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SHUTDOWN AND CLOSURE OF THE EXPERIMENTAL BREEDER REACTOR - II

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ABSTRACT

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 maintain 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 EBR-II is a pool-type reactor. The primary system contained approximately 325 m^3 (86,000 gallons) of sodium and the secondary system contained 50 m^3 (13,000 gallons). In order to properly dispose of the sodium in compliance with the Resource Conservation and Recovery Act (RCRA), a facility was built to react the sodium to a solid sodium hydroxide monolith for burial as a low level waste in a land disposal facility.

Deactivation of a liquid metal fast breeder reactor (LMFBR) presents unique concerns. Residual amounts of sodium remaining in circuits and components must be passivated, inerted, or removed to preclude future concerns with sodium-air reactions that could generate potentially explosive mixtures of hydrogen and leave corrosive compounds. The passivation process being implemented utilizes a moist carbon dioxide gas that generates a passive layer of sodium carbonate/sodium bicarbonate over any quantities of residual sodium. Tests being conducted will determine the maximum depths of sodium that can be reacted using this method, defining the amount that must be dealt with later to achieve RCRA clean closure.

Deactivation of the EBR-II complex is on schedule for a March, 2002, completion. Each system associated with EBR-II has an associated layup plan defining the system end state, as well as instructions for achieving the layup condition. A goal of system-by-system layup is to minimize surveillance and maintenance requirements during the interim period between deactivation and decommissioning. The plans also establish document archival 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 decommissioning, which could occur decades in the future.

Keywords: EBR-II, closure, sodium, deactivation, LMFBR.

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 Fig. 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, through a below grade tunnel, to the Fuel Conditioning Facility (FCF), a large inert atmosphere hot cell facility. The FCF hot cell is used to support sodium bonded fuel handling and research. The 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 (Fig. 2) prior to defueling. The 1.70 m (67 inch) diameter vessel and its shield were immersed in a sodium pool within the 7.9 m (26 feet) diameter by 7.9 m (26 feet) high primary tank. The primary sodium contained within this tank represented the primary coolant 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 contained about 325 m^3 (86,000 gallons) of sodium, and transferred heat to the secondary sodium system (which contained about 50 m^3 (13,000 gallons) of sodium) 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 generators 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 and subsequent treatment at the FCF.

Subsequent to completion of defueling, the sodium coolant from the primary and secondary systems was converted to sodium hydroxide at the Sodium Process Facility (SPF). Surface layers of residual sodium remaining in the primary and secondary systems will be passivated as part of the EBR-II Plant Closure Project (EPCP). The sodium bearing systems will be permitted as a RCRA treatment and storage facility, where residual quantities of sodium will be ultimately reacted.

SODIUM REMOVAL AND DISPOSAL

The SPF reacted the elemental sodium from the EBR-II primary and secondary systems to sodium hydroxide per the following chemical formula:

$$Na + H_2O \longrightarrow NaOH + \frac{1}{2} H_2$$

Sodium was injected into a nickel reaction vessel containing a 73 wt % solution of sodium hydroxide. Water was also injected, maintaining the 73 wt % concentration by controlling the boiling point of the solution. The sodium hydroxide was then transferred to barrels and allowed to cool. At this concentration, it is solid at room temperature, and is a low level radioactive waste form acceptable for burial in the state of Idaho. Figure 3 depicts the SPF flow process.

The sodium hydroxide was disposed of in 270 liter (71 gallon) polyethylene-lined barrels, four to a pallet. These barrels are square in cross-section, allowing for maximum utilization of the space on a pallet, minimizing the landfill space required for disposal.

CLOSURE OF EBR-II

The closure plan for EBR-II is contained in the Environmental Assessment (EA) for the Shutdown of Experimental Breeder Reactor - II at Argonne National Laboratory – West (Reference 1). The items presented therein have been presented to the public for comment and have 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.

Closure of the EBR-II complex was addressed through the following actions: reactor defueling, primary tank draining, secondary sodium system and EBR-II major components draining and treatment, and sodium system passivation.

<u>Reactor Defueling</u>. 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, 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. These locations were provided for future activities such as passivation, moist gas deactivation, and inspection.

<u>Primary Tank Draining</u>. A pumpdown system was designed and installed for removing the primary tank sodium. An annular linear induction pump (ALIP) was utilized to pump the primary sodium to the SPF via the Secondary Sodium Drain Tank (SSDT). This method proved successful, draining the tank to a depth of approximately 1 cm (0.38 in) as verified by a video inspection of the tank. To accurately monitor the sodium level in the primary tank during the draining process, a bubbler system was used. This bubbler system operated during the draining process until the sodium level was less than 2 cm (1 inch) deep.

Temperature of the primary sodium was maintained at 175^{o}C (350^{o}F) by operation of the primary pumps and the use of immersion heaters. When the draining operation commenced, the primary pumps were secured. As the level of the primary sodium decreased, the immersion heaters became less effective. In order to assure the primary sodium remained molten throughout draining, an auxiliary heating system was implemented. This system circulated hot air in the annular region between the primary vessel and the shield tank.

Draining of the primary tank was accomplished using the ALIP with a transfer rate of approximately 55 liters/minute (15 gallons/minute), using the SSDT for intermediate storage. This allowed for fewer cycles of the ALIP, and accommodated draining of the final 1 meter (3 feet) of sodium in one continuous cycle until pump suction was lost.

The sodium in the primary tank, along with the secondary sodium, was pumped through a transfer line from the SSDT to the SPF in 17 m^3 (4500 gallon) batches for reaction to sodium hydroxide. This heat traced transfer line is constructed per ASME B31.3 requirements of 1½ IPS, schedule 40, 304 stainless steel, and runs from the sodium boiler building to SPF, approximately 300 m (900 feet). Figure 4 shows the routing of the line from the Sodium Boiler Building to the SPF. The transfer line is single wall construction, and in order to satisfy RCRA, was gravity drained and cooled after each transfer.

In conjunction with draining, 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. The estimated quantity of sodium remaining in the primary tank is less than 1200 liters (300 gallons).

A viewing system was installed in the primary tank to inspect tank components and assess areas where pockets of sodium remained after draining. The camera was equipped with lighting, zoom, pan, and tilt features to allow assessment of the entire primary tank. The internals of the tank were in remarkably good condition, with writing still visible on components that was apparent in photos taken prior to filling the tank with sodium.

<u>Secondary Sodium System.</u> The secondary sodium was gravity drained into the SSDT. Transfer and treatment of the secondary sodium in the SPF was accomplished in the same manner as the primary sodium.

The secondary sodium system will be transformed into a stable, environmentally sound configuration through component removal, residual sodium passivation/reaction, and ultimately a water flush.

The secondary sodium cold trap (which contains uncontaminated sodium-potassium [NaK]) has been removed and replaced with a spool piece. The cold trap will be cleaned at the Sodium Components Maintenance Shop (SCMS) and disposed of. Installation of the spool piece aided in the draining of the primary sodium and will allow purge gas flow through that portion of the system during the reaction and flushing process.

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

Residual sodium in the secondary system is undergoing passivation. The passivation process is being allowed to run until completion, at which time the depths reacted will be assessed. The remainder of the residuals will then be reacted in place using a moist nitrogen process followed by a water flush. It is anticipated that the flush water will be evaporated from the system using existing heating capabilities.

EBR-II Major Systems. The primary nuclide (cesium) trap and the primary cold trap were removed and placed in the Radioactive Storage and Waste Facility (RSWF) at ANL-W. Since these items are highly contaminated they were removed and will be stored until final disposition is determined.

The EBR-II cesium trap is very small, containing 0.01 m^3 (0.35 ft^3) 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 370°C (700°F). The cesium trap was operated at a nominal 195°C (380°F), and the crystallizer cold point was operated at a nominal 120°C (250°F). The cesium trap is integrally shielded for ease of removal and storage following the end of its useful life. Overall dimensions, including the shield, is 0.9 m x 0.9 m x 0.6 m (3 ft x 3 ft x 2 ft).

The IHX was isolated from the secondary system, and the approximately 3 m^3 (750 gallons) of secondary sodium were pumped to the primary tank and processed with the primary sodium. It is estimated that less than 150 liters (40 gallons) of secondary sodium remain in the IHX. This sodium will be passivated with moist CO_2. Plans are being formulated for reacting the remainder of the sodium after passivation.

The two EBR-II shutdown coolers are natural circulation, passive systems that used sodium-potassium (NaK) alloy to remove decay heat during reactor shutdowns. The shutdown coolers were removed from service by draining the maximum achievable amount of the 2 m^3 (550 gallons) of NaK into the primary sodium. The NaK was treated with the sodium at the SPF. The shutdown cooler bayonets, which extend into the primary tank, were isolated from the rest of the system and capped for disposition during the interim storage period. These bayonets each contain approximately 75 liters (20 gallons) of NaK that will be removed and treated at a later date. The residual NaK in the remainder of the system was reacted using steam and nitrogen, then flushed to achieve a RCRA clean-closure.

Sodium System Passivation/Reaction. Following the draining of sodium from the primary and secondary systems, a volume of sodium estimated at less than 1200 liters (300 gallons) remains in the primary tank, 375 liters (100 gallons) in the secondary system, 375 liters (100 gallons) in auxiliary systems, and 150 liters (40 gallons) in the IHX. This residual sodium is being passivated in place to facilitate the industrially and radiologically safe configuration required during the interim storage period. This approach will provide a stable environment that will support a long term surveillance and maintenance operational state that will minimize the number of personnel involved and will support future D&D activities by placing the components in a stable and known state.

For the purpose of this program, passivation is defined as placing a passive layer of sodium carbonate/bicarbonate over all exposed surfaces of sodium. This has been accomplished by introducing a moist carbon dioxide purge to the sodium systems and venting the hydrogen gas that is generated. Experimentation has shown that this method is capable of reacting depths of sodium in excess of 5 cm (2 in), and the use of this method for reacting the depths of residual sodium is being explored.

In conjunction with the moist carbon dioxide experiments, Argonne National Laboratory is currently conducting tests to determine to what extent a steam/nitrogen mixture can penetrate the carbonate layer left by passivation. If successful, this method may be employed to react remaining depths of sodium left after passivation.

As passivation proceeds, details pertaining to the RCRA closure of sodium systems are beginning to be addressed. In order to satisfy U.S. EPA requirements specified in the RCRA Part B Permit for clean dosure, a water wash of the sodium systems will be required. Estimations of the amounts of sodium remaining after passivation and steam/nitrogen reaction are being formulated, with locations being defined. This will allow a maximum quantity of sodium available for reaction with water to be defined for the purposes of determining the safety aspects of the water wash.

As the EPCP moves into the interim storage period, sodium system components and systems may have been configured in or are nearing their interim status condition. Activities include layup of primary tank systems and components, removal/treatment of additional major components, and final reactor building system layup. Also included in the layup activities is removal of hazardous material, access to reactor building, and closure of remaining EBR-II complex buildings and related facilities.

Primary Systems. The primary tank pump down system has been isolated at the reactor building floor and retired in place.

The safety rod drive shafts and fuel storage basket shaft have been sealed to the primary tank cover, while the main core transfer arm shaft was sealed to the rotating plug. The six primary tank heaters will be remain in the primary tank for potential future use during final sodium deactivation.

Upon completion of deactivation of residual sodium, a CO_2 blanket will be maintained on the primary tank. Hydrogen will be monitored to assure no unanticipated sodium reactions are taking place.

Removal/Treatment of Additional Major Components. 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. This line is currently maintained in the stand-by condition in anticipation of future sodium reaction missions. Some missions currently being evaluated include the 9.5 m^3 (2500 gallons) of sodium in miscellaneous configurations at ANL-W, and other inventories within the DOE complex ranging in size from 5.5 m^3 (1450 gallons) to 1,140 m^3 (300,000 gallons).

Cover Gas Cleanup System components, including the controlled temperature profile condenser, aerosol filters and preheater will be passivated with moist CO_2. Further evaluations will be required to determine if a water flush of the system will be feasible, addressing configuration and safety concerns.

The Argon Cooling System molecular sieves and vapor traps have been removed and will be cleaned at the SCMS and disposed of.

Final Reactor Building System Layup. The purpose of reactor building systems layup is to secure any plant systems that are unnecessary for further activities or which may still require excessive maintenance and surveillance after individual system components have been removed. Layup includes electrical/mechanical equipment removal, tagging of electrical breakers, and system purging and/or sealing. Layup will not be applied to any systems or equipment deemed necessary for support of personnel entry into the EBR-II reactor building, or required to support further system deactivation, sodium reaction/removal, or component removal. It is suggested that since the Reactor Building's main polar crane and associated electrical controls might be utilized during D&D, they will undergo periodic testing and maintenance.

Some Reactor Building systems that have been placed in layup condition 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 maintain an industrially and radiologically safe condition while minimizing surveillance and maintenance activities, hazardous materials are being removed from the EBR-II complex. Hazardous materials include lead no longer required for 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 acids, 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.

Access to Reactor Building. Personnel access to the Reactor Building after completion of the EPCP will be controlled by facility personnel. Access will be required for periodic surveillance and maintenance, decommissioning activities, and tours.

Closure of Remaining EBR-II Complex Buildings and Related Facilities. Any remaining building systems which are no longer required will be closed and decommissioned pending availability of funding. Decommissioning may include electrical/mechanical equipment removal, electrical breaker tagout, system purging or sealing. Systems necessary for personnel entry, such as abbreviated lighting, heating and ventilation, will remain operational. 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 which was removed in 1999.

Related facilities include the Sodium Components Maintenance Shop and the Sodium Processing Facility.

CONCLUSIONS

The goal of the Plant Closure Project is to maintain EBR-II in an industrially and radiologically safe condition, posing no risk to the environment or to persons, while requiring minimal maintenance and surveillance activities in the interim period between closure and D&D. Current schedule and milestone commitments place the EBR-II facility in the industrially and radiologically safe condition in March, 2002.

ACKNOWLEDGMENTS

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REFERENCES

1. DOE/EA-1199, Environmental Assessment – Shutdown of Experimental Breeder Reactor-II at Argonne National Laboratory-West, U.S. Department of Energy, Chicago Operations Office, September 25, 1997.

Fig. 1. EBR-II Complex

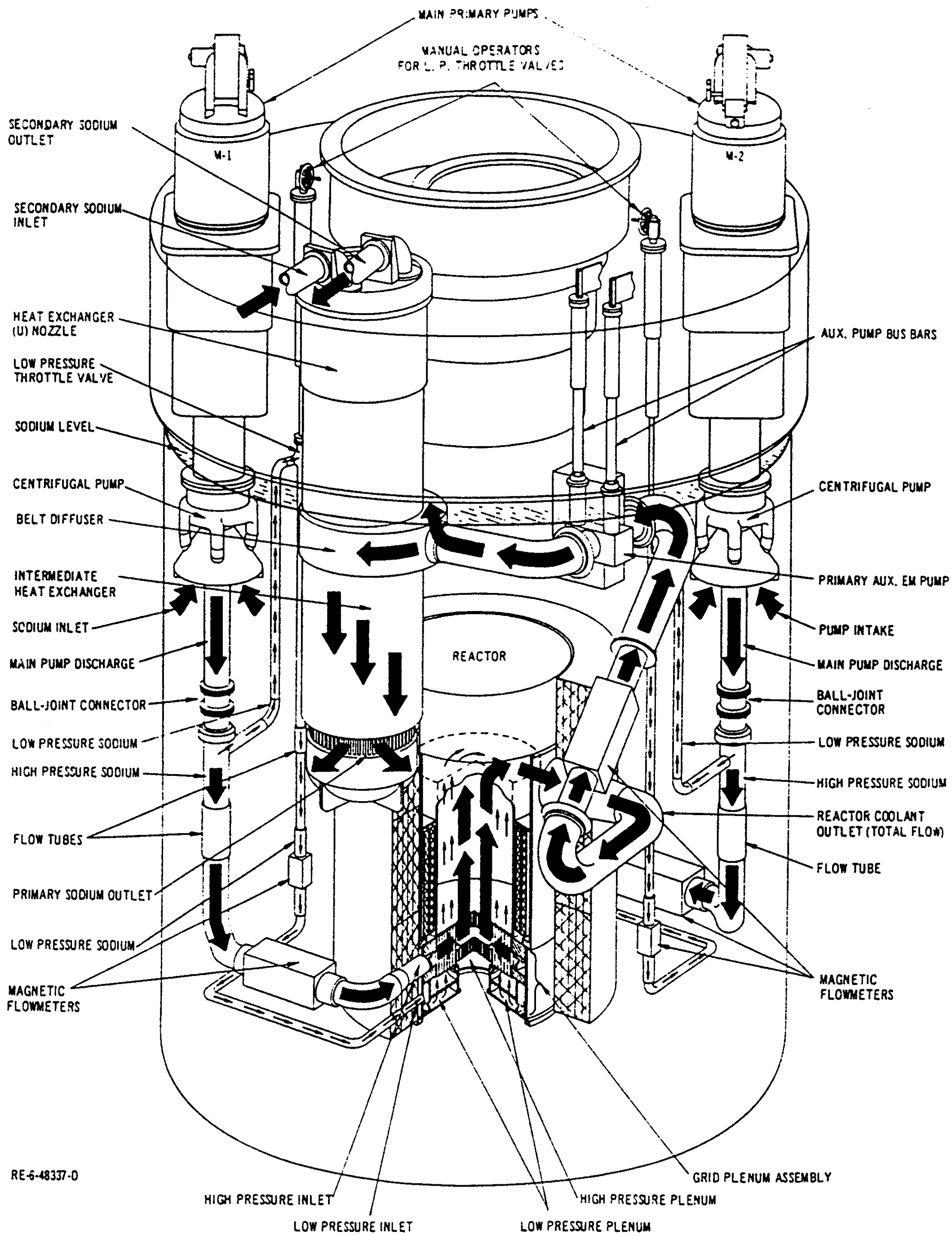

Fig. 2. EBR-II Primary Tank

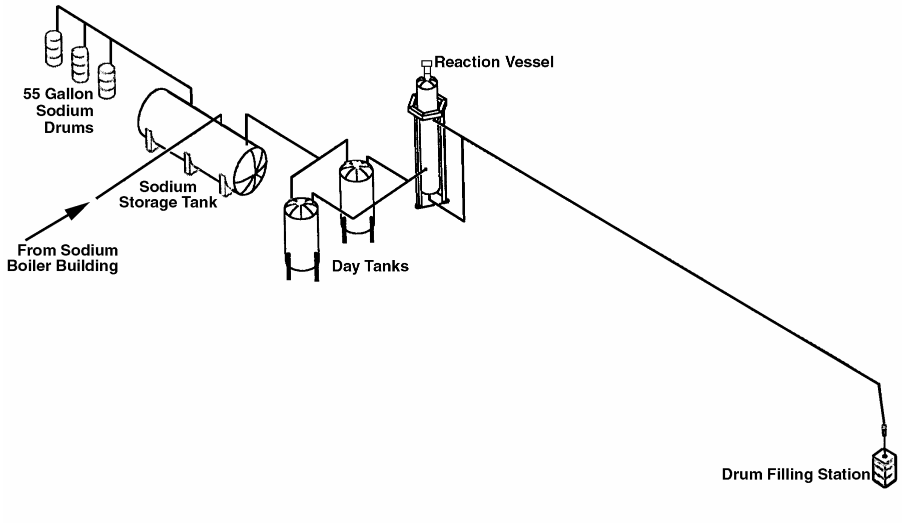

Fig. 3. Sodium Process Facility Flow Diagram

Fig. 4. Sodium Transfer Line