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FFTF BACKUP DESIGN INTERFACE DEFINITION DISCUSSION OF SYSTEM REQUIREMENTS

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U.S. ATOMIC ENERGY COMMISSION
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BETWEEN PACIFIC NORTHWEST LABORATORY
AND THE GENERAL ELECTRIC COMPANY

BREEDER REACTOR DEVELOPMENT OPERATION

GENERAL ELECTRIC

SUNNYVALE, CALIFORNIA

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SECTION I

INTRODUCTION

General Electric performed analysis on the plant systems' requirements for a pipe loop FFTF backup design in 1967 and early 1968. Results of this effort were reported in the following documents:

1. GEAP-5552, "Conceptual Design of the Backup Reactor System for the Fast Flux Test Facility," August 1967.
2. GEAP-5551, "The Selection of a Pipe Loop System for the Fast Flux Test Facility," October 1967.
3. GEAP-5550, "Fast Flux Test Facility Backup Design Project, First Quarterly Report, May - August 1967," October 1967.
4. GEAP-5614, "Fast Flux Test Facility Backup Design Project, Second Quarterly Report, September - November 1967," April 1968.

"FTTF Backup Design Definition - Discussion of System Requirements" as represented by this document completes the reporting of the General Electric contribution to this area of FFTF design activity.

The plant systems design work is presented in a manner that clearly describes the general interface between the backup design and the PNL dispersed core design. The systems considered by General Electric and reported in this document are the following:

- Reactor Containment System
- Main Primary Sodium Coolant System
- Primary Sodium Service System
- Test Irradiation Facilities in FFTF Backup Design
- Reactor Plant Atmosphere, and Radiation Control
- Radioactive Gas Waste System
- Safety Tank and Cooling System
- Argon Supply System
- Argon Recirculating System for Refueling Cell
- Argon Purification System for Refueling Cell
- Nitrogen Supply System
- Cell Nitrogen Atmosphere Recirculating System
- Emergency Power Supply System

SECTION II

REACTOR CONTAINMENT SYSTEM

2.1 INTRODUCTION

The purpose of this section is to establish and set forth design objectives and bases for the conceptual design of the reactor containment system.

The containment philosophy which is used to describe the reactor containment system for the backup design is based primarily upon SEFOR experience. The double barrier concept is utilized as in SEFOR.

The major considerations affecting containment design are release of radioactive products during the DBA and the potential pressure buildup caused by a sodium fire breaching the containment. The containment system should be such that damage to the containment due to a sodium fire without a DBA is avoided and also that release of radioactive products following the DBA in conjunction with the maximum pressure due to sodium fires which result from the DBA is within the specified limits of 10 CFR 100.

The potential pressure buildup of a spray fire is very high, on the order of 100 psi if all available oxygen in air is used up. Such a pressure is impractical to design for on buildings of the size involved. The recommended approach is to design so a sodium spray into air would be inconceivable.

The fire potential coupled with other design considerations leads to the requirement of an inert atmosphere over the reactor. Maintaining such an atmosphere during operation limits the sodium fire potential following the DBA. The containment requirements reduce to establish a leak rate from the refueling cell and equipment cell atmospheres so radioactive release from the building is below allowable levels. The largest uncertainty is in predicting the quantity of plutonium discharged to the cell atmosphere as aerosols and in the rate of settling. Because of the unknowns in the mechanics of such processes a conservative approach has to be taken. There are significant (several orders of magnitude) differences between what various industrial groups and the regulatory bodies consider an adequate analytical approach. This resulted in SEFOR requiring two low leakage barriers between the cell atmosphere and the environs. The inner barrier is formed by the steel lined concrete walls of the equipment and refueling cells; the outer barrier being the steel containment dome. We recommend that the two barriers be provided: i. e., a steel containment shell as well as lined concrete cells, and the penetrations through each should be designed so the combined leakage of each barrier permits a conservative approach to the quantity of aerosol borne plutonium and so the rate of settling of these can be taken. This recommendation is specific to the FFTF and is not a generalization that should be applied to all sodium cooled reactors.

The containment system for the Fast Flux Test Facility is designed to minimize the external effects of a number of design accidents which are believed to represent upper bounds on the magnitude of accident effects.

The containment system is specifically designed to perform the following functions:

- Provide containment of radioactive material resulting from any of the design accidents so sufficient design margin exists to establish compliance with federal regulations 10CFR100 and 10CFR20.
- Contain the energy and dynamic effects of any of the design basis accidents.
- Reduce the leakage associated with the pressure and temperature effects resulting from chemical reactions from any design accident.
- Contain the inert atmosphere associated with the refueling cell and the heat transfer cells during normal operation.
- Provide weather and environmental protection for the reactor system.

2.2 SUMMARY CONTAINMENT DESCRIPTION

The containment system is made up of two barriers between the reactor and primary sodium process equipment and the environment. The first barrier encloses the reactor, primary coolant systems, and the refueling cell. The second barrier completely encloses the first barrier and provides a containment envelope to further reduce leakage of radioactive material to the environment, to withstand the temperature and pressure associated with chemical reactions, and provide weather protection for the reactor systems.

The inner containment barrier includes a massive reinforced concrete cellular structure designed to resist the loading from the design basis accident and provide biological shielding. A welded steel liner is provided which contacts the concrete surface, prevents leakage, and preserves in the inert atmosphere of the heat transfer cells and the refueling cell. The containment configuration is illustrated in Figure 2-1.

During reactor operation the inner barrier is isolated from the outer containment region and the atmosphere is inerted. Penetrations are sealed and isolation capability is provided. Typical penetrations are shown in Figure 2-1.

The inner barrier is designed to withstand the temperature and pressure effects of the design basis accident.

The outer containment barrier is a steel cylindrical structure approximately 130 feet in diameter and 250 feet tall, including the hemispherical heads. All penetrations into the building are sealed in a manner similar to the inner barrier. A typical penetration seal is shown in Figure 2-1. In addition, access locks are provided for passage of personnel and small equipment during reactor operation without violation of containment integrity. Large equipment items (pumps, heat exchangers, etc.) will be transferred through the containment during scheduled plant outages.

PENETRATION DETAIL A

PENETRATION DETAIL B
(PENETRATIONS NORMALLY NOT)
(ACCESSIBLE)

FIGURE 2-1. CONCEPTUAL REACTOR CONTAINMENT SYSTEM

The atmosphere between the inner and outer barriers is normally maintained as an air system and free personnel access is allowed. Cooling and ventilation systems are provided.

Containment of both the inner and outer systems is actuated by signal from the safety system.

2.3 DESIGN REQUIREMENTS

The basis for containment is to confine the effects of the design basis accident to a local area and protect the site and environs. The design criteria are given below. The inner barrier shall be designed to withstand the effects of the design basis accident. The containment design basis shall be equivalent to the detonation of a compact charge of 750 pounds of TNT (assumed to be approximately equivalent to 1500 MW-sec) within the reactor vessel, as established by PNL. In addition to the nuclear incident, inner containment shall be designed for a chemical reaction between the depleted air within the containment and the sodium coolant. Sufficient post-incident cooling shall be provided to remove fuel generated decay heat and prevent breach of the inner containment barrier as described in Section VIII.

The outer containment shall be designed to further reduce the consequence of the design basis accident by reducing the amount of leakage of radioactive materials to the environs. The outer barrier shall be designed to accommodate the pressure and temperature effects associated with the chemical reaction between sodium and air for any accident involving a maintenance activity where the inner barrier contains an air atmosphere. The outer barrier shall provide protection from weather and other environmental conditions, including earthquake.

2.3.1 Design Requirements - Inner Barrier

The following systems shall be enclosed within the inner containment barrier:

- Reactor Vessel
- Main Primary Heat Transfer System
- Primary Safety Tank Cooling System
- Primary Sodium Service System
- Refueling System
 - Refueling Cell
 - Fuel Storage and Cooling System
 - Cell Transfer Lock
- Primary Sodium Storage System
- Closed Loop Primary Heat Transfer and Service Systems.

2.3.2 Penetrations - Process Systems

No single valve failure shall cause a loss of containment integrity in conjunction with the design basis accident. Three types of penetrations are envisioned:

- TYPE 1 - Lines which penetrate containment and are open to the environment external or internal to the containment.

Protection: Double valves are provided either external to containment or on either side of the containment. At least one valve closes automatically to prevent outward flow. At least one valve closes upon isolation trip signal.

- TYPE 2 - Lines that function during operation which form secondary closed loops either within the containment or external to the containment which have a low probability of failure and which do not contain radioactive materials, or a direct connection with the reactor.

Protection: Since these lines form closed loops, no isolation valve is required. These systems require testing as a part of the containment system.

- TYPE 3 - Lines that do not function during operation.

Protection: These lines shall have at least a single valve that is locked closed during normal operation.

Examples of the types of penetrations are listed in Table 2-1.

TABLE 2-1

TYPICAL PROCESS SYSTEM BARRIER PENETRATIONS

<u>Service</u>	<u>Type Penetration</u>
Refueling Cell	
Slave Manipulator	Elastomeric "O" Ring-Buffer Seal
Periscope	Elastomeric "O" Ring
Argon Supply	1
Air Supply	3
Window	Elastomeric Seal, Buffer Zone
Electrical	Sealed Conduit
Argon Cooling and Supply	2
Argon Purification	2
Reactor	
Cover Gas Supply	1
Cover Gas Exhaust	1
Cell	
Nitrogen Supply	1
Secondary Main Sodium Coolant System	2
Secondary, Fuel Storage Cooling	2
Secondary, Safety Tank Cooling	2
Cold Trap Cooling System	2
Nitrogen Circulation and Cooling	2

2.3.3 Other Inner Barrier Design Requirements

Those penetrations which are not accessible during normal plant operation or are subject to deterioration and wear shall be designed to accommodate periodic leak testing on an individual basis. Normally inaccessible penetrations shall be designed for leak testing by remote means.

The inner barrier and concrete cellular structure shall be designed for structural loads consistent with the design basis accident and other expected loading conditions. The following load sources should be considered: Accident, Operation, Live Load, Testing, Seismic, Hydrostatic.

The loadings shall be combined with appropriate thermal gradients across the concrete in such a manner that the effects are conservatively upper bounds of the expected design loading conditions.

The steel liner within the concrete structure shall be designed to be supported by the concrete. In addition, the liner shall be rigidly attached to the concrete at intervals sufficient to allow the liner to deform, allowing elastic buckles to relieve large thermal loadings created by a sudden application of heated sodium coolant to the liner surface.

The inner barrier shall be arranged such that no kinetic energy is transmitted to the barrier as a result of the design basis accident. Energy absorption is accomplished by the blast shield, reactor vessel, and other structure surrounding the reactor.

The inner barrier shall be designed or arranged so no missiles are transmitted to the inner containment structure.

The following codes and standards are applicable for the design of the inner containment barrier:

- American Standard Building Code
- American Concrete Institute - Code Requirements for Reinforced Concrete
- American Institute of Steel Construction Specification for the Design, Fabrication and Erection of Structural Steel for Buildings
- ASTM Standards

2.3.4 Design Requirements - Outer Barrier

The following systems, or portions of, shall be enclosed between the inner and outer containment barriers

- Air breathing system supply
- Radioactive gas waste compressors
- Instrument nitrogen compressor

- Nitrogen cooling equipment
- Refueling cell operating stations
- Argon recirculation blowers and purification

Access: Normal access to the outer containment is not limited. Pressure locks shall be supplied to permit passage without interrupting containment integrity.

Isolation: During normal operation the outer containment is serviced by a cooling and ventilating system. Accident conditions shall trigger an automatic system for providing isolation of the outer containment.

Maintenance: The outer barrier shall serve as a backup for the inner barrier. The outer barrier shall serve as the primary containment barrier during maintenance periods when the reactor is shut down and the inner containment is open.

Design loads: The outer barrier shall be designed for structural loading consistent with the effects of the design basis accident or a chemical reaction between the air and coolant. The following loading conditions should be considered:

• Accident - DBA	• Vacuum
• Dead + Snow	• Live
• Wind	• Test
• Seismic	• Normal

The loadings shall be combined to give conservative upper bounds of the expected design conditions.

The containment shell shall be insulated and the milductility temperature shall be well below the minimum expected operating temperature.

Vacuum breakers in the building shall be provided to assure the building does not sustain a large negative pressure capable of inducing permanent damage.

Penetrations are of the same type and class as for the inner containment barrier. Typical examples are given in Table 2-2.

Penetrations which are subject to cyclic loadings, deterioration, or are located in not readily accessible areas shall be provided with the capability for individual leak testing. A typical penetration is illustrated in Figure 2-1.

The following construction codes and standards apply to the outer containment system:

- ASME Nuclear Pressure Vessel Code, Section III, Class B
- AISC Specifications for Design Fabrication and Erection of Structural Steel for Buildings
- ASTM Standards for Material
- ASA Standards for Design Loads

TABLE 2-2

TYPICAL PROCESS SYSTEM BARRIER PENETRATIONS

<u>System</u>	<u>Type</u>
Main Secondary Sodium System	2
Cold Trap Cooling System	2
Refrigerant Systems	2
Ventilation - Inlet and Outlet	1
Closed Loop Secondary System	2
Secondary Fuel Storage Cooling	2
Secondary Safety Tank Cooling	2
Argon Supply	1
Nitrogen Supply	1
Radioactive Gas Waste	1

2.4 AVAILABILITY CONSIDERATIONS

Availability of the containment system should be very high. Since the containment isolation system is tied in to the reactor safety system, close attention must be given to design detail to ensure system availability consistent with the design goals. The following considerations should be utilized in developing an effective system concept:

- Redundant sensors are utilized for isolation signals. Either high pressure, or high temperature (2 of 3) signals in the inner and outer containments zones will initiate isolation.
- Periodic containment leak testing will be scheduled during normal plant outage (refueling) and should not appreciably affect plant operation, although the outage might be extended.
- Capability to leak test certain individual penetrations shall be provided. Leak checks of these penetrations could be performed during operation.

2.5 PRINCIPLES OF OPERATION

Operation of the containment system is largely automatic. The system is principally passive, requiring essentially no attention during plant operation.

The inner barrier contains an inert atmosphere and is maintained at a slightly higher pressure than the air zone to minimize oxygen inleakage. The inert atmosphere around all primary sodium equipment ensures that no appreciable chemical reactions will occur during a sodium coolant leakage accident.

The air zone between the inner and outer barriers is used as an operating area for refueling stations and maintenance activities. Normal personnel access to this area is unrestricted.

In the event of an incident causing high radiation, pressure, or temperature within the containment building, a signal activates the isolation valves across both barriers, closing off those systems which are open to the environment. The double barrier effectively attenuates leakage and reduces the dose at the site boundary.

During plant operation it may be desirable to enter the refueling cell, or pass fuel and equipment from the cell. This is accomplished without violating containment by utilizing a batching process. Personnel and small equipment entry is provided through the personnel lock. Fuel is transferred out through a long transfer lock which penetrates the lower portion of the building.

During refueling and maintenance operations, containment is maintained by the outer barrier. The inner barrier may be open to the atmosphere within the building for repair purposes.

2.6 REPAIR, MAINTENANCE AND TESTING

Periodic testing of each containment barrier is required. The required frequency of testing should be determined in the context of a detailed containment design and test program.

Certain penetrations in the outer barrier that are subject to cyclic loading, deterioration, or that are not easily accessible, are testable on an individual basis.

Preventative maintenance programs shall include regular periodic inspection and testing of those penetrations subject to wear and deterioration such as access doors and ports.

2.7 SYSTEM INTERFACE

The reference design is responsible for all structure outside of the reactor vessel involving the containment systems. The backup concept is responsible for supplying a reactor head that is compatible with the containment criteria.

Responsibility for design of the containment system lies with the reference designer. The backup design requires certain safety and design features to ensure effectiveness, design margin, and compatibility. The backup requirements should be supplied to PNL by GE.

SECTION III

MAIN PRIMARY SODIUM COOLANT SYSTEM

3.1 INTRODUCTION

This section reports the system design objectives which were established for conceptual design of the backup core main primary sodium coolant system, prior to the definition of the reference design heat transport system.

The main primary sodium coolant system transfers thermal energy from the reactor core to the secondary sodium coolant system for all normal operating conditions and for all single failure modes within the system.

Specifically the main primary coolant system is to perform the following functions:

- Remove reactor core generated thermal energy during all full and partial load operating conditions.
- Remove core decay heat generated when reactor is in shutdown condition.
- Maintain coolant temperatures within prescribed limits during steady state and transient operating conditions. Transient operating conditions and limits are described in subsection 3.8.
- Supply reliable, controlled, coolant flow to the reactor vessel for all phases of operation.
- Transfer thermal energy from the primary system to the secondary system through the intermediate heat exchanger.
- Provide natural convection core cooling capability for removal of decay heat following reactor shutdown. Cooling requirements shall be consistent with design decay heat curve and transient limitations.
- Provide the emergency core cooling requirements for coolant system accidents described in subsection 3.2.

3.2 SUMMARY MAIN COOLANT SYSTEM DESCRIPTION

The system consists of three main primary piping loops elevated above the core. Each loop is rated at 1/3 power, or 133 MWt.

Reactor outlet coolant is directed from the core through the 18-inch reactor outlet piping to the suction side of the free surface centrifugal pump. Sodium enters the suction side of the pump and discharges through a 16-inch pipe to the heat exchanger. A small amount of discharge sodium is directed to the hydrostatic bearing. Excess sodium from the bearing is allowed to

rise in the case and then flow through an overflow pipe back to the reactor vessel upper plenum. Main coolant enters the heat exchanger at the upper end at 1000°F, flows through the unit transferring 133 MWt of energy to the secondary system and exits at 700°F. Return sodium passes through a check valve, enters the reactor vessel through a 16-inch nozzle, and flows into the reactor lower plenum. Three piping loops enter symmetrically into the reactor vessel; each loop is located within a shielded cell. Piping expansion loops are used between major components to accommodate thermal expansion. Figure 3-1 illustrates a preliminary system P&ID diagram. Piping arrangement of the primary system is shown in Figures 3-2 through 3-6.

Elevated coolant loops have been selected based upon overall system safety and performance considerations. Elevated loops prevent core drainage by siphon action, improve natural circulation decay heat removal, and provide a drainage path back to the reactor upper plenum.

3.3 SYSTEM DESIGN REQUIREMENTS

The system design requirements emphasize safety, performance, and conservative design practice. Conservative system design is consistent with the requirements for the backup vertical compact core open cell refueling concept.

The coolant system safety criteria has centered upon protection of the core for a series of accident situations.

Five accidents have been identified with the primary coolant system of the FFTF for which adequate safeguards must be provided. The accidents which have been identified are:

- Loss of site power
- Loss of a single coolant loop without sodium leakage
- Sodium leakage from a single loop
- Guillotine piping failure
- Vessel leakage

The consequences of the above accidents should be limited by the built-in capabilities of the primary coolant system coupled with a reactor scram. For coolant system accidents, the cladding temperature limit is the criteria most influential in determining the heat transport system design concept. The following limits are currently utilized for the accidents:

<u>Condition</u>	<u>Class</u>	<u>Hot-Spot Cladding Limit</u>
Loss of Site Power	Probable Accident	1300°F
Loss of One Loop		
Small Leakage		
Guillotine Pipe Failure	Improbable Accident	1500°F

3.3.1 Design Requirements

- a. The heat transport system is to be designed to transfer 400 MWt from the reactor core to the secondary coolant system and finally to the atmosphere.

FIGURE 3-1. P&ID MAIN PRIMARY SODIUM SYSTEM

FIGURE 3-2. CONCEPTUAL REACTOR BUILDING — OPERATING BAY AND REFUELING CELL PLAN

FIGURE 3-3. CONCEPTUAL REACTOR BUILDING — REFUELING, CLOSED LOOP, AND SODIUM SERVICE CELLS (ELEVATION)

FIGURE
PRIMARY LOOP, CLOSED LOOP
+ SERVICE CELLS PLAN

FIGURE 3-4. CONCEPTUAL REACTOR BUILDING — PRIMARY LOOP, CLOSED LOOP AND SERVICE CELLS

FIGURE
EQUIPMENT & SERVICE CELLS
PLAN

FIGURE 3-5. CONCEPTUAL REACTOR BUILDING — EQUIPMENT AND SERVICE CELLS PLAN

FIGURE
REFUELING CELL AND
MEZZANINE PLAN
ARRANGEMENT

FIGURE 3-6. CONCEPTUAL REACTOR
BUILDING — REFUELING CELL
AND MEZZANINE PLAN
ARRANGEMENT

- b. System design temperature:

	<u>Structural</u>	<u>Operation</u>
Hot Leg Piping	1200°F	1000°F
Cold Leg Piping	900°F	700°F

System Design $\Delta T = 300^\circ\text{F}$

- c. The coolant loops shall be designed to provide natural convection core cooling capability. Convection requirements shall be based upon the core damage criteria and design fuel decay heat curve.
- d. Each coolant loop shall be independent of the other such that a malfunction in one loop cannot propagate to the other loop(s).
- e. A minimum of two independent coolant loops shall be available at all times to provide the emergency core cooling function.
- f. The plant shall be designed for a service life of 20 years at full capacity.
- g. A design goal of 75% overall plant availability is required. The availability target requires continuous review and reappraisal to verify that the goal is consistent with the costs to achieve that goal. Unavailability target for the main heat transfer system should be low ($\leq 3\%$).
- h. The available system pressure across the reactor, from outlet nozzle to inlet nozzle, shall provide sufficient margin to allow for design changes in the core. A plenum-to-plenum pressure drop of not less than 120 psig must be available, at full power reactor operating conditions.
- i. The coolant system shall be designed to accept the expected temperature and pressure transient conditions over the plant lifetime.
- j. Structural design codes: The following codes are to be applied to the structural design where applicable:
- ASME Boiler and Pressure Vessel Code, Section III, Nuclear Vessels
 - ASME Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels
 - A.S.A. Code for Pressure Piping
 - Uniform Building Code
 - For noncode items a design criteria will be developed
- k. Standards: The following standards apply to the sodium systems and associated equipment:
- ASTM Standards for materials.

1. Federal Regulations: The following Federal Regulation shall be followed:

"General Design Criteria for Nuclear Power Plant Construction Permits" proposed regulation 10CFR50.

3.4 SYSTEM CONCEPT SELECTION

As a result of the design criteria and the design requirements, a study has been made to determine the most effective heat transfer system concept. The results were presented in GEAP-5551, "The Selection of a Pipe Loop System for FFTF" by W. Kendall and G. Kruger, October 1967. To summarize this study the elevated loop concept has been selected as the preferred concept. The elevated loop system can provide satisfactory protection against loss of cooling and sodium leakage from the reactor vessel and piping. The concept provides benefits in terms of natural convection cooling and inherent safety by providing core cooling capability for the accidents considered above. Initial coolant leakage accident evaluations have confirmed that the main heat transfer system has the capability of providing core cooling under the coolant system accident considered. Details of the coolant system accident studies are reported in the Second Quarterly, GEAP-5614. Utilizing the main coolant system to satisfy the emergency cooling function has the following advantages:

- The main heat transfer system is the most reliable source of core cooling available. Because of the high reliability it is natural to utilize this asset.
- The use of a separate emergency cooling system has the disadvantage that failures can also occur in this system. Since it is different from the main system, it has different failure modes. These failure modes may have consequences more severe than in the main system.
- Safety requires a minimum of two sources of emergency cooling at all times. If two emergency cooling loops separate from the main system are utilized, this increases capital cost and decreases plant availability.

It is estimated that eliminating the additional two coolant loops will increase the plant availability by ~6%. Equated to cost, this is a considerable saving.

In summary, the concept satisfies the design and safety requirements consistent with a conservative design philosophy and general program objectives.

3.5 MAIN COOLANT SYSTEM FEATURES

In order for the concept to satisfy the safety criteria and the design requirements, several characteristic design features are required. The significant features of the Backup Design are:

- a. The coolant loops are to provide natural convection heat removal capability, in the event of loss of site power, or coolant leakage through the remaining loops. The coolant loops are to be designed consistent with the core damage criteria and design decay heat.

- b. The coolant loops are to be elevated to prevent drainage of the core vessel by siphon action to a lower elevation.
- c. The cover gas pressure in the reactor vessel should be near atmospheric as an effective means of preventing coolant expulsion from the core because of a gas pressure difference between the reactor vessel and the cell atmosphere following a piping break accident.
- d. A reference datum elevation is established within the reactor vessel which is the minimum coolant level. This elevation is equal to the top of the fuel extensions.
- e. The primary loops are to be independent of one another so a malfunction of one loop cannot propagate to the other loop(s). This permits the unaffected loop(s) to remove decay heat under natural convection flow conditions. Loop independence requires the following.
 - The primary inlet and outlet lines are to pass below the minimum elevation before common plenums are available.
 - The gas vent lines provided at the heat exchanger vents are to be separate, interlocked, and independent, so the sodium level cannot be adjusted in more than one loop at a time.
 - The level control methods provided for the main coolant pumps are to be separate and interlocked similar to that provided for the heat exchanger vents.
- f. A safety tank surrounds the reactor vessel and extends upward to an elevation above the minimum coolant level in the reactor vessel.
- g. All penetrations of the reactor vessel below the minimum level are to be made so the associated piping is contained.
- h. Piping connected to the main coolant systems is to be arranged so siphon actions cannot occur.
- i. A sodium volume is provided above the core sufficient to completely fill the annulus between the core tank and safety tank, maintaining core coverage in the event of a tank rupture, or coolant system leak.
- j. The reactor vessel is to be provided with a level probe to sense a loss of coolant, and controls are to be provided to shut down all main coolant pumps to prevent continued leakage in a pump discharge line.
- k. The safety tank is to be provided with an independent backup cooling system for decay heat removal. The backup system is required to function when all main loops are inoperative. This requires that the safety tank and its coolant system be protected from the effect of the DBA.

3.6 SYSTEM CHARACTERISTICS

Table 3-1 lists nominal characteristics of the primary sodium system.

TABLE 3-1

NOMINAL MAIN PRIMARY SODIUM SYSTEM CHARACTERISTICS

	<u>Design Condition</u>	<u>Operating Condition</u>
System Heat Removal Capability	400 MWt	400 MWt
System Temperatures		
Hot Leg Components	1200°F*	1000°F
Cold Leg Components	900°F*	700°F
System Full Power ΔT	300°F	300°F
Minimum Operating Temperature above Plugging Temperature	100°F	>> 100°F
Maximum Plugging Temperature for Operating	375°F	- - -
Flow		
Total Flow	1.5×10^6 lb/h	1.5×10^6 lb/h
Flow/Loop	5.6×10^6 lb/h	5.6×10^6 lb/h
gpm/Loop at 850°F	12,000 gpm	12,000 gpm
Pressure		
Reactor to Pump	6 psi	
Pump to IHX	8.3 psi	
IHX to Core	17.5 psi	
IHX Pressure Loss	15 psi	
Piping System Pressure Loss Total	46.7 psi	
Pressure Drop - (Plenum-to-plenum)	120	100
System Pressures - Piping		
Reactor to Pump	50 psig	
Pump to IHX	175 psig	140 psig
IHX to Core	175 psig	120 psig
System Pressure - Components		
Pump Case	175 psig	140 psig
IHX - Primary Side	175 psig	132 psig
- Secondary Side	175 psig	142 psig
Check Valve	175 psig	117 psig

* Structural design only for 1200°F condition

3.7 SYSTEM COST EFFECTIVENESS

In order to satisfy the design requirements for high plant availability (goal 75%), a detailed study of the system has been performed to evaluate the system and determine the availability characteristics, the cost and effects of achieving the design goals. Rather than evaluate availability only, the cost to achieve availability was considered. The "worth" of the plant was assumed to be equal to the cost to the customer over the 20-year plant lifetime. Details of the system cost effectiveness considerations are reported in the First (GEAP-5550) and Second Quarterlies (GEAP-5614). Emergency cooling requires a minimum of two available loops at all times. Thus, three main heat transfer loops are required as a minimum.

The basic conclusions from these studies are:

- a. Four 133 MWt loops give the highest system availability ($U = 3.6\%$). However, the costs of providing this availability may not warrant the additional loop.
- b. The 3/133 MWt ($U = 7.8\%$) loop system is the recommended on a cost effectiveness basis. The incremental capital cost penalty for the additional loop ($\sim \$10 \times 10^6$) is more than the benefits which would be received from operating at higher plant availability (benefits $\sim \$7.7 \times 10^6$).
- c. The range of uncertainty in the availability calculations is estimated to be about $\pm 1\%$ in absolute availability. This results in a cost of uncertainty of about $\pm \$2 \times 10^6$. The uncertainty stems from the lack of failure data on sodium systems and the engineering judgments that were required to correlate the existing data. In the same manner, there is an uncertainty associated with capital cost. This has not been estimated, but it certainly could be of the same order of magnitude as availability uncertainties at this stage of development.
- d. Thus, 3/133 MWt and 4/133 MWt loop systems appear to be nearly equal choices, considering the uncertainties. The selection of one system over another will not drastically affect the overall program objectives.

3.8 DETAILED SYSTEM COMPONENT DESCRIPTION

This section is intended to be brief and general in nature.

3.8.1 Primary Sodium Pump

The sodium pump is a vertical centrifugal, free surface, single stage unit similar to HNPF, FERMI and EBR II pumps. The pump shaft extends from the impeller and hydrostatic bearing assembly upward through the shielding to the shaft seal, coupling, speed control coupling, and drive motor mounted in the operating area. The pump is designed so that all rotating parts and internals may be removed, including impeller, bearing, shaft, wear rings, diffuser and labyrinth seals. This allows maintenance to be performed without cutting into the system.

Radial alignment of the pump shaft is accomplished with the hydrostatic bearing. High pressure coolant supplied from the discharge of the pump is directed through small holes in the journal to maintain shaft concentricity. There is no contact of metal surface except during pump startup and shutdown transition periods. The bearing surfaces are hard-faced to ensure long life under the expected operating conditions. Leakage past the bearing and labyrinth seals is allowed to return back to the reactor vessel through the overflow piping.

The atmosphere above the free surface is argon gas whose pressure is controlled externally. During normal operation pressure control maintains the argon at the same pressure as the reactor vessel.

The pump shaft seal is an oil lubricated face seal located in the operating floor area; where inspection and maintenance functions may be accommodated. The shaft seal acts as a gas barrier to isolate the pump atmosphere from the operating floor where the speed control device and drive motor are located.

Pump instrumentation includes thermocouples fixed to the case and pump intervals, level probe, and shaft speed tachometer; pump instrumentation includes measurement of pump seal oil temperature, reservoir oil level, drive motor temperature, voltage, and current.

The pump is required to operate smoothly over all operating conditions. In particular, the pump control should be stable over the operating range and have negligible drift.

3.8.2 Sodium Pump Development

The sodium pump is a component which has reached a relatively advanced state of development for use in sodium systems. There is a considerable body of operating experience of free-surface pumps in sodium-cooled reactor plants and test facilities. Operating experience has been generally satisfactory.

A review of the operating history of these pumps indicates that for the most part the operating difficulties were caused by design deficiencies or oversights on the part of the system and pump designer.

Because of the large body of rather favorable pump operating experience, the pump developments required to provide a system compatible with the FFTF environment are minimal. Actually, most recommendations take the form of check-out prior to plant operation. Plant construction must allow scheduling for pump check-out with sodium at reactor conditions prior to actual fuel loading and plant operation.

The following development program is recommended for the backup concept pump:

- a. Pump Shaft Seal: The shaft seal recommended is a well developed oil lubricated face seal. Proper design and seal lubrication can minimize seal wear and potential lubricant leakage. No development of shaft seals is recommended.

Proof testing of the selected seal under operating conditions is recommended. This could be done during preoperational testing prior to plant operation.

- b. Pump Drive and Controls: There is considerable latitude in selection of pump drives to satisfy the requirements of the FFTF pumps. An a-c, 3 ϕ induction motor drive with eddy-current coupling is considered a good choice at this time.

Proof testing of the drive-system under load during plant preoperational testing is recommended.

- c. Pump Hydrostatic Bearings: The bearing design used in the FERMI pump will be directly applicable to the FFTF system. However, there is little operating experience at high temperature with large sodium pumps ($>950^{\circ}\text{F}$), and there is some concern for the compatibility with sodium of the hard surfacing materials used previously. These materials suffer considerable reduction in hardness above 1000°F , and it is suspected there may be adverse reactions with sodium at 1200°F .

For pump operation at 1000°F and below, no hydrostatic bearing development is recommended. Existing pump operating history has shown the bearings currently in use to exhibit little or no wear characteristics.

Pump operation at 1200°F will require a hard bearing surface material compatible with sodium. For this condition it is recommended that the following development is considered:

- Select several candidate materials.
- Test materials in sodium, under expected loading condition.
- Develop method of applying hard surface materials to bearing surfaces.

Much of the necessary information is available in the literature. It is anticipated that the development required would be minimal, perhaps proof testing the selected materials under load.

- d. Pump structure, impeller, hydraulics: Pump structural considerations involving the casing, impeller, and shaft require high strength materials and design for thin wall sections to reduce thermal shock effects. Hydraulic considerations are similar to designs used for water pumps. No development in this area is anticipated.
- e. Pump Testing: Two phases of pump testing are recommended. These tests take the form of proof tests at the site of the vendor and in the reactor facility.

Water testing of the assembled pump should be performed under load at the vendor's plant. The pump drive seal, speed controller, and controls should be available at this time. The piping system external to the pump should be mocked up to duplicate the system performance characteristics. The following information will be available from the test:

- Pump hydraulic performance
- Pump drive and control performance
- Impeller sizing
- Weep hole sizing
- Hydrostatic bearing performance
- Pump case level changes with load
- Pump overflow characteristics
- Pump seal performance

Fluid performance can be converted to performance capabilities in the sodium. The performance should include a continuous 200/h run under load.

Testing in sodium, under the expected thermal and hydraulic load conditions should be accomplished at the FFTF facility. This test would demonstrate the long term running characteristics and allow final debugging of the system when necessary. In addition, pump operation and sodium circulation allows checkout of the other plant sodium components. A long term performing run of about 1000/h duration will give information relative to:

- Pump thermal distortion and deflections
- Pump case cooling
- System vibration characteristics
- Seal performance
- Pump control performance
- Hydraulic performance

3.8.3 Intermediate Heat Exchanger

The detail design of the intermediate heat exchanger is not well established at the present time. The functional requirements have been defined in a limited fashion. Several areas of heat exchanger design have a considerable amount of uncertainty.

At the present stage of sodium heat exchanger development there is a great deal of uncertainty in the ability to predict the thermal performance of a low pressure drop unit. This is because of the difficulty in predicting flow distribution patterns on the low pressure drop side of the unit. Also, a low pressure drop may require a considerable amount of margin with respect to the overall unit pressure drop to assure compatibility with other systems.

Past experience with liquid metal heat exchangers has been generally satisfactory. Reliability in terms of leakage has been very good. One of the most difficult design problems has been assurance of adequate flow distribution with baffling on the shell side of the unit to avoid bypass flow and degraded thermal performance. Adequate thermal performance depends upon predictable flow paths and fluid mixing on the shell side of the unit. Baffles are generally used to promote cross flow and mixing. The more baffles the better the flow distribution and a corresponding higher overall shell-side pressure drop.

To minimize design uncertainties, a conservative approach with respect to ensuring shell-side flow distribution should be taken. In view of the present state of technology a conservative design approach would allow a significant margin on pressure drop through the shell side to permit sufficient baffling. It is difficult to justify a low pressure drop unit and have a high degree of confidence in the performance capability of the unit. Actually, adequate performance of a low pressure drop unit is contingent upon a successful development program. The cost of such a program must be assessed and the chances of success or failure determined, along with the benefits which would accrue from such development.

A design study is necessary that will provide preliminary engineering and cost information on the comparison of high and low pressure drop units. The development programs necessary to provide guaranteed performance need to be identified. Results of this study are necessary in order to proceed with the preliminary design of the heat transport system. Results in this sensitive area are mandatory to ensure the FFTF reactor system meets the goals and program objectives as scheduled.

Rather than rely upon a development program to assure success of the system, it seems appropriate to minimize the unknown or doubtful areas and emphasize system features which demonstrate a high degree of confidence of success. The backup plant system has been developed with this philosophy as the basis for design.

The nominal performance conditions for the Backup Design are given in Table 3-2.

TABLE 3-2

NOMINAL INTERMEDIATE HEAT EXCHANGER (IHX) REQUIREMENTS

General:

No. of Units	3
Heat Transfer/Unit	133 MWt
Reactor Power	400 MWt

Design Conditions:

Temperature	1200°F
Pressure (maximum)	
Primary Side	175 psig
Secondary Side	150 psig
Pressure (minimum)	Vacuum at 70°F
Loop Flow Rate	5.05×10^6 lb/h
Fouling Factor	0
Maximum Temperature Difference	< 125°F

Normal Operating Conditions:

Temperature	
Primary Side	700/1000°F
Secondary Side	575/875°F
Pressure	
Primary Side	131 psig
Secondary Side	151 psig
Pressure Drop	
Available	< 15 psig

3.8.4 Instrumentation

In general, the instrumentation provided for the primary system should be reliable and accessible. Redundancy should be utilized where failure could affect reactor operation. The necessary instrument functions are given in Table 3-3.

TABLE 3-3

PRIMARY COOLANT INSTRUMENT FUNCTION

	<u>Information</u>	<u>Control System</u>	<u>Safety System</u>
Temperature			
Reactor Outlet	X	X	X
IHX Outlet	X	X	
Secondary Cooler Outlet	X		X
Pump Case	X		
IHX Shell	X		
Piping	X		
Flow			
Main System	X	X	X
Pump Overflow	X		
Level			
Pump Case Sodium	X		X
Vent Tank	X		
Pump			
Shaft Speed	X	X	
Motor			
Speed	X		
Current	X		
Voltage	X		
Temperature	X		
Speed Coupling			
Speed	X		
Current	X		
Voltage	X		
Temperature	X		
Seal-Bearing			
Temperature	X		
Level	X		
Power Loss			X
Pressure			
Inlet IHX	X		
Outlet IHX	X		

In addition, consideration is being given to monitoring the pump shaft runout and, possibly, vibration measurements as a diagnostic tool. The instrumentation system must have a small effect upon plant availability in order to achieve the design goals for plant availability. The system availability must be consistent with the design targets. The target for the entire primary system, including the instrumentation sensors, is an unavailability of 3.0%. The target unavailability for the plant control and reactor safety system is 0.5%.

Table 3-4 shows typical types of instrumentation to achieve these required functions.

TABLE 3-4

MAIN PRIMARY SODIUM SYSTEM INSTRUMENTATION

<u>Function</u>	<u>Sensor</u>
Preheat Temperature	C/A T/C, MI Cable
Control and Protectives System Temperature	C/A T/C
Sodium Flow	E-M Flowmeter Venturi - D-P Cell
Pump Level	Resistance Probe
Pressure	
Pump Discharge	NaK filled D/P Cell
IHX Outlet	NaK filled D/P Cell
Leak Detection	Radiation Detector in Nitrogen System

3.8.5 Primary System Piping

Primary piping is a standard size connecting each of the major components. Piping size is adjusted to minimize the loop pressure drop and still maintain a reasonable piping size.

- a. Piping material is austenitic stainless steel. May be either Type 304 or 316. Type 316 has appreciable higher allowable stresses at the 1200°F design condition.
- b. Preliminary piping flexibility analysis has been completed to determine feasibility. Piping flexibility and stresses shall conform to the latest revision of the ASA Code for pressure piping, ASA B31.1.
- c. Piping Design Conditions Are:

<u>Run</u>	<u>Temperature</u>	<u>Pressure</u>
Reactor/Pump	1200°F	50 psi
Pump/IHX	1200°F	175 psi
IHX/Reactor	900°F	175 psi

- d. Minimum wall thickness will be Schedule 40 for piping diameter 6 inches and less, Schedule 20 for diameter 8 inches, and Schedule 10 for diameters greater than 14 inches.
- e. Piping shall be arranged for complete gravity drainage.
- f. No drain lines or service connections are to be appended to the main coolant system.
- g. A vent line is supplied to the high point in the system. The vent line is utilized during filling operations to remove all gas from the system.
- h. Gas purge and vent lines are provided on the main pump case.
- i. There are no unusual discontinuities, branch lines, tee's, or pockets in the system which might serve to collect particulate or gas, or act as cold fingers.
- j. Piping and equipment shall be arranged and supported to facilitate inspection. This is particularly true of nozzles, joints, and other system discontinuities.
- k. Piping and components shall be arranged and supported in such a manner that any component may be replaced or serviced during the plant lifetime.

Particular attention shall be given to allowance of space for shielding purposes, to any special tools required for maintenance, and to the provision for remote removal or in place repair. Drawings and repair procedures shall be developed for maintenance purposes.

3.8.6 Valves

- a. No stop valves are used in the main heat transfer system.
- b. A check valve is provided in the cold leg piping.
- c. The valve is to be located down stream of the heat exchanger, as close to the reactor inlet as is practical.
- d. The valve is to be accessible, or removable for repair or replacement during the plant lifetime.
- e. The valve shall have demonstrated ability to:
 - Close with an adequate response to prevent significant system backflow following a pump trip in one loop.
 - Demonstrate adequate damping upon closure to prevent serious shock and vibration forces.
 - Not obstruct natural convection cooling flow.
 - Have adequate design to avoid sticking, thermal destruction, oxide and particulate accumulation.

3.9 PRINCIPLES OF OPERATION

3.9.1 Startup

This section briefly describes the initial preheat, fill, and sodium coolant circulation through the main system.

- a. Following construction or prolonged maintenance periods, air is purged from the system by introducing argon at the low point of the system and displacing the air while venting from the high point in the system.
- b. The system is slowly preheated until all piping and vessels are at a uniform temperature of about 350°F.
- c. Sodium from storage tanks is introduced through a filter and cold trap into the reactor vessel. The plugging temperature of the sodium must be low (<250°F) prior to filling. As coolant rises in the vessel, argon gas is displaced and vented through the vent lines located at the system high point. As coolant reaches the normal operating level in the reactor vessel, a slight pressure difference is created between the vessel and vent system by pulling a slight vacuum to raise the coolant level to the system high point. As coolant displaces the gas it will rise, fill the system and heat exchanger, enter the vent line and the vent tank. When a level indication is received at the vent tank, the system fill operation is completed. The vent tank valve is closed and the connecting lines frozen.
- d. Circulation is achieved by starting the pump at minimum speed (~ 20%).

3.9.2 Plant Startup - Normal Operation

Sodium is circulated through the main system at ~ 400°F. Temperature is raised to ~ 700°F by any combination of pumping energy, electric heating, and nuclear heating. Normal temperature increase is ~ 50°F/h. Normal power increase would be accomplished by operating the pumps at the nominal design condition while power is increased to 400 MWt by spreading the core ΔT , keeping the cold leg return temperature constant. Rate of temperature increase is determined by limitations in the system, but probably would be limited to ~ 50°F/h.

Any loop may be isolated from the reactor system by shutdown of the pump in that loop. A check valve prevents backflow through the system. It is expected that shutdown and startup in any loop will take place during reactor shutdown with the sodium systems isothermal.

3.9.3 Power Operation

Normal power operation is conducted near the 400 MWt power level and design temperature conditions. Control is flexible enough to allow either temperature, power, or flow setpoints and adjust either rod position or flow to achieve the desired operating conditions. The control system should have enough flexibility to allow partial load operation, lower temperature, and flow conditions. In general, power operation will be characterized by steady state 400 MWt power operation to achieve the test conditions and irradiation data required by the experimenter.

3.9.4 Plant Shutdown

Normal shutdown is accomplished in the reverse manner of a startup. Sodium flow is held constant and the outlet temperature is reduced along with reactor power until isothermal conditions are achieved. Fast shutdown, or scram causes the pumps to trip and coast down. Natural circulation decay heat removal is controlled by adjusting the secondary system heat rejection to minimize thermal transients.

3.9.5 Refueling

During refueling, the coolant level in the tank will remain at the normal level. Fuel is retrieved and replaced by grappling through the sodium pool. Occasionally it may be desirable, however, to lower the sodium level to a point where the tops of the fuel rods are visible. During this operation coolant is pumped from the reactor upper pool through a drain line into the drain tank. Transfer time is about 1 hour. Sodium coolant flow is maintained through the main loops. Two mechanisms are used to maintain the coolant level in the free surface pump case. The pumps are operated so sufficient coolant level is maintained in the case, and, in addition, the pressure in the pump case is controlled to prevent loss of coolant should the pump lose power.

3.9.6 Abnormal Operating Conditions

3.9.6.1 Reactor Scram (Full Power)

This is a fast shutdown initiated by a signal from the safety system. Control rods are driven into the core, terminating reactor power. Power is removed from the pump and the pump is allowed to coastdown by its own inertia. Core thermal energy is dissipated through the pump coast-down flow and later by system natural circulation.

3.9.6.2 Loss of Site Power

Loss of power initiates a scram accompanied by pump coastdown. For this transient pump flow decay is initiated at the instant of scram rather than having a short delay period that would be possible for normal scram.

3.9.6.3 Loss of a Single Loop

Single failure in any one loop such as pump trip or shaft seizure would be accompanied by a scram. The sequence would involve a pump seizure, flow deviation, sensing, reactor scram, pump coastdown, and flow-temperature decay.

3.9.6.4 Leakage from a Single Loop

Leakage is detected by either leak detectors in the heat transfer cell, flow deviation in the loop, or level loss in the reactor vessel. The reactor is shutdown either in a normal manner or by scram, depending upon the extent of the leakage. Coolant from the affected loop is allowed to drain to the system storage tanks.

3.10 TRANSIENT OPERATION DESIGN CRITERIA

Transient behavior of the sodium system to cyclic temperature and pressure transients shall be considered in the design. Table 3-5 lists the transient conditions that shall be accommodated by the design. The damage criteria for these conditions shall be that the system design must comply with the latest edition of the following codes:

- ASME Boiler and Pressure Vessel Code, Section III, Nuclear Vessels.
- Proposed ASME Code for Nuclear Power Piping.
- Proposed Code for Nuclear Valves.
- ASA Code for Pressure Piping, B31.1.

TABLE 3-5

MAIN COOLANT LOOPS TRANSIENT DESIGN CRITERIA

<u>Condition</u>	<u>Transient Description</u>	<u>Design Cycle</u>
Reactor Startup	Normal Flow, Temperature Changes	1000
Reactor Shutdown	Normal Flow, Temperature Changes	1000
Refueling	300° - 400°F Steady State	500
Power Operation	±30° - 50°F Temperature Changes	~10 ⁶
Reactor Power Scram	Temperature and Flow Transient	1000
Loss of Site Power	Temperature and Flow Transient	500
Loss of Single Loop	Temperature and Flow Transient	100
Leakage from Single Loop:	Temperature and Flow Transient:	
Small		50
Large		1
Design Basis Accident	Shock Wave and Pressure Excursion	1
Scram with Pumps Running	Rapid Temperature Transient	5
Pump Trip with Delayed Scram	Rapid Temperature Transient	5

3.11 SYSTEM REPAIR, MAINTENANCE, AND INSPECTION

Consideration must be given to aspects of the system design to ensure that the high system availability targets are met. Achievement of availability must be consistent with cost. Likewise repair and maintenance functions must be realistic in terms of what repairs will be necessary, and the frequency, repair time, cost of repair tools, etc. The suggested general philosophy is:

- Design for low-frequency replacement, with 20-year life target.
- Design for direct contact maintenance.
- Design for temporary shielding to allow direct contact maintenance.
- Locate critical components, instrumentation, connectors, and mechanisms out of radiation zone, if possible.

- Provide for complete coolant drainage of primary system.
- Provide consistent supply of spare parts, with logistics for replacement.
- Establish failure reporting system and means to upgrade faulty equipment.
- Perform system availability and failure mode and effects analysis during design phase to correct deficiencies.

3.11.1 Primary Pump

- a. Motor: Motor drive maintenance and replacement may be performed from the operating floor during loop shutdown.
- b. Variable Speed Drive: Drive repair or replacement is accomplished from the operating floor during loop shutdown.
- c. Seal: Seal maintenance is performed within a temporary enclosure placed over the pump-seal unit. The enclosure prevents the spread of any contamination from the gas space above the pump free surface. Reactor is shutdown. Spare seal assembly should be provided.
- d. Pump Internals: Pump internals, shaft, bearings, impeller, and wear rings may be removed from the case by withdrawing into a bag or cask following reactor shutdown, loop drainage and sodium-24 decay. The pump is then transported to a maintenance facility where residual sodium and fission products are removed allowing direct contact maintenance. Spares of critical components should be provided, such as the pump shaft.
- e. Instrumentation: Instrumentation sensors, thermocouples and level probes are removable from the operating floor area. Redundancy is supplied. Removal will require reactor shutdown, sodium decay, and possible local shielding. All other instruments are located externally and may be readily maintained.

3.11.2 Piping

Access: The piping system is inaccessible during power operation. Following system operation, 10 days must be allowed for Na-24 decay. Access into the main heat transfer compartment is then possible if significant amounts of fission products are not present. Direct access is provided to all points in the piping system for inspection and repair purposes.

3.11.3 Instrumentation

Flowmeters, thermocouples, connectors, and leads are arranged so they do not penetrate the coolant pressure boundary. Replacement is accomplished without cutting into the sodium system. All switches, connectors, terminal boxes, etc., are external to the shielding and readily accessible.

3.11.4 Inspection

Provision is made for complete visual inspection of the coolant piping pressure boundary. Inspection is accomplished by removing sections of insulation covering the portion of interest or radiographing through the insulation.

3.12 SYSTEM INTERFACE

The BNW reference design responsibilities include the reactor vessel, piping, and main heat transport system which will be based on the approved BNW CSDD No. 51. GE has performed system studies in an effort to define the requirements of the backup design. BNW is responsible for assuring that the reference and backup designs are compatible.

The reference design is responsible for all structure outside of the reactor vessel including the vessel, safety tank, nozzle penetrations, etc.

The following requirements are determined to be necessary for the backup design:

- Reactor inlet and outlet nozzles should be located symmetrically for uniform flow distribution across the inlet and outlet plenums.
- Reactor outlet nozzle locations must be established to allow the coolant level in the upper pool to be lowered to allow visual inspection of the tops of the fuel handling knobs.

SECTION IV

PRIMARY SODIUM SERVICE SYSTEM

4.1 INTRODUCTION

The purpose of this section is to establish design objectives and present pertinent data sufficient to describe the conceptual design and establish the backup reactor system design requirements.

The functions of the primary sodium service system are:

- a. Store entire primary system sodium volume contained in the main heat transfer system and auxiliary systems.
- b. Control and remove oxygen impurities from the primary sodium system, so plant operation is not appreciably affected nor controlled by operation of the sodium service system.
- c. Provide on-line sodium samples and tab material samples as required.
- d. Measure the relative oxide in sodium impurity. Measure other impurities if required.
- e. Provide pumping capability for cold trapping, sampling, filling, and draining.
- f. Provide reactor level control during refueling or during the time interval that the sodium level is lower to the tops of the fuel element handles.
- g. Provide means to measure carbon-in-sodium impurity. Provide space for later additions of carbon hot traps.
- h. Provide for safely and reliably filling the system initially, with allowance for makeup as required.
- i. Separate sodium vapor from the cover gas when removing gas from the system.
- j. Provide a supply of sodium whose purity is sufficient to satisfy all requirements of the plant.

4.2 SUMMARY PRIMARY SODIUM SERVICE SYSTEM DESCRIPTION

To provide all the system functional requirements. Four separate but interconnected subsystems are involved: (a) sodium charging, (b) sodium storage, (c) sodium sampling and purification, (d) fuel storage cooling and purification.

The fuel storage system is independent of the other systems as it contains its own purification system, cooling system, and drain tanks.

Each of these systems is located independent from the other in separate shielded cells with the exception of the sodium charging system located outside of the containment building. Shielding each system provides a degree of independence for the subsystems and accessibility to each of them.

The lines connecting systems and components are insulated to minimize thermal losses and all lines are sloped to allow gravity drainage. All sodium lines are provided with electric heaters sufficient to maintain the system at 700°F as a minimum. The system is illustrated schematically in Figure 4-1.

4.2.1 Sodium Charging System

The design of the fill system requires certain design principles and bases to be utilized. Bulk sodium is transported to the site by railway tank cars. Sodium is preheated in the tank car by circulating hot oil through the tank car heating system. Sodium is discharged from the tank through a particulate filter and through temporary heated lines to a transfer tank. At about 250°F to 400°F sodium flow is established by differential pressure between the tank car and the transfer tank. Provision is also made for the transfer of smaller charges by drum.

Sodium may be routed to either the primary or secondary sodium system from the transfer tank. Removable flanged connections are provided to allow transfer from the charge station to either the primary or secondary system. Following system purge, sodium is transferred by pressure from the transfer tank to the drain tank in the primary system. During the fill, sodium is then recirculated through the cold traps until the oxide content reaches the desired level. The primary traps are removed as required, as they accumulate oxide from the system. Sodium is circulated through the cold trap system until the plugging temperature is reduced to 300°F.

4.2.2 Sodium Storage System

The sodium storage system is shown in Figure 4-1. The sodium storage system can accommodate the entire primary system volume in the two tanks provided. The storage system is located at the lowest point in the sodium system, allowing gravity drainage from the primary radioactive sodium systems. System fill from the drain tank is accomplished with the service pump, assisted by a modest pressure differential (0 to 10 psig).

The storage system is designed for 1200°F system operation at 40 psig. Argon gas is supplied and vented through vapor traps located off of each tank.

During normal operation, the tanks are vented to a common atmosphere with the reactor gas plenum. This provides a cushion of gas for maintaining essentially atmospheric cover gas pressure during normal operation and for normal system temperature changes.

4.2.3 Sodium Purification System

The sodium purification system is shown in Figure 4-1. The purification system is designed to remove oxygen, particulate, and possible fission product contaminants from the sodium coolant. The system piping is arranged to circulate coolant from the reactor upper

FIGURE 4-1. P&ID PRIMARY SODIUM SERVICE SYSTEM

plenum through the purification system and return, or recirculation through the fill-drain tanks, or a combination of these. No provision is made for trapping the individual main heat transfer systems. This feature is provided to minimize system penetrations, provide independence, minimize valves, and increase overall plant availability. The main heat transfer systems are purified through their common connections to the reactor upper plenum.

Pumping capability is provided which is sufficient to lower and raise the coolant level within the reactor vessel for fuel handling operations. The reactor vessel level can be raised from the minimum level to the operating level in about 1 hour.

The sodium service system is designed to accept 1200°F coolant, and purify at a maximum rate of 200 gpm using two traps. This provides a minimum system turnover time of less than 8 hours. This trapping rate should allow rapid oxide removal following system outage in order to minimize plant downtime.

Two cold traps are provided, one acting as a spare. This allows a spent unit to be decaying while the spare is in operation. Replacement may be scheduled as convenient for plant operation.

The cold traps are cooled by NaK jackets on the outside. NaK is utilized because of its good heat transfer properties and compatibility with sodium. The NaK coolers, surge and fill-drain tank, and pump are all located outside the containment building in accessible areas.

Measurement of oxide impurities is accomplished by means of a plugging indicator located in parallel with the cold trap units. The detector unit consists of a flowmeter, a cooler, a flow restriction, and temperature and flow indicating recorder. In determining the plugging temperature, the incoming sodium stream is slowly cooled down to the saturation temperature. Oxide precipitation causes plugging at the orifice resulting in a sharp break in flow at the saturation temperature. Plugging temperature measurements are taken in an automatic sequence when desired.

Space is provided for a carbon hot trap facility within the reactor complex. At the present time, the need for carbon control has not been identified for the 1000°F operating conditions.

A sampling station is provided which can accommodate various sampling devices. The detail design of the sample station has not been completed. It is anticipated that the station would be located somewhat separate from the service system and be designed to operate independent from the service system so that samples could be removed from the system without disturbing reactor operation. As a minimum, the sample station shall be designed to accommodate materials and sodium samples.

4.2.4 Fuel Storage Service and Vent System

The fuel storage service system stores, purifies, and removes heat from the sodium coolant used in the fuel storage tanks within the refueling cell. The service system is independent of the reactor service system, but operates on the same principles. Coolant from the storage tank is circulated through the cooling system intermediate heat exchanger

and back to the storage tank. The cooling system has the capability for removing decay heat generated by 25% of a full core loading 1 day after shutdown. A bypass stream around the storage tank service pump is directed to the cold trap and plugging meter circuits. This system is illustrated schematically in Figure 4-2.

The vent system is used in filling or draining any particular sodium loop. Its purpose is to remove and effectively disengage gas from the coolant when filling the system. In filling, the primary system gas is vented from the high point in the system and coolant is allowed to rise in the vent pipe until a level is established in the vent tank. Valves are closed isolating the vent tank from the system. The coolant in the vent tank may then be transferred to the fill-drain tank. Independence between the loop's gas systems is maintained.

4.3 SYSTEM DESIGN CRITERIA

The system design criteria are intended to emphasize safety, performance, and reliability using conservative design practices. The design criteria are listed.

4.3.1 Sodium Charging Subsystem

- a. Capable of safely transferring fresh sodium from tank car or sodium drum to either primary or secondary system.
- b. Supply particulate-free sodium coolant to the systems.
- c. Construction and operating costs consistent with system functions.

4.3.2 Storage System

- a. Capable of storing the entire primary sodium system volume.
- b. Capable of acting as a large volume gas surge tank for reactor cover gas pressure changes.
- c. Located to allow gravity drainage from all primary sodium systems.
- d. Capable of transferring sodium to the primary heat transfer system or to the sodium service system.

4.3.3 Sodium Purification System

- a. Reduce sodium oxide concentration in the primary system sodium to a level that results in a plugging temperature of 300°F or less.
- b. Reduce sodium oxide concentration in primary system from saturation to acceptable levels within 2 days or less.
- c. System design for 1200°F reactor operation.

FIGURE 4-2. FUEL STORAGE COOLING AND SERVICE SYSTEM

- d. Provision shall be made for future carbon removal facilities.
- e. Cold trap capacity shall be consistent with economical replacement schedules including capital cost and replacement and effect upon plant availability.
- f. Provision shall be made for measuring the oxide concentration in sodium.
- g. Provision shall be made for taking sodium samples and exposing material specimens.
- h. Sodium Purity: Initial sodium purity requirements must be acceptable for all phases of reactor operation.

4.3.4 Fuel Storage Service System

- a. Provide fuel decay heat removal for one-quarter core loading 1 day after plant shutdown. This amounts to approximately 1 MWt.
- b. Provide sodium purification independent from the main heat transfer system purification.
- c. Provide sodium storage for the fuel storage system.
- d. Purification system shall be capable of reducing the sodium oxide content sufficiently to avoid fouling or plugging fuel assembly passages or piping.
- e. Cold trap capacity and replacement shall be consistent with economics and shall consider effects upon plant availability.
- f. Provide sodium oxide measuring device.
- g. Provide instrumentation and control functions for simple, safe, reliable, system operation.

4.3.5 Sodium Vent System

- a. Safely and effectively separate gas from sodium during fill operations.
- b. Remove gas from the sodium system piping at the high point in the system.
- c. Prevent gas entrainment in circulating sodium systems.

4.4 DESIGN REQUIREMENTS

4.4.1 Sodium Charging System

- a. Provide removable flanged or flexible connections between the tank car and receiving station.

- b. Size the sodium transfer tank to accommodate four drums of sodium. Provide a two-drum capacity unloading station.
- c. Provide insulation and line heaters sufficient to maintain system temperature at 400°F.
- d. Provide gas connections to allow transfer of sodium from the tank to either the primary or secondary system.
- e. Provide filters for removing small particulate from the sodium.
- f. Material Requirement:
 - Carbon steel
- g. Code Requirements:
 - Piping - ASA Code for Pressure Piping B31.1
 - Vessels - ASME Boiler and Pressure Vessel Code Section VIII.

4.4.2 Sodium Storage System

- a. Size the drain tanks to hold the entire primary system sodium volume of 11,000 ft³.
- b. Tank design for:
 - Temperature (1200°F)
 - Pressure (40 psig)
- c. Sodium storage tanks are to be arranged to allow gravity drainage from the sodium system.
- d. The tanks shall be vented to the reactor cover gas.
- e. Heating capability shall be provided to maintain tank at 900°F.
- f. Instrumentation shall be provided to measure level, pressure, and temperature.
- g. Code Requirement:
 - ASME Boiler and Pressure Vessel Code Section III, Class C.

4.4.3 Sodium Purification System

The purification system consists of two cold traps, cold trap economizer, plugging indicator, sample station, cold trap cooler, and service pump.

- a. Cold Trap Design Requirements:
 - Flow 100 gal/min
 - Replacement 6 months or longer

• Dimensions	Consider transportation and disposal	
• Oxygen Sources	Refueling Periodic maintenance Normal inleakage	
• Trap Residence Time	5 minute minimum	
• Internal Temperature	50°F below saturation	
• Mesh	4-5 mill diameter, 20 lb/ft ³ packing	
• Efficiency	Assume 20% efficiency for accumulation of oxides	
• Construction	All welded	
• <u>Temperature</u>	<u>Operation</u>	<u>Design</u>
Maximum	600°F	700°F
Minimum	250°F	70°F
• <u>Pressure</u>		
Maximum	40 psig	100 psig
Minimum	Vacuum	Vacuum
• Codes	ASME Section III Class C Material - Carbon Steel	

b. Design Requirements for Cold Trap Economizer:

• Flow	150 gal/min	
• Design Life	20 years	
• Style	Tube and shell exchanger	
• Rating	5 MW	
• <u>Temperature</u>	<u>Operation</u>	<u>Design</u>
Hot Terminal	1000°F/950°F	1200°F
Cold Terminal	325°F/275°F	1200°F
• <u>Pressure</u>		
Maximum	40 psig	100 psig
Minimum	Vacuum	Vacuum
• Materials	Austenitic stainless steel	
• Codes	ASME Section III, Class C	
• Drainage	Provision for complete gravity drainage	
• Instrumentation	Temperature	
• Design Code	ASME Section III, Class C	

c. Design Requirements for plugging indicator:

• Flow	1/2 to 1 gpm
• <u>Temperature</u>	
Operation	250 to 1000°F
Design	1200°F
• Cooler	Utilizes nitrogen gas blown over a finned section
• Orifice	Plate with hole
• Instrumentation	Temperature, and flow instrumentation arranged for automatic plugging cycle with recorded output
• Codes	ASA Code for pressure piping Section B31.1

d. Sample Station Design Requirements:

- No comprehensive design information is available at this time.

e. Cold Trap Cooling System Design Requirements:

- Cooling Design Load 400 kW
- Trap Internal Temperature 250°F minimum
- Service Life 20 years for piping and vessels
- Alternate Concepts { NaK cooled cold trap
N₂ gas cooling

f. Sodium Purity Requirements:

- Initial charge of fresh sodium must meet the minimum requirements to be acceptable for reactor service.

4.4.4 Fuel Storage Cooling System Design Requirements

- a. System Heat Load (1 MWt)
- b. Cooling system is to be capable of maintaining less than a 100°F ΔT at maximum cooling load, 400°F pool surface temperature:
- c. Purification system to be capable of maintaining the oxide level at or below a 300°F plugging temperature.
- d. Sufficient redundancy in components and systems shall be supplied to avoid loss of cooling to the fuel storage system.
- e. Cold traps shall be sized for yearly replacement schedule, or longer.
- f. Sodium storage facilities shall be provided to store entire service system volume as required.
- g. Capability shall be provided to drain individual storage tanks as required.
- h. Code Requirements:
 - Piping (ASA B31.1)
 - Vessels (ASME Section III, Class C)

4.5 SYSTEM CHARACTERISTICS

The data shown in Table 4-1 have been used in establishing the FFTF Backup Design concept of the sodium service system. The data presented is typical and subject to change as the design progresses.

TABLE 4-1

NOMINAL PRIMARY SODIUM SERVICE SYSTEM CHARACTERISTICS

<u>Item</u>	<u>Design Condition</u>	<u>Operating Condition</u>
Sodium Charging System		
Design Flow	100 gpm	-
Temperature	600 °F	300-400 °F
Pressure	50 psig	10-20 psig
Primary Sodium Storage System		
Storage Capacity	11,000 ft ³	-
Temperature	1200 °F	300-900 °F
Pressure	40 psig	0-1 psig
Sodium Purification System		
Cold Trap		
Number	2	-
Flow/each	100 gpm	10-75 gpm
Temperature	700 °F	250-600 °F
Pressure		
Maximum	100 psig	40 psig
Minimum	Vacuum	Vacuum
Oxygen Trapping Capacity	1100 lb O ₂	Vacuum
Cold Trap Economizer		
Heat Load	5 MW	
Temperature		
Hot Terminal	1200 °F	1000/950
Cold Terminal	300 °F	325/275
Pressure		
Maximum	100 psig	40 psig
Minimum	Vacuum	Vacuum
Flow	150 gpm	-
Plugging Meter		
Flow	0-1 gpm	0-1 gpm
Temperature	700 °F	250-600 °F
Pressure	100 psig	0-40 psig
Cold Trap Cooler		
Heat Load	400 kWt	-
Temperature	700 °F	250 °F
Fuel Storage Cooling and Purification		
Heat Load	1.6 MWt	-
Temperature		
Maximum	1050 °F	1000 °F
Minimum	70 °F	300 °F
Pressure		
Maximum	100 psig	-
Minimum	Vacuum	Vacuum

4.6 SYSTEM AVAILABILITY, COST EFFECTIVENESS

System availability studies have been conducted for the sodium service system including the sodium storage system and sodium purification systems.

The unavailabilities of the systems are defined as follows:

$$U_p = \frac{\text{plant down time contributed by sodium service system}}{\text{total time}}$$

$$U_{ss} = \frac{\text{sodium service system downtime contributed by components}}{\text{total time}}$$

Knowledge of U_p is most important in evaluating the effect of the service system upon overall plant availability. U_{ss} must be evaluated in light of the system requirements: how often the system is required to be available for operation, when repairs can be affected (during plant outage, during plant operation, or during system operation), etc. Table 4-2 gives the results of these evaluations.

Operation of the service system is not required continuously during reactor operation. The system is used during periods of time oxygen may be introduced into the system, such as plant outage for refueling, during equipment maintenance, or during startup. Thus, the service system is usually required when the plant is down, which amounts to some 15% to 25% required system availability. Repair and maintenance of the system may be accommodated usually during reactor operation.

TABLE 4-2

UNAVAILABILITY SUMMARY

<u>Sodium Service System</u>	U_p	U_{ss}
Sodium Valves	0.014	0.120
Cold Trap Replacement	-	0.060
Cold Trap Flange Leaks	-	0.012
Cold Trap Economizer	-	0.003
EM Pump	-	0.005
Cold Trap Cooler	-	0.002
Sodium Lines	-	0.001
Instrumentation and Power	-	0.001
Miscellaneous		0.008
U_p due to System Outage = 10% (0.15) -	<u>0.015</u>	_____
Total	0.027	0.212

It is estimated that outages in the service system would affect plant operation about 10% of the time. About 15% U_{ss} is contributed by unscheduled outages. Thus, U_p due to outages in the service system amounts to about 10% $(0.15) = 0.015$.

From Table 4-2 it is seen that the sodium service system can be expected to be out of service some 20% of the time because of equipment malfunction and replacement. The effect upon plant availability is a reduction in availability of about 3%. This is caused by a combination of valve failures connecting the service system to the main heat transfer system and failures in the service system during the period where the system was required to function.

The target unavailability for the entire sodium system is only 3%. With a calculated unavailability of 2.7%, the service system appears to be a serious source of plant outage. It appears that the service system can be an appreciable source of plant unavailability. Careful attention to the detail system design is required to minimize unscheduled plant outages.

4.7 DETAILED COMPONENT DESCRIPTION

This section is intended to be brief and descriptive in nature.

4.7.1 Primary Storage Tank

The storage tanks are two horizontal, cylindrical tanks, 14 feet in diameter and 42 feet long, located below the reactor system and capable of containing the entire primary system sodium volume of about 11,000 ft³. The tank is the lowest point in the sodium system. All sodium systems drain by gravity into the storage system.

Sodium is removed from each drain tank through the dip line which takes suction from the bottom of the tank. Coolant is then pumped into the individual systems. Gas supply and vent to each tank is routed through a vapor trap. Instrumentation consists of level probes, preheating equipment, thermocouples, and leak detectors.

4.7.2 Sodium Purification System

4.7.2.1 Service Pump

The service pump is a helical induction electromagnetic pump designed to deliver 250 gpm. The pump is hermetically sealed and has no moving parts. The service pump satisfies a number of functions. It is used to fill or drain the main heat transfer system, the sodium service system, and reactor. The reactor sodium level cannot be lowered below the minimum elevation unless a special piping dip tube is added to the drain line. In addition, the service pump is used to provide flow to the purification system including the cold traps, hot traps (if required), and sample station. The service pump is also used to provide recirculation and sodium level control during refueling operations.

The pump throat section consists of a concentric duct with outer helical flow passage. Inlet sodium is directed through the outer annular passages, turns at the end and passes back through the central pipe. A stator winding surrounds the duct, and wiring is covered with high

temperature insulation. Cooling gas from the surrounding nitrogen atmosphere is ducted over the windings to provide the stator assembly cooling requirements.

Instrumentation consists of thermocouples which monitor coolant, duct, and winding temperature.

4.7.2.2 Cold Traps

Two cold traps are supplied to provide the purification functions. Each is rated at 100 gpm flow. The purification system is designed to reduce the oxide content in the main sodium system from saturation to a plugging temperature $<300^{\circ}\text{F}$ within 2 days. Because of the capacity of the trap, it is expected that under normal conditions it will have a service life of 1 year or greater. The trap contains 4-to 5-mil stainless knitted wire mesh packed to about 20 lb/ft³.

Flow through the trap is directed downward through an outer annular region where it is cooled below the saturation temperature. Coolant is then directed upward through the mesh, exiting at the top. Isolation valves and mechanical flanged joints are provided to allow a spent trap to be removed from service without disturbing system operation.

The trap cooling system is under study. Two alternatives are proposed. Either a finned gas cooled unit, or a NaK cooling system may be used.

4.7.2.3 Cold Trap Economizer

A cold trap economizer unit is supplied to lower the temperature of the inlet sodium sufficiently near the oxide saturation point that it may be trapped efficiently. The economizer unit is separate from the cold trap and plugging indicator units. The unit is a tube and shell exchanger rated at about 5 MWt. Coolant flow from the reactor enters on the shell side of the unit at 1000°F and exits at near the oxide saturation temperature, say 325°F . The coolant is then directed through the trap and returns to the tubeside of the unit.

4.7.2.4 Plugging Indicator

The plugging indicator is designed to record plugging temperature down to 250°F with 1/2 to 1 gpm sodium flow. The unit consists of two concentric pipes with an orifice located in the return line. Sodium enters through a flowmeter section and down the outer annular pipe where it is cooled by an economizer section and then a finned cooler section. Sodium turns at the bottom, passing the orifice plate, and returns upward through the inner tube. Nitrogen gas is blown past the finned section providing the required cooling flow.

Instrumentation is provided to measure coolant flow and plugging temperature.

4.8 SODIUM SERVICE SYSTEM OPERATION

The sodium charging system is operated principally during the initial reactor fill or following major system outages. Sodium is introduced into either the primary or secondary

sodium storage tanks from the charge station. Sodium may be charged into the system either by tank car or by drum. Filling by tank car is accomplished by first circulating hot oil through the tank car heating jacket. Coolant flow is established by a combination of pressurizing the tank car cover gas and electromagnetic pump operation.

Filling by drum is accomplished by heating the individual drums and allowing them to drain into a transfer tank. The transfer tank is then pressurized, forcing the coolant into the storage system.

Filling the reactor and main heat transfer systems may be accomplished by either pressurizing the storage tank or electromagnetic pumping or both. As the reactor vessel is filled, coolant will flow into the loops as the level rises. When the proper reactor level is reached the pump is shut off and the drain line isolated. The elevated portion of the main heat transfer system may be filled by evacuating the gas space or creating a pressure difference between the reactor cover gas and the loop. As the coolant rises in the loop it displaces the gas. Gas is vented at the high point in the system. Coolant is allowed to rise past the high point and into the vent tank where a level is established. The vent valve is closed and a freeze seal established to ensure that no gas leakage will occur.

Operation of the service system occurs generally during periods when the reactor has been down for maintenance or refueling.

Reactor service periods are generally the periods when the system is most susceptible to oxide contamination. This is when the purification system is required to operate, removing oxygen as it accumulates.

The purification system is arranged to circulate coolant from the reactor or from the storage tanks, as desired. From the reactor, the electromagnetic pump takes suction from the upper plenum and discharges to the cold trap economizer. Coolant returns from the cold traps, passes through the economizer and returns to the reactor upper plenum. In the same manner coolant may be circulated and purified through the storage tanks.

4.9 REPAIR AND MAINTENANCE

Repair and maintenance functions have not been identified in detail.

Some of the specific features considered desirable are:

- Cold traps located in individual shielded cells so isolation and removal will not affect system operation.
- Storage system located in separate shielded region from purification system.
- Sample station located shielded and separate from service system to allow independent operation.

- Fuel storage cooling and purification system separate and independent from main service system.
- Valves located in accessible areas wherever possible. Minimize the number of valves.

4.10 SYSTEM INTERFACE

The sodium service system design is primarily the responsibility of the reference designer. Backup design system studies have been performed in an effort to define the requirements of the backup design. Continual review and exchange of information are necessary to ensure compatibility at the system interface. The backup design requires certain safety and design features and design conditions at the interface.

SECTION V

TEST IRRADIATION FACILITIES IN FFTF BACKUP DESIGN

5.1 INTRODUCTION

The purpose of this section is to describe the test irradiation facilities in sufficient detail for the definition of an interface between the reference design and the FFTF Backup Design.

The purpose of the FFTF is to provide irradiation services for fast reactor fuels and materials. These services are (a) to be available at an early date, target 1972; (b) to have a high degree of availability, target 75% and (c) to be useful for a long period, target of 20 years. This requires:

- Existing technology be used where possible to minimize the delays due to the time required for development work.
- The allocation of downtime for reactor servicing and for failures in the rest of the plant requires that a faulty test can be removed in a short period of time so the reactor irradiation services will be available to others in the remainder of that irradiation cycle.
- The facilities are to be capable of convenient modification so that irradiation services can be provided to a test not now envisioned.
- The reliability of safeguards features are to be at least as high or higher than for comparable size reactor plants.

It is to be anticipated that the personnel responsible for plant operation will review all irradiation tests for design, fabrication, inspection and verification of the "as-delivered" condition of the tests. One of the purposes of this review will be to verify that all requirements of the facility have been satisfied.

5.2 IRRADIATION FACILITIES

The number of irradiation facilities is not intended to represent the optimum or the projected requirements but are described to illustrate the interface between the reference and backup designs. The backup design provides the following facilities:

- a. Closed loop facilities: The design provides loops each consisting of an in-pile heat transport system. It is possible to operate the reactor without the in-pile tube in place and without the out-of-pile portion of the loop being in operation.
- b. Open loop facilities: Two different arrangements are possible: (1) an open loop test assembly having a vertical extension for instrumentation and located in a closed loop position which is not otherwise occupied or (2) an open loop having a flexible extension for instrumentation and located in a position so the instrumentation extension can pass around the refueling plug.

- c. Capsule irradiation facilities: Variation for these facilities is similar to those for the open loop facilities. Similar design features are to be expected.
- d. Flexible size for irradiation test space: Although the backup design shows a single hex position for each of the open and closed loop tests, it is possible to combine hex positions so that larger tests are possible. Modification to removable structure would permit accommodation of an unforeseen future test need.

The experimenters will need advance information on whether the reference or backup design is to be used for their test design and fabrication. There will be different hardware for the two designs but it is the neutron flux which determines the fuel enrichment for their test and this item may control the lead time required for the experimenter. It is expected that the experimenter will receive essentially the same review to verify the performance of the test irradiation regardless of whether it is for the reference or backup design.

5.3 CLOSED LOOP FACILITIES

The function of the closed loop facility is to provide the means to irradiate an experiment at a known fast neutron flux and in a known and controlled, thermal, and hydraulic environment.

The heat transport circuit for the individual closed loop facility consists of (a) a primary coolant loop which is enclosed so there is no exchange of fluids with the main reactor coolant system, (b) a nonradioactive coolant system to transport the heat to the outside of the containment building, and (c) the final system which dumps heat to the outside air as shown in the conceptual flow diagram, Figure 5-1. The primary loop may be considered as two parts: (a) the closed loop facility tube which is located in the reactor vessel and contains the test irradiation and (b) the out-of-pile portion of the primary loop which is located in the corresponding closed loop equipment cell. The connecting piping between the cell and the facility tube passes through a shielding trench, through the reactor vessel wall, and to the connecting flange located inside the reactor vessel.

The requirements to be satisfied are a combination of those imposed by reactor safeguards, allocation of irradiation capabilities to the experiments, and the satisfaction of experimenter's desires.

Reactor safeguards considerations require that means be provided to protect the reactor and to remove heat from the test in the following events:

- Loss of site power: This is a probable event and the severity of the resulting transient is to be no greater than for the driver fuel.
- Loss of heat removal capability: The probability of this event is to be reduced through design for a high degree of availability in the system and the test irradiation is to be designed to withstand such a transient with no loss of material from the closed loop.

FIGURE 5-1. CLOSED LOOP (FUELS OR MATERIALS RADIATION)

- Loss of coolant flow through the facility tube: This event is a design condition and might be caused by events such as a plug in the test assembly or guillotine failure in the primary closed loop piping. The consequences in this event shall not lead to a penetration of the facility tube for the loop. Shutdown heat is to be removed by heat loss to surrounding main primary coolant.

The major provision for the experimenter is flexibility, i. e., permitting a degree of change through possible modification or replacement of structures.

The typical conditions of interest are:

- a. Irradiation power range: From 2.3 MW maximum fuel down to a materials test only.
- b. Coolant temperature: 800°F inlet/1300°F outlet, with near isothermal irradiations at 700°F, 900°F, 1100°F and 1300°F.
- c. Coolant chemistry: The purity of sodium is to be controllable. Most of the projected conditions require purity comparable to current technology with a maximum of 5 ppm oxygen and 20 ppm carbon above 1000°F.
- d. Sampling: Equipment for providing sodium samples for chemical analysis is to be available.
- e. Interim examination: Emphasis on completing the examination in time to enable further irradiation on the next cycle.
- f. Instrumentation: The information required may be classified according to the location of the sensor elements as follows:
 - Inlet and outlet temperature measurements in the core.
 - Sensors that may be attached to the fuel bundle are fuel thermocouples, pressure sensors, and fuel cladding thermocouples. (It is not planned that this type of instrumentation survives an interim examination.)
 - Measurements that can be taken from the closed loop equipment cell include coolant flow, temperature, and coolant sampling information.
 - Measurements that can be taken from the plant instrumentation include reactor power level as a function of time.
- g. Signals and reactor power reduction for such malfunctions as loss of coolant flow, fuel element failure, and plugged test bundle.
- h. Irradiation availability of 75% on a definite schedule is expected.

In addition to the requirements given, there is the need to provide flexibility in the permanent structure surrounding the closed loop facilities for convenience in making future modifications. This would consist of making space available for equipment additions, provision for personnel access to the cell, and additional cell penetrations that can be obtained through the generous use of cell access plugs.

5.4 DETAILED DESCRIPTION OF CLOSED LOOP PRIMARY LOOP COMPONENTS

5.4.1 Closed Loop Facility Tube

This is regarded as a component in the primary coolant system since it is removable as an entity. The facility tube is to be compatible with the reactor and its internals. This tube is to receive the test assembly, to be the primary coolant piping inside the reactor vessel, and is to provide the heat loss required in the event that the closed loop flow stops.

5.4.2 Closed Loop Pump

The EM pump used in the SEFOR auxiliary loop provides more than adequate flow. It is expected that the closed loop pump duty can be obtained with two such pumps in series to provide the discharge pressure. Undoubtedly a better design could be obtained in a single unit. This type of pump offers freedom from maintenance and wide range for control. Pumping power for emergency cooling is not necessary and would be almost useless for severe accidents.

5.4.3 Intermediate Heat Exchanger

The unit could be similar to the SEFOR unit in the auxiliary loop which is the approximate size needed for the closed loops. It features an all-welded construction in which all welds are inspected to provide a high degree of integrity. It also features a design that provides for extreme transients and emergency conditions.

5.4.4 Loop Coolant Purification Facilities

Equipment is to be provided for the conventional means for cold trapping, making a plugging indicator run, and for hot trapping. Space for the future installation of a hot trap is to be provided for future testing requirements. Since radioactivity is expected to collect in this equipment, means for adding and containing shot shielding is to be provided around each component.

5.4.5 Closed Loop Sampling Provisions

The means to take a sodium sample which can be chemically analyzed for oxygen, hydrogen, carbon, and nitrogen is required. The same type of sample could be used for other chemical and radiochemical analysis since atmospheric contamination would not be a problem. Further samples may be desired from loop cover gas and the main sodium loop piping. Sample ports on the main loop piping and extending through the closed loop shielding may be desired.

5.4.6 Tanks and Piping

A basic requirement for the loop is to provide for complete venting and draining of all piping and components. Horizontal surfaces where the coolant velocity is low are to be minimized in view of the particulate radioactivity that can be expected to accumulate there. The drain tank is to be sized and piped to drain the complete contents of coolant from the primary loop. A head tank is required to provide venting for all high points in the primary system. The main loop piping is to be sloped for both venting and draining and arranged so there is a minimum of stagnate locations and branch piping which is not part of the main loop.

5.4.7 Heaters and Insulation

All piping and components except the facility tube will require electrical heaters and thermal insulation.

5.4.8 Closed Loop Cell Arrangement

The equipment is to be arranged within the cell so entry can be obtained through a removable plug and so working space exists around each component. A preliminary estimate of the total space required in the closed loop cell is 8000 cu ft.

5.5 OPERATION MODES

5.5.1 Initial Fill and Shakedown

Initially a jumper connection is to be used instead of a facility tube, to enable convenient initial closed loop operation almost independent of work in the reactor vessel. The initial fill will consist of the conventional operations of drying, purging with inert gas, heating up, filling and circulation of sodium in the primary loop. The shakedown will consist of the above conventional operations, but it will have greater significance since future testing will probably reduce the contact maintenance time.

5.5.2 Shakedown Operation Including the Facility Tube

This is the closed loop shakedown above but with the facility tube instead of the jumper connection. The shakedown operation is to include installation of, circulation with, and removal of the facility tube. Partial draining of the primary loop will be required whenever the flange connections are to be made or taken apart. Dripping from the flanges is to be expected during such operations, and the procedures involved are to be checked out.

5.5.3 Standby Status for the Loop

It is expected that there will be irradiation periods in which there is no closed loop irradiation to be performed. During such a period, the jumper can be connected to the flanges in the reactor vessel and reactor space used for other purposes. It is not necessary to circulate the coolant in the primary loop during this period, but it is left to the operators' choice to circulate coolant or to drain the loop.

5.5.4 Maintenance Philosophy

The maintenance philosophy for the out-of-pile portion of the closed loop equipment is similar to that for the main coolant loops with the exception that jumper connections may be used instead of the facility tube, thus isolating the loop from the reactor operation. Thus, maintenance work in the closed loop cell is possible with work proceeding nearly independent of reactor operation which enables maintenance work to include loop modification and cleanup for a subsequent user as well as the expected equipment repair work.

5.6 INTERFACE BETWEEN THE REFERENCE AND BACKUP DESIGN

The envelope is complicated because the closed loop piping must take different routes to get to the reactor in the reference and backup designs. Also there is the requirement for venting and draining the closed loop piping over these routes. Because of this complication and because of the inaccessibility of the reactor vessel, the backup closed loop piping vessel nozzles must be installed initially.

The envelope for the gas supply and vent piping is expected to be similar to that for the sodium piping.

The situation for the instrumentation leads is similar to that for the closed loop piping; however, the solution is not as involved. It is reasonable to identify the boundary for this envelope as being a multi-connector plug mounted in the refueling cell. The changeover would consist of replacing the leads from the plug to the facility tube of the loop.

5.7 OPEN LOOP AND OTHER IRRADIATION FACILITIES

The system design requirements to provide the conditions required by the backup design consistent with a feasible design concept is discussed.

The function of the open loop facility is to provide the means to irradiate an experiment at a known fast neutron flux and a known thermal and hydraulic environment using the main primary coolant for the test irradiation. The degree of control of the environment is left to the experimenter's ingenuity within the limits imposed by the available space and the main primary reactor coolant system. The open loop and other irradiation facilities consist of irradiation space in the core and the provisions for bringing instrumentation leads out of the reactor. These leads can be brought out vertically or brought out around the refueling plug to a connector located above in the refueling cell. Many other combinations of instrumentation and control of environment within the test irradiation assembly have been considered.

The requirements to be satisfied are similar to those of the driver fuel, and a maximum flexibility is to be provided for the irradiation in terms of space restrictions imposed by permanent structural members.

The instrumentation leads have different routes in the reference and backup designs. It is reasonable to identify the interface boundary as being a multi-connector plug mounted in the refueling cell. Then the changeover would consist of replacing the lead cable from the plug to the loop as is the case for the closed loop changeover.

SECTION VI

REACTOR PLANT ATMOSPHERE AND RADIATION CONTROL

6.1 INTRODUCTION

The reactor plant access and radiation control system provides a means of controlling access and separating various plant operating areas. The system provides a separation of equipment and operating areas to effectively control contamination and radiation exposure, while providing ready maintenance and access capability. A schematic of this system is illustrated in Figure 6-1.

The broad functions of the system are described in general terms as follows:

- Provide inert atmospheres capability in areas exposed to primary sodium system equipment in order to reduce fire potential.
- Provide control of airborne contaminations to minimize personal exposure consistent with high plant availability and the applicable federal regulations.
- Provide accessibility for equipment maintenance.
- Provide pressure control barriers, adequate ventilation, and cooling.
- Provide proper shielding to allow operation and maintenance to function with minimum disturbance of reactor operation.

In order to satisfy the system functions, the reactor systems have been arbitrarily divided into four functional equipment zones as follows:

ZONE 1

- Clean, uncontaminated air
- Zone unrestricted for personnel access
- Airborne contamination potential low
- Shielding provided allowing unrestricted occupancy
- Pressure maintained at 1 atmosphere.

ZONE 2

- Air atmosphere ventilated
- Probable contamination zone
- Controlled personnel access
- Zone penetrations are sealed
- Pressure doors permit zone isolation
- Ventilation system maintains negative pressure (-1 in. water gauge).

ZONE 3

- Inert nitrogen atmosphere
- Inaccessible during reactor operation; high radiation
- Restricted access during plant outage
- Sealed from Zones 1 and 2 by "inner barrier"
- Pressure maintained slightly positive (~6 in. water gauge)

ZONE 4

- Inert argon atmosphere
- Normally contaminated atmosphere
- Restricted access; occupied by suited personnel on a limited controlled basis
- Access locks provided
- Shielding provided to allow entry during reactor operation
- Pressure maintained slightly negative (-2±1 in. water gauge)

Various classes of equipment are located in the zones listed above. The systems located in these areas are as follows:

ZONE 1

- Normal plant and refueling cell operating stations
- Electrical equipment and control panels, pump drives
- Operating floor and mezzanine

ZONE 2

- Argon coolers and blowers
- Argon purification equipment
- Nitrogen coolers and blowers
- Rad gas waste compressors
- Vent compressors
- Instrument compressor and gas supply

ZONE 3

- Main primary heat transfer system cell
- Closed loop heat transfer system cell
- Sodium storage system
- Fuel storage cooling system

ZONE 4

- Refueling cell and equipment

	ZONE	ACCESS	ATMOSPHERE	DESIGN NORMAL PRESSURE	DESIGN RADIATION LEVEL	FOLD
1.	OPERATING AREA	UNRESTRICTED	VENTILATED AIR	1 DT	<1.0 MR/HR	
2.	SERVICE EQUIPMENT	RESTRICTED	VENTILATED AIR	-1 IN wg	≤ 50 MR/HR	
3.	HEAT TRANSFER CELLS (SODIUM)	RESTRICTED REQUIRES PLANT SHUTDOWN AND 24 DECAY 3. SODIUM DRAIN	NITROGEN	±(1-6) IN wg		
4.	REFUELING CELL	RESTRICTED SUITED ACCESS DURING OPERATION	ARGON	0 ± 6 IN wg	≤ 50 MR/HR	

FIGURE 6-1. BUILDING ATMOSPHERE CONTROL SYSTEM

6.2 DESIGN PHILOSOPHY

General broad design philosophies have been developed to aid in the design.

ZONE 1

- Zone is designed for continuous occupancy. Design of shielding and contamination control barriers shall be consistent with this objective.
- Building ventilation and cooling shall be designed with consideration of the equipment cooling requirements and personnel occupancy.
- The pressure shall be maintained constant at 1 atmosphere. Other systems shall control pressure relative to the building atmosphere.

ZONE 2

- Zone is designed for limited occupancy and possible contamination.
- Zone is air ventilated. Exhaust is directed to rad gas system, or stack.
- Penetrations are sealed. Access doors are pressure tight.
- Local shielding is utilized where required.
- Equipment maintenance is to be performed in general by direct contact.

ZONE 3

- Zone is designed to contain inert nitrogen atmosphere.
- Zone is lined by "inner containment" barrier. Penetrations are sealed.
- Zone is designed for occupancy only with plant shutdown and following appropriate decay period.
- Entrance into primary equipment cell is allowed only following system drain to minimize sodium fire probability.

ZONE 4

- Zone is designed to contain argon atmosphere.
- Zone is designed for controlled limited occupancy during plant operation. Appropriate personnel shielding is provided.
- Negative cell pressure capability is retained to minimize contamination of environment external to cell.
- Double entry lock shall be provided to prevent loss of atmosphere and spread of contamination.
- Cooling and purification system shall be provided to maintain low oxygen content in cell.

6.3 SYSTEM CHARACTERISTICS

Preliminary system characteristics are illustrated in Table 6-1 that represent good design practice.

TABLE 6-1

NOMINAL CONTROL ZONE CHARACTERISTICS

	Control Zone			
	1	2	3	4
Pressure - Operation	1 atm	-1 in. wg	0-6 in. wg	-2±1 in. wg
Radiation Level - Operation	<1 mr/h	<50 mr/h	High	<50 mr/h
Contamination Level Shutdown	None	Low	Low	Moderate
Personnel Access				
During Operation	Yes	Yes	No	Yes
During Outage	Yes	Yes	Yes	Yes*
Ventilation	Yes	Yes	No	No
Access				
Single Barrier		X	X	
Double Barrier	X			X

* No access during fuel movement

6.4 SYSTEM OPERATION

During normal operation the atmosphere in each zone is controlled independently. The zone operating pressure is referenced to Zone 1.

A ventilated, conditioned air atmosphere is maintained in Zone 1. Unrestricted personnel occupancy is expected during power operation and refueling outages.

Zone 2 is an area of potential contamination. Normally this area draws air from Zone 1 and discharges to the rad gas stack. This zone is provided with pressure tight access doors which will allow the region to be isolated or perhaps inerted in the event of unusual contamination or radiation surges. All penetrations are sealed. Equipment in this zone is normally maintained by direct contact. Local shielding may be necessary.

Zone 3 is an area of high radiation and potential contamination. Inert nitrogen atmosphere is maintained to avoid oxygen contamination, thus minimizing the sodium fire potential. Entry into the heat transfer systems is possible after reactor shutdown, sodium-24 decay, draining and cooling of the particular system. During system maintenance, temporary enclosures are provided for contamination control.

Zone 4 is maintained as a highly pure argon atmosphere. Contamination is expected in this region and high radiation sources may be present during fuel transfers or when the reactor head is removed. Entry into Zone 4 is possible during plant operation utilizing protective "space suits." A double entry lock is provided to avoid loss of cell argon or spread of contamination. Pressure in the cell is controlled slightly less than Zone 1 to minimize spread of contamination.

Since the atmosphere and radiation control system is largely passive, little maintenance is required. Automatic controls are supplied for pressure and ventilation control in the various systems. These devices are located in accessible regions (Zone 1, 2) where maintenance may be performed without affecting plant operation.

System operation has little or no effect upon plant availability. Failure of automatic controls for the various atmospheres will not normally result in plant outage since they can be operated manually. Seals between barriers are tested and repaired during normal containment testing periods. However, careful attention must be given to proper equipment location during the design phase. Effort must be made to locate controls, instrumentation transducers, and rotating equipment outside of Zone 3 in an accessible area as Zone 2.

The reference design is responsible for all structure, hardware, and equipment associated with the control of atmospheres, radiation, and contamination control.

SECTION VII

RADIOACTIVE GAS WASTE SYSTEM

7.1 INTRODUCTION

The purpose of this section is to discuss design objectives for the FFTF Rad Gas Waste System. The radioactive gas waste system provides disposal of gaseous wastes generated during plant operation. The functions of the system are:

- Eliminate direct release of radioactive material, providing retention and storage capabilities.
- Provide a controlled release process which is monitored and will not release activity in excess of the allowable biological limits of 10CFR20 under normal circumstances.

7.2 DESCRIPTION

The radioactive gas waste system concept depends primarily upon the expected release rates of activated gaseous material from the reactor systems. It is anticipated that the system will be operated on the principle of holding up the radioactive material for a specified decay period, then releasing the gas in a controlled manner to the stack. As the gas passes upward, it is diluted and then dispersed to the atmosphere.

Safety instrumentation and monitoring equipment is provided to ensure against an uncontrolled release of radioactive material. Prior to proceeding with the system design, it is necessary to define the expected fission product release rates, consideration of vented fuel, and possible future requirements.

The various sources of radioactive gas are tabulated below:

- Areas vented to decay tanks
 - Reactor vessel cover gas
 - Drain tank cover gas
 - Fuel storage tank cover gas
 - Refueling cell-transfer lock
 - Closed loop cover gas
 - Sodium system vent tank
 - Nitrogen cell vents
- Ventilated areas to stack
 - Reactor auxiliary equipment cells
 - Argon recirculation, cooling and purification
 - Nitrogen cooling system
 - Instrument nitrogen
 - Radwaste systems

7.3 INTERFACE

The reference design is responsible for all structure outside the reactor vessel involving the radioactive gas waste system. The backup design is responsible for the reactor gas vent and refueling cell gas vent hardware description.

The backup design is also responsible for estimating the following:

- Reactor Fuel: Expected release rates from driver core. Consideration of vented core.
- Reactor Cover Gas: Expected leakage rates; expected feed and bleed rates. Refueling purges required.
- Argon Refueling Cell: Expected gas activity; feed and bleed requirements; maintenance activities requiring change of atmosphere.

SECTION VIII

SAFETY TANK AND COOLING SYSTEM

8.1 INTRODUCTION

The purpose of this section is to establish and set forth design objectives and present design data sufficient to describe the conceptual design and provide information sufficient to proceed with the preliminary system design phase.

The safety tank system is utilized as a safety structure to assure containment of sodium, core coverage, and core cooling, following vessel rupture and loss of the main heat transfer system.

The specific functions of the safety tank system are:

- Provide containment of sodium coolant following a leak in the reactor vessel, maintaining the level so the coolant supply to the core is not interrupted and that the core damage criteria is satisfied.
- Provide containment of sodium coolant and core debris following the DBA.
- Provide core cooling following the DBA. Remove heat generated by fission products.

8.2 SUMMARY SYSTEM DESCRIPTION

The safety tank and cooling system are located outside of the reactor vessel. The safety tank is placed outside the blast shields and crush structure. A gap is retained between the blast shield and the tank which allows the shield to deform elastically under the DBA blast forces without interfering with the function of the safety tank. Likewise, the crush structure beneath the reactor is designed to allow compressive loads to be transmitted to the safety tank without excessive forces being generated.

The tank is an austenitic stainless steel cylindrical vessel supported from the bottom, extending upward to the minimum coolant level. The inlet and outlet coolant piping may be doubly contained from the point of penetration upward to above the minimum coolant level. The concept utilizes a secondary containment guard pipe surrounding the main coolant lines.

The tank is a free standing, unsupported unit. However, the outside surface is backed up by the dense concrete shielding structure which provides support of the tank wall for any short duration pressure transients resulting from the DBA excursion.

The flat bottom tank is supported from the concrete substructure and is allowed to expand upward, the upper flange of the safety tank being unrestricted. A flexible continuous seal is made between the cell liner and the safety tank flange. The liner then extends outward to the heat transfer cells and provides a gas leakage barrier.

Tank cooling is provided by NaK filled cooling coils extending down the tank wall and across the bottom. The cooling coils have the cooling capability to remove fission product decay heat following the DBA and maintain the surfaces of the tank within reasonable temperature limits.

Cooling coils along the bottom of the tank should be protected by a material with a high melting point and good thermal conductivity. The material for this application has not been selected. However, B_4C is under consideration and has promising characteristics.

The cooling system is designed with three independent circuits in the safety tank. These are connected to a common header outside in an accessible area. Figure 8-1 illustrates the cooling system concept. NaK is used in this concept but other fluids might be considered. The electromagnetic pump takes suction from the expansion tank in the cold leg and discharges to the cooling coil header. Coolant returns through the cooling system intermediate heat exchanger, expansion tank, to the pump section. A secondary system is provided which rejects heat to the atmosphere outside the containment. In addition, fill and drain tanks are provided for the primary and secondary systems.

8.3 SAFETY CRITERIA

- a. The fuel damage sustained following a reactor vessel or nozzle rupture accompanied by scram shall be within the "improbable accident limit" as defined by the "fuel overpower damage severity criteria." This limit requires that the peak local cladding temperatures be within 1500°F. The safety tank system shall be designed in keeping with these limitations.
- b. The safety tank shall be designed to contain a major portion of the fuel-fission product conglomerate following the design basis accident.
- c. The safety tank cooling system shall be designed to remove decay heat from the fuel-conglomerate following the design basis accident. The cooling system shall be designed to prevent a pressure increase within the "inner containment" envelope greater than the design pressure, which would result in an increased release of fission products in excess of the established allowable limit.

8.4 DESIGN REQUIREMENTS

The design requirements are based upon the safety criteria, AEC regulatory practice, and conservative design philosophy.

- a. The net free volume between the safety tank and reactor vessel shall be designed to be equal to or less than the volume of coolant above the "minimum coolant level." This level is above the reactor outlet nozzles in the backup design.
- b. The energy absorbing structure surrounding the reactor vessel shall be designed so excessive loads are not transmitted to the safety tank during the DBA.

LEGEND - INSTRUMENTATION

T - TEMPERATURE

F - FLOW

L - LEVEL

FIGURE 8-1. SAFETY TANK COOLING SYSTEM

- c. The safety tank design shall be consistent with the expected transient temperature and pressure conditions expected during either a sodium leak or DBA excursion.
- d. The safety tank cooling system shall be designed for continuous operation. The cooling system shall be designed to provide sufficient cooling to the tank to prevent gross sodium boiling following the DBA excursion. The cooling system shall be protected from effects of the blast.
- e. Inspection: The design shall allow component inspection and maintenance during the service life.
- f. Design life shall be 20 years.
- g. Structural codes for vessel and piping:
 - ASME Boiler and Pressure Vessel Code, Section III, Class C.
 - ASA Code for Pressure Piping.
 - Uniform Building Code.
- h. Design to accommodate expected seismic loads.
- i. Standards: ASTM standards for materials.
- j. Federal Regulations: The following federal regulations shall be followed in the design:
 - "General criteria for nuclear power plant construction permits" proposed Regulation 10CFR50.
 - AEC Regulations 10CFR20 and 10CFR100.

8.5 SYSTEM CHARACTERISTICS

The backup design safety tank and cooling system have the nominal characteristics shown in Table 8-1.

8.6 SYSTEM AVAILABILITY

Availability of the safety tank and cooling system must be very high. System failure could result in a plant shutdown, and attention must be given to providing redundancy and highly reliable systems. The following items either were utilized or should be considered to increase the cooling system effectiveness:

- a. Three independent coolant circuits are provided within the safety tank. Two of the circuits are capable of removing the heat load at design conditions.
- b. Elimination of valves in the system should increase availability.

TABLE 8-1

NOMINAL SAFETY TANK AND COOLING SYSTEM CHARACTERISTICS

	<u>Design Condition</u>	<u>Operating Condition</u>
Safety Tank		
Temperature	1200°F	150°F
Pressure	40 psig	0-20 psig
Thermal Transient		
No. of Cycles	1	
Temperature Change	1050°F (instantaneous)	
Material	304 stainless steel	
Safety Tank Cooling System		
Heat Removal	10 MW	-
Flow	1000 gpm	1000 gpm
Temperature (ΔT)	400/1200°F	150°F
Coolant	NaK	

-
- c. Use of NaK provides good thermal properties and avoids use of heaters and excess instrumentation.
 - d. Use of redundant pumps and air cooler fans should be considered.
 - e. Access to the cooling system components is required.

8.7 COMPONENT DESCRIPTION

The concept of each system component is described in a brief and general way.

8.7.1 Safety Tank

The safety tank is a 304 stainless steel cylindrical vessel about 20 feet in diameter and 28 feet long. The flat bottom vessel rests upon reinforced concrete substructure and is backed up by concrete structure along its length. It is intended that the concrete backing prevent excess loads from being transmitted to the tank during the DBA excursion.

Reactor inlet lines penetrate the safety tank near the bottom of the vessel. Guard piping extends around the pressure piping, then upward to the top flange on the safety tank.

The safety tank is fabricated and inspected in accordance with ASME Pressure Vessel Code, Section III Nuclear Vessels, Class B.

8.7.2 Safety Tank Cooling Coils

The tank cooling coils are 1-inch diameter tubes installed within the tank sides and bottom surface. The coils are sized to remove about 10 MW of heat with a 300°F ΔT . Larger heat loads can be accommodated with a larger temperature drop. The system is designed for a maximum of 1200°F operation with an 800°F ΔT . The coils are located near the tank wall and serve to protect the tank surface from excessive temperature. Three independent cooling circuits are provided.

8.7.3 Safety Tank "Meltdown Tray"

Cooling coils along the bottom surface of the tank are imbedded in a protective "meltdown tray." The purpose of this device is to prevent the post DBA fuel-steel conglomerate from penetrating the safety tank barrier and breaching containment. Other high temperature melting point ceramic materials may be more appropriate and should be considered.

8.7.4 Safety Tank Primary Coolant System

- Heat Exchanger:

The heat exchanger is a tube and shell unit designed for 1200°F operation, 1000 gpm flow, and a 100°F mean temperature difference.

- Pump:

An electromagnetic pump provides increased system reliability and minimizes penetrations. The pump takes suction on the expansion tank and provides 1000 gpm flow.

- Drain Tank:

A drain tank is provided which will contain the system coolant volume during maintenance intervals.

8.7.5 Safety Tank Secondary Coolant System

- Air Cooler:

The air cooler is a single unit capable of operating at 1100°F hot leg, with 300°F cold leg, at 1000 gpm flow. Consideration should be given to utilizing the natural draft through the gas rad waste stack to provide cooling. This would increase the system reliability.

- Pump:

The pump is similar to the primary cooling system. It is located external to the containment in an accessible zone.

- Drain Tank:

The drain tank contains the coolant system volume and is connected to the system through a single transfer line and valve.

8.8 PRINCIPLES OF OPERATION

8.8.1 Safety Tank

The safety tank is normally maintained near ambient temperature by the cooling system within the tank. Cooling coils imbedded within the surrounding concrete shield provide additional cooling and maintain the concrete within prescribed limits. Normal tank pressure is maintained near 1 atmosphere. The safety tank is designed to provide containment in the event of a single failure such as a vessel leak or DBA excursion. In the event of a vessel rupture, the safety tank contains the coolant and provides core coverage. Volumes between the upper plenum and safety tank are arranged to maintain the coolant level above the outlet nozzle penetrations. The tank is designed to sustain one cycle of thermal shock of 1200°F coolant filling the vessel.

8.8.2 Cooling System

The safety tank cooling system is normally maintained in operation at low flow during plant operation. Flow is maintained through the primary and secondary systems, and the air cooler louvers are throttled to minimize heat losses. In the event of vessel leakage or a DBA excursion, full flow is established and control instrumentation maintains the cold leg temperature at a preset level. Power to the cooling system is supplied by the emergency power supply system.

8.9 SYSTEM REPAIR, MAINTENANCE AND INSPECTION

General inspection, repair, and maintenance guidelines have been developed to aid in the design. Consideration must be given to the system design so the safety tank and associated cooling system are accessible for repair. Maintenance, inspection, and repair techniques need to be developed in coordination with the design effort.

8.9.1 Safety Tank

8.9.1.1 Inspection and Testing

The vessel shall be fabricated and inspected in accordance with Section III of the ASME Boiler and Pressure Vessel Code. Under normal circumstances the vessel is unloaded and maintained under atmospheric pressure and ambient temperature conditions. Inert gas with low moisture content is retained on both surfaces of the vessel. During the service lifetime, no significant deterioration of the vessel is expected.

Because of the high integrity of the vessel manufacture and the nominal conditions expected during plant operation, no post operational testing or inspection is required provided there is no deterioration of the vessel. Long term deterioration will be monitored by exposing material samples to the vessel atmosphere and radiation environment and periodically removing these sample tabs for examination.

A pressure test of the safety tank can be performed periodically as a regular part of the testing program, if desirable.

8.9.1.2 Repair and Maintenance

No repair or maintenance is required since the safety tank is a passive, unloaded system. Access ports are available, however, at certain locations around the vessel, and these could serve for repair and maintenance functions in the unlikely event that it should be necessary.

8.9.2 Safety Tank Cooling System

8.9.2.1 Inspection and Testing

The systems external to the reactor are inspected in the same manner as the primary heat transfer system. The secondary systems are readily accessible and are located outside containment. The primary system may be inspected following decay and drainage of the system. Piping may be visually inspected by removing insulation up to the point where it enters the reactor cavity.

The cooling system region within the reactor cavity is generally not accessible for inspection. However, access ports in the shielding above the loop piping are available for semi-remote inspection of selected areas.

8.9.2.2 Repair and Maintenance

The system requires very little maintenance. Use of redundant instrumentation sensors and leads provides high system reliability. System maintenance in the secondary system is readily achieved by direct contact. Maintenance in the primary system may be performed following a 2 week decay period. The cooling coils within the reactor cavity are not accessible. However, the use of redundant cooling loops external to the cavity will permit continued plant operation in the unlikely event of a single tube failure. Access ports above the inlet and return headers allow semi-remote access to the reactor cavity and safety tank cooling system.

8.10 INTERFACE

The reference design is responsible for all structure outside of the reactor vessel including the safety tank post DBA cooling, meltdown trays, and energy absorbing structure external to the core.

SECTION IX

ARGON SUPPLY SYSTEM

9.1 INTRODUCTION

The purpose of this section is to describe and set forth the design objectives of the Argon Supply System.

The backup argon supply system is specifically designed to perform the following functions:

- Provide a source of continuous inert gas blanketing of every sodium free surface.
- Provide argon pressure for the motivating source for sodium transfers from the transfer tank, primary drain tank, and secondary drain tank to appropriate parts of the sodium system.
- Provide argon gas for the refueling cell atmosphere.
- The completed system shall be capable of accomplishing desired operations such as transfers and system filling within reasonable time periods.
- Provide the capability of purging the reactor cover gas to remove radioactive cover gas or nitrogen.
- Provide for remote and local operation and control of the argon supply to the primary system.
- Supply argon for filling, venting, and other use requirements of the primary argon system services.

9.2 SYSTEM DESCRIPTION

A representative supply system consists of an argon supply station consisting of two industrial liquid argon storage and supply units connected in parallel with the necessary regulators, valves, and controls. The system is designed so two separate and simultaneous failures must occur before the complete plant argon supply is lost. In addition to the supply station, a direct line from the supply station area to the refueling cell is provided to receive large volumes of argon gas from a tank truck to facilitate infrequent refueling cell purges.

From the outdoor supply station, the argon passes into the argon supply purifier that is provided to assure the argon gas distributed throughout the plant is dry and of low oxygen content to prevent oxidation of the sodium or NaK in the various liquid metal systems. The argon then enters the distribution header which passes through the reactor containment vessel to supply argon for the primary and secondary liquid metal systems cover gas and the refueling cell. A preliminary list of argon services for the primary sodium system and the refueling cell is shown in Table 9-1. Figure 9-1 is a simple schematic, illustrating the argon supply system.

TABLE 9-1.

ARGON SYSTEM PRIMARY SERVICES

<u>Service</u>	<u>No.</u>	<u>Argon Supply Pressure (psig)</u>	<u>Operating Pressure (psig)</u>
Reactor Vessel Cover Gas	1	30	0-3
Primary Sodium Pump Cover Gas	3	30	0-15
Primary Sodium Drain Tank Cover Gas	2	30	0-15
Fuel Storage Tank Cover Gas	6	30	0-1
Refueling Cell Control Panel	1	100	0-100
Refueling Cell Argon Supply	1	30	0-15
Fuel Transfer Cell	1	30	0-15

9.3. SYSTEM DESIGN REQUIREMENTS

The basis for the design and selection of the argon supply system are described below (the criteria listed represent good design practice):

- The argon system piping shall be fabricated, erected, and tested in accord with the Code for Pressure Piping, ASA-B31.1, Section 2.
- Tanks, vessels, and vapor traps within the system shall be fabricated, erected, and tested in accord with the ASME Code for Unfired Pressure Vessels, Section VIII.
- An adequate reserve supply of argon for 2 weeks of plant operation at maximum emergency demands shall be available at all times.
- Flanged joints shall be kept to a minimum and only used where necessary for connections to equipment.

FIGURE 9-1. P&ID ARGON SUPPLY SYSTEM

- The argon gas shall be dry and of low oxygen and other impurity content to prevent oxidation of sodium. Table 9-2 gives typical values.
- The design target for system availability shall be consistent with the 1% availability target for the auxiliary system.
- The system shall be designed for a service life of 20 years at full capacity.

TABLE 9-2

ARGON COMPOSITION

<u>Analysis</u>	<u>Guarantee</u>
Argon	99.995%
Oxygen	less than 0.001%
Hydrogen	less than 0.0002%
Nitrogen	less than 0.004%
Methane	less than 0.0002%
Carbon Monoxide	less than 0.0001%
Carbon Dioxide	less than 0.0002%

9.4 SYSTEM CONCEPT SELECTION

The following information provides the basis for the selection of argon for use in a cover gas and for the refueling cell atmosphere for the lockup concept.

9.4.1 Corona Losses

Both argon and helium are worse than air for corona losses, but argon is preferred of the two. This property affects the electrical equipment in the cell, and experience with both EBR-II and SEFOR cell atmosphere have demonstrated equipment operating experience in an argon atmosphere.

9.4.2 Heat Conductivity

Helium has the greater conductivity, but both gases have nearly equal heat capacity per unit volume. This property is a consideration in fuel handling after the fuel is removed from the tank, but does not appear to be a controlling consideration for either gas.

9.4.3 Gas Leakage

Both gases will have handling losses, but losses for argon being less for orifice and capillary leaks.

9.4.4 Purity

Both gases can be obtained commercially at a very high purity. Hydrocarbons are a source impurity for helium, and nitrogen is the source impurity for argon. The atmosphere in the refueling cell is reprocessed to remove oxygen impurity obtained from the in-leakage of air with an NaK bubbler. A chemical system to remove impurities is also under consideration. The nitrogen impurity in the reference design is to be controlled by a feed and bleed system with periodic cell purges. However, if it is determined that continuous removal of nitrogen is necessary, chemical purification equipment is available which will reduce the impurity level in either argon or helium systems to less than 3 ppm.

9.4.5 Availability

Argon is produced from air and independent suppliers exist. Helium is produced from natural gas and its use is often restricted.

9.5 DETAILED COMPONENT DESCRIPTION

A description of the major components, instrumentation, and services of the supply is provided in this section.

9.5.1 Argon Supply Station

The argon supply station consists of two industrial liquid argon storage and supply units, with the necessary regulators, pressure relief valves, and controls, connected in parallel. This duplex supply system is designed to alarm on low supply pressure and low supply level. The supply station is located outside the containment building and is readily accessible for maintenance, replacement, and deliveries of liquified gas by transport truck. The gas supply pressure delivered to the distribution piping is 100 psig. Pressure reduction will be made as required throughout the distribution piping as determined by the system requirements.

In addition to the supply station described above, a separate, direct line from the supply station area to the refueling cell is provided to receive additional gas under special situations, such as refueling cell purges. This supply line bypasses the argon purification system, is normally locked shut, and is sized for 25,000 cu ft/h.

9.5.2 Argon Supply Purifier

The argon purification unit consists of a purification tank, a backflow trap, and a demister tank. The purification tank removes oxygen and other impurities by passing the argon through NaK. The purifier contains a bed of pall rings in NaK to assure adequate liquid upon contact. The demister tank is sized to hold the NaK volume in the purifier to prevent NaK from entering the cover gas streams. The demister tank is located downstream of the purifier tank and is equipped with a wire mesh demister. The backflow trap, located upstream of the purifier, is provided to prevent NaK discharge in the event of a pipe break and consists of an empty tank large enough to contain the NaK in the purifier. The differential pressure across the purifier is indicated locally to show when the purifier becomes clogged. A flow recorder is located

downstream of the purifier to measure plant argon consumption. A pressure indicator with low pressure alarm is also located downstream of the purifier to indicate loss of supply pressure.

9.5.3 Argon Supply to Primary System

The argon supply header distributes one portion of the supply argon through the reactor containment vessel to supply argon for the primary liquid metal systems' cover gas and for the refueling cell purge.

Pressure regulating and control stations are to be located in accessible areas and are equipped with block valves and a bypass. The number of penetrations into the nitrogen and argon cells are to be minimized. A local pressure indicator and a pressure relief valve are located downstream of each header pressure regulating station.

The supply of argon to a given primary sodium vessel is controlled by an on-off diaphragm operated valve which is actuated by a pressure or level control instrument. The argon control valves are equipped with position indicators and have block valves on either side for maintenance. A pressure indicator with a low pressure alarm is located downstream of the valve to indicate the vessel operating pressure.

9.5.4 Argon Supply to Secondary System

Argon supply for the secondary system is not covered by the backup concept and the responsibility for supplying argon to the secondary system is left to the reference designer.

9.6 PRINCIPLES OF OPERATION

9.6.1 Startup

Upon completion of construction of the primary sodium system or after prolonged maintenance which necessitated draining of the system, the air is purged from the system by introducing argon from a low point in the system and venting the displaced air from a high point in the system. The argon for this operation may be supplied by a tank truck or railroad car supply. The argon supply station will begin operation when this initial filling is completed.

9.6.2 Normal Operation

Normal operation of the supply system will perform the following functions for the service areas listed on Table 9-2.

9.6.2.1 Reactor Vessel Cover Gas

Argon will provide a static blanketing or a continuous purge of the space above the primary sodium level in the reactor vessel. Capability for purging requires inlet and outlet lines to be provided on the reactor vessel. Operating pressure will be automatically controlled to ± 10 inches water gage.

9.6.2.2 Primary Sodium Pump(s)

Argon will be provided to maintain a gas space between the sodium free surface in the pump and the pump-seal unit to maintain sodium level.

9.6.2.3 Primary Sodium Drain Tank(s)

Argon provides an inert cover gas for the free sodium surface in the tank(s). Argon gas pressure is used as the motivating force for sodium transfers from the tank(s) to appropriate parts of the sodium system.

9.6.2.4 Fuel Storage Tank(s)

Argon will provide static gas blanketing or continuous purge of the space above the fuel storage tank sodium level. The argon cover gas will be purged prior to removing the heads for access. The purge will consist of about 5 volumes of cover gas which is vented to the gaseous radwaste system.

9.6.2.5 Refueling Cell Argon Supply

The refueling cell argon supply is necessary to provide argon to make up cell and systems argon leakage when operating at a positive pressure.

9.6.2.6 Fuel Transfer Cell Supply

The fuel transfer cell is tentatively provided with an argon atmosphere to accommodate removal of fuel and equipment from the refueling cell with the least effect on the operation of the refueling cell.

9.6.2.7 Vessel Head Cooling Supply

Argon gas is supplied to the vessel head cooling system which circulates argon through the vessel head to keep the vessel head at required temperature.

9.6.2.8 Reflector Control Rod(s)

The present design of the seals for the reflector control rods requires a continuous supply of argon gas flowing by the seals to maintain proper sealing at the control rod shafts.

9.6.3 Shutdown Operation

The argon supply system will continue to supply inert cover gas for the sodium systems during a normal shutdown. Supply may be valved off to a particular area when maintenance or repair is required. The area is then purged to regain an air atmosphere, and the maintenance is performed. Upon completion, the supply system will supply argon to the area until the desired argon atmosphere is attained and the operational conditions are reestablished.

9.6.4 Refueling Operation

During refueling, argon supply to the reactor vessel and fuel storage tanks is thoroughly purged and the gas pressure equalized before the heads are removed. The supply to these vessels is stopped until the refueling operation is completed, and the heads are replaced on the vessels. The refueling cell argon will act as the cover gas for the vessel and tanks during refueling.

9.6.5 Emergency Operation

Following a reactor scram condition, argon supply will continue to provide cover gas for the sodium systems. Isolation valves in the supply lines are activated when a leak is detected in the sodium piping or components to prevent additional discharge of sodium due to the argon pressure. Check valves in the argon supply lines prevent backflow and loss of argon from the sodium system should a failure occur in the supply system or piping.

9.7 SYSTEM AVAILABILITY AND MAINTAINABILITY

To ensure that the high system availability targets are met, consideration must be given to the system design, repair, and maintenance functions. The following criteria has been adopted to meet these targets:

- System components shall be designed for low-frequency replacement. A 20-year design life should be used for most equipment.
- Equipment shall be located to allow for maximum accessibility for inspection and maintenance.
- Spare parts inventory should be sufficient to cover 1-year's operation. Particular attention should be given to items which are known to require periodic replacement.
- System components will be of standard design and construction with emphasis toward availability of replacements.
- Procedures will be established for a failure reporting system that will provide means to upgrade faulty equipment.
- A system availability and failure mode and effects analysis is to be performed during design phase to correct system deficiencies.
- Design target unavailability for the auxiliary systems is 1.0%.

9.8 INTERFACE

Responsibility for the design of the argon supply system lies with the reference designer. The Argon System Primary Services were given in Table 9-1. The backup design requires certain safety and design features at the interface (Table 9-3).

TABLE 9-3

SAFETY AND DESIGN INTERFACE FEATURES OF
THE ARGON SUPPLY SYSTEM

<u>Item</u>	<u>Responsibility</u>
Argon Supply Station	
Design	Reference
Requirements	
Pressure	Backup
Storage Capacity	Backup
Use Rates	Backup
Argon Supply Purifier	
Design	Reference
Requirements	
Temperature	Backup
Pressure	Backup
Capacity	Backup
Primary System Argon Users	Backup
Secondary System Argon Users	Reference
Safeguards Criteria	Backup
Refueling Cell Argon Requirements	Backup

The structure and hardware which make up the system infer responsibility for design, procurement, and installation.

- The reference design is responsible for all structures and locations to accommodate the installation of the argon supply system equipment.
- The argon piping and penetrations required for the refueling cell argon supply are the responsibility of the backup design.
- Argon system connections for filling, venting, and purging shall be located and sized in accordance with the requirements of the backup design.

SECTION X

ARGON RECIRCULATING SYSTEM FOR REFUELING CELL

10.1 INTRODUCTION

The purpose of this section is to establish design objectives and present pertinent data sufficient to describe the conceptual design, establish the backup reactor system design requirements, and describe the interface relationships.

In order to circulate cooling argon in the cell, a large capacity, forced circulation, cooling system provides heat removal and gas cooling. A separate pressure control system is operated in conjunction with the gas cooling system to attain required pressure levels to preserve cell argon, to provide makeup for cell leakage, and to control pressure during temperature transients.

The argon recirculating system should be designed to meet the following functional requirements:

- Provide adequate cooling capacity and controls which will maintain the refueling cell temperature below 120°F.
- Supply adequate cell pressure control equipment which will control the cell pressure from +6 to -6 inches of water differential pressure relative to the containment building.
- Provide the capability of maintaining adequate pressure control during cell temperature changes of up to 40°F.

10.2 SYSTEM DESIGN REQUIREMENTS

- The system shall be capable of maintaining the cell temperature below 90°F during man access operations.
- Upon detection of radioactive gas in the cell, the pressure control system shall be capable of operating the cell at negative pressure to minimize gas outleakage.
- Normal operation will be at a slightly positive pressure to prevent nitrogen in-leakage.
- System design shall not preclude adjustment and maintenance of the components during normal operation.
- The code requirements for the system are:
 - ASME Code for Pressure Piping, B31.1, Section 2.
 - ASME Boiler and Pressure Vessel Code, Section VIII.
- The system shall be designed for a service life of 20 years at full capacity.
- Preliminary estimates of system requirements are outlined in Table 10-1.

TABLE 10-1

ARGON RECIRCULATING SYSTEM FOR REFUELING CELL

Cooling Loop Flowrate	~11,500 scfm/loop 60,000 lb/h
Cell Temperature	
Design	<150°F
Operating	80°F to 120°F
Cell Pressure (Range)	-6 in. to +6 in. H ₂ O
Cooling Heat Load	~600,000 Btu/h

10.3 DETAILED DESCRIPTION

10.3.1 Refueling Cell Cooling System

The cell cooling system is comprised of two argon cooling loops. Each loop is capable of removing one-half of the heat load generated by the cell. The estimated cell heat loads are tabulated in Table 10-2. Each circulating loop consists of a duct system to and from the cell, an argon cooler, and a circulating argon blower.

10.3.2 Argon Cooler

The argon coolers are self contained, automatic unloading, reciprocating refrigeration units with the capacity to remove up to 300,000 Btu/h at a flow rate of 12,000 scfm. Each refrigeration unit is controlled independently and is operated as required by the argon cell pressure controller and associated instruments. The proposed coolant is Freon-12.

The blower shall be of standard design and will be used to recirculate argon gas through a cooler, filter, and refueling cell as required by plant operating characteristics. The blower shall be of the nonoverloading type with the capability of continuous operation and shall be of substantial construction to eliminate vibration and unnecessary noise.

10.3.3 Refueling Cell Pressure Control System

The refueling cell pressure control system consists of an argon reservoir tank (surge tank), an argon compressor, and the necessary valves and equipment to provide cell pressure control and safety relief. The system is designed to maintain cell pressure within allowable pressure ranges under normal cell temperature changes of 10°F.

TABLE 10-2

REFUELING CELL HEAT LOADSLoads During Refueling

Sodium Pool (16 ft head removed at 400°F)	
Convection	15.1 kW
Radiation	7.6 kW
Cell Lighting	99.0 kW
Fuel Storage and Decay Tank	5.8 kW
Miscellaneous Refueling Equipment	13.0 kW
Cell Cooling Required	140.5 kW

Load During Plant Operation

Cell Lighting	99.0 kW
Miscellaneous Equipment	13.0 kW
Cell Cooling Required	112.0 kW

Adding 25% for contingency = $(140.5) (1.25) = 175 \text{ kW}$

Cooling Load Required = $175 (3413) = \underline{\underline{600,000 \text{ Btu/h}}}$

Under normal operation, the system provides for continuous makeup and bleedoff of the cell argon to and from the argon reservoir tank in order to maintain the required cell pressure. In addition, the system conserves the cell argon by storing the portion bled from the cell in the reservoir tank rather than venting the gas. The stored gas can then be returned to the cell when argon must be added to maintain cell pressure. The system also provides an ideal location where make-up argon can be fed into the cell without the need of an additional cell penetration.

10.3.4 Argon Reservoir Tank

The argon reservoir tank shall be constructed of carbon steel and designed, constructed, inspected, and stamped in accordance with the applicable requirements of Section VIII of the ASME Boiler and Pressure Vessel Code.

10.3.5 Argon Compressor

The argon compressor is used to compress the excess argon from the cell for storage in the argon reservoir tank. The compressor shall be of standard design for the service contemplated.

10.4 PRINCIPLES OF OPERATION

The cell cooling and pressure system will be set to maintain the required temperature and pressure upon completion of cell inerting. Under normal operation, two cooling loops will remove the heat loads from the cell.

During reactor shutdown the loops will be capable of operation at rates commensurate to the change in cell heat load. The use of multiple cooling loops ensures the system against total loss of argon circulation in the event of failure in a blower or cooler.

10.5 AVAILABILITY AND RELIABILITY REQUIREMENTS

The following principles were used to establish the criteria for the system reliability and availability:

- No single failure in a component of the system will affect the operation of the reactor.
- No single failure may propagate to other systems to impair the operation of other systems or their components.

Some of the major areas of the recirculating system which were considered in the design are discussed below:

- Two independent cooling loops are provided for the cell cooling system. In this manner, a failure in any one loop would allow the system to operate up to 1/2 capacity while repairs are completed.
- Pressure control can be maintained by filling from the argon supply station and venting to the building ventilation or radwaste system in the event of failure of the pressure control system without affecting reactor operations.
- Isolation valves are provided on all major components to provide for ease in maintenance and leak protection.
- System components will be of standard design and construction wherever possible with emphasis directed toward availability of replacement parts in the selection of system components.

System unavailability target is 1%.

10.6 MAINTENANCE

Capability for inspection and repair of any of the system components should be provided in the design. Emphasis should be placed on locating equipment in the air zone wherever possible.

The components shall be designed and located to allow for ease in replacement. Spare parts inventory should be sufficient for 1-year's operation.

REFUELING CELL HEAT LOADS

The multiple loops for the cooling systems allow for partial cooling in the event that a breakdown occurs in one of the loops.

10.7 INTERFACE Medium Pool (16 ft head removed at 400°F)

Convection	15.1 kW
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The structure and hardware which make up the system infers responsibility for design, procurement, and installation.

Cell Lighting	99.0 kW
---------------	---------

- The reference design will provide the cell structure and facility necessary for installation of the backup argon recirculation system.

5.8 kW

- The backup design will determine the sizes and capacities of the equipment and ducting for the system.

Cell Cooling Required	140.5 kW
-----------------------	----------

Load During Plant Operation

Cell Lighting	99.0 kW
---------------	---------

Miscellaneous Equipment	13.0 kW
-------------------------	---------

Cell Cooling Required	112.0 kW
-----------------------	----------

Adding 25% for contingency = $(140.5) (1.25) = 175 \text{ kW}$

Cooling Load Required = $175 (3415) = \underline{\underline{600,000 \text{ Btu/h}}}$

Under normal operation, the system provides for continuous makeup and bleedoff of the cell argon to and from the argon reservoir tank in order to maintain the required cell pressure. In addition, the system conserves the cell argon by storing the portion bled from the cell in the reservoir tank rather than venting the gas. The stored gas can then be returned to the cell when argon must be added to maintain cell pressure. The system also provides an ideal location where make-up argon can be fed into the cell without the need of an additional cell penetration.

10.3.4 Argon Reservoir Tank

The argon reservoir tank shall be constructed of carbon steel and designed, constructed, inspected, and stamped in accordance with the applicable requirements of Section VIII of the ASME Boiler and Pressure Vessel Code.

10.3.5 Argon Compressor

The argon compressor is used to compress the excess argon from the cell for storage in the argon reservoir tank. The compressor shall be of standard design for the service contemplated.

SECTION XI

ARGON PURIFICATION SYSTEM FOR REFUELING CELL

11.1 INTRODUCTION

The purpose of this section is to establish design objectives and present pertinent data sufficient to describe the conceptual design and establish the backup reactor system design requirements.

The argon purification system is designed to meet the following functional requirements:

- Provide continuous filtering and controlling of the oxygen and moisture content of the refueling cell gas.
- Purify the refueling cell argon to remove impurities such as sodium aerosols, carbonaceous materials, halogen fission products, and particulates.
- Monitor cell argon for gamma and alpha radiation.
- Reduce impurities in the argon gas to prevent them from entering the sodium system.
- Monitor nitrogen concentration in the argon to ensure that it is below the allowable 5 vol %.

11.2 SUMMARY DESCRIPTION

To reduce impurities from entering the sodium system, provisions are made for the continuous filtering and controlling of the oxygen and moisture content of the refueling cell gas.

The system will be comprised of the necessary equipment to remove sodium aerosols, oxygen, carbonaceous materials, halogen fission products, and particulates. Nitrogen removal is not planned for the backup design and occasional cell purging will be necessary to reduce nitrogen content to within operating limits. If nitrogen exclusion is necessary, steps can be taken to provide nitrogen purification equipment.

The backup design shown in Figure 11-1 utilizes a NaK bubbler cell purification unit to remove oxygen and moisture and a high efficiency filter to remove particulate matter. Gas purity monitoring instruments include gamma and alpha detectors along with instruments to detect and record moisture and oxygen content. A chemical catalyzer and dryer system to be used in place of the NaK bubbler is also under consideration.

11.3 SYSTEM DESIGN REQUIREMENTS

The design requirements are intended to emphasize safety, performance, and reliability using conservative design practices:

- Purification equipment will be sized using the estimated air in-leakage rate during negative pressure operation of the refueling cell.
- Cell oxygen levels will be controlled to maintain oxygen at levels near 10 ppm, during periods when sodium surfaces are exposed to the refueling cell atmosphere.
- The monitor and filter system will be designed for continuous operation.
- The purification unit will operate as required to control the cell-oxygen concentration.
- The Code requirements for the system are:
 - ASA Code for Pressure Piping B31.1, Section 2.
 - ASME Boiler and Pressure Vessel Code, Section VIII.
- The purification system shall be designed for a service life of 20 years at full capacity.

11.4 DETAILED COMPONENT DESCRIPTION

A brief description of the system components is given below. Detailed information is contained in the equipment specifications.

11.4.1 Argon Purification Unit

The backup concept utilizes a NaK bubbler cell purification unit, but a chemical catalyzer unit is under consideration. The purification system shall remove oxygen, moisture, oil and hydrocarbon, and sodium vapor, from a continuous stream of argon.

11.4.2 Argon Purifier Compressor

The loop blower will be a standard unit sized to recirculate the cell atmosphere at required rates for adequate purification. Table 11-1 describes typical characteristics.

11.4.3 Instrumentation

Gas purity monitoring instruments include gamma and alpha detection equipment along with special instruments to detect and record moisture and oxygen content. Table 11-2 describes typical characteristics.

11.5 PRINCIPLES OF OPERATION

Air initially present or present after major maintenance will be displaced by argon by the use of an intermittent purge and recirculate filling operation. This inerting procedure is similar to the procedure discussed in the Nitrogen Supply System, Section XII.

Oxygen removal to near 10 ppm will be completed by recirculating the argon in the cell through the purification system.

FIGURE 11-1. P&ID REFUELING CELL PRESSURE CONTROL

TABLE 11-1

ARGON PURIFIED COMPRESSOR CHARACTERISTICS

Service	Argon
Type	Sealed
Location	Reactor Building
Number	1
Surrounding Gas	Air
Temperature of Surrounding Gas	80°F normal; 100°F maximum
Temperature of Gas through Compressor, in/out	80°F - 150°F
Suction from	Refueling Cell
Discharge to	Refueling Cell Argon Purifier
Capacity	~600 scfm
Total Developed Heat	
Static Pressure at Compressor Inlet	+6 in. H ₂ O to -6 in. H ₂ O
Miscellaneous	To be leak tight, no leakage of surrounding gas to circulating steam. Recommend use of double-face mechanical seals which are designed for pressure and intermediate vacuum gas service. These seals require cooling and lubrication. This is accomplished by use of a light oil circulated within the seal chamber which is forced into the seal chamber by an auxiliary seal oil system.

TABLE 11-2

GAS PURITY MONITORING INSTRUMENTATIONOxygen Detector

Range	0-25 and 0-125 ppm oxygen
Accuracy	±5% of reading
Response Time	Initial, 30 seconds (63%), 1 minute (90%)
Output	0-5 m.V. to potentiometer recorder
Power Requirements	115 volts, 60 cycles, 200 watts
Purge Fittings	Standard
Sample Requirements	
Recommended flow	100 cc/min
Pressure required	2-30 psig

Moisture Detector

Range	0-10, 0-30, 0-100, 0-300, 0-1000 ppm vapor by volume
Accuracy	±5% of full scale
Output	0-10 millivolts d c
Power Requirements	110 volts, 60 cycles, 20 watts
Sampling Requirements	
Recommended flow	100 cc/min
Inlet pressure range	10-100 psi
Upper temperature limit	212°F

The purification system will continue to operate as required to control the cell oxygen concentration.

Air in-leakage will tend to increase the nitrogen concentration in the cell atmosphere. Should nitrogen concentration become a problem, an appropriate removal scheme will be devised. The backup design calls for purging of the cell atmosphere at nitrogen levels above 5 vol %.

Should the cell impurity levels exceed the capacity of the purification system, provision for venting cell atmosphere to the gaseous radwaste may be necessary for emergency operation.

11.6 AVAILABILITY AND RELIABILITY REQUIREMENTS

The following principles were used to establish the criteria for the system reliability and availability:

- No single failure in a component of the system will affect the operation of the reactor.
- No single failure may propagate to other systems to impair the operation of other systems or their components.

The major areas of the purification system design which were considered under this criteria are discussed below:

- A purification unit failure is tolerable since the cell purification can be maintained by purging to radwaste while maintenance is being performed. Also, the purification system is used on an intermittent basis, and it is likely that only occasional use of the system will be necessary.
- Isolation valves are provided on all major components to affect ease of maintenance or replacement.
- Replaceable elements, such as filters, are provided with a bypass or dual installations to maintain system operation during the installation or repair.
- Spares are provided for components which are known to have relatively short operational lives.

The availability design target for the auxiliary systems is 1.0%.

11.7 MAINTENANCE

The capability shall be provided for simple replacement of any portion of the system which is consumed, must be replaced, or in any way possesses a limited life. The potential for internal contamination with plutonia shall be taken into consideration during replacement of any consumable or replaceable portion of the system. The purifier system shall include all necessary spare parts for operation for 1 year.

11.8 INTERFACE

The structure and hardware which make up the system infers responsibility for design, procurement, and installation.

- The reference design will provide the necessary cell structures and locations to accommodate the installation of the argon purification system.
- All equipment including ducting and penetrations shall be located and sized in accordance with the requirements of the backup design.
- The purification system shall meet all the functional requirements of the backup design.
- Design compatibility studies by the reference designer will be required periodically as the reference and backup concepts progress toward the final design phase.

SECTION XII

NITROGEN SUPPLY SYSTEM

12.1 INTRODUCTION

The purpose of this section is to describe the conceptual design and set forth the criteria necessary to arrive at a firm system design for the Nitrogen Supply System. This document is presented to form the basis for preparation of preliminary equipment arrangements.

The nitrogen supply system shall be comprised of the necessary equipment and facilities to receive, purify, and distribute nitrogen gas to the various cells requiring a nitrogen atmosphere. The supply system is designed to meet the following functional requirements:

- One month's normal usage will be maintained in storage at all times.
- The completed system shall be capable of accomplishing operations such as system filling and purging within reasonable time limits.
- Normal system process control for regulating flow, makeup flow, and purging will be automatic with respect to the temperature and pressure in the cells.
- Instrumentation to assure system gas purity requirements shall be provided.
- Oxygen and moisture purifiers will be provided and operated as required to meet operational impurity levels.
- Consideration must be given to the repair or replacement of certain system components since their location is such that access will be restricted due to radiation and atmosphere conditions.

The nitrogen supply system is designed to provide inert atmosphere to the cells and equipment as well as provide the storage necessary for makeup due to leakage and purging. The system will operate so the nitrogen cell atmosphere is never open to the environs external to the reactor building.

Liquid nitrogen passes through an evaporator where it is vaporized and goes into the storage or surge tank as nitrogen gas. The gas then enters the containment building through the necessary isolation and control valving, where it enters the nitrogen distribution header through the nitrogen coolers and blowers. The supply lines to each contain remotely operated dampers for pressure and flow control and isolation capability. Nitrogen gas is supplied to the following major equipment areas:

• Primary coolant loop cell	• Closed loop test cells
• Drain tank cell	• Decay and fuel storage cell
• Sodium service cell	• Safety tank cooling equipment cell

Upon completion of initial purging and filling of the nitrogen atmosphere cells from tank trucks, the nitrogen supply station is used to provide a ready supply of make-up nitrogen to account for leakage and consumption in the cells.

Pressure regulating and control stations are to be located in accessible areas and are equipped with block valves and a bypass. The number of penetrations into the nitrogen cells are to be minimized. A local pressure indicator and a pressure relief valve are located downstream of each header pressure regulating station. The relief valve is sized to relieve the header in the event of a regulator failure.

The use of sodium as the reactor coolant creates a potentially hazardous condition should a leak occur in the cooling system piping or equipment due to the reaction of sodium with the oxygen or moisture in the air. A possible solution is to provide an inert atmosphere in the areas where sodium or sodium equipment would be located.

The nitrogen supply system is designed to supply dry nitrogen gas to displace the air in these cells. The purging of the cells is to continue until a concentration of 3% oxygen is reached. When the oxygen concentration reaches 5%, the system is again activated until a concentration of 3% is again established.

Besides supplying the inerting gas for the nitrogen atmosphere cells, the system provides make-up nitrogen for the cell nitrogen atmosphere recirculating system. It also serves as the reserve nitrogen supply for this system.

12.2 DETAILED COMPONENT DESCRIPTION

12.2.1 Nitrogen Supply Station

The nitrogen supply station is typical of a bulk liquid nitrogen system designed for heavy industrial service. Two liquid nitrogen storage units with the necessary regulators, evaporators, valves, and controls are connected in parallel to automatically convert the liquid nitrogen to gas as it is required. A gas storage or surge tank is provided in the gas supply line which acts as a reservoir of gas for makeup to the cell nitrogen recirculating system.

12.2.2 Control and Instrumentation

The nitrogen supply lines contain remotely operated dampers for pressures and flow control and isolation capability. Check valves are installed at the penetration into the reactor building to ensure containment isolation. In addition, remote readout oxygen and hydrogen analyzers and internal pressure gauges are installed in each cell to monitor gas purity and protect against cell overpressure. Cell temperature will be controlled by the Nitrogen Recirculating System.

Liquid and gaseous nitrogen are available from commercial sources with guaranteed purity analyses. Therefore, no instrumentation is planned to monitor or purify the nitrogen at the supply station.

12.2.3 Nitrogen Atmosphere Areas

A preliminary list of the areas requiring a nitrogen gas service was given in Section

12.1. A description of each of these areas and the nitrogen service required is given below:

12.2.3.1 Primary Coolant Loop Cell(s)

Each of the three primary sodium piping cells is supplied with cooling nitrogen from ducts in the upper and lower areas with the return taken from ducts in the top of the cell. The nitrogen supply butterfly valves are controlled by sensing the nitrogen return temperature at the inlet to the nitrogen return duct. The cooling nitrogen protects the concrete structure of the cell(s) from the heat load given off by the primary system piping, pumps, and heat exchangers.

12.2.3.2 Drain Tank Cell

Cooling nitrogen is supplied to the drain tank area through a single duct with enough outlets to distribute the flow. The nitrogen cooling flow from the EM pumps in the cell is discharged into the drain tank cell. The mixing of the cooling nitrogen with the cell atmosphere has a negligible effect on the cell temperature and can be returned to the nitrogen cooling system by a common return duct.

12.2.3.3 Sodium Service Cell

The cold traps in the sodium service cell are supplied with cooling nitrogen through a motor controlled butterfly valve; one cold trap is operated while the other is a standby. The plugging indicator is supplied with nitrogen by a motor-controlled butterfly valve which opens when the plugging indicator discharges into the cell area while the hot nitrogen from the cold traps is ducted directly to the nitrogen return ducting.

12.2.3.4 Gaseous and Liquid Radwaste Cell

Cooling nitrogen is distributed throughout the radwaste cell to cool the liquid and gaseous decay tanks and their associated piping and equipment. A separate supply and return header is provided for the liquid and the gaseous radwaste components to accommodate the cooling requirements of each system.

12.2.3.5 Closed Loop Test Cells

The capability of cooling these cells with nitrogen will be provided with the necessary controls to meet the cooling requirements of the particular testing being performed.

12.2.3.6 Miscellaneous Equipment Cell

The miscellaneous equipment cell is a large interconnected cell which will house sodium and sodium service equipment such as the nitrogen coolers and compressors. Cooling nitrogen will be ducted to each compartment of the cell and returned by a common header. Valves and dampers will control the supply rate to the various compartments.

12.2.3.7 Decay and Fuel Storage Cell

Nitrogen gas is supplied to the cell to provide cooling for the irradiated fuel storage tanks.

12.3 PRINCIPLES OF OPERATION

12.3.1 Cell Inerting

Personnel are evacuated from cell to be inerted after all local operations have been completed. Remotely operated valves are opened and the nitrogen gas for initial purging from supply trucks is allowed to enter the cells. Remote pressure readouts for the various cells allow operators to keep a close watch on the internal pressure of the cells. Oxygen analyzers are used to determine the oxygen concentration of each cell and when all sample heads indicate a concentration of 3% oxygen, the remote valves are shut off.

In introducing an inerting gas into a volume it is advantageous for reasons of economy and storage limitations to keep the volume of inerting gas to a minimum. Various methods have been proposed and tested to arrive at a reasonable inerting procedure. The best method would be to create a "piston effect" and displace the cell atmosphere with an equal volume of inerting gas. The other method would be to promote diffusion and mixing so that every mole of inerting gas is mixed perfectly with the air in the room.

Both methods were tested, and the paper on "Large Volume Operational Room Inerting" by Boyer, Otway, and Parker for the AEC reported that approximately 1.7 volume were required by either method to attain O₂ concentrations of 4% in about 20 minutes. The diffusion method seemed to require less insertions to attain the 4% concentration.

12.3.2 Normal Operating

Upon completion of initial purging, the nitrogen supply station will operate whenever additional nitrogen is needed for makeup for cell leakage and purging, or when the oxygen concentration reaches 5%, necessitating additional purging.

12.3.3 Shutdown Operation

Shutdown operations should not differ from normal operation. A nitrogen cell was purged for man access and required reinerting.

12.3.4 Emergency Operation

Failure of the nitrogen recirculating system may require that the nitrogen system serve as the emergency cell cooling system. This would be accomplished by bleeding in cool nitrogen and venting of the cell nitrogen as needed to maintain the required cell temperature.

12.4 SAFETY PRECAUTIONS

Check valves are provided in each line to the various cells to provide capability of isolation of any cell where leakage or contamination may affect the rest of the supply system. Component materials used in the nitrogen system may come in contact with sodium or sodium vapor and should be compatible with this duty. The piping and equipment will be designed to withstand the seismic loads established by the safeguards analysis.

12.5 RELIABILITY AND MAINTAINABILITY

The following principles were used as criteria in establishing system design:

- No single failure of a component in the system shall affect the operation of the reactor.
- No single failure may propagate to other systems to impair the operation of other systems or their components.

Some major areas of the supply system which were designed to the above criteria are described below:

- The supply station is provided with multiple liquid nitrogen storage tanks in parallel so a constant nitrogen source is available during draining and filling operations or when there is a failure in the tank being operated.
- Isolation capability is provided to each of the areas being supplied so failure in any one cell will not affect the supply to the balance of the nitrogen cells.
- The system components will be of standard designed construction wherever possible with emphasis toward ease and availability of replacement.
- The design availability target for the entire auxiliary system is 1.0%.

To ensure that the system design will meet the availability targets, the following guidelines for maintenance are to be followed for the system design:

- System components shall be designed for low-frequency replacement. A 20-year design life should be used for most equipment.
- Equipment shall be located to allow for maximum accessibility for inspection and maintenance.
- Separate parts inventory should be sufficient to cover 1-year's operation. Particular attention should be given to items which are known to require periodic replacement.
- Procedures are to be established for a failure reporting system and provisions are to be made for ways to upgrade faulty equipment.

12.6 INTERFACE

The reference designer is responsible for the nitrogen supply system. At present, no interface exists between the reference and the backup concepts. The backup nitrogen system appears to be compatible with the reference design.

SECTION XIII

CELL NITROGEN ATMOSPHERE RECIRCULATING SYSTEM

13.1 INTRODUCTION

The purpose of this section is to establish and set forth the design objectives and present sufficient data to describe the Nitrogen Cooling System.

The cell nitrogen atmosphere recirculating system is provided to maintain and circulate the nitrogen gas in the primary and secondary equipment cells. In order to protect the concrete structure of these cells by maintaining a desired temperature, a large capacity, forced circulating cooling system provides a means for removing heat from the cells. A separate nitrogen system is operated in conjunction with the gas cooling system to provide makeup for cell leakage and to control cell pressure. The following functional requirements are to be provided by the nitrogen recirculating system:

- The completed system shall be capable of accomplishing operations such as purging and system filling within reasonable time periods.
- The nitrogen cells will be constructed as minimum leakage cells (less than 1% total volume per day at a pressure of 10 psig).
- Cell pressure will be controlled to maintain a positive cell pressure with respect to the building air pressure of 1 in. to 5 in. H_2O .
- The cells will be provided with a nitrogen cooling system capable of controlling and maintaining the cell temperatures below 120° F.
- The system will be designed to operate so that the nitrogen cell atmosphere is never open to environs external to the reactor building.
- Allowance must be given to repair and maintenance of certain system components since, because of their location, access for maintenance will be restricted due to radiation and atmospheric conditions.

13.2 SYSTEM DESCRIPTION

The nitrogen atmosphere will be cooled by circulation through at least two constant speed blowers operated in parallel. Each blower takes suction through a filter box containing dry type disposable filters and then through a Freon expansion coil. Provision must be made to maintain the cell at a low humidity. The atmosphere must always be at a dew point 5° F below the Freon coil temperature to prevent moisture condensation on the coils.

The refrigeration system units (condensers and compressors) will be located outside the reactor building in the operations building. The type of unit recommended is a Freon refrigerant multi-ton unit using a sealed condenser compressor. The system should be monitored to detect a leak in the Freon system.

The nitrogen main recirculation system will be continuously monitored for radiation and oxygen. When the oxygen in the nitrogen approaches the maximum allowable limits of 5%, a portion will be bled off (blown down) to the radwaste system. If the normal radiation levels are exceeded, this bleed should cease and reactor operation shut down, as this would be an indication of a leak in the primary sodium system.

Individual nitrogen cells shall be provided with temperature and pressure monitoring for automatic control purposes. In addition, some equipment within the cells will require separate and individual temperature monitoring and control. Means for local area nitrogen sampling during operation will also be provided. These nitrogen samples are required to aid in detecting and locating the area of a sodium leak.

Normal system process control will be automatic with respect to temperature and pressure in the cells. Control for purity and radiation will be remote manual from a local station.

The entire nitrogen cooling system will be designed such that loss of any piece of equipment will result in a maximum loss of 33-1/3% cooling capacity to any or all cooling loads relying on this cooling system.

13.3 DESIGN REQUIREMENTS

To ensure a safe, reliable, and conservative system design, the following criteria is to be followed:

- Component materials used in the nitrogen system may come in contact with sodium and sodium vapor and should be compatible with this type duty. Carbon steel, brass, copper tubing and galvanized iron and aluminum are acceptable.
- Special precautions should be provided to minimize the possibility of sodium leaking directly to the refrigerant lines of the coils.
- Nitrogen system duct work carried outside the equipment cells must be designed for at least 10 psig, 300°F, and total leak rate of 1% or less of total volume in 24 hours at 10 psig.
- Certain equipment pieces are so located that access for maintenance will be restricted because of radiation and atmospheric conditions.
- Piping and equipment will be designed to withstand seismic loading to be established.
- In order to minimize the potential energy released in a sodium-Freon reaction, the Freon volume shall be kept as small as possible.
- The system shall be designed for a service life of 20 years.

The choice of nitrogen cooling systems favored centrally located, large capacity Freon cooling coils to cool the circulating nitrogen ducted to and from the sodium equipment cells as

opposed to individual cooling coils located within the cells for the following reasons:

- Piping Freon to individual cooling units in the sodium cells greatly increases the possibility of a sodium-Freon reaction caused by the increase in the Freon volume in the reactor building and the enlarged area of exposure of Freon to potential sodium contact.
- A centrally located cooling system offers many advantages in terms of accessibility for system maintenance and repair.
- The use of smaller cooling units in or near the sodium equipment cells increases the problem of locating critical components, instrumentation, connectors, and other mechanisms out of radiation zones.
- Considering the economics of the two designs, a preliminary estimate of the equipment costs definitely favors the large, centrally located cooling units over the numerous, small, individual cooling units.

13.4 SYSTEM FEATURES

In order to satisfy the concept safety criteria and design requirements, the following characteristic design features are required:

- To remove any moisture that may be transferred to the nitrogen atmosphere from the reactor building concrete walls, a refrigerant type nitrogen gas dryer is located in parallel with the cooling units.
- Radiation monitors are installed in the nitrogen return ducts in the area of the operations building.
- Sample lines, connected to the discharge of the nitrogen blowers, pass through the primary containment and are headered to a halogen leak detector to monitor leaks from the nitrogen cooling Freon coils.
- On loss of plant power, one nitrogen blower will always be on the essential bus connected to the emergency power supply to supply nitrogen to the cell at reduced flows.
- Nitrogen cell pressure control is provided to maintain a positive N_2 atmospheric pressure with respect to the reactor building air zone pressure to prevent air in-leakage to the cells.
- A differential pressure transmitter centrally located in the nitrogen cells will actuate alarm contacts on high or low cell pressure to make a solenoid valve open and allow pneumatic pressure to open the nitrogen bleed valve to the wastegas header or the nitrogen makeup valve.

13.5 DETAILED COMPONENT DESCRIPTION

This section is included to describe the major components and instrumentation of the cell nitrogen recirculating system.

13.5.1 Nitrogen Blower(s)

The nitrogen blower is a centrifugal, single stage, nonoverloading unit of manufacturer's standard design. The blower housing is carbon steel and shall be provided with single flanged inlet and outlet duct connections. All bearings shall be prelubricated and provided with suitable lubricating connections, located and extended to readily accessible positions.

The blower shall be provided with an electric motor drive and coupling (where required). Steel plate guards shall be provided over all exposed couplings, belts, pulleys and all rotating items. The blower is furnished with all dampers, duct work, foundations, anchor bolts, and external wiring and controls. Maximum free-field noise pressure level shall in no circumstance exceed 90 decibels for any reading taken at any point 5 feet from the fan unit in any direction at shaft level, on the "C" scale of a sound level meter. Tests shall be conducted in accordance with ASA Standard S1.2 of the latest date.

13.5.2 Nitrogen Cooler(s)

The nitrogen cooler is a direct Freon expansion coil which is enclosed in a casing of heavy galvanized steel having supports and top and bottom channels for rigidity and strength. The casings have flanged inlet and outlet connections which connect into the nitrogen duct work. The cooler is connected on the suction side of the nitrogen blower.

The nitrogen cooler is used to remove heat from the dry nitrogen gas. The direct expansion coil material shall be copper tubing, per ASTM B-88, Type M, with pressure test to the maximum allowable working pressure in accordance with ASTM B-88. Expansion coil is to be rigidly inspected to assure zero leakage.

13.5.3 Nitrogen Dryer

The nitrogen dryer will be used to remove moisture from nitrogen gas. A portion of the nitrogen gas flow will be diverted from the main supply header to the dryer and from the dryer back to the main system. The dryer shall be designed for continuous operation.

The dryer shall be of the packaged refrigeration type gas dryer, complete with compressor, condenser, cooling coil housing, refrigerant, integral cooling system for compressor and condenser, and all required insulation, motor drives, controls, and integral wiring. The refrigerant shall pass through the cooling coils, and the nitrogen gas shall flow around the coils through the coil housing.

13.5.4 Nitrogen Control and Isolation Damper(s)

A manual leaf damper at the inlet to the filter box on the cooler inlet is provided with position switches. When the damper is closed, the associated blower control circuit is tripped and the blower cannot be started. The damper is provided to allow for replacement of the filter element. The damper shall be of multiple leaf, opposed blade, rectangular, flanged type. All materials in the dampers, operators, and accessories shall have a useful life of 10 years while located in an ambient temperature of 120°F and a gamma radiation field of 100 R/h.

13.5.5 Filter(s)

The filter installed in the suction of each of the cooler units is provided to remove particulate matter from nitrogen gas system during initial operation. A dry type disposable filter is used and provision for periodic replacement is required.

13.5.6 Halogen Leak Detector

The halogen leak detector will be used to detect from (R-22) leaks from the direct expansion coils in the argon cooler. Nitrogen gas samples will be taken from the outlet side of the nitrogen coolers and checked with the detector. The halogen leak detector will provide a signal to a remote panel mounted indicator and recorder.

13.6 PRINCIPLES OF OPERATION

13.6.1 Startup

Upon completion of the initial purging of the air from the nitrogen cells, the nitrogen recirculating system will be operated to purge the gas system ducting of air and to pick up any dust or particulates in with the filters.

13.6.2 Normal Operation

During normal operation, the nitrogen in the cells is circulated by the argon blowers through the nitrogen coolers. The coolers are controlled to maintain a constant outlet temperature at the blower discharge. The system is designed to maintain the nitrogen cell temperatures at ~100°F to protect the concrete structure of the cells. Each blower and its associated inlet damper are operated by a control switch on the control room panel. The horsepower requirement of each nitrogen blower is automatically maintained by a throttling valve in the suction line of the blower to prevent overloading of the motor.

The nitrogen to the cells enters through manifold ducting arrangements with manually adjustable dampers for balancing. The hot N₂ leaves the cells through similar ducting arrangements. The return N₂ is measured by a resistance temperature device, and the temperature is converted into a signal which controls a butterfly valve in the inlet ducting to the cell area for adjustment of the flow in a direction that maintains the set point temperature.

13.6.3 Shutdown Operation

The nitrogen circulating system cooling rate is controlled to reduce along with the reduction of heat from the sodium systems until isothermal conditions are achieved. The nitrogen atmosphere will be held slightly positive to the air zone atmosphere even after circulation for cooling has been terminated.

13.6.4 Abnormal Operation

The system will be designed to accommodate the following abnormal operating conditions:

13.6.4.1 Loss of Site Power

A reactor scram would be initiated in the event of loss of power. Reserve gas from the N₂ supply system storage or surge tank would be available to provide adequate cooling gas to maintain cell temperatures below allowable limits.

13.6.4.2 Leakage in a Sodium Equipment Cell

Capability is provided to isolate any of the cells from the cooling system in the event of a sodium leak. Cooling will continue for the remaining sodium cells, and the supply system will provide emergency cooling for the leakage area by purging in cool nitrogen and venting to the gaseous radwaste system.

13.6.4.3 Loss of a Single Cooling Loop

Redundancy is provided so loss of a single blower or cooler will allow the systems to operate at a reduced rate until repair is completed. The system will operate at 2/3 capacity following loss of a single component.

13.7 SYSTEM AVAILABILITY

To ensure that the high system availability targets are met, consideration must be given to the system design, repair, and maintenance functions. The following criteria represent good design practice to meet these targets:

- System components shall be designed for low-frequency replacement. A 20-year design life should be used for most equipment.
- Equipment shall be located to allow for maximum accessibility for inspection and maintenance.
- Spare parts inventory should be sufficient to cover 1-year's operation. Particular attention should be given to items which are known to require periodic replacement.
- System components will be of standard design and construction with emphasis toward availability of replacements.

- Procedures will be established for a failure reporting system that will provide means to upgrade faulty equipment.
- The design availability target for the auxiliary systems is 1.0%.

13.8 SYSTEM INTERFACE

The design of the Nitrogen Recirculation System is the responsibility of the reference designer. The use of a nitrogen gas cooling system for controlling the atmosphere and temperatures of the sodium equipment cell is a requirement of both the reference and backup design concepts. At present, no interface conditions exist between the two concepts.

SECTION XIV

EMERGENCY POWER SUPPLY SYSTEM

14.1 INTRODUCTION

The purpose of this section is to establish and set forth design objectives and present data sufficient to describe the conceptual design.

The emergency power supplies perform dual functions upon loss of electrical power to the plant. The first is to provide power to important process functions which must be electrically maintained to protect the reactor and associated equipment from serious damage. The second is to provide uninterrupted power to key instrument systems and process controls to assure continued operation during short transient and for continuous monitoring during extended power outages. The specific functions of the emergency power supply system are:

- a. Supply power to those critical items which are required to function in the event of a loss of normal power to the plant.
- b. Provide uninterrupted electric power to critical instrumentation and process controls to assure continuous monitoring during loss of plant power for extended periods of time.
- c. Provide emergency power for all loads which are necessary for a safe shutdown of the reactor.
- d. Provide uninterrupted emergency power for the following critical loads:
 - One neutron monitoring source range channel and recorder.
 - One neutron monitoring wide range channel and recorder.
 - Central annunciator.
 - Reactivity control device position indicators.
 - Partial emergency lighting.
 - Primary relays of the reactor safety system.
 - All main breakers of the electrical distribution system.
 - All isolation valves.
- e. Provide an interruptable but essential bus to supply emergency power for the following:
 - Instrument Transformer
 - Fuel Handling Equipment
 - Emergency Cooling Equipment
 - Emergency Heaters
 - Control Rod Drives
 - Interruptable Lighting

14.2 SYSTEM DESCRIPTION

The emergency power supply system is designed to provide electrical energy for continued operation of important electrical devices during periods when the external electrical power source is out of service. An emergency electric a-c power generator system and a battery-stored electrical energy system make up the emergency power supply system.

The diesel electric generating sets are provided to handle the heaviest and bulk loads of this system. The diesel generator starts automatically upon loss of voltage in the main bus by means of a battery-operated starter. As soon as the generator voltage is normal, this power is automatically switched to the emergency motor control center bus. Prior to transfer of the diesel-generator to the emergency bus, the incoming breaker which feeds station power to the bus is automatically tripped. Some loads classified as "immediate nonessential" that operate from this bus may be automatically tripped off and switched on manually by the operator.

A minimum of two independent diesel electric generating sets are required to allow for failure of one system. The emergency electric power system must be arranged so that one set may be shut down at any time, even during emergency power conditions.

Three separate battery systems make up the stored electrical energy system. To power nuclear instruments which are specifically built for this voltage, a plus and minus 26.5 volt system is required. This system is reserved solely for instruments so electric noise on the d-c busses is kept to an absolute minimum. Another 26.5 volt system is provided for the primary and by-pass relays of the reactor safety system and for miscellaneous lights and relay functions that require uninterrupted power. The third system is a 125-volt system which provides power for the central annunciator system, the secondary contactors of the safety system, the isolation system solenoids and motors, emergency lighting, and main breaker operation.

14.3 SYSTEM DESIGN REQUIREMENTS

The design requirements are based upon conservative design practices which are consistent with the safety criteria.

- a. All equipment shall comply with the latest applicable NEMA and ASA standards.
- b. All electrical equipment shall be accurate within 2% or less.
- c. The engine-generator shall be designed to start reliability at ambient temperatures as low as -30°F (suggest heated enclosure).
- d. Batteries shall be enclosed in a separate, well-ventilated room that contains only battery banks.
- e. The system shall be designed to allow component inspection and maintenance during service.

- f. System shall be designed for a service life of 20 years.
- g. The emergency electric generating sets will be capable of supplying a-c power to the plant within a minimum of 10 seconds following initiation of a start signal.
- h. The battery circuits shall be divided and equipped with manual feeder breakers at a central panel arranged so that the operator can quickly remove all but the most essential loads from the batteries.
- i. Establish automatic circuitry to disconnect the emergency bus from the off-site power supply upon loss of voltage and connect to the emergency supply as soon as power is established at the emergency generator output bus.
- j. Power outage extended beyond a few minutes and failure of the diesel electric generators to start demands immediate removal of all but the most essential loads from the emergency bus.
- k. Batteries will be continuously float-charged by battery chargers and with automatic load limiting features with battery output current beyond 120% of rated load by rapidly diminishing output voltage, without tripping an overload.

14.4 DETAILED COMPONENT DESCRIPTION

This section describes the major components and service of the emergency power supply system.

14.4.1 Diesel Electric Generating Set(s)

The diesel electric generator set will be used for emergency a-c power for the plant and shall have the ability to pick up electrical load within a minimum of 10 seconds following initiation of a start signal. The engine, generator, and engine-generator accessories that comprise the set shall be assembled on a common base as an integral unit. The motor generating sets supply emergency power to the loads outlined in subsection 14.1.a. to 14.1.e.

14.4.2 Battery-Storage System

14.4.2.1 Batteries

Each battery shall include the cells, intercell, and inter-tier connectors, terminal lugs, rack and accessories required for the stored electrical energy system. The cell jars are to be made of transparent plastic and fitted with sealed covers that will remain tight during life of the cell. The batteries shall be arranged on racks treated to resist acid and designed to withstand plant seismic design loads.

The batteries will supply uninterrupted power to the critical loads given in subsection 14.1.a. to 14.1.d.

14.4.2.2 Chargers

- Battery chargers shall be full wave silicon rectifier-type, filtered output, regulated by means of automatic magnetic amplifier controls or other approved method.
- Voltage regulation shall be less than $\pm 1\%$ from no load to full load with $\pm 10\%$ supply voltage variation.
- Charger battery circuit shall be isolated from the a-c power system by a transformer and shall include a d-c ammeter, d-c voltmeter, a-c and d-c circuit breakers, alarm relay to indicate loss of a-c power, and two-ratio potentiometers for float and equalizing charge settings.

14.5 PRINCIPLES OF OPERATION

As the name implies, the emergency power supply system would not be in operation during normal plant operation. The motor generator will be started periodically to ensure that they will start on command, and the battery charge levels will be monitored to assure that they are charged to the proper levels.

Operation of the system is essentially automatic upon loss of plant power. The operator may add some loads classified as "immediate nonessential" to the emergency bus after the generator has come on. The battery system provides instant d-c power to the emergency bus which meets the uninterrupted power requirements during the delay between loss of plant power and start of generator power. Should power outage extend beyond a few minutes and the diesel electric generating sets fail to start, the battery systems will maintain power to the emergency bus containing only the most essential loads for a full 8-hour period.

14.6 REPAIR, MAINTENANCE, AND TESTING

The following requirements are provided to assure that the high availability targets of the system design are met:

- Major equipment shall be located for maximum accessibility for inspection and maintenance.
- Spare parts inventory for 1-year's operation shall be maintained.
- System components will be of standard design and construction with emphasis on availability of replacement.
- A system availability and failure mode and effect analysis is to be performed during design phase to correct system deficiencies.

14.6.1 Testing

Procedures will be established for periodic testing of the diesel generating sets. Preventive maintenance programs will be required for all parts of the system subject to wear and deterioration.

14.7 INTERFACE

The reference design is responsible for the installation and procurement of the components and equipment that comprise the emergency power supply system. The backup design requirements will be considered by the reference design in selecting the size and capacity of the equipment and components.

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