CURRENT STATUS OF EXPERIMENTAL BREEDER REACTOR - II SHUTDOWN PLANNING

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ABSTRACT

The Experimental Breeder Reactor - II (EBR-II) at Argonne National Laboratory - West (ANL-W) in Idaho, was shutdown in September, 1994 as mandated by the United States Department of Energy. This sodium cooled reactor had been in service since 1964, and 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 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 Sodium Process Facility.

The sodium environment and the EBR-II configuration, combined with the radiation and contamination associated with thirty years of reactor operation, posed problems specific to liquid metal reactor deactivation. The methods being developed and implemented 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. 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 Idaho National Engineering and Environmental Laboratory electrical grid.

An aerial view of the EBR-II complex, as shown in Fig. 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 Building. 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 (0.5 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 reactor vessel is shown in Fig. 2. Prior to defueling, the EBR-II core and blanket subassemblies were contained within the reactor vessel. 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 sodium system (about 330 m^3 (87,000 gallons)) transfers heat to the secondary sodium system (about 50 m^3 (13,000 gallons)) through a sodium-to-sodium intermediate heat exchanger. 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. The fueled assemblies were replaced with non-fueled assemblies of the same configuration to assure stability of the core and to aid in removal and replacement of the remainder of the core. The fueled assemblies were packaged for storage at the Radioactive Scrap and Waste Facility at ANL-W.

SODIUM PROCESS FACILITY

The Sodium Process Facility (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 sodium hydroxide was scheduled to be used to neutralize acid produced in the Purex process at the Hanford site in Washington state. Due to a change in the Purex mission, the sodium 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 the primary and secondary sodium was identified. In 1996, ANL-W engineering and operations undertook the task of upgrading the existing SPF to convert the sodium hydroxide to a dry, nonhazardous sodium carbonate waste which is acceptable for burial in the State of Idaho. Using thin film evaporator technology, the 50 wt % sodium hydroxide is combined with carbon dioxide in the reaction section of the thin film evaporator to form sodium carbonate product and water per the chemical equation $2NaOH + CO_2 \bullet Na_2CO_3 + H_2O$. The sodium carbonate product and water are heated in the evaporation section of the thin film evaporator to remove the water and dry the sodium carbonate product into a powder. After testing the thin film evaporator for approximately one year, it was determined that this technology was not suitable for our application due to plugging of equipment, minimal throughput, and powder containment issues. In 1998, it was decided to convert the sodium to 70 wt % sodium hydroxide, a substance that solidifies at 65°C (150°F) and is also acceptable for burial in Idaho.

Sodium can be introduced into the SPF from two sources. The first source is the 208 liter (55 gallon) Fermi-1 barrels which are melted and drained at the SPF. The second source is the EBR-II primary and secondary sodium which is transferred to the SPF through a transfer line. The sodium is then 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. Figure 3 depicts the SPF flow process.

The sodium hydroxide is transferred from the reaction vessel into specially fabricated square 269 liter (71 gallon) drums, four to a pallet. The square drums occupy the same volume as the standard 208 liter (55 gallon) cylindrical drums; however, the square drums maximize utilization of the space on a pallet, minimizing the landfill space required for disposal.

As part of the hazardous waste permit, daily drum samples were required to assure solid sodium hydroxide was produded. After completion of the secondary sodium processing, drum sampling revealed some liquid in drums that should have been solid. Upon investigation, it was determined that the liquid was due to inadvertent water addition into the reaction vessel which diluted the sodium hydroxide concentration. In addition, the process was operated at temperatures that were too low causing the sodium hydroxide concentration to fall below 69 wt % (the sodium hydroxide monohydrate crystallization concentration). At the lower sodium hydroxide concentration, not all of the solution solidifies at nominal ambient temperatures. The SPF was shutdown in August 1999 to undergo upgrades to the process to ensure the cooled product drums solidify and liquid is not present. Process system upgrades included increasing the operating temperature from 177°C (350°F) to 191°C (375°F), and installing physical and computer controls to prevent inadvertent water addition.

During this shutdown, modifications to the Off-gas System were also performed. Sodium hydroxide carryover in the Off-gas System attacks the borosilicate glass HEPA filters and requires replacement after approximately seven days. Off-gas System modifications included changing the HEPA filter media to Teflon, which is resistant to sodium hydroxide, and installing parallel HEPA filters to increase the operating time between HEPA filter changeouts.

The sodium is scheduled to be processed in five separate and distinct campaigns, based on their radiation levels. 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. Approximately 145 m^3 (38,000 gallons) of Fermi-1 primary sodium was processed initially to gain operator experience with the least radioactive sodium. Second, all of the 50 m^3 (13,000 gallons) of EBR-II secondary sodium was processed. Next, approximately 106 - 125 m^3 (28,000 - 33,000 gallons) of Fermi-1 primary sodium will be processed to validate modifications made to the SPF. This is scheduled to start in June 2000. Fourth, all of the 330 m^3 (87,000 gallons) of EBR-II primary sodium will be processed. Finally, the remaining Fermi-1 primary sodium, approximately 20 - 39 m^3 (5000 - 10,000 gallons) will be processed as a flush of the SPF systems.

CLOSURE PLAN FOR EBR-II

The closure plan for EBR-II is contained in the Environmental Assessment for the Shutdown of EBR-II at ANL-West. The items presented herein have been presented to the public for comment period and have been discussed at public meetings. The Environmental Assessment was granted a Finding of No Significant Impact from the United States Department of Energy. This Finding of No Significant Impact 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 Department of Energy recommendations for managing deactivation and decommissioning 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 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.

Primary Tank Draining Preparations

To prepare the primary tank for draining, the sodium remaining within the Primary Purification System, Fuel Element Rupture Detection System, and Radioactive Sodium Chemistry Loop may 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 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.

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 differential pressure level system has been designed, installed, and tested. This level system will operate during the draining operation until the tank level is less than 2 cm (1 inch) deep.

The primary nuclide (cesium) trap has been removed and placed in the Radioactive Scrap and Waste Facility 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 intermediate heat exchanger has been isolated from the secondary system, and the approximately 3 m^3 (750 gallons) of secondary sodium was 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 have been 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 addressed in the layup plan for that system.

Currently, the temperature of the primary sodium is maintained at 175°C (350°F) by operation of the installed immersion heaters. 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 has been designed and will be installed prior to initiating primary drain. 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 inspect tank components, and assess areas where pockets of sodium remain after draining. 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.

Primary Tank Draining

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 2.54 cm (1 inch nominal pipe size), schedule 40, 304 stainless steel constructed per ASME B31.3, 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.

The primary draining will be accomplished using the annular linear induction pump. 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.

Residual Primary Sodium Disposition

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. Several options are currently being evaluated concerning the disposition of the residual primary sodium. These options range from residual reaction to air passivation to inert blanket.

Primary Tank Isolation

The primary tank will be isolated to reduce the background radiation level in the reactor building. The fuel transfer port 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 and 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 remain in the primary tank. The potentially contaminated sodium (tritium) from the six heaters will be solidified.

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 is in 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 Sodium Components Maintenance Shop 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 aids 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 intermediate heat exchanger has been cross connected outside of the reactor building.

Residual sodium within the secondary system will be dispositioned in a manner similar to the primary systems.

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 hazardous waste permit issued by the State of Idaho.

The fuel unloading machine will be dispositioned in place. Cover Gas Cleanup System components, including the controlled temperature profile condenser, aerosol filters and preheater will be deactivated. The Argon Cooling System molecular sieves and vapor traps will be cleaned and disposed of.

Final Reactor Building System Closure

The purpose of reactor building system closure is to secure any plant systems which may still be unsafe after individual system components have been removed. Closure may include electrical/mechanical equipment removal, tagging of electrical breakers, and system purging and/or sealing. Closure 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 future deactivation and decommissioning, they should be maintained.

The reactor building systems to be placed in closure 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.

Hazardous Material Removal

In order to achieve an industrially and radiologically safe condition, certain hazardous material will be removed from the EBR-II complex. Hazardous materials that may 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 argon cooling system batteries stored in the Power Plant Building. The station batteries, 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 Sodium Components Maintenance Shop for cleaning and disposal.

<u>Reactor Building Penetration Cover Installation</u>
Completion of this work 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 cover will be installed. Since personnel will still be required to enter the reactor building, the penetration covers for the personnel airlock and the emergency personnel airlock 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.

<u>Remaining EBR-II Complex Buildings and Related Facilities Deactivation</u>
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, Cover Gas Cleanup System 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 decommissioning. Current schedule and milestone commitments place the EBR-II facility in the final deactivation configuration by March, 2002.

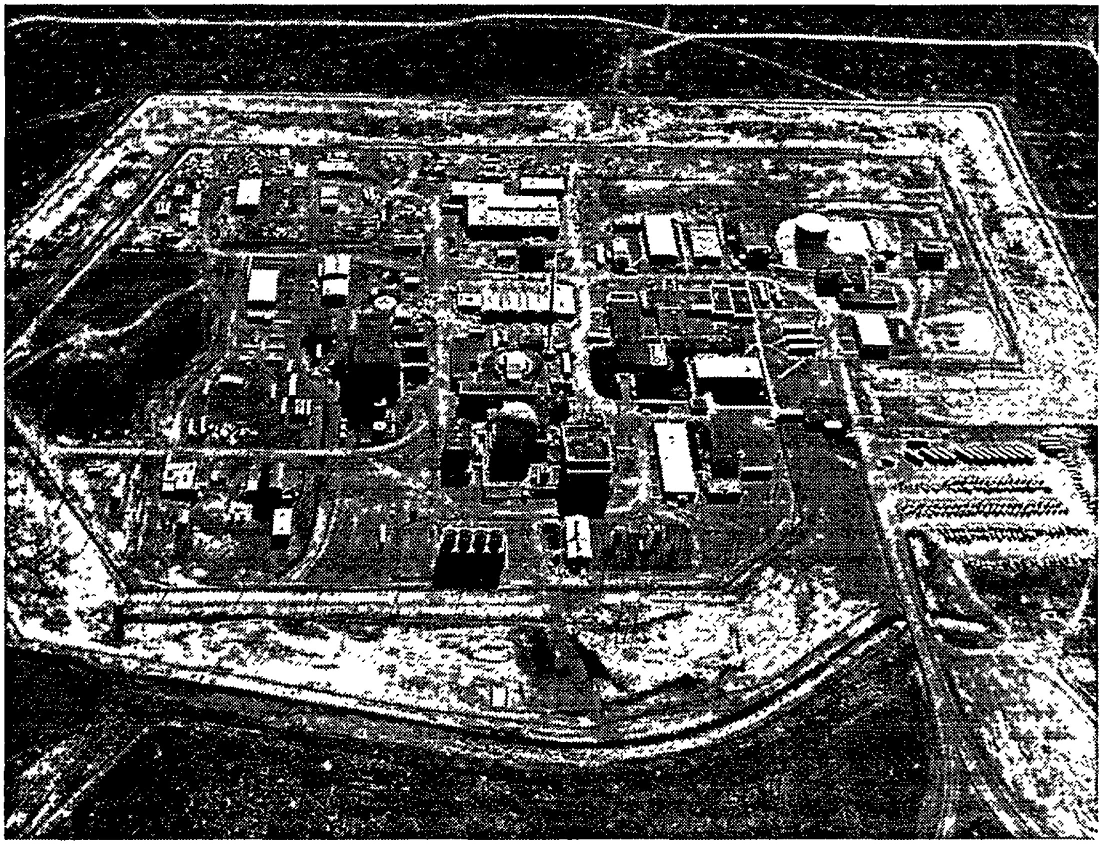


Figure 1. EBR-II Complex

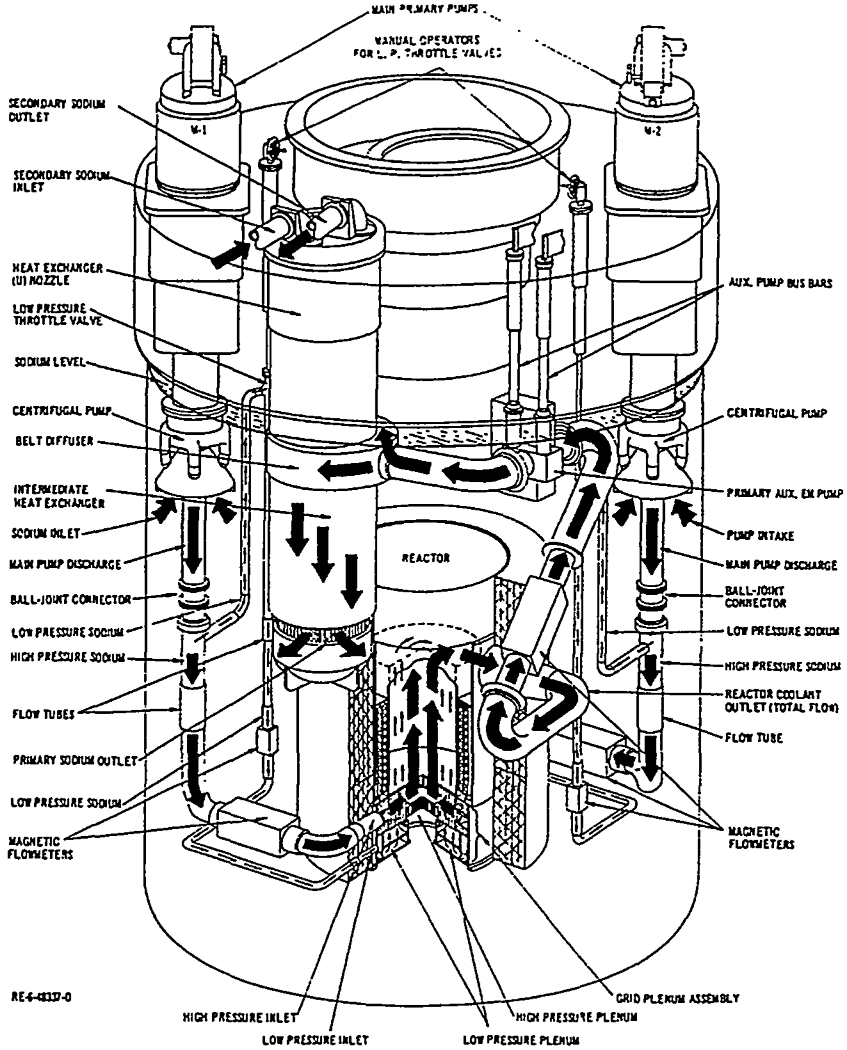


Figure 2. EBR-II Reactor Vessel

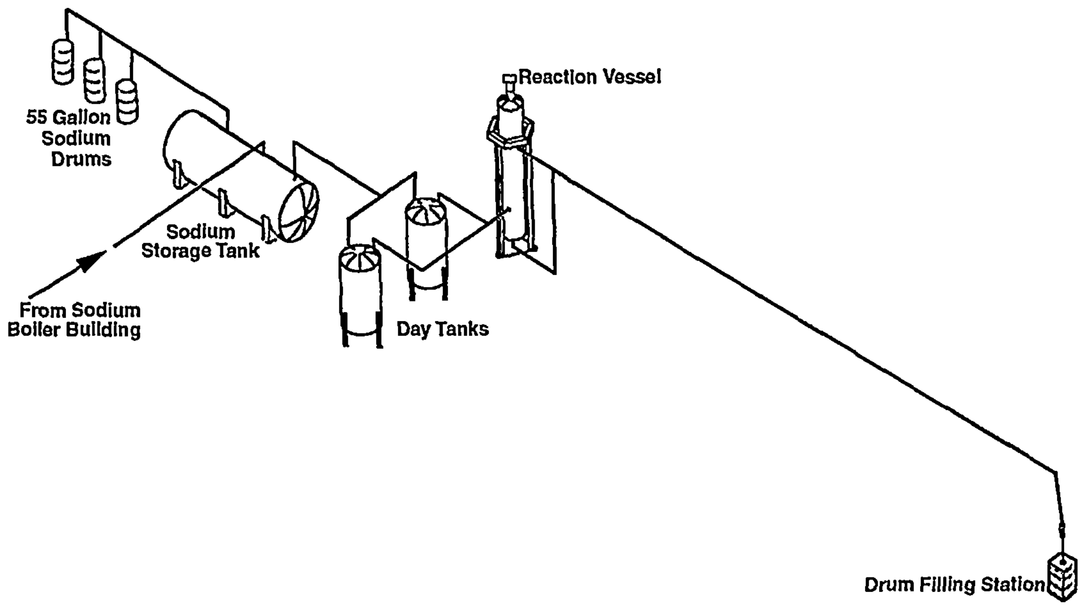
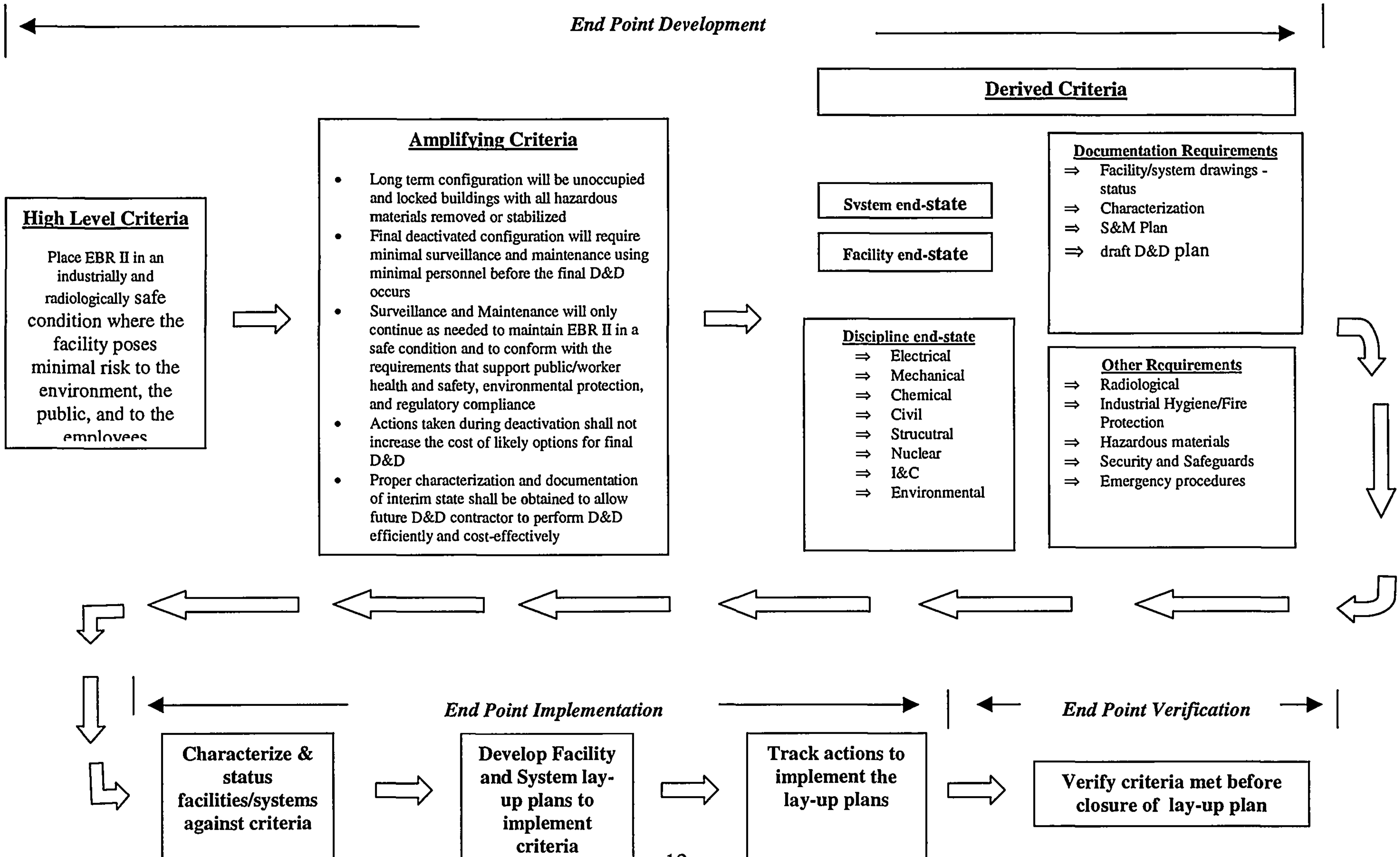


Figure 3. Sodium Process Facility Flow Diagram

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



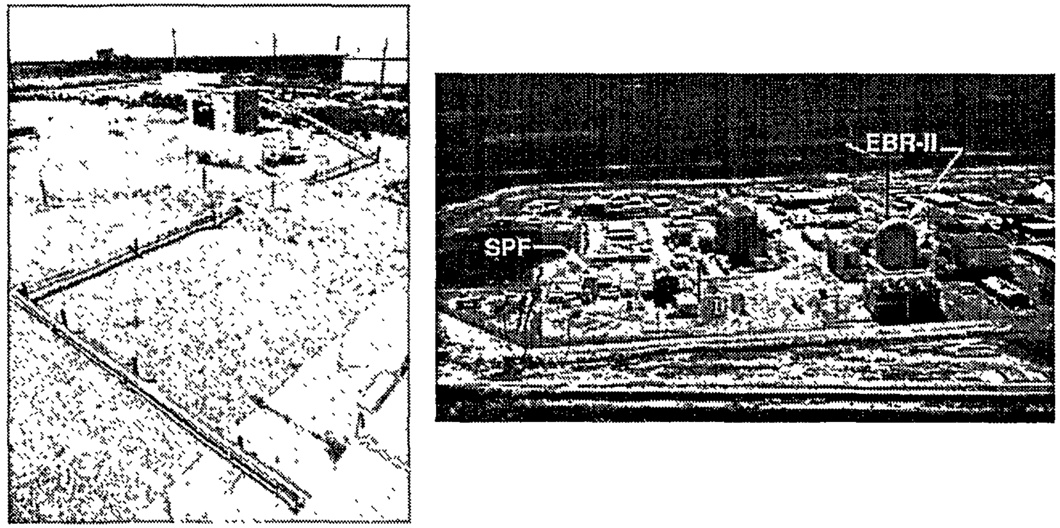


Figure 5. Sodium Transfer Line