lifting slings failed. Recovery operations included replacing the broken slings (and the other two existing slings) and removing the interference with a plasma arc cutting torch.

A. Results of Incident Investigation

A series of miscommunications had occurred before and during this lift. The first occurred as a misinterpretation of drawing dimensions. It was originally thought that the outer diameter shown on the drawing included a small plate welded to the side of the shroud. By close inspection, however, it was determined that the plate was not included. The concern about inadequate clearance was dismissed when it was thought that the plate did not line up with the internal interferences in the vessel. None of this information was communicated to the managers, supervisors or workers involved with the lift. Additionally, although an individual was tasked with observing the lift, his position and perception of the lift did not allow him to notice that the assembly had become wedged. As the lift continued, two of the four slings failed and the assembly became stuck in place.

B. Lessons Learned

1. Close-tolerance lift dimensions must be communicated to all personnel involved in the work. This information would have enabled the signalman to closely monitor the lift at the point of interference and rotate the load as necessary. This would have prevented the sling failure incident.

2. Additional spotters may be required to adequately observe the load. This could also be accomplished by using video cameras and remote monitors.

IV. ELECTRIC SHOCK DURING UNDERWATER PLASMA ARC USE

Plasma arc underwater size reduction of the EBWR core assembly was performed by a team of three: one person performed cutting operations, a second held the piece to be segmented with grips attached to an extension tool and the third observed the operation and controlled the power to the plasma arc torch. During cutting operations the observer noticed the helper shaking and immediately cut power to the torch and went to aid the helper. A 911 emergency call was placed. The helper was not injured and did not require treatment by responding medical personnel.

A. Results of Incident Investigation

The grips and extension tool were constructed of metal and the worker was wearing sweaty protective clothing. Additionally, he was leaning over a metal guardrail during the operation. It is speculated that when the piece being segmented was cut free of the core assembly, electrical ground shifted to the segmented piece and the current went up from the extension tool to the helper's body, and then to the guardrail.

B. Lessons Learned

1. Tools used in plasma arc underwater cutting operations should be made from non-conductive material.

2. Metal guardrails and the work area floor should be covered with heavy rubber material to prevent accidental grounding.

3. The use of an observer, able to cut power instantly, can prevent a potentially lethal accident. The observer in this incident was credited with quick response.

V. INADVERTENT CUTTING OF ENERGIZED WIRES

During the removal of the Janus reactor control panels two energized wires were cut. The problem was identified when it was noticed that exit lights were off in the stairway. Work was stopped and an investigation started.

A. Results of Incident Investigation

All identified circuits had been Locked Out and Tagged Out (LOTO), and verified as deenergized by taking voltage measurements at every terminal inside the control panels. Workers began cutting wires at the point where they entered the panel instead of disconnecting the wires, pulling them free of the panel and then cutting them. One of the workers, in what he believed to be an added safety measure, was checking each wire again after he had cut it to verify it was deenergized. This method resulted in two energized wires being cut and subsequently capped with wire nuts. The wires had been installed in the early 1990's as part of an emergency light system upgrade. The circuits had been incorrectly routed through the panels instead of through their own conduit. Because the wires never terminated inside the panel, they were not identified as energized before the work began.

B. Lessons Learned

1. Use inductive-type electrical detection equipment to augment voltage measurements during LOTO verification. This type of equipment would have identified energized circuits before the work began.

2 Personnel should be frequently reminded to immediately stop work and report any unexpected condition to management. The worker cutting the wires told his supervisor that he had found the first energized wire. A few minutes later he told his supervisor he had found another. The supervisor was on the other side of the panel and thought the worker was performing initial voltage checks, not wire removal activities. The work should have been stopped by the worker upon finding the first energized wire.

3. Never, never depend on the accuracy of old facility drawings to be correct.

VI. POSSIBLE NEAR MISS ELECTRICAL CONDITION

Prior to removing the cooling tower at the Janus facility a review of existing prints and drawings was made to determine the electrical LOTO requirements. After LOTO, verification checks were made for voltage and for current with proximity testers. Wiring to electrical components was then cut and the components and tower equipment removed. An ANL electrician was later terminating the wires at the electrical panel when he discovered a cut wire was attached to an open breaker that was not tagged out.

A. Results of Incident Investigation

A review of the breaker listing for the electrical panel revealed that the breaker in question was marked as a "spare." Apparently, modifications to the cooling tower systems had been made and at some point the "spare" breaker had been used to supply a load. The drawings had not been updated, and the breaker panel listing had not been changed to reflect the use of this breaker. Since the breaker was open at the time verification checks were performed, no one was aware of the potential hazard present.

B. Lessons Learned

1. Electrical panel inspections should be made early in a project to verify that no circuits are connected to "spare" breakers.

2. This occurrence served to reinforce the need for daily verification checks prior to beginning work under LOTO.

VII. FUEL POOL CLEANOUT DIFFICULTIES AFTER PLASMA ARC CUTTING

The EBWR core assembly was size reduced in the fuel pool. A three-part process was used for cleaning the cutting debris from the pool: 1) grips attached to a long pole were used to remove large pieces of material, 2) a dustpan-like scoop was used to remove medium sized pieces and 3) a hydro vacuum was used to remove the fine tailings that remained. The entire operation was estimated to take eighty hours; however, many large pieces hidden by the finer tailings were difficult to maneuver when found. The dustpan scoop tended to ride at the surface of the slag rather than penetrating and gathering the slag. Also, the hydro vacuum became clogged due to the presence of the larger materials. The actual cleanup of the fuel pool took six times longer than expected.

A. Lessons Learned

1. A method of collecting slag pieces should be used to prevent cleanup problems before they occur. One method that could be used would be to perform all cutting operations over or in a catch tank. This was not done, however, due to the size of the entire core assembly.

2. Contamination control during slag packaging is very difficult. Underwater plasma arc cutting produces small molten pieces of metal that form into spherical metal shapes. Rapid cooling causes the spheres to be hollow as the interior metal is drawn to the outer wall of the piece. These small, light spheres can be easily moved by air currents or by personnel movement in the area. The largest of the spheres are visible to the unaided eye, but most are too small to be seen and can give off tens of thousands disintegrations per minute. They do not stick to smear paper and easily escape detection by any type of smear method. The radiation background near the fuel pool work area prevented detection by direct survey. The particles can become imbedded in rubber or leather shoe soles and may be first detected at frisking stations. Careful "sweeping" of the floor in work areas will gather enough material to allow detection by direct survey. However, because these particles are so light, sweeping may spread, rather than collect them. Vacuuming the entire area with High Efficiency Particulate Air (HEPA) filter equipped vacuums was another method of recovery used by the project. The work area can also be equipped with contamination control "walls" several feet high to prevent the spheres from rolling out of the work area. Control of the slag particles at the source is the most effective and best method.

VIII. PORTABLE HEPA VENTILATION SYSTEM FIRE

While cutting the steel bioshield shell with cut-off saws, a fire erupted in the contractor's portable HEPA ventilation system during the Janus reactor D&D. A flame permit had been issued by ANL-E for the work and all combustible material had been removed from the work area. Apparently a spark from the cut-off saw was pulled into the suction of the HEPA system approximately twenty feet away. The work was being done inside a containment tent and the workers were wearing particulate filtered respirators. The workers were unaware of the fire until notified by a health physics technician who had come into the area and observed the smoke. The D&D worker shut down the HEPA system and opened the filter cabinet. The pre-filter was completely engulfed in flames. A fire extinguisher was used to extinguish the fire.

A. Lessons Learned

1. Inexpensive metal spark arresters should be installed on the HEPA intake hose. Available at hardware stores in eight-, ten- and twelve-inch diameters these arresters prevent any sparks from entering the system.

2. Cloth pre-filters on portable HEPA units were replaced with metal reusable prefilters. These are available from the same suppliers of paper prefilters and can be cleaned and reused. The use of metal prefilters provides defense-in-depth protection against HEPA filter fires.

3. An inexpensive household-type smoke detector can be installed near the discharge of portable HEPA systems to provide early warning of HEPA fires to workers who are inside tents or other enclosures. This should always be in addition to, never in place of, Code-required fire detection equipment.

IX. SEGMENTATION OF A LEAD SHIELD WALL

The walls, floor and ceiling of the Janus facility high-dose room were covered with lead to reduce the gamma radiation in the room. The wall lead was 4 inches (10.16 cm) thick. When the lead bricks that comprised the wall were installed, the gap between the bricks was filled with molten lead creating a solid lead wall. Several cutting techniques to allow removal of the wall were investigated.

A. Lessons Learned

1. Electric-powered chisels only pushed the lead around or became wedged.

2. Routers cut well only to a depth of about 0.5 inch (1.27 cm). Attempts to go deeper resulted in binding of the router bit. The router also threw hot chips up to 25 feet (7.62 m) away from the work area.

3. An electric circular saw with a non-ferrous blade worked well but the cut depth was limited by the size of the saw. The full thickness of the wall could not be cut. The saw also threw chips, but vertically instead of to the sides.

4. An electric chain saw worked the best of all methods tried. Full depth cuts were easily made, and the saw could penetrate the upper and lower corners of the wall where the circular saw could not. The chain saw was not modified in any way. The chain saw completed over 150 feet (45.7 m) of full depth cut and never required sharpening. The nylon drive gear was replaced several times. The chain saw threw chips in the downward direction making it easy to contain the chips in the work area.

X. BIOSHIELD CONCRETE REMOVAL

Removal of high density bioshield concrete from around and above the Janus reactor was more difficult than the contractor expected. After weeks of trying to remove the concrete with hand-held jackhammers, the contractor obtained a remotely operated BROKK 150 equipped with a 750 pound (340.2 kg) jackhammer and an operator.

A. Lessons Learned

1. The BROKK 150 is compact enough to go through a standard sized door; it is only about 4 ft (122 cm) high, but powerful enough to effectively demolish high density bioshield concrete. Larger units are available if access is not restricted. The machine can be quickly fitted with a bucket for loading the concrete rubble into disposal containers. An experienced operator can load several disposal bins per hour.

2. The equipment can be located inside a clear-walled containment while being operated remotely from outside the containment, thus isolating the operator from concrete dust and falling rubble. In some cases, this may reduce training requirements since the operator does not have to enter radiologically contaminated areas to operate the machine.

3. The BROKK removed and packaged over 90% of the concrete in less than three weeks. Equipment downtime for maintenance and repair was less than 2 days.

XI. USE OF PORTABLE AIR CONDITIONING UNITS TO COOL CONTAINMENT TENTS

From late June through August, excessive temperatures and humidity at the project placed the containment tent work crews into a heat stress situation. With the onset of high temperature conditions, worker stay times for tasks requiring protective clothing were severely curtailed. At times, the crew was limited to working 15 minutes and required to rest for 45 minutes. The contractor's schedule was jeopardized by these shorter stay times. The contractor set up a portable, diesel-powered 20,000 BTU air conditioning unit outside the building. The cool air was directed into the containment, and the ambient containment air temperature fell from 95 degrees F to 75 degrees F with a corresponding 35% decrease in humidity.

A. Lessons Learned

1. Worker stay time restrictions were eliminated. This also decreased the number of change-outs of PPE, reducing cost and low level waste.

2. Worker productivity increased. There was better job continuity with fewer interruptions for breaks or crew substitutions.

3. Crew morale improved significantly. It was obvious to everyone that management was concerned about worker safety and comfort.

4. Total cost for the air conditioning system including fuel and maintenance, was less than $28 per hour. This cost was easily offset by the elimination of required heat stress stay times.

XII. CONCLUSIONS

Many important lessons learned have been documented during the D&D of the Experimental Boiling Water Reactor and the Janus Reactor. Application of this knowledge to future reactor decommissioning may improve worker safety, eliminate unnecessary costs and allow project completion as scheduled.

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