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**Regional Training Course on Decontamination and Decommissioning of
Research Reactors and Other Small Nuclear Facilities**

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Lecture 14.2

**The Decommissioning of a Research Reactor in the USA:
A Case Study from Planning to Site Release**

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CONTENTS

Overview	1
1 Introduction	2
2 Background	2
3 Phase I - Preparatory Activities	3
4 Phase II - Reactor System Piping and Associated Equipment	3
5 Phase III - Reactor Disassembly	3
5.1 Mobilization	3
5.2 Phase IIIA - Reactor Vessel Internals	4
5.3 Phase IIIB - Reactor Vessel	4
6 Phase IV - Biological Shield	4
7 Final Survey Objectives	4
7.1 Project Objectives	5
7.2 Unrestricted Release Criteria	5
8 Waste Volumes	6
8.1 Radiological Waste	6
8.2 Special Waste	6
9 EBWR D&D Project Exposure Summary	7
10 EBWR D&D Project Cost	7
11 Project Closeout	7
Appendix A: Lessons Learned	8
Appendix B: Suggested Reading	11

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OVERVIEW

Argonne National Laboratory (ANL) has completed the D&D of the Experimental Boiling Water Reactor (EBWR). The project consisted of the decontamination and/or packaging as radioactive waste the reactor vessel and internals, contaminated piping systems, miscellaneous tanks, pumps, and associated equipment. The dismantling process involved the removal and size reduction of equipment and associated plumbing, ductwork, drain lines, etc. Size reduction of reactor vessel internals was performed in the fuel pool. All radioactive and mixed waste was packaged and manifested. A thorough survey of the facility was performed after the removal of contaminated and activated material. Non-radioactive waste was disposed of in the ANL landfill or recycled as appropriate.

The EBWR D&D project was divided into four phases. Phases I and II were completed by ANL personnel, while Phases III and IV were done by a contractor under ANL management. The final survey was performed by the contractor, while the verification survey was performed by ANL.

The project lasted 118 months. Phase I was initiated in April 1986 and the final report was issued February 1996. The duration of the project was driven by the availability of funding for decommissioning. Total exposure to project personnel was 208.7 person-mSv (20.87 person-rem), with no personnel exceeding the EBWR project dose limit of 15 mSv (1.5 rem).

A total of 360,205 kg (792,452 lbs) of radioactive waste was packaged for off-site disposal at a low level radioactive disposal site. The total activity of these packages was 24,798 Gbq (670.23 Ci). Additionally, 26,829 kg (59,023 lbs) of mixed waste (lead contaminated with radioactivity), with a total activity of 3,171 Mbq (85.7 mCi) was packaged for disposal. The total cost of the EBWR D&D project, including labor, management, and waste disposal, was 19.6 M US dollars.

The EBWR containment building will be used by the Laboratory for interim storage of packaged transuranic waste. A very small amount of inaccessible residual contamination was left in place for either economic or structural reasons.

In January 1996, the EBWR facility was formally decommissioned and transferred from the Decommissioning Program to Waste Operations. This lecture will discuss the details of this ten-year effort.

The Appendix to this lecture provides technical and management lessons learned for your use.

1 INTRODUCTION

The EBWR D&D project began in 1986 with general facility preparations (Phase I D&D). This work consisted of typical mobilization activities including the establishment of a project management structure and preparation for hands-on dismantling work. The remainder of Phase I was dedicated to asbestos insulation removal throughout the facility. Phase II of the D&D began in 1988 and consisted of the removal of all reactor system piping, components, and associated equipment, both radioactively and non-radioactively contaminated. This Phase of the D&D was completed in 1990.

Phase III of the D&D included the removal of the reactor vessel components. A D&D subcontractor was hired to perform decontamination activities for this phase and Phase IV. Preparations for this phase involved the setup of the ventilation system and the containment tent, the refilling of the fuel storage pool, and mockup training. This portion of Phase III was completed in 1993. The remainder of Phase III was divided into two parts, Phase IIIA and IIIB. Reactor vessel closure items were removed as part of Phase IIIA. Items within the reactor vessel were removed next, including control rods, core assembly, and thermal shields. Phase IIIB included the removal of the reactor vessel, which was sectioned for disposal. Phase III (including Phases IIIA and IIIB) of the project was completed in June 1995.

Phase IV involved activities associated with the removal of the biological shield. Components of the biological shield were removed and decontaminated for salvage or were disposed of. Remaining radioactivity that could not be removed was sealed in place so that all accessible areas in the EBWR shell were at or below background levels of radioactivity. Phase IV also included the performance of any final decontamination activities. This phase was completed in November 1995. Project closeout included the performance of the final surveys and issuance of project reports and other miscellaneous documentation. The D&D contractor performed a final release survey to confirm the residual activity in the EBWR facility was below unrestricted limits. The ANL Health Physics group performed a verification survey to confirm the contractor's results before releasing the site.

2 BACKGROUND

The Experimental Boiling Water Reactor (EBWR) was built as a test reactor to demonstrate the feasibility of operating an integrated power plant using a direct cycle boiling water reactor as a heat source. The reactor was designed to produce 20,000 kilowatts (kW) of heat as 600 lbs/in² gage saturated steam fed directly to a turbogenerator producing 5,000 kW of electricity. Full power operation at its design output of 20,000 kilowatts thermal (kWt) was achieved in December 1956.

Following intermittent operation of power levels up to 61,700 kWt, the EBWR was modified to increase its power output capability to 100,000 kWt. The modifications included the addition of a reboiler plant to use 80,000 kW of thermal energy in addition to the 20,000 kWt used by the turbogenerator. In November 1962, the reactor was successfully operated at 100,000 kWt. Experimental work on EBWR was completed in July 1967 and the plant was shut down permanently and placed in a dry lay-up condition. The nuclear fuel was removed from the reactor and was

shipped to the DOE Savannah River Plant. Several outbuildings and cooling towers were either demolished or converted for reuse before 1980. Surveillance and maintenance of the facility continued throughout the dry lay-up period. The facility was maintained in a safe storage mode until the actual D&D project was initiated in the first quarter of fiscal year 1986.

3 PHASE I - PREPARATORY ACTIVITIES

Phase I included preparatory activities associated with the EBWR D&D project. This included a review of all existing documentation, reports, and radiological surveys. This review was limited by the lack of important informational sources including "as built" drawings and accurate records from the EBWR period of operation.

4 PHASE II - REACTOR SYSTEM PIPING AND ASSOCIATED EQUIPMENT

The turbine generator was disassembled and removed, followed by a general clean up of the plant. The condenser, circulation water systems, and all steam piping was removed and size-reduced using conventional power tools (saws-alls, portable band saws, air saws) and oxyacetylene torches.

Decontamination of larger equipment items, including the condenser unit, was very effective. These decontamination efforts using conventional and blasting equipment released about 90 percent of these components to a metal recycler. The fuel pool was also cleaned out, drained, and repainted. A general clean up of the facility was conducted. After completion of Phase II, safety railings were erected as deemed necessary by project staff to maintain a safe work area.

5 PHASE III - REACTOR DISASSEMBLY

5.1 Mobilization

Preparation for Phases IIIA and IIIB included the design and construction of a water filtration and transfer system for the fuel pool. A 113.2 m³/min (4,000 cfm) HEPA filtration system was installed near the reactor vessel to filter out airborne radioactivity during cutting operations and to provide fresh air turnover during operations. ANL Central Shops constructed mockups of the reactor vessel and internals so that the mobilization activities could include mock-up training. Additional electrical outlets and wiring were added, the gantry crane was installed, work tables were built, and a video system was installed.

Three different transfer shields were also constructed at this time. A basket shield was designed to transfer baskets containing irradiated hardware segments to a 208 liter (55 gallon) drum. A drum shield was constructed identical to the basket shield except for rigging. The control rod shield was manufactured for the transfer of the control rods.

5.2 Phase IIIA - Reactor Vessel Internals

Phase IIIA consisted of removing all reactor internals and transferring them to the fuel pool for size-reduction. Phase IIIA D&D activities started in March 1994. The control rods and the reactor core assembly were removed from the reactor and placed in the fuel pool for size-reduction and packaging. The core assembly has contact dose rates of up to 200 R/hr.

In April 1994, the underwater size-reduction of the reactor core began using a 45-amp underwater plasma arc torch. All remaining reactor internals (such as the steam ducts, shock shields, thermal shields, and experimental appendages) were removed from the vessel using the plasma arc system and were transferred to the fuel pool for further size-reduction as needed. All reactor vessel nozzle penetrations were cut flush to the reactor vessel using a split-frame pipe cutter. An access man-way was cut into the reactor vessel to provide personnel and equipment access.

5.3 Phase IIIB - Reactor Vessel

Phase IIIB consisted of removing and size-reducing the reactor vessel. Phase IIIB activities ran concurrent with Phase IIIA activities. In May 1994, the cutting and removal of the reactor vessel was performed. The vessel was segmented using a split-frame inside-diameter cutting machine. The vessel bowl cut was done first and the bowl piece was removed. The vessel barrel was cut four times, producing five ring segments. Each ring was lowered to the bottom of the vessel cavity until all cuts were completed. The top vessel section was then removed and staged in a holding area on the fourth level of the containment building. Each additional ring was removed with the last ring being placed in the cutting tent for size-reduction.

6 PHASE IV - BIOLOGICAL SHIELD

Removal of the activated portion of the bio-shield concrete began in August 1994. This work was accomplished using an electro-hydraulic remote-controlled impact machine. Approximately 22,727 kg (50,000 lbs) of activated concrete was removed.

Approximately 3,000 lead bricks were removed from the bio-shield. Approximately 61,136 kg (143,500 lbs) of this lead (90%) was surveyed and free-released for recycling. This lead was smelted and formed into biological shield blocks for the Advanced Photon Source Accelerator at Argonne National Laboratory-East. A total of 15,909 kg (35,000 lbs) of concrete and 3,591 kg (7,900 lbs) of steel from the bio-shield was free-released for recycling or scrap.

7 FINAL SURVEY OBJECTIVES

The purpose of the final status survey was to prove that the radiological conditions in the accessible areas of the EBWR facility satisfy the ANL unrestricted release criteria. Areas of contamination above releasable levels were rendered inaccessible by using rubber plugs and bolted metal caps.

Survey units included the accessible areas of these plugs and caps.

7.1 Project Objectives

The specified objectives of the release survey included ensuring:

- Average contamination levels for each survey unit was within the authorized values.
- Small areas of residual radioactivity (hot spots) did not exceed three times the guideline value. The average activity within the 1 m² area containing the hot spot was within the guideline.
- Reasonable efforts were made to clean up removable activity, and removable activity did not exceed the guideline value.
- Exposure rates in occupiable locations were less than 5 μ R/hr (micro roentgen per hour) above background. Exposure levels were measured at 1 meter from floor/lower wall surfaces and were averaged over floor areas, not to exceed 10 m². The maximum exposure rate at 1 meter did not exceed 1 μ R/hr above background.
- The average maximum dose rates associated with surface contamination resulting from beta-gamma emitters did not exceed 2 μ Gy (0.2 mrad) per hour at 1 cm.
- Reasonable efforts were made to identify and remove all activated structural material.
- Reasonable efforts were made to identify and remove contaminated paint or coatings on EBWR shell surfaces.

7.2 Unrestricted Release Criteria

Release criteria applicable to the EBWR shell are based on DOE Order 5400.5 and the ANL Health Physics Procedures. Based on the combination of radiological contaminants present within the EBWR shell, the surface contamination guideline values for beta-gamma contamination were:

83 Bq (5,000 dpm)/100 cm², fixed and removable, average over 1 m²;
5 Bq (300 dpm)/100 cm², maximum fixed and removable; and
17 Bq (1,000 dpm)/100 cm², removable contamination including tritium.

Surface contamination guidelines for transuranic alpha contamination were:

1.67 Bq (100 dpm)/100 cm², fixed and removable, average over 1 m²;
5 Bq (300 dpm)/100 cm², maximum fixed and removable; and
0.3 Bq (20 dpm)/100 cm², removable contamination.

Exposure rates in occupiable locations were reduced to less than 5 μ R/hr above background. Exposure levels were measured at 1 meter from floor/lower wall surfaces and averaged over floor areas (not exceeding 10 m²). Exposure rates at 1 meter did not exceed 10 μ R/hr above background in any location (i.e., upper walls and ceiling).

8 WASTE VOLUMES

The EBWR D&D project generated low level radioactive waste, mixed waste, and clean waste. These wastes consisted of both liquid and solid wastes. All liquid waste was transferred directly to ANL Waste Management Operations in approved containers or pipelines according to the procedures and requirements outlined in the ANL Waste Management Operations Handbook. Additionally, all waste was packaged and shipped/disposed of according to the procedures and requirements outlined in the Waste Management Procedures Manual.

Clean waste was free released and recycled or disposed of in a sanitary facility. A total of approximately 102,725 kg (226,000 lbs) of steel and 15,909 (35,000 lbs) of concrete were scrapped or recycled as clean material. Mixed waste was transferred to Waste Management Operations and stored on-site. Liquid radioactive waste was treated on-site. Low level radioactive waste was packaged at the EBWR facility and shipped to the low level waste disposal site at INEL (Phases I and II) or Hanford, WA (Phases III and IV).

8.1 Radiological Waste

The EBWR D&D project generated approximately 420.4 m³ (14,841 ft³) of low-level radioactive waste requiring off-site disposal. The waste included materials and equipment that could not be decontaminated, including the reactor vessel and its internals, process and drain systems piping, ion exchangers, pumps, tanks, filters, and contaminated building materials comprised primarily of concrete. Neither high level nor TRU wastes were generated during this project. The approximate amounts of radioactive material generated during this project are as follows:

Type	Volume m ³ (ft ³)	Weight kg (lbs.)
Metal	200.0 (7,061)	167,712 (368,966)
Concrete	63.8 (2,252)	85,705 (188,550)
Compactibles & Miscellaneous	156.6 (5,528)	106,789 (234,936)
TOTAL	420.4 (14,841)	360,206 (792,452)

8.2 Special Waste

Approximately 72.9 m³ (2,574 ft³) of asbestos was removed from the facility. Approximately 71.9 m³ (2,538 ft³) of non-radiologically contaminated asbestos was disposed of on-site at the ANL landfill. Approximately 1 m³ (36 ft³) of asbestos weighing 292 kg (642 lbs) containing low level radioactivity was shipped to the INEL disposal site as low level radioactive waste. Activated lead

was disposed of as mixed waste with a total volume of 11.7 m³ (413 ft³). A total of 17,491 kg (38,480 lbs) of material containing 1,736 Mbq (46.93 mCi) of activity was sent to Hanford, WA, as mixed waste.

The paint on the EBWR retention tanks was found to contain lead and PCB's. Additionally, PCB's were found in some electrical equipment. Both the electrical equipment and the paint were removed and disposed of as hazardous waste.

9 EBWR D&D PROJECT EXPOSURE SUMMARY

Total radiation exposure to all project personnel was 208.7 person-mSv (20.87 person-rem). The original estimated Project dose equivalent was 400 person-mSv (40 person-rem). Specific lessons learned are detailed in the appendix.

10 EBWR D&D PROJECT COST

The estimated total cost of the project was 19,586,000 US dollars.

11 PROJECT CLOSEOUT

Project closeout activities included closing out all outstanding Radiation Work Permits and submitting results to the appropriate division. All final worker dose records were archived by Health Physics. The contractor demobilized and removed all temporary housing, equipment, etc., off-site. All waste was removed from the facility and disposed of appropriately.

The EBWR D&D project report was developed, summarizing the D&D activities and the results. The EBWR facility was transferred from the Decommissioning Program to Waste Operations on January 19, 1996 for use as a transuranic waste storage facility.

APPENDIX A

Lessons Learned

Technical Lessons Learned

The decommissioning of a nuclear reactor has associated with it many unforeseeable difficulties that may be unique to a particular facility. However, the solution to these problems may be applicable to situations encountered during other similar D&D projects. The following are some selected problems encountered in decommissioning the EBWR:

Inability to Strike & Maintain an Arc Underwater

An underwater plasma arc was used during the segmentation of reactor internals in the fuel pool. Initial difficulty arose when striking an arc in the pool. Due to the chemistry of the water and the presence of metallic filings, the pool water was highly conductive, preventing the formation of the underwater arc. Once different combustible gases were used to compensate for this conductivity, there were no difficulties striking the arc. The initial gas mixture was 100% Nitrogen, but this was later changed to a 95% Argon and 5% Hydrogen mixture.

Electric Shock During Underwater Plasma Arc Use

Three individuals were used to cut a portion of a reactor core shroud from the main body. One individual performed cutting operations, a second individual held the segmented piece with grips connected to a 25-foot extension, and the third individual observed the operation and controlled the power to the plasma arc torch. The grips and extension were constructed of metal, and the worker wore sweaty protective clothing. Additionally, he was leaning against a metallic guardrail during the operation. It is speculated that once the segmented piece broke away from the shroud, electrical ground shifted to the metallic grips. Current ran up the grips and formed a connection through the man's body to the guardrail. The observer cut power to the torch immediately and no one was injured. Insulation was placed on the guardrail and floor area, and insulating segments were placed in all tools associated with the plasma arc. No further electrical shock incidences occurred.

BROKK Machine Contaminated

During the concrete demolitions, the BROKK machine was thoroughly wrapped in protective plastic to prevent contaminated dust from penetrating the machine. However, during the demolition, the machine broke down, and to gain access to the malfunctioning parts the integrity of the plastic covering was broken. This integrity was not reestablished before work recommenced, resulting in the contaminated machinery. The result was a long decontamination process for the contractor.

Clean-out and Decontamination of the Fuel Pool More Difficult than Expected

The original concept for cleaning the fuel pool after the completion of cutting operations was a three-part process: 1) Grips attached to a pole would be used to remove large pieces of slag; 2) a dustpan-like scoop would be used to remove medium size pieces; and 3) a hydro vacuum would be used to remove the fine tailings that remained. The entire operation was estimated to take 80 hours. However, many large pieces were hidden by the finer tailings, and were difficult to maneuver when found. The dustpan scoop was similarly very difficult to maneuver, and remained ineffectual at the surface of the slag rather than penetrating and gathering the slag. Finally, the hydro vacuum became clogged due to the presence of the larger material. The result was the cleanup of the fuel pool took much longer than anticipated. Contamination control problems also occurred during transfer of slag filled baskets and disassembly of system packaging. This caused delays in scheduled work while surveys were done to identify and clean up the small, spherical metal pieces of slag. The cause of this problem was attributed to inadequate contamination control and inadequate survey methods/procedures. These slag pieces were hollow, extremely small and easily scattered. They would not adhere to smear paper and were difficult to detect due to high background radiation.

One method that may be used to contain the slag would be to perform all cutting operations over a basket in the pool. For the EBWR facility, however, the entire core assembly was removed in one lift rather than in segments as originally envisioned. While reducing the overall exposure to personnel doing the lifts, cutting the structure became much more difficult. The size of the intact assembly also precluded the use of a catch basket. Additionally, inexperienced plasma arc operators may have created unnecessary slag during the initial cuts.

Monitor to Detect Nuclides Reasonably Expected Based on Past Operations, Even If They're Not Found in Characterization

During the D&D of a radiological facility, and especially in an experimental facility, radionuclides that were not expected may be encountered. It is necessary periodically to perform full gamma and alpha spectroscopy of air samples to detect radionuclides that may be present, even if they were not detected in the initial characterization.

Thorough Knowledge of Historic Operations is the Key Factor of Quality Characterization, Especially at Experimental Facilities

The lack of detailed documentation for the EBWR reactor operations significantly impeded the characterization and subsequent D&D activities performed during this project. The lack of detailed drawings resulted in conservative assumptions in the cost estimate, including the waste volumes, activity durations, and personnel exposure. The lack of accurate records from the operational period resulted in an incomplete characterization of the facility, which may have contributed to an unexpected Am²⁴¹ uptake.

Establish Personal Protective Equipment Levels Conservatively

By conservatively choosing personal protective equipment, 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.

Management Lessons Learned

Contractor Forces vs. In-house Forces

Early in the 1980's, funding was identified to perform final decommissioning of the EBWR. The early phases of the work were performed by the ANL Crafts groups. However, as more funding was made available for additional decommissioning work, it also became obvious that crafts staffing for this work was not optimized since it was work of a "one time" nature. Therefore, at the midpoint of this project, a decision was made to optimize our decommissioning capabilities, by bringing a contractor onto the project to perform all of the remaining decommissioning work. ANL D&D project staff then managed the contractors on the job.

Waste Disposal Sites

The ANL site has never had an on-site radioactive waste disposal facility. Over the years, this was (and will always be) a sensitive matter for all of our planning for radioactive waste requiring disposal from decommissioning of our research facilities. Most of the DOE disposal sites are in states that have historically always been DOE sites accepting both wastes for facilities "on-site" and certain "off-site" wastes. The sensitivity to this "historical" arrangement has been heightened over the last 10 years or so and this has caused many problems in maintaining an appropriate flow of wastes off-site during the life of this project. This generally caused several instances of much unnecessary paperwork, negotiating, and oversight than was appropriate or warranted. This is a reality in the decommissioning of many older facilities at many older research facilities.

APPENDIX B**Suggested Additional Reading**

1. "Design - Development and Operation of the Experimental Boiling Water Reactor Facility (EBWR) 1955-1967," L.E. Boing, E.A. Wimunc, and G.A. Whittington, November 1990, ANL-91/13.
2. "Decontamination and Decommissioning of the Experimental Boiling Water Reactor (EBWR): Project Final Report, Argonne National Laboratory," C. Fellhauer, L. Boing (ANL), and J. Aldana (NES), March 1997, ANL/D&D/TM-96/4.
3. "An Evaluation of Alternative Reactor Vessel Cutting Technologies for the Experimental Boiling Water Reactor (EBWR) at Argonne National Laboratory," by L.E. Boing, D.R. Henley (ANL), W.J. Marion, and J.W. Gordon (NES), December 1989, ANL-89/31.
4. "The Experimental Boiling Water Reactor," Argonne National Laboratory, May 1957, ANL-5607.
5. "Radiological Status Report for the EBWR Containment Building - Volume 1, Summary and Analysis," B.T. Murdoch, February 1996, ANL/ESH-HP-96/01.