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LIQUID METAL REACTOR DEACTIVATION AS APPLIED TO THE EXPERIMENTAL BREEDER REACTOR - II

by

J. A. Michelbacher, O. K. Earle, D. F. Pfannenstiel, P. B. Wells

Argonne National Laboratory - West
P. O. Box 2528
Idaho Falls, ID 83403-2528
208-533-7177

ABSTRACT

The Experimental Breeder Reactor - II (EBR-II) at Argonne National Laboratory - West was shutdown in September, 1994. This sodium cooled reactor had been in service since 1964, and by the United States Department of Energy (DOE) mandate, was to be placed in an industrially and radiologically safe condition for ultimate decommissioning.

The deactivation of a liquid metal reactor presents unique concerns. The first major task associated with the project was the removal of all fueled assemblies. In addition, sodium must be drained from systems and processed for ultimate disposal. Residual quantities of sodium remaining in systems must be deactivated or inerted to preclude future hazards associated with pyrophoricity and generation of potentially explosive hydrogen gas.

A Sodium Process Facility (SPF) was designed and constructed to react the elemental sodium from the EBR-II primary and secondary systems to sodium hydroxide for disposal. This facility has a design capacity to allow the reaction of the complete inventory of sodium at ANL-W in less than two years. Additional quantities of sodium from the Fermi-1 reactor are also being treated at the SPF.

The configuration of EBR-II presented several problems with meeting the DOE mandate. The EBR-II is a pool-type reactor, and the primary system was not designed to be drained. A system, including an annular linear induction pump and a transfer line, was designed and installed to drain the sodium from the primary system to the SPF. The secondary sodium was previously drained to a storage tank, where it will be transferred to the SPF using the same transfer line as the primary sodium. Once the sodium is removed from these systems, residual amounts in the form of pools and films remain. An extensive testing and development program was implemented to determine appropriate methods for reacting and/or draining these quantities, minimizing future maintenance and surveillance activities, and satisfying Resource Conservation and Recovery Act (RCRA) requirements. RCRA is a United States law governing control and disposal of hazardous wastes.

Other development activities have been undertaken to assure success of the project. In order to

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maximize draining of the primary vessel and react residual quantities of sodium, the sodium must remain molten. The existing heating system will not function efficiently to assure temperatures will remain above the molten sodium temperature. An auxiliary system has been designed for this purpose. In order to verify sodium draining and inspect the interior of the primary vessel, a viewing system will also be designed and installed. Due to the harsh environment, this system requires special considerations.

The sodium environment and the EBR-II configuration, combined with the radiation and contamination associated with thirty years of reactor operation, pose problems specific to liquid metal reactor deactivation. The methods being developed at EBR-II can be applied to other similar situations in the United States and abroad.

BACKGROUND

The EBR-II is a sodium cooled research reactor located in the southeastern portion of the Idaho National Engineering and Environmental Laboratory (INEEL). The EBR-II is a 62.5 MW thermal reactor that began operations in July 1964, and when fully operational, was capable of producing up to 19.5 MW of electrical power for the INEEL electrical grid.

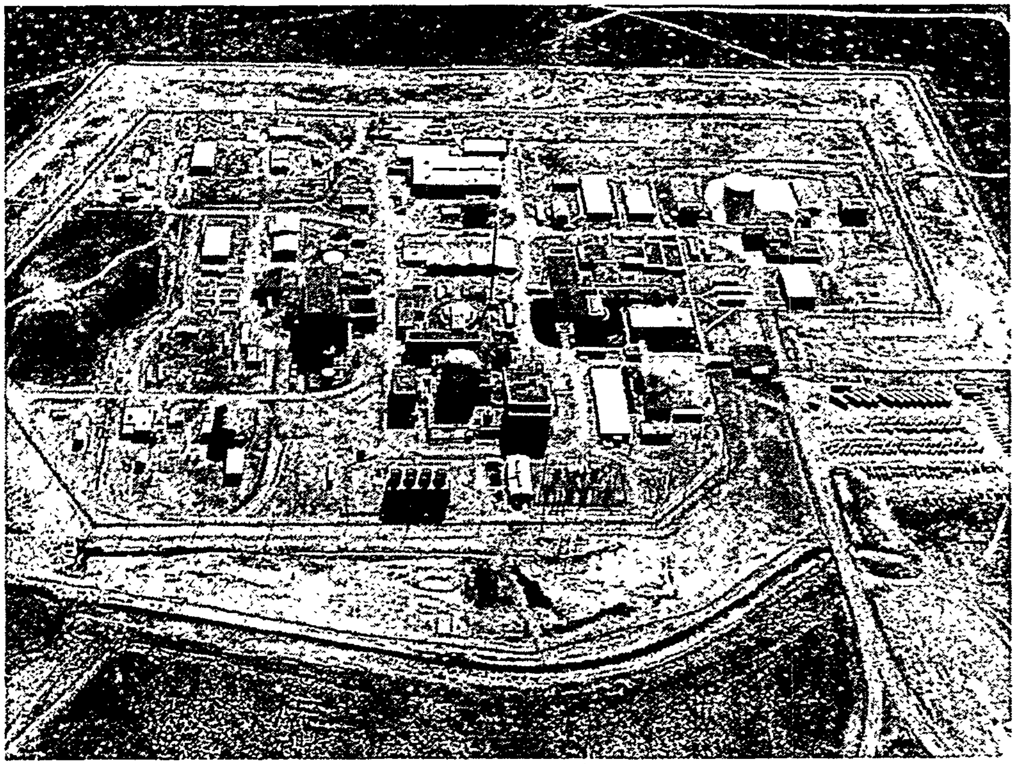


Figure 1. EBR-II Complex

The EBR-II complex, as depicted in Figure 1, consists of the reactor and reactor building, the Sodium Boiler Building (SBB), the electrical power plant, reactor cooling towers, water chemistry laboratory support facilities, and the Cover Gas Cleanup System (CGCS). The EBR-II reactor building is connected to the Fuel Conditioning Facility (FCF), a large inert atmosphere hot cell facility. The EBR-II reactor building, a cylindrical structure with a hemispherical domed top, has a steel containment shell with an inner diameter of 24.4 m (80 feet) and a height of 42.4 m (139 feet). The bottom and sides are 2.54 cm (1 inch) thick steel plate and the dome is 1.27 cm (0.5 inch) thick, lined with a 10.2 cm (4 inch) concrete missile shield.

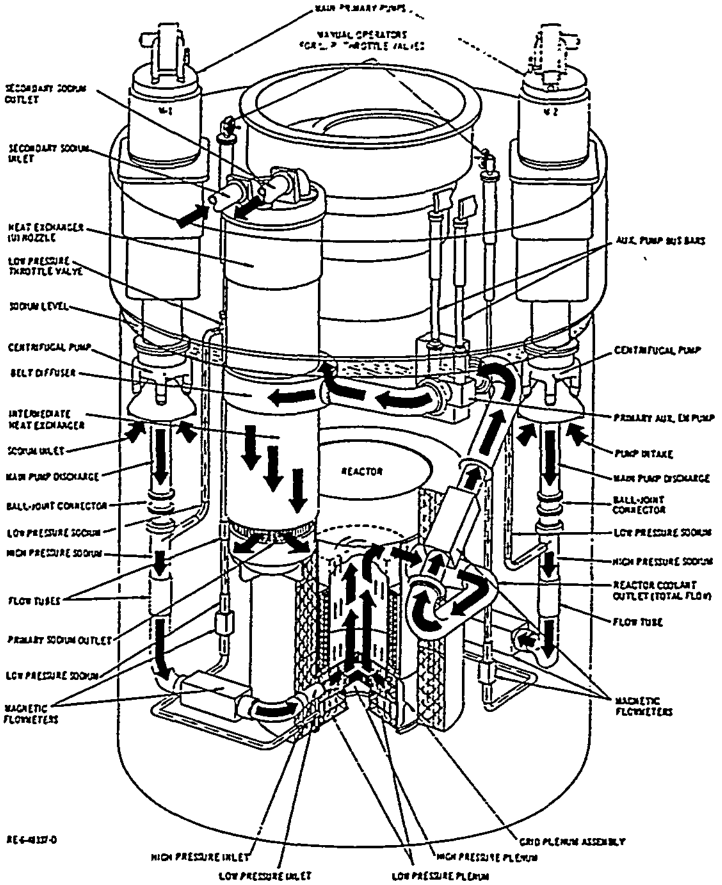


Figure 2. EBR-II Reactor Vessel

The reactor was a test facility for fuels development, materials irradiation, system and control theory tests, and hardware development. The EBR-II core and blanket subassemblies were contained within the reactor vessel (Figure 2) prior to defueling. The 1.70 m (67 inch) diameter vessel and its shield are immersed in a sodium pool within the 7.9 m (26 foot) diameter by 7.9 m (26 foot) high primary tank. The primary sodium contained within this tank represents the primary cooling system for removal of the heat from the reactor core. Liquid sodium, with a boiling point of approximately 927°C (1700°F), has excellent thermal properties and is thus an optimum coolant. The primary system contains about 330 m^3 (87,000 gallons) of sodium, and transfers heat to the secondary sodium system (about 50 m^3 (13,000 gallons)) through a sodium-to-sodium intermediate heat exchanger (IHX). The secondary sodium was circulated in a closed loop through superheaters and steam generators outside of the reactor containment in the SBB. The high pressure steam produced in the steam generator drove a turbine-generator to produce electric power.

The EBR-II termination activities began in October 1994 with the commencement of fuel removal from EBR-II. The fueled assemblies were replaced with non-fueled assemblies of the same configuration to assure stability of the core and to aid in removal/replacement of the remainder of the core. The fueled assemblies were packaged for storage at the Radioactive Scrap and Waste Facility (RSWF) at ANL-W. Subsequent to completion of defueling, the sodium coolant from the primary and secondary systems will be converted to sodium hydroxide at the SPF, currently undergoing startup testing at ANL-W. Residual quantities of sodium remaining in the primary and secondary systems will be deactivated as part of the Plant Closure Project.

SODIUM PROCESS FACILITY

The SPF reacts elemental sodium to sodium hydroxide. Sodium is injected into a nickel reaction vessel into a 70 wt % solution of sodium hydroxide. Water is also injected, maintaining the 70 wt % concentration by controlling the boiling point of the solution. The sodium hydroxide is solid at room temperature, and is a waste form acceptable for burial in the state of Idaho. Figure 3 depicts the SPF flow process.

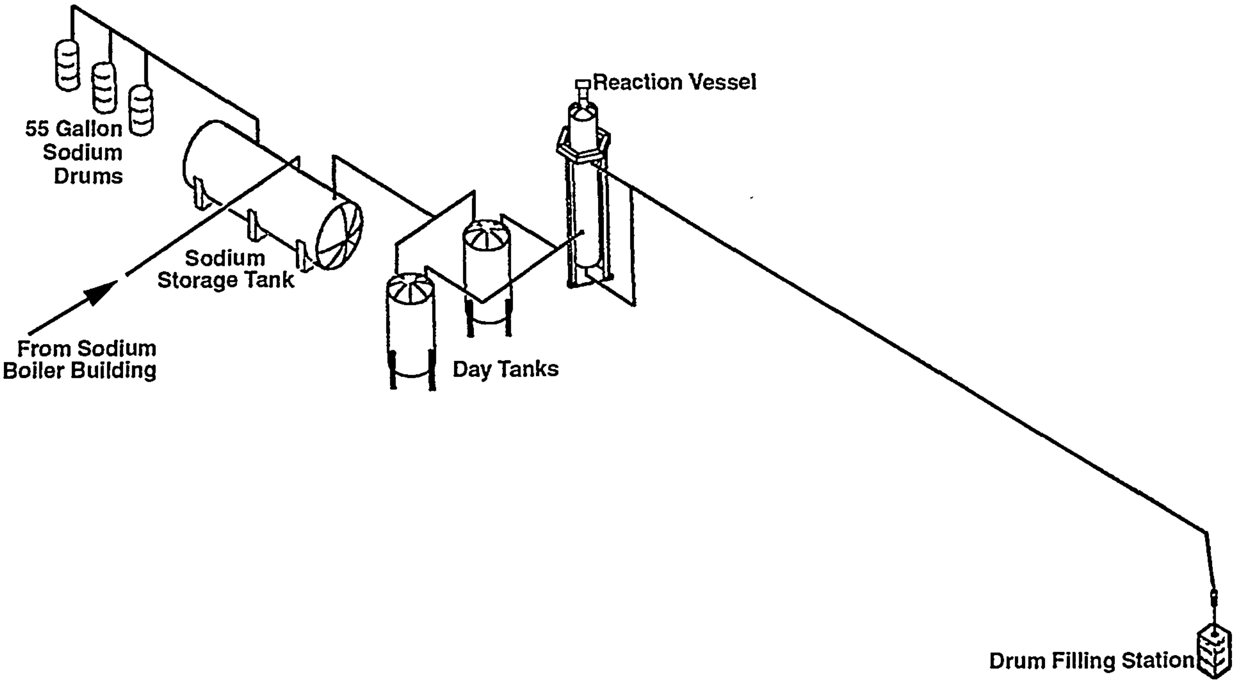


Figure 3. Sodium Process Facility Flow Diagram

The SPF was originally designed and built in the 1980s for reacting the 290 m^3 (77,000 gallons) of Fermi-1 primary sodium to a 50 wt % sodium hydroxide solution. The hydroxide was slated to be used to neutralize acid produced in the Purex process at the Hanford site. Due to a change in the Purex mission, the hydroxide was no longer required and the SPF was never started up.

With the shutdown of the EBR-II, the necessity for a facility for reacting sodium was identified. ANL-W engineering and operations undertook the task of upgrading the existing facility. In order to comply with RCRA requirements, the sodium had to be converted into a waste form acceptable for burial in the State of Idaho. The SPF was originally modified to process the 50 wt % sodium hydroxide to a sodium carbonate powder using thin film evaporator (TFE) technology. The TFE is a device designed to react sodium hydroxide with carbon dioxide and dry the solution to a powder. After testing the TFE for approximately one year, it was determined that this technology was not suitable for our application due to plugging, throughput, and powder containment issues. It was decided to convert to 70 wt % sodium hydroxide, a substance that solidifies at 65°C (150°F) and is acceptable for burial in Idaho. At the time of preparation of this paper, over 80 m^3 (20,000 gallons) of sodium have been processed, and the facility is undergoing upgrades to the off-gas system.

The sodium will be processed in three separate and distinct campaigns; the 290 m^3 (77,000 gallons) of Fermi-1 primary sodium, the 50 m^3 (13,000 gallons) of EBR-II secondary sodium, and the 330 m^3 (87,000 gallons) of EBR-II primary sodium. The Fermi-1 and EBR-II secondary sodium contain only low levels of radiation, while the EBR-II primary sodium has radiation levels of approximately 40 millirem per hour at 1 meter. The EBR-II primary sodium will be processed last, allowing the operating experience to be gained with the less radioactive sodium prior to reacting the most radioactive sodium.

The sodium hydroxide will be disposed of in 269 liter (71 gallon) drums, four to a pallet. These drums are square in cross-section, allowing for maximum utilization of the space on a pallet, minimizing the required landfill space required for disposal.

CLOSURE PLAN FOR EBR-II

The closure plan for EBR-II is that contained in the Environmental Assessment (EA) for the Shutdown of Experimental Breeder Reactor - II at Argonne National Laboratory - West. The items presented herein have been presented to the public for comment period and been discussed at public meetings. The EA was granted a Finding of No Significant Impact (FONSI) from the United States Department of Energy. This FONSI documents that the proposed action does not constitute a major federal action significantly affecting the quality of the human environment, negating the necessity for the preparation of an Environmental Impact Statement.

The procedural controls for closure of EBR-II follow DOE recommendations for managing Deactivation and Decommissioning (D&D) projects. Figure 4 depicts the process. End-point criteria were established to implement the goal to place EBR-II in an industrially and radiologically safe condition. After investigating and statusing (characterizing) the facility/system against the detailed criteria, lay-up plans were then developed at the system and facility level to determine the specific actions needed to achieve the detailed criteria. The actions are then tracked individually to completion. Note that the criteria include not only technical criteria but documentation requirements as well.

Following is a discussion of the key technical steps to achieve EBR II closure and their status:

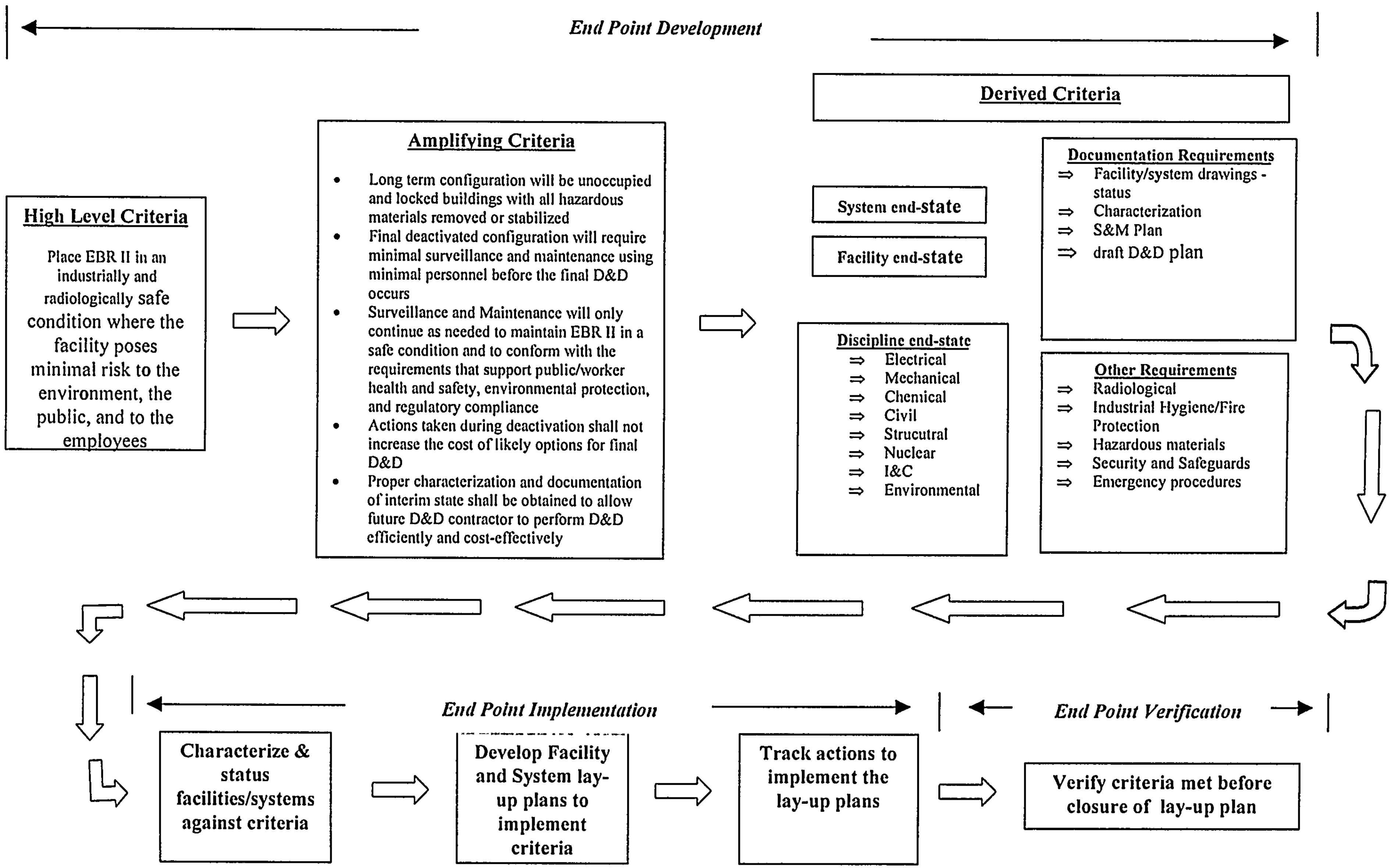
Reactor Defueling/Configuration. All fueled assemblies were removed from the reactor as of December 1996, and replaced with non-fueled assemblies identical in configuration.

To provide openings in the reactor vessel's grid plates for access to selected locations and for gases generated during the reaction of residual sodium after the primary tank is drained, selected non-fueled assemblies were removed from the reactor vessel. Fifty-six such assemblies were placed in the storage basket internal to the primary tank.

Prepare Primary Tank for Draining. To prepare the primary tank for draining, the sodium remaining within the Primary Purification System, Fuel Element Rupture Detection (FERD) System, and Radioactive Sodium Chemistry Loop (RSCL) will be transferred into the primary tank to the maximum extent practicable. These are locations that will not drain freely into the primary tank.

A pumpdown system has been designed, installed, and tested for removing the primary tank sodium. An annular linear induction pump (ALIP) is utilized in a system designed to pump the primary sodium to the SPF. Methods are under consideration for removing the sodium to the maximum extent practicable, minimizing the sodium remaining that will have to be dealt with using alternative draining methods and/or moist gas deactivation.

Figure 4. End Point Process for Managing Closure Activities at EBR II



End Point Development

High Level Criteria

Place EBR II in an industrially and radiologically safe condition where the facility poses minimal risk to the environment, the public, and to the employees

Amplifying Criteria

- Long term configuration will be unoccupied and locked buildings with all hazardous materials removed or stabilized
- Final deactivated configuration will require minimal surveillance and maintenance using minimal personnel before the final D&D occurs
- Surveillance and Maintenance will only continue as needed to maintain EBR II in a safe condition and to conform with the requirements that support public/worker health and safety, environmental protection, and regulatory compliance
- Actions taken during deactivation shall not increase the cost of likely options for final D&D
- Proper characterization and documentation of interim state shall be obtained to allow future D&D contractor to perform D&D efficiently and cost-effectively

Derived Criteria

System end-state

Facility end-state

Discipline end-state

⇒ Electrical
⇒ Mechanical
⇒ Chemical
⇒ Civil
⇒ Strucutral
⇒ Nuclear
⇒ I&C
⇒ Environmental

Documentation Requirements

⇒ Facility/system drawings - status
⇒ Characterization
⇒ S&M Plan
⇒ draft D&D plan

Other Requirements

⇒ Radiological
⇒ Industrial Hygiene/Fire Protection
⇒ Hazardous materials
⇒ Security and Safeguards
⇒ Emergency procedures

End Point Implementation

End Point Verification

Characterize & status facilities/systems against criteria

Develop Facility and System lay-up plans to implement criteria

Track actions to implement the lay-up plans

Verify criteria met before closure of lay-up plan

An extensive review of the Primary Tank and its internals was performed to determine areas that may not drain and to assess the quantities of sodium that will remain and require subsequent action. Some areas of concern include the inner shield annulus that could potentially contain 1.9 m^3 (500 gallons) of sodium, and the low pressure plenum (1.3 m^3 (350 gallons)). Methods to monitor the draining of these areas are being developed as well as contingency plans for draining these areas.

To accurately monitor the sodium level in the primary tank during the draining process, a bubbler system has been designed, installed, and tested. This bubbler will operate during the draining operation until the tank level is less than 2 cm (1 inch) deep.

To access core regions to monitor draining and potentially install an auxiliary draining device, the main core gripper will be removed from the primary tank prior to the initiation of draining. The gripper will be cut up and packaged for disposal. The gripper is the device that attaches to the fuel assemblies for placement in and removal from the core.

The primary nuclide (cesium) trap has been removed and placed in the Radioactive Storage and Waste Facility (RSWF) at ANL-W. The primary cold trap will be removed after draining the primary sodium. Since these items are highly contaminated they will not be cleaned immediately. They will be removed and stored until final disposition is determined. After removal, these components will be replaced with pipeline spool pieces to facilitate subsequent purging and residual sodium reaction.

The EBR-II cesium trap was very small, containing 0.01 m^3 (2.6 gallons) of reticulated vitreous carbon with a surface area of 370 m^2 (4000 ft^2). The trap was installed between the economizer and crystallizer in the inlet line to the cold trap. The temperature at this point was ideal for maximizing removal of cesium without risking plugging of the trap with other materials. EBR-II bulk sodium temperature was 371°C (700°F). The cesium trap was operated at a nominal 193°C (380°F), and the crystallizer cold point was operated at a nominal 121°C (250°F). The cesium trap was integrally shielded for ease of removal and storage following the end of its useful life. Overall dimensions, including the shield, was 0.9 m x 0.9 m x 0.6 m (2.9 ft x 2.9 ft x 2.0 ft).

The IHX will be isolated from the secondary system, and the approximately 3 m^3 (750 gallons) of secondary sodium will be pumped to the primary tank to be dispositioned with the primary sodium.

The EBR-II shutdown coolers are natural circulation, passive systems that use sodium-potassium (NaK) alloy to remove decay heat during reactor shutdowns. Since no fuel resides in the primary tank, the shutdown coolers will be removed from service by draining the maximum achievable amount of the 2 m^3 (550 gallons) of NaK into the primary sodium. The NaK will be treated with the sodium at the SPF. NaK remaining in the shutdown coolers will be dealt with at the Sodium Components Maintenance Shop (SCMS) at ANL-W. The SCMS is a RCRA permitted facility with the capability to clean sodium wetted components with ethyl alcohol or water, as well as perform maintenance, disassembly, and packaging of contaminated equipment.

Temperature of the primary sodium is maintained at 175°C (350°F) by operation of the primary pumps and the use of installed immersion heaters. When the draining operation commences, the primary pumps will be secured. As the level of the primary sodium decreases, the immersion heaters become less effective. In order to assure the primary sodium remains molten throughout draining and residual deactivation, an auxiliary heating system is being designed. This system will circulate hot air in the annular region between the primary vessel and the shield tank.

A viewing system will be installed in the primary tank to monitor draining, inspect tank components, and assess areas where pockets of sodium remain after draining. Due to the harsh environment, the camera will be equipped with cooling and a method to assure the lens does not become fogged with sodium vapors and/or aerosols. The camera will be equipped with lighting, and zoom, pan, and tilt features to allow assessment of the entire primary tank. Two diametrically opposite nozzles in the primary tank cover have been identified for installation of the viewing system to maximize viewing capabilities.

Drain Primary Tank. The sodium in the primary tank, along with the secondary sodium, will be pumped through a transfer line to the SPF for reaction to sodium hydroxide. This heat traced transfer line is constructed per ASME B31.3 requirements of 1" IPS, schedule 40, 304 stainless steel, and runs from the sodium boiler building to SPF, approximately 300 m (900 feet). Figure 5 shows the routing of the line from the Sodium Boiler Building to the SPF.

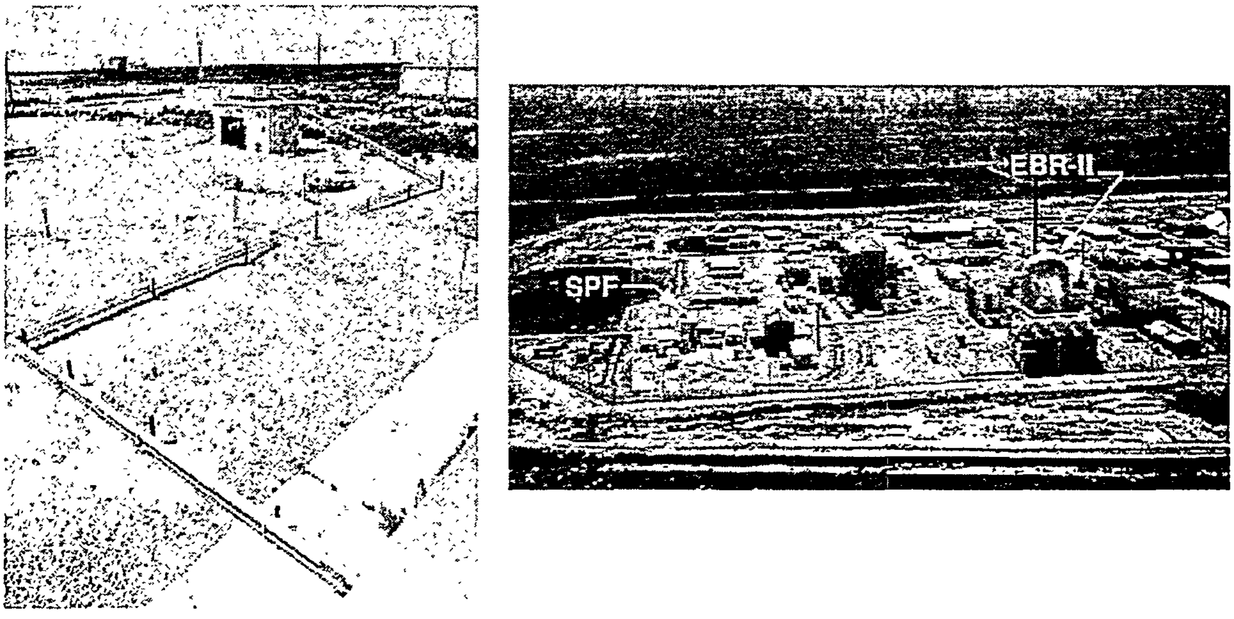


Figure 5

The primary draining will be accomplished using the ALIP. The transfer rate will be approximately 55 liters/minute (15 gallons/minute), requiring less than an eight hour shift to transfer the 20 m^3 (5000 gallons) required to fill the sodium storage tank at SPF. The transfer line will be gravity drained and cooled after each transfer.

React Residual Primary Sodium. Following the draining of sodium from the primary tank there will be a considerable volume of sodium remaining; between 0.6 and 5.7 m^3 (170 and 1500 gallons) depending on whether drain holes exist in annular and plenum regions. This residual sodium will be reacted in place within the primary tank to facilitate the safe, effective, and complete removal of all reactive sodium and sodium compounds. This approach will provide a stable in-tank environment that will support a long term surveillance and maintenance operational state that will minimize the required amount of personnel involved and will support future D&D activities by placing the primary tank components in a stable and known state. The method for reaction of the residual quantities of sodium, with the sodium molten, will be a nitrogen purge with superheated steam, generating sodium hydroxide and hydrogen. The hydrogen will be vented, while the sodium hydroxide will be either removed, reacted to sodium carbonate via the introduction of carbon dioxide to the primary tank, or allowed to solidify. Areas of the primary tank difficult to access with the purge will be given further consideration, including access with pressurized lances located using robotic devices. The goal, upon completion of residual sodium reaction, is to flush the primary tank with water to remove all accessible sodium. A safety analysis is being performed to determine if the water flush can be performed without unacceptable energy releases.

Isolate Primary Tank. The primary tank will be isolated to reduce the background radiation level in the reactor building. This will be done through several steps. The fuel transfer port (FTP) will be removed, including the removal of a large mass of lead shielding no longer required due to the removal of the fuel from the reactor. The components will be cleaned and scrapped. Contaminated piping external to the primary system will be cleaned and scrapped. To the maximum extent practicable, all remaining primary tank nozzles will be disconnected and gasketed blank flanges installed. If installed, the primary tank inspection equipment will be removed.

The primary tank pump down system will be isolated at the reactor building floor and retired in place.

The safety rod drive shafts and fuel storage basket shaft will be sealed to the primary tank cover, while the main core transfer arm shaft will be sealed to the rotating plug. The six primary tank heaters will be removed from the primary tank. The potentially contaminated sodium (tritium) drained from the six heaters will be transferred to the SPF for processing, while the heaters will be cleaned and scrapped or reinstalled in the primary tank.

Although the guide thimbles penetrate the reactor vessel, the actual wide range nuclear detectors are removable from the guide thimbles. Removal of the detectors supports the program to remove all uranium from the EBR-II complex.

It is anticipated that, upon completion of residual deactivation, an air blanket will be placed on the primary tank with a passive, HEPA filtered ventilation system that allows the primary tank to "breathe". Hydrogen will be monitored to assure levels remain below the lower explosive limit and also as an indication that no exposed sodium remains in the vessel.

Secondary Sodium Systems. The secondary sodium system will be transformed into a stable, environmentally sound configuration.

The cold trap (which contains uncontaminated NaK) has been removed and replaced with a spool piece. The cold trap will be cleaned at SCMS and disposed of. Installation of the spool piece allows purge gas flow through that portion of the system during the reaction and flushing process, as well as aid in the draining of the primary sodium.

To facilitate purge gas flow during the reaction and flushing process, secondary sodium piping that directs sodium to the IHX will be cross connected outside of the reactor building.

Residual sodium within the secondary system will be drained and reacted. Sodium heels have been identified, and those greater than 1.5 cm (0.5 in) in depth will be drained by drilling. The remainder of the residuals will be reacted in place using nitrogen with superheated steam while maintaining the secondary system at approximately 150°C (300°F). It is anticipated that nearly all the sodium residuals in the secondary system will be reacted. Upon completion of the purge, the system will be flushed with water, sampled, and neutralized as required with carbon dioxide. The tritium contamination levels are low enough that it is anticipated that the flush water will be discharged to the local settling ponds and evaporated. If system surveys reveal free release of the secondary components and piping, ANL-W will contract a salvage company to remove the systems for the scrap value of the materials.

Additional Major Component Removal. Highly contaminated components will be removed from the reactor building to lower background radiation levels as well as reduce the amount of hazardous material stored in the building.

The primary tank drain and transfer pipeline will be removed and the pipe sections cleaned and scrapped. The pipeline must be removed within 6 months after completion of usage in order to comply with the RCRA permit issued by the State of Idaho.

The fuel unloading machine (FUM) will be disassembled and all contaminated components removed, cleaned and disposed of. Cover Gas Cleanup System components, including the controlled temperature profile condenser, aerosol filters and preheater will be removed. The condenser will be temporarily stored until a suitable storage facility can be identified, while the filters and preheater will be cleaned and disposed of.

The Argon Cooling System molecular sieves and vapor traps will be cleaned and disposed of.

Final Reactor Building System Deactivations. The purpose of reactor building system deactivations is to secure any plant systems which may still be unsafe after individual system components have been removed. Deactivation may include electrical/mechanical equipment removal, tagging of electrical breakers, and system purging and/or sealing. Deactivation will be applied to selected portions of the reactor building heating/cooling systems, but not to any systems or equipment deemed necessary for support of personnel entry into the EBR-II reactor building. It is suggested that since the Reactor Building's main polar crane and associated electrical controls might be utilized during D&D, they should be maintained.

The Reactor Building systems to be deactivated include the Primary Purification System, Fuel Element Rupture Detection System, Radioactive Sodium Chemistry Loop System, Liquid Metal (NaK) Dump System, Cover Gas Cleanup System, Argon Cooling System, Thimble Cooling System, and MET-L-X System.

Removal of Hazardous Material. In order to achieve an industrially and radiologically safe condition, all hazardous material will be removed from the EBR-II complex. Hazardous materials to be removed include lead used for shielding, or ballast such as in the fuel transfer arm counterweight, depleted uranium also used as shielding, primary auxiliary pump batteries and ACS batteries stored in the Power Plant Building. The station batteries (UPS), also stored in the Power Plant Building, will be retained for site power backup. Other hazardous materials include sulfuric acids (if any remains), hydraulic oils stored in pumps and motors, silicone (used as a heat transfer medium), and Dowtherm™ (used as a heat transfer medium). Asbestos is currently in good condition, and will be inspected on a periodic basis to assure degradation does not occur.

Removal of flammable material (electrical cabling, located under the main floor steel deck plates inside the Reactor Building) must be worked in conjunction with the building system deactivations.

This phase will be completed by moving all components stored within the reactor building storage pit to SCMS for cleaning and disposal.

Installation of Reactor Building Penetration Cover. Completion of this section will help establish control of personnel and equipment into, and out of, the reactor building. To provide permanent isolation between the Reactor Building and the Fuel Conditioning Facility, the equipment air lock (EQUAL) cover will be installed. Since personnel will still be required to enter the reactor building, the penetration covers for the personnel airlock (PERAL) and the emergency personnel airlock (EMRAL) will not be installed. A fourth entrance, for transfer of large components into and out of the building, is normally bolted in place and will not require a separate cover.

Deactivation of Remaining EBR-II Complex Buildings and Related Facilities. Any remaining building systems which are no longer required will be deactivated pending availability of funding. Deactivation may include electrical/mechanical equipment removal, electrical breaker tagout, system purging or sealing. All systems shall be deactivated, except those necessary for minimal personnel entry, such as abbreviated lighting, heating and ventilation. Equipment which may provide some excess value shall be evaluated for transfer to the appropriate facilities. Facilities included in the EBR-II complex are the Sodium Boiler Building, CGCS Building, Experimental Equipment Building, and the Cooling Tower. Related facilities include the Sodium Components Maintenance Shop and the Sodium Processing Facility.

CONCLUSIONS

The goal of the deactivation project is to place EBR-II in an industrially and radiologically safe condition, posing little or no risk to the environment or to persons, while requiring minimal maintenance and surveillance activities in the interim period between deactivation and D&D. Current schedule and milestone commitments place the EBR-II facility in the final deactivation configuration in early 2002.

From: Michelbacher, John
Sent: Wednesday, April 28, 1999 3:48 PM
To: Heilig, Linda
Subject: LIQUID METAL REACTOR DEACTIVATION AS APPLIED TO THE EXPERIMENTAL BREEDER REACTOR - II

Linda - This is the paper that goes with the abstract that was accepted - ID # 98713. Call if you have questions. Thanks,
Bert

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