EBR-II PRIMARY-SODIUM-STORAGE FACILITY

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ABSTRACT

This report describes a primary-sodium-storage facility that has been designed for Experimental Breeder Reactor II (EBR-II). The facility would provide for the capability of removing sodium from the EBR-II primary tank.

The EBR-II primary tank contains approximately 86,000 gal of sodium. The primary-sodium-storage facility would have a capacity of 90,000 gal, large enough to contain all of the sodium from the primary tank. The facility would include an argon-cover-gas and vacuum system, an electrical heating system, the necessary instrumentation, and a 25-gpm sodium pump located within the EBR-II primary tank.

An evaluation of the need for this facility has indicated that factors other than the time required to construct the facility will be controlling. Therefore, under the present philosophy, construction of the facility would begin after and not before the occurrence of a failure requiring the draining or partial draining of the primary tank.

I. INTRODUCTION

A. Experimental Breeder Reactor II (EBR-II)

EBR-II is an unmoderated, heterogeneous, sodium-cooled reactor. It was originally designed as an engineering demonstration plant but is currently the primary facility for irradiation of reactor fuels and structural materials in the USAEC's Liquid Metal Fast Breeder Reactor program. The reactor was designed for a thermal output of 62.5 MW and a gross electrical capacity of 20 MW. It currently operates with a thermal output of 50 MW.

The reactor consists of a core that utilizes enriched uranium as driver fuel. The core is surrounded by a blanket of ^{238}U , the initial purpose of which was to demonstrate the breeding of plutonium. Each of the driver-fuel subassemblies in the reactor core holds an array of 91 small-diameter cylindrical elements in a hexagonal tube that measures approximately 2-1/4 in. across its flats. Each fuel element contains a uranium-alloy fuel pin, which fits loosely into a thin-walled stainless steel tube that is closed at both ends. The annulus between the fuel pin and the inside wall of the tube is filled with static sodium, which acts as a heat-transfer bond. Heat is removed from the outside wall of the fuel element by liquid sodium under forced convection.

The hexagonal subassembly contains upper and lower stainless steel reflector sections and is equipped with suitable end adapters for handling and positioning. The core region contains 91 hexagonal subassemblies, including driver, control, safety, and experimental subassemblies.

The reactor, the primary-sodium pumps and piping, the sodium-to-sodium heat exchanger, and part of the fuel-handling system are all submerged in a primary tank containing about 86,000 gal of sodium coolant. The tank is 26 ft in diameter and approximately 30 ft high. This "submerged" concept has the following advantages: (1) Any leakage in the piping system for the primary coolant will be within the primary tank, (2) essentially all radioactivity is confined to the primary tank, (3) the heat capacity of the large mass of sodium in the tank prevents rapid thermal transients, and (4) spent fuel elements can be stored in the primary tank until the rate of heating due to gamma radiation has decreased to a reasonable level.

The entire primary system is in a steel containment vessel that is approximately 86 ft in diameter and 145 ft high. About 50 ft of the vessel is below ground level. The vessel is cylindrical, is made of carbon steel, and has a hemispherical top closure and a semi-elipsoidal bottom closure. It is a prototype of a design that would be required if the reactor were located near a populated area. Figure 1 shows the location of the reactor plant in the EBR-II complex near Idaho Falls, Idaho.

Fig. 1. Isometric View of the EBR-II Complex

B. Purpose of the Primary-sodium-storage Facility

The primary-sodium-storage facility would permit the removal of sodium from the primary tank if the need should arise. The philosophy behind the initial design of EBR-II included avoiding any possibility of losing primary sodium coolant. Because of this philosophy, neither a drain system nor a storage facility for the primary sodium was provided.

It is beyond the scope of this report to examine in detail the circumstances that might require the removal of the sodium from the primary tank. Each circumstance would have to be analyzed in detail, as it occurs, to determine if removal of the sodium is necessary or desirable.

It is possible that an upper adapter of either a driver-fuel sub-assembly or a reflector subassembly could be damaged in such a way as to prevent removal of the subassembly with the normal fuel-handling equipment. In this case, visual access to the damaged area could conceivably be very desirable if not absolutely necessary. A similar case is one in which a sub-assembly or other component is dropped to the upper grid of the reactor or to the bottom of the primary tank.

A more remote possibility is fuel meltdown. In this case, detailed planning would be necessary, and special handling tools and equipment would have to be fabricated. Here, too, visual access, to aid in the manipulation of handling tools, would be necessary. If a meltdown occurred because of a flow restriction external to the fuel subassemblies (e.g., in the lower plenum region), all core subassemblies and possibly all reflector subassemblies might have to be removed to provide access to the region. In addition, the primary tank would have to be drained to within 24 in. of the bottom. This type of incident occurred in the Fermi reactor.⁽¹⁾ A discussion of the storage and disposition of subassemblies is presented in Section IV of this report.

According to the design philosophy behind the EBR-II primary-sodium-storage facility, the facility would be constructed after the occurrence of major failure or damage of components within the primary tank, such as those discussed in the preceding paragraphs. Because of this philosophy, components for the facility should be readily available. The only component that cannot be supplied within a reasonable length of time is the sodium transfer pump. This component is a "long lead" item. The design philosophy will be discussed further in Section V.

II. DESCRIPTION OF THE FACILITY

For convenience, the description of the primary-sodium-storage facility will be divided into three parts: (1) the part of the system external to the reactor containment vessel, (2) the sodium-piping transition from the penetration of the containment vessel to the primary tank, and (3) the sodium transfer pump.

A. Portion External to Reactor Containment Vessel

The portion of the facility outside the reactor containment vessel would consist of three 30,000-gal tanks, an argon-cover-gas and vacuum system, sodium piping from the tanks to the reactor containment vessel, an electrical heating system, and the necessary instrumentation.

The design of the three storage tanks is based on the 1965 ASME Boiler and Pressure Vessel Code, Section VIII.⁽²⁾ The tanks would be fabricated with A-285 grade C carbon steel, and they have been designed to contain sodium at 350°F. At this temperature, the rate of carbon transfer from carbon steel to the liquid sodium would be negligible. By this criterion, sodium stored in the tanks for an indefinite period could be reused in the EBR-II primary system. The internal and external design pressures of each of the storage tanks are 12.2 psia and 50 psig, respectively. Figure 2 shows the proposed location of the tanks in the EBR-II complex.

The storage tanks would be thermally insulated with rigid molded-block hydrous calcium silicate to a thickness of 4 in. The insulation would be protected with aluminum sheeting on its cylindrical sections and with polyester resin on the heads.

Radiation shielding for the storage tanks would consist of a 1-ft-thick (minimum) concrete retaining wall with a gravel backfill. The retaining wall was designed to support a cover shield suitable for the prevention of "sky shine".

Sodium piping from the storage tanks to the containment vessel would consist of 2-in. Schedule-40 black seamless carbon steel pipe, ASTM-A-106, grade B. In general, the piping would be below ground level to reduce any radiation hazard. It would be insulated with 2-in.-thick rigid molded hydrous calcium silicate.

Fig. 2. Proposed Location of Primary-sodium-storage Facility in EBR-II Complex

The storage tanks and associated sodium piping would be heated with electrical-resistance heaters. The system temperature would be controlled automatically at 300°F by use of Mercoid line-voltage thermostats having an approximate temperature differential of 2°F. Cartridge-type thermostats would provide over-temperature protection.

In addition to supplying an inert-gas blanket for the sodium in the storage tanks, the argon system would provide a means of controlling the pressure in the tanks. This system would include one M-27 single-regulator argon manifold equipped for six 225-cu-ft gas cylinders. In conjunction with the vacuum system, the argon system would be used to purge the facility of air.

The vacuum system would consist of one 47-cfm pump, one 80-cfm pump, and an absolute filter. The vacuum pumps for this application are available in storage at the EBR-II site. The discharge from the pumps would be filtered to prevent atmospheric contamination.

The only instrumentation in addition to that already discussed is the liquid-level detectors for the storage tanks. Each detector consists of a conducting wire or rod, which is inserted into the storage tank to a desired level. The conductor is insulated and sealed at the penetration into the tank. When the sodium in the tank contacts the wire or rod, an electrical circuit is completed. This type of detector indicates a specific liquid level only; it does not give a continuous series of level indications. Each tank will be equipped with three of these detectors: one near the bottom, one near the midpoint, and one near the top. This type of liquid-level indicator is adequate in this application.

B. Sodium Fill Line

The existing sodium fill line would be used for the piping transition from the containment-vessel penetration to the primary tank. This line, depicted in Fig. 3, was used for the initial filling of the EBR-II primary-sodium system. It is complete with insulation, an electrical heating system, and a mechanical filter. If the sodium in the storage tanks is to be reused, filtration may be desirable.

Since the sodium fill line was designed to transfer nonradioactive sodium, radiation shielding for the line was not required. The need for

Fig. 3. EBR-II Primary-sodium Fill Line

radiation shielding in this area would be determined in the analysis of the failure or damage that has occurred within the primary tank. If a fuel-element failure has not occurred, radiation shielding of the sodium fill line may not be required. Temporary radiation shielding could be installed in this area of the system just before transferring sodium from the primary tank to the storage tanks.

C. Sodium Transfer Pump

Several methods for transferring the sodium from the primary tank to the storage tanks were investigated. At the elevation of the EBR-II site, sodium can be lifted about 24 ft by atmospheric pressure. About 35 ft of lift would be required to drain the primary tank. By evacuating the storage tanks, the primary tank could be drained to an intermediate level. Sufficient head to drain the primary tank almost completely could be produced by pressurizing the primary tank to about 5 psig in addition to evacuating the storage tanks. In spite of the apparent simplicity of this method, there were two reasons for not pursuing it. First, as a part of a conceivable reactor failure the primary tank could be damaged in such a way as to prevent its pressurization. Second, stresses produced in various sections of the primary tank as a result of the pressurization would be of concern.⁽²⁾

It was concluded that pumping would be the most practical method of transferring the sodium from the primary tank. One of the design criteria for the sodium pump is that it must be capable of submersible operation in sodium at a minimum temperature of 350°F. A centrifugal pump mounted on the top of the primary tank would not be capable of draining the tank. As indicated in the preceding paragraph, such a pump could lower the level of sodium in the primary tank only about 24 ft, even with evacuation of the storage tanks. This would leave about 11 ft of sodium in the primary tank.

The most convenient nozzle for penetration into the primary tank is the access nozzle for the primary-sodium fill system. The minimum diameter of this access nozzle is 5.785 in. Since the pump will have to be installed in the primary tank by inserting it through this nozzle, the maximum diameter of the pump is restricted. Larger access nozzles could be made available by rerouting the piping in this area, but this would be difficult.

The criterion for the capacity of the sodium transfer pump is quite arbitrary. A reasonable minimum capacity would be 5 gpm at 5 psig. At a rate of flow of 5 gpm, approximately 10 days would be required to drain the primary tank to a level of a few inches above the bottom. A higher rate of flow, however, would be more desirable.

Several types of sodium pumps were investigated for use in this application, including a reciprocating pump, a jet-type pump with an auxiliary driving pump, three types of electromagnetic pumps, and a centrifugal pump. Because of the relatively low-capacity requirements, almost any of the pumps investigated could be designed to meet the requirements for use with the primary-sodium-storage facility. The design, development, and prooftesting of a pump was not within the scope of this project.

A centrifugal pump has been used in a similar application at the Fermi reactor. This pump was supplied by the Byron-Jackson Pump Division of Los Angeles, California. A representative of that organization tentatively agreed that they could supply a pump that would meet the requirements for use in the EBR-II primary-sodium-storage facility. The suggested pump would have a capacity of approximately 25 gpm at a head of 10 psig. The estimated delivery time for the pump is one year.

The advantages of this pump when compared with the other pumps investigated are that no development or prooftesting would be required. For that reason, this pump was selected for the design of the primary-sodium-storage facility.

One of the problems associated with the design of the centrifugal pump is that the drive motor must be located outside the primary tank and the pump must be located inside and near the bottom of the primary tank. This results in the need for a drive shaft approximately 30 ft long. This relatively long drive shaft would require several support bearings capable of operating in a sodium environment.

The pump assembly would include an argon seal at the penetration into the primary tank (Nozzle R). A specially designed shield plug to accommodate the penetration of the pump-shaft housing through Nozzle R would be included in the pump design.

The outer tube of the pump assembly would be heated with small-diameter stainless-steel-clad heaters that also would be included in the

pump design. Figure 4 shows the relationship of the sodium pump to the EBR-II primary tank. A minor change in the piping of the sodium fill line in the area of Nozzle R would be required.

III. OPERATION OF THE FACILITY

Because of economic considerations, the operation of the facility would be entirely manual with the exception of the electrical heating system. The exact method of operation would be determined after analyzing the damage or failure which has occurred within the primary tank. A typical operating procedure, however, is described here.

The system, up to the isolation valve nearest the primary tank, must be evacuated and purged with argon gas before the transfer of sodium can be started. With the storage tanks evacuated, sodium transfer would be initiated by opening the isolation valves and energizing the sodium transfer pump. At the expected maximum flow rate of 25 gpm, about two and one-half days would be required to drain the primary tank. The temperature of the sodium in the primary tank would be 350°F during the transfer, and the temperature of the storage tanks and associated sodium piping would be maintained at 300°F. The operation would be completed by closing the isolation valves and deenergizing the transfer pump.

A similar procedure would be used if it is necessary to drain the primary tank to an intermediate level, e.g., to the top of the subassembly adapters. For that case, it would be necessary to install an accurate liquid-level monitoring device or to make provisions for visual monitoring.

The evaluation of the failure would determine the disposition of the sodium. If the sodium is to be reused in the reactor, it could be transferred back to the primary tank by pressurizing the storage tanks with argon. In this procedure the storage tanks first would be pressurized to approximately 5 psig, and then the isolation valves would be opened. The storage-tank pressure could be maintained at 5 psig until any one of the low-liquid-level sensors is activated. The pressure would then be reduced to atmospheric and the remaining sodium transferred by syphon action. This procedure eliminates the possibility of overpressurizing the primary tank. It should be noted that once flow is initiated, the entire transfer can be accomplished by syphon action, but at a slower rate.

Fig. 4. Sodium Transfer Pump

IV. HANDLING AND STORAGE OF SUBASSEMBLIES

One of the more difficult problems associated with a major failure of EBR-II would be the disposition of the core and reflector subassemblies if their removal becomes necessary. The maximum rate that subassemblies can be removed from the reactor is about six a day on an emergency basis. Since there are 91 core subassemblies, approximately three weeks would be required to complete the removal.

At present, storage space for 36 subassemblies is available in the air cell of the Fuel Cycle Facility. At any one time about half of this space could be made available for storage. A facility for the emergency storage of fueled subassemblies is in the preliminary design stage. This facility will consist of two or three storage racks, each capable of holding 36 subassemblies, and will include an air-circulating system for cooling the subassemblies. After this facility has been completed, sufficient storage space will be available on the EBR-II site for the 91 core subassemblies.

If it is considered necessary to remove all of the reflector subassemblies in addition to the core subassemblies, storage space at the Idaho Chemical Processing Plant (ICPP) could be utilized. With the present capabilities, however, only three subassemblies a day can be transferred from EBR-II to the ICPP. Since there are over 800 reflector subassemblies, approximately one year would be required to transfer all of them.

There are many other serious problems concerning the removal of subassemblies from the reactor and their disposition. The resolution of such problems will be dependent on the exact nature of the failure.

V. CONCLUSIONS

From the discussion in Section II of this report, it is clear that many different types of failures of primary-system components can be postulated that would require draining or partial draining of the primary tank. Complete draining would be required in those cases in which all subassemblies or at least the core subassemblies have to be removed from the reactor to gain access to the damaged area. Partial draining would be suitable in

other types of failures, such as the type cited earlier in this report, in which the upper adapter of a fuel subassembly is damaged to the extent that its removal cannot be accomplished by normal procedures. Complete removal of the core subassemblies would be unnecessary, and a much shorter cooling time would be required for the core subassemblies. A detailed study of this case would be required to determine the number of subassemblies to remove and the nature of any special handling tools and equipment that might be required. It would probably be necessary to design and fabricate all of the special handling tools.

Except for the selection of a sodium transfer pump for this application, the design of the facility was straightforward. The most difficult decision concerning the facility was when, and if, it should be constructed. The decision to construct the facility after and not before the occurrence of a failure requiring the removal of sodium from the primary tank was based on (a) the estimated cost of the facility, (b) the improbability of such a failure, and (c) the premise that sufficient time would be available after a failure to permit construction of the facility without increasing downtime beyond that which would be required because of other considerations. It is fully realized that for the case in which only partial draining of the primary tank is required, the construction of the facility might become the controlling factor in returning the reactor to normal operation.

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