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Deactivation of the EBR-II Complex*

by

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DISCLAIMER

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ABSTRACT

In January of 1994, the Department of Energy mandated the termination of the Integral Fast Reactor (IFR) Program, effective October 1, 1994. To comply with this decision, Argonne National Laboratory-West (ANL-W) prepared a plan providing detailed requirements to place the Experimental Breeder Reactor - II (EBR-II) in a radiologically and industrially safe condition, including removal of all irradiated fuel assemblies from the reactor plant, and removal and stabilization of the primary and secondary sodium, a liquid metal used to transfer heat within the reactor plant.

The ultimate goal of the deactivation process is to place the EBR-II complex in a stable condition until a decontamination and decommissioning (D&D) plan can be prepared, thereby minimizing requirements for maintenance and surveillance and maximizing the amount of time for radioactive decay. The final closure state will be achieved in full compliance with federal, state and local environmental, safety, and health regulations and requirements. The decision to delay the development of a detailed D&D plan has necessitated this current action.

The EBR-II is a pool-type reactor. The primary system contains approximately 87,000 gallons of sodium, while the secondary system has 13,000 gallons. In order to properly dispose of the sodium in compliance with the Resource Conservation and Recovery Act (RCRA), a facility has been built to react the sodium to a dry carbonate powder in a two stage process.

Deactivation of a liquid metal fast breeder reactor (LMFBR) presents unique concerns. Residual amounts of sodium remaining in the primary and secondary systems must be either reacted or inerted to preclude future concerns with sodium-air reactions that generate explosive mixtures of hydrogen and leave corrosive compounds. Residual amounts of sodium on components will effectively "solder" components in place, making future operation or removal unfeasible. The sequence of events used to "lay-up" sodium wetted systems is thus crucial in assuring these concerns do not occur. After removal of selected components, unique methods, potentially employing unique robotic applications, will be employed to assure complete reaction of the residual sodium.

Specialized components/systems exist within the primary system, include primary cold traps, a cover gas condenser, and miscellaneous systems containing a sodium-potassium (NaK) alloy. The sodium or sodium-potassium alloy in these components must be reacted in place or the components physically removed in order to achieve a radiologically and industrially safe condition. The Sodium Components Maintenance Shop, a facility at ANL-W, provides the capability for washing primary components, removing residual quantities of sodium or NaK while providing some decontamination capacity.

Major primary components will be removed from the primary tank for cleaning and disposition. An integral part of the primary component removal is for providing the necessary access to primary tank internal components for D&D activities, removal of hazardous materials, and removal of stored energy sources. ANL-W's plans for the deactivation of the EBR-II address these issues, providing for an industrially and radiologically safe complex, and requiring minimal surveillance during the interim period between deactivation and D&D. The plan also establishes a document archive of not only all the closure documents, but also the key plant documents (P&IDs, design bases, characterization data, etc.) in a convenient location to assure the appropriate knowledge base is available for D&D which could occur decades in the future.

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.

The EBR-II complex, as depicted in Figure 1, consists of the reactor and reactor building, the Sodium Boiler Building , the electrical power plant, reactor cooling towers, water chemistry laboratory support facilities, and the Cover Gas Cleanup System . The EBR-II reactor building is connected to the Fuel Conditioning Facility , 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 (½ inch) thick, lined with a 10.2 cm (4 inch) concrete missile shield.

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 transferred 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 Sodium Boiler Building. 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. Currently, all the fuel has been removed, the steam plant has been placed in lay-up, and the secondary sodium has been drained to the secondary sodium storage tank. Subsequently, secondary sodium will be converted to sodium carbonate at the Sodium Process Facility (SPF), currently undergoing startup testing at ANL-W. The primary sodium will be drained and similarly converted, and final residual sodium deactivation actions will be taken.

SODIUM PROCESS FACILITY

The SPF was designed to react elemental sodium to sodium carbonate through a two-stage process. The sodium is first reacted to sodium hydroxide in the caustic facility side of the SPF. Sodium is injected into a nickel reaction vessel filled with 50 wt % solution of sodium hydroxide. Water is also injected, maintaining the reaction rate by controlling the boiling point of the solution. In the carbonate side of the facility, the sodium hydroxide is reacted with carbon dioxide in a thin film evaporator to form sodium carbonate. This dry powder, similar in consistency to baking soda, is a waste form acceptable for burial in the state of Idaho as non-hazardous radioactive waste.

The caustic facility was originally designed and built in the 1980s for reacting the 77,000 gallons of Fermi-1 primary sodium to sodium hydroxide. 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 caustic facility was never started up.

With the shutdown of the EBR-II, the necessity for a facility for reacting sodium was identified. In order to comply with RCRA requirements, the sodium had to be converted into a waste form acceptable for burial in the Radioactive Waste Management Complex, a low-level radioactive waste disposal facility located on the Idaho National Engineering and Environmental Laboratory. Sodium hydroxide is a RCRA regulated waste. It was decided to convert the hydroxide to sodium carbonate, a substance that is not RCRA regulated. ANL-W Engineering and Operations Divisions undertook the task of upgrading the caustic facility, and designing and constructing the carbonate facility. At the time of preparation of this paper, the facilities are undergoing testing and startup activities.

The sodium will be processed in three separate and distinct campaigns; the 77,000 gallons of Fermi-1 primary sodium, the 13,000 gallons of the EBR-II secondary sodium, and the 87,000 gallons of the EBR-II primary sodium. The Fermi-1 and the EBR-II secondary sodium contain only low levels of radiation, while the EBR-II primary sodium has radiation levels up to 50 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 the reacting the most radioactive sodium.

The sodium carbonate will be disposed of in 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 presented herein for EBR-II is that contained in the Environmental Assessment (EA) for the Shutdown of Experimental Breeder Reactor - II at Argonne National Laboratory - West (Reference 1). The items presented herein have been presented to the public for comment period and have been discussed at public meetings. The EA is currently awaiting a Finding of No Significant Impact (FONSI) from the United States Department of Energy.

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 gases generated during the reaction of residual sodium after the primary tank is drained, selected non-fueled assemblies located in the reactor vessel's outer blanket region will be removed from the reactor vessel. Three such assemblies have been identified, and will be placed in the storage basket internal to the primary tank.

Remove Major Primary Tank Components. Prior to draining the sodium from the primary tank, both primary sodium pumps and the intermediate heat exchanger (IHX) will be removed. This will provide access into the primary tank if and when detailed exploratory examinations are required. The tank openings will be sealed with specially designed covers. Consideration is also being given to reinstalling these components into the primary tank after they have been cleaned and the residual sodium in the primary tank has been reacted. The cleaning of these components will be performed at the Sodium Components Maintenance Shop (SCMS) at ANL-W. This facility was designed to deal with these large components, and will react and remove any residual sodium from these components, as well as provide for a level of component decontamination.

Prior to removal of the IHX, the secondary sodium within the IHX will be pumped into the primary tank. An unremovable 'heel' of sodium (~ 100 gal.) will remain trapped in the bottom of the lower head. This sodium will be reacted and removed from the IHX at the SCMS. A RCRA Permit for SCMS is also presently being sought.

Liquid metal sodium-potassium (NaK) alloy is present in the shutdown coolers and the primary purification system. The NaK will be transferred into the primary tank to be processed with the primary sodium, or placed in suitable containers for future disposition. The two shutdown coolers will be flushed, purged, sealed, and retired in place. The primary purification system will be flushed, purged, and sealed.

Prepare Primary Tank for Draining. To prepare the primary tank for draining, the sodium remaining within the primary purification system, fuel element radiation detector (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.

It will be necessary to design and install a system for removing the primary tank sodium. An annular linear induction pump (ALIP) will be utilized in a system designed to pump the primary sodium to the

Sodium Process Facility. An ALIP is a small diameter three-phase electro-mechanical pump that requires no external cooling and may be fully immersed in the hot sodium. Since the ALIP will lose suction prior to completing the draining operation, a method is under development for removing the remainder of the sodium to the maximum extent practicable, using differential pressure and intermediate storage for the transfer.

The primary cold trap will be removed and placed in the Radioactive Scrap and Waste Facility (RSWF) at ANL-W. Since this item is highly contaminated it will not be immediately cleaned, instead it will be removed and stored until final disposition is determined. After removal, the trap will be replaced with a pipeline spool piece to facilitate subsequent purging and residual sodium reaction.

Drain Primary Tank. The sodium in the primary tank, along with the secondary sodium, will be pumped thru a transfer line to the SPF for reaction to sodium carbonate. This heat traced transfer line is constructed per ASME B31.3 requirements and consists of 1½ IPS, schedule 40, 304 stainless steel piping that runs from the secondary storage tank in the sodium boiler building to SPF, approximately 900 feet.

As stated above, the primary draining will be accomplished using an ALIP. The transfer rate will be approximately 15 gpm, requiring less than a shift to transfer the 5000 gallons required to fill the sodium storage tank at SPF. The transfer line is sloped to the secondary storage tank, and will drain to the tank. The line will be cooled after each transfer.

React Residual Primary Sodium. Following the draining of sodium from the primary tank there will be a residual of sodium remaining. 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. Argonne is currently in the process of developing the reaction method for the primary sodium residuals. Methods for reaction of the residual quantities of sodium include a moist nitrogen purge, generating sodium hydroxide and hydrogen. The hydrogen will be vented, while the sodium hydroxide will be either removed or reacted to sodium carbonate via the introduction of carbon dioxide to the primary tank. 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.

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 and access ports sealed.

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

The safety rod drive shafts, fuel storage basket shaft, control rods, and holddown will be sealed to the primary tank cover, while the main core transfer arm shaft will be sealed to the rotating plug. The seal alloy in the rotating plugs, a eutectic mixture of tin and bismuth, will be frozen to provide a positive seal. Because the six primary tank heaters will be used to provide heat during the draining process, they will be removed from the primary tank after the tank is drained and the sodium residual deactivated. The heaters contain potentially contaminated sodium (tritium). This will be drained from the six heaters and 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.

Secondary Sodium Systems. The secondary sodium system will also be transformed into a stable, environmentally safe configuration. Currently, the secondary sodium has been drained to the secondary sodium storage tank and allowed to solidify. The sodium will be remelted and pumped to SPF for processing through tank drains and the transfer line previously discussed using existing ALIPs in the secondary system.

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

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 a moist nitrogen and carbon dioxide purge while controlling parameters such as temperature and pressure. It is anticipated that nearly all the sodium residuals in the secondary system will be reacted to sodium carbonate. Upon completion of the purge, the system will be flushed with water, sampled, and neutralized as required. The tritium contamination levels are low enough that it is anticipated that the flush water will be discharged to the local settling ponds. 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 stainless steels.

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 sodium 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 Resource Conservation and Recovery Act (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 filter 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 the primary tank purge system or any other 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 major 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 unless used for primary tank purge 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), Dowtherm® (used as a heat transfer medium), and asbestos (Reactor Building, Sodium Boiler Building, Power Plant Building, and Main Cooling Tower).

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

This phase will be completed by transporting all sodium contaminated 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. 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.

CONFIGURATION CONTROL

The entire process of closure and deactivation will be controlled by use of a controlled procedure for generating and executing lay-up (closure) plans. Every system, component, and facility will be covered by a lay-up plan. The first part of the plan provides for an assessment of the defined system, component, or facility against closure criteria which provide specific definition for "industrially and radiologically safe" and adherence to applicable portions of DOE orders for transition to D&D.

The result of the assessment will define the specific closure actions to be taken. Completion of these actions plus archival of system drawings, procedures, and status documents (surveys, etc.) as well as tagging the system isolation boundaries with a special "lay-up" tag system will complete the closure. Also, part of the final documentation archive will be a draft D&D plan which will detail the recommended D&D approach for the future.

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 until final D&D of the facility occurs. Current schedule and milestone commitments place the EBR-II facility in the final deactivation configuration by the end of CY 2001. Actual D&D could occur decades into the future pending budget availability and allowing for maximum radioactive decay of activated primary tank internals.

REFERENCES

1) "Pre-Approval Draft Environmental Assessment - Shutdown of Experimental Breeder Reactor - II at Argonne National Laboratory - West", DOE/EA-1199, U. S. Department of Energy, Chicago Operations Office, April 21, 1997.