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Subject: Submittal of Design Description for the 4S Reactor (Non-Proprietary)

Enclosed is a copy of the non-proprietary Design Description document for the 4S (Super-Safe, Small and Simple) reactor plant that is currently the subject of a pre-application review among NRC, Toshiba, and its 4S affiliates including Japan's Central Research Institute for Electric Power Industry (CRIEPI).

The pre-application review for the 4S reactor commenced in the fourth quarter of 2007. Pre-application review meetings were held among NRC, Toshiba and the 4S affiliates in October 2007 and February 2008. Subsequent meetings are planned for May 2008 and additional future dates to be determined.

The Design Description is provided to serve as a reference for Staff participating in the pre-application review. No specific NRC review or comment on this document is requested.

Additional technical reports pertaining to the 4S design will be submitted as the pre-application review progresses. If you have any questions regarding this document, please contact Mr. Tony Grenci of Westinghouse at (412) 374-3619, or grencit@westinghouse.com.

Very truly yours,

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4S Design Description

May 2008

TOSHIBA CORPORATION

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LIST OF ACRONYMS AND ABBREVIATIONS

ac	alternating current
ASTM	American Society for Testing and Materials
ATWS	anticipated transient without scram
BOP	balance of plant
CTG	combustion turbine generator
EMP	electromagnetic pump
GCB	generator circuit breaker
HEPA	high efficiency particulate air
HVAC	heating, ventilation, and air conditioning
IHTS	intermediate heat transport system
IHX	intermediate heat exchanger
IRACS	intermediate reactor auxiliary cooling system
ISPS	intermediate sodium processing subsystem
kW	kilowatt
LMFBR	liquid-metal fast breeder reactor
LP	low pressure
MI	mineral insulated
MW	megawatt
MWe	megawatt electric
MWt	megawatt thermal
NMS	neutron monitoring system
NSFPS	nonsodium fire protection system
PCS	plant control system
PFPS	plant fire protection system
PHTS	primary heat transport system
PIP	plant investment protection
PMG	plant main generator
PSPS	primary sodium processing subsystem
RAT	reserved auxiliary transformer
RPS	reactor protection system
RVACS	reactor vessel auxiliary cooling system
SFPS	sodium fire protection system
SRTS	sodium receiving and transfer subsystem
UAT	unit auxiliary transformer
UPS	uninterruptible power supply

1 INTRODUCTION

1.1 GENERAL PLANT DESCRIPTION

The 4S (Super-Safe, Small and Simple) is a small liquid-metal fast reactor (LMFR), which, in combination with power generation equipment, is designed for use as a power source in remote locations and intended to operate for 30 years without refueling. A pool-type fast neutron reactor, the 4S, when coupled to power generation equipment, has a primary electrical output of 10 MWe (30 MWt). The reactor vessel is located below grade, and it contains the intermediate heat exchanger (IHX), electromagnetic pumps (EMPs), internal structures, core and shielding, and containment system (consisting of the top dome and guard vessel). Heat from the intermediate heat transport system (IHTS) is exchanged in a steam generator (also located below grade) to produce steam, which drives the conventional steam turbine generator equipment.

Figure 1-1 is a schematic drawing of the overall 4S-based power generation facility depicting its major components. The overall area covered by the below-grade and above-grade structures of the plant is approximately 50 m long by 30 m wide. The nuclear island is below grade (this includes the steam generator as well as the reactor vessel and all vital equipment). The balance of plant (BOP) includes facilities located within the security barrier (turbine building, gas turbine generator, switchgear, control area, and security facilities) and facilities located outside the security barrier, but within the owner-controlled area (administration facility, offices, and the like). The BOP facilities are designed to conventional industrial construction requirements.

Figure 1-2 is a schematic cross-sectional view of the 4S power generation facility, showing its main features. As seen in the figure, the 4S reactor assembly is housed in a reactor building, which includes and supports the reactor vessel, the guard vessel/top dome containment configuration, the steam generator, and the equipment cells. The reactor building itself is supported by seismic isolators, which provide horizontal seismic isolation. These are depicted schematically in Figure 1-3. Composite rubber/steel/lead core isolation pads limit horizontal seismic input to the reactor assembly, guard vessel/top dome, reactor vessel auxiliary cooling system (RVACS), intermediate reactor auxiliary cooling system (IRACS), and steam generator.

1.1.1 Reactor and Core

The major components comprising the reactor assembly are the reactor vessel, the shielding plug, the guard vessel, and the top dome. Structures internal to the reactor vessel include the core support structures, the upper vertical baffle, the EMPs, and the IHX.

Primary sodium is directed via the vessel outer plenum down through the IHX, exchanging heat to the intermediate loop. It then passes to the suction of the EMPs, where it is pumped downward to the lower head region and redirected up through the core. The sodium is heated in the core, it exits the core, and it is redirected downward into the IHX to continue the cycle.

The core height is 2500 mm. The high thermal conductivity of the metal core allows it to operate at relatively low temperatures. Inherent core reactivity feedback causes reactivity shutdown for postulated beyond design basis events, such as anticipated transient without scram (ATWS). The core reactivity also limits core power to a safe level for a postulated transient overpower caused by reflector raise without scram.

During normal operating conditions, reactor core power is controlled by a movable reflector. The reflector drive consists of a combination of fine and fast adjustment mechanisms. To scram the reactor, the clutch of the fast adjustment mechanism releases and the reflector lowers (withdraws) via gravity causing the reactor to shutdown. The shutdown rod is also inserted for a scram at the core center position to increase neutron absorption.

Burnup reactivity compensation and margins for uncertainties in temperature effect, criticality, and fissile enrichment are considered in the reflector and fixed neutron absorber design. The radial reflectors are adjustable, and they are incrementally raised slowly during the service life of the core via the fine adjustment mechanism to maintain neutron flux and power levels. In case of electrical power loss or failure of the reflector drive, the assembly lowers to the bottom of the reactor. Reflector (lowering) withdrawal reduces reactivity and stops the nuclear reaction.

1.1.2 Reactor Coolant System and Connected Systems

The power generation facility for the reference design consists of the reactor, the steam generator, and one turbine generator. Two sequentially oriented EMPs of 50-percent capacity each combine to circulate primary sodium within the reactor vessel. A single IHX transfers reactor thermal energy to the single IHTS loop. Heat is transferred from the IHTS via the steam generator to a single steam turbine generator. The primary heat transport system (PHTS) is contained entirely within the reactor vessel. It consists of the hot pool, the tube side of the IHX, the pumps, and the pump plenum. As shown in Figure 1-4, sodium from the reactor enters and flows through the IHX where it is cooled as it heats the intermediate sodium. The primary sodium then exits the IHX, and it is drawn into the pump plenum. The primary EMPs discharge the sodium down into the bottom of the reactor. The sodium is then heated as it flows up through the core and back through the IHX. The IHX consists of upper and lower tube sheets separated by straight tubes. The cold leg intermediate sodium flows down through the IHX shell and, as it is being heated, flows up to leave the IHX through the intermediate outlet nozzle for use in the IHTS.

The IHTS transports heat from the primary system to the steam generator system. The IHTS consists of a piped loop thermally coupled to the primary system by the IHX located in the reactor vessel and to the steam generator system located in the steam generator compartment. The IHTS is a closed loop system with an expansion space in the steam generator plenum using argon cover gas to accommodate thermally induced system-wide volume changes. An EMP, located separately from the steam generator, circulates intermediate sodium through the shell side of the IHX and steam generator. All materials for the IHTS piping and components are designed to minimize corrosion and erosion, and to ensure compatibility with the operating environment. The steam generator is a helical coil shell and tube heat exchanger with water/steam on the tube side and sodium on the shell side. The double tubes, which include a wire mesh layer between the inner and outer tube, are adapted to the steam generator. The double wall tube provides high reliability and significantly reduces the probability of sodium/water interaction.

The generator is powered via a steam turbine that operates at 3600 rpm at rated steam conditions. The generator exhausts to a single condenser. A feedwater pump system for the water/steam loop circulates water from the condenser back to the steam generator.

1.1.3 Shutdown Heat Removal Systems

The 4S reactor shutdown heat removal systems consist of the main condenser cooling; the IRACS, which uses an air cooler located in the intermediate sodium loop; and the RVACS, which removes heat directly from the reactor vessel.

When the reactor is brought from full power to cold shutdown conditions under normal operation, the cooling is provided by routing steam through the steam generator bypass directly to the condenser. In the condenser, the steam condenses to water and, using the feedwater pumps, it is fed back to the steam generator. Feedwater flow to the steam generator is maintained by the local control system.

The EMP of the intermediate sodium loop maintains sodium flow within the IHTS with power supplied by an auxiliary generator. The IRACS can remove additional heat from the core via an air cooler, which is located in the piping between the IHX and the secondary EMP.

In the event that normal condenser cooling is not available, such as with a loss of power supply, decay heat can be removed by the RVACS. The RVACS is a passive system. The system transports heat to the atmosphere by natural circulation of air. It functions continuously with its heat transport rate governed by the reactor vessel temperature. The RVACS operates continuously at all operating conditions, including normal power operations. The flow of sodium within the reactor is aided by natural convection caused by heating in the core and cooling along the reactor vessel wall caused by RVACS. Air flow in the RVACS is maintained by natural draft in the main RVACS riser.

1.1.4 Auxiliary Systems

Sodium receiving and transfer subsystems consist of equipment and piping to liquify the contents of sodium drums and transfer the molten sodium to the respective heat transfer systems. The primary sodium processing subsystem provides for the purification of sodium contained in the reactor vessel during initial startup.

1.2 COMPARISON OF 4S WITH OTHER LIQUID-METAL FAST BREEDER REACTORS

Table 1-1 provides plant information for comparison of the 4S design with other LMFBRs.

Table 1-1
Basic Liquid-Metal Fast Breeder Reactor[1] Plant Information

Plant	Power Thermal/ Electrical (MWt)/(MWe)	FC[2]	PCC[3]	MCT[4] (°C)	Type of Fuel	Country
Experimental Fast Reactor						
Rapsodie	40/none	1967	Loop	510	MOX	France
KNK-II	58/20	1972	Loop	525	MOX	Germany
FBTR	40/13	1985	Loop	516	PuC-UC	India
PEC	120/none	P/C	Loop	550	MOX	Italy
JOYO	100/none	1977	Loop	500	MOX	Japan
DFR[1]	60/15	1959	Loop	350	U-Mo alloy	UK
BOR-60	55/12	1968	Loop	545	MOX	Russia
EBR-II	62.5/20	1963[5]	Pool	473	U-Zr alloy	USA
Fermi	200/61	1963	Loop	427	U-Mo alloy	USA
FFTF	400/none	1980	Loop	565	MOX	USA
BR-10	8/none	1958	Loop	470	UN[8]	Russia
Prototype Fast Reactor						
Phenix	563/250	1973	Pool	560	MOX	France
SNR-300	762/327	P/C	Loop	546	MOX	Germany
PFBR	1210/500	TBD	Pool	530	MOX	India
MONJU	714/280	1994	Loop	529	MOX	Japan
PFR	650/250	1974	Pool	550	MOX	UK
CRBRP	975/380	P/C	Loop	535	MOX	USA
BN-350	750/130[6]	1972	Loop	430	MOX	Kazakhstan
BN-600	1470/600	1980	Pool	550	MOX[9]	Russia
Demonstration or Commercial Fast Reactor						
Super Phenix	2990/1242	1985	Pool	542	MOX	France
PRISM	425/138.3[7]	TBD	Pool	499	U-Pu-Zr alloy	USA
4S[10]	30/10		Pool	510	U-Zr alloy	JPN/USA

Notes:
1. The type of coolant for all LMFBRs in this table is sodium, except for DFR, the coolant is NaK.
2. First criticality
3. Primary circuit configuration
4. Mixed coolant temperature in primary circuit at inlet to IHX
5. Dry criticality: 1961, wet criticality: 1963
6. 150 MWt used for desalination
7. One module
8. Early PuO_2, UC
9. UO_2 first, partly MOX later
10 Fast Reactor

References for Table:
1. "Fast Reactor Database," IAEA-TECDOC-866, IAEA, February 1996.
2. PRISM PSID.

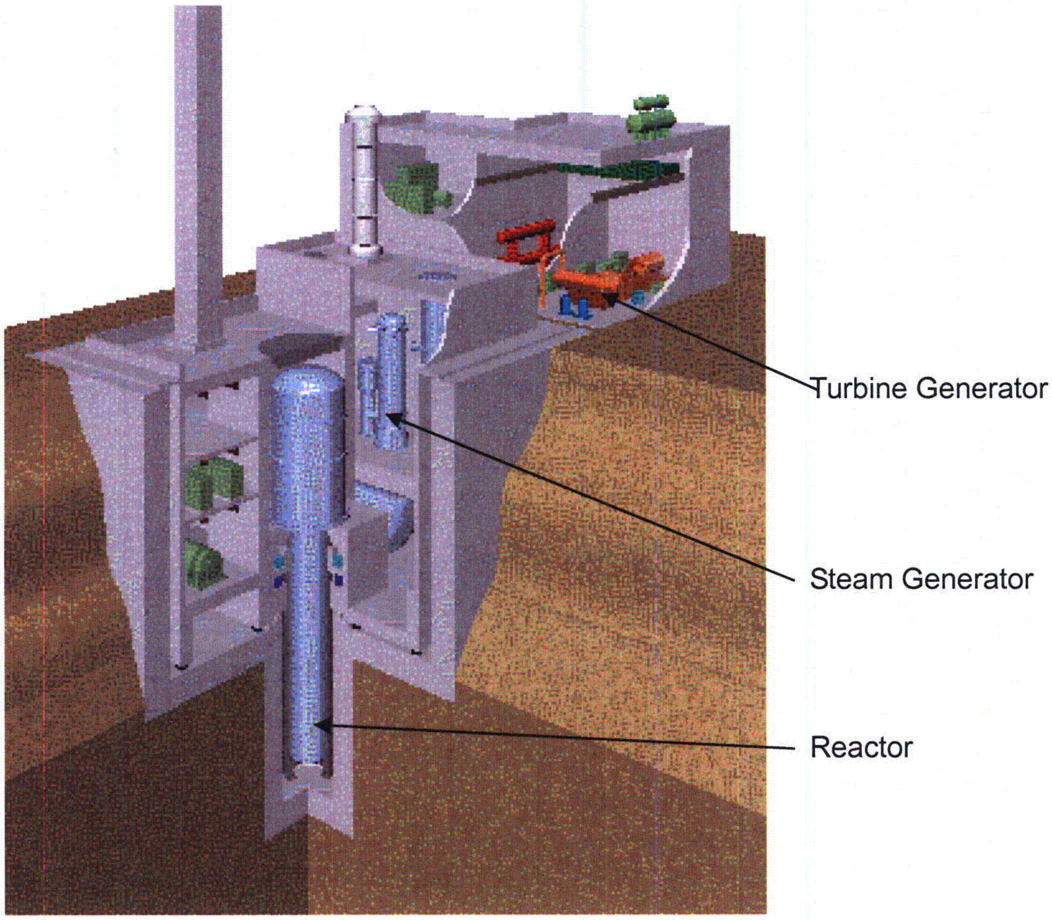

Figure 1-1 Schematic Drawing of 4S Power Generation Facility

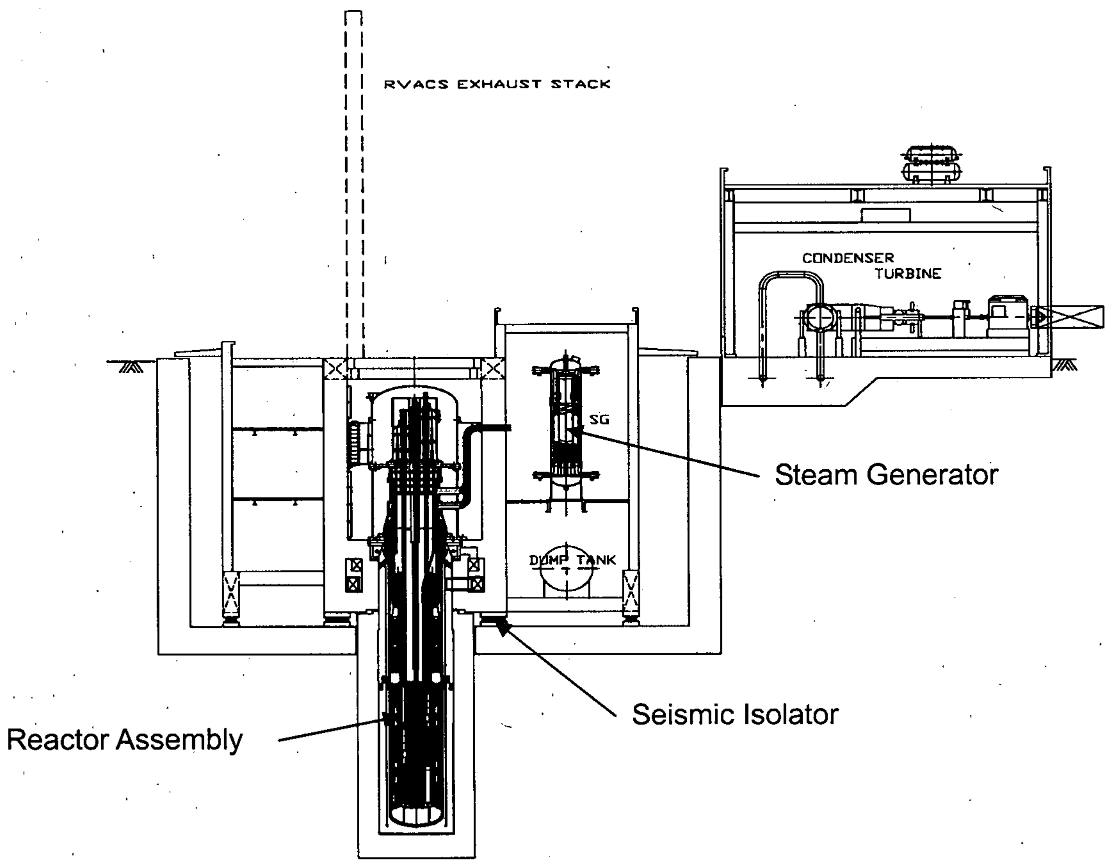

Figure 1-2 Section View of 4S Power Generation Facility

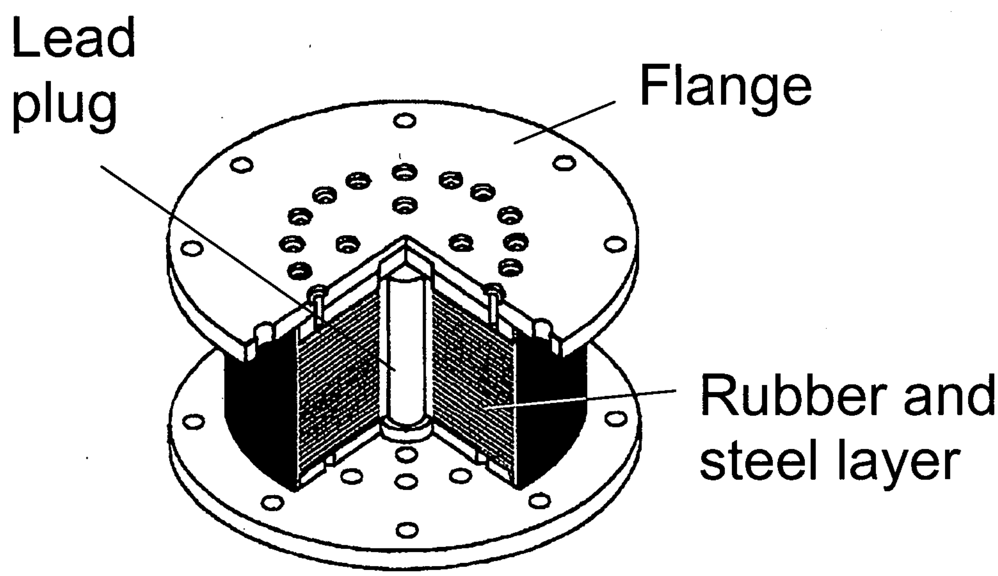

Figure 1-3 Configuration of 4S Seismic Isolator

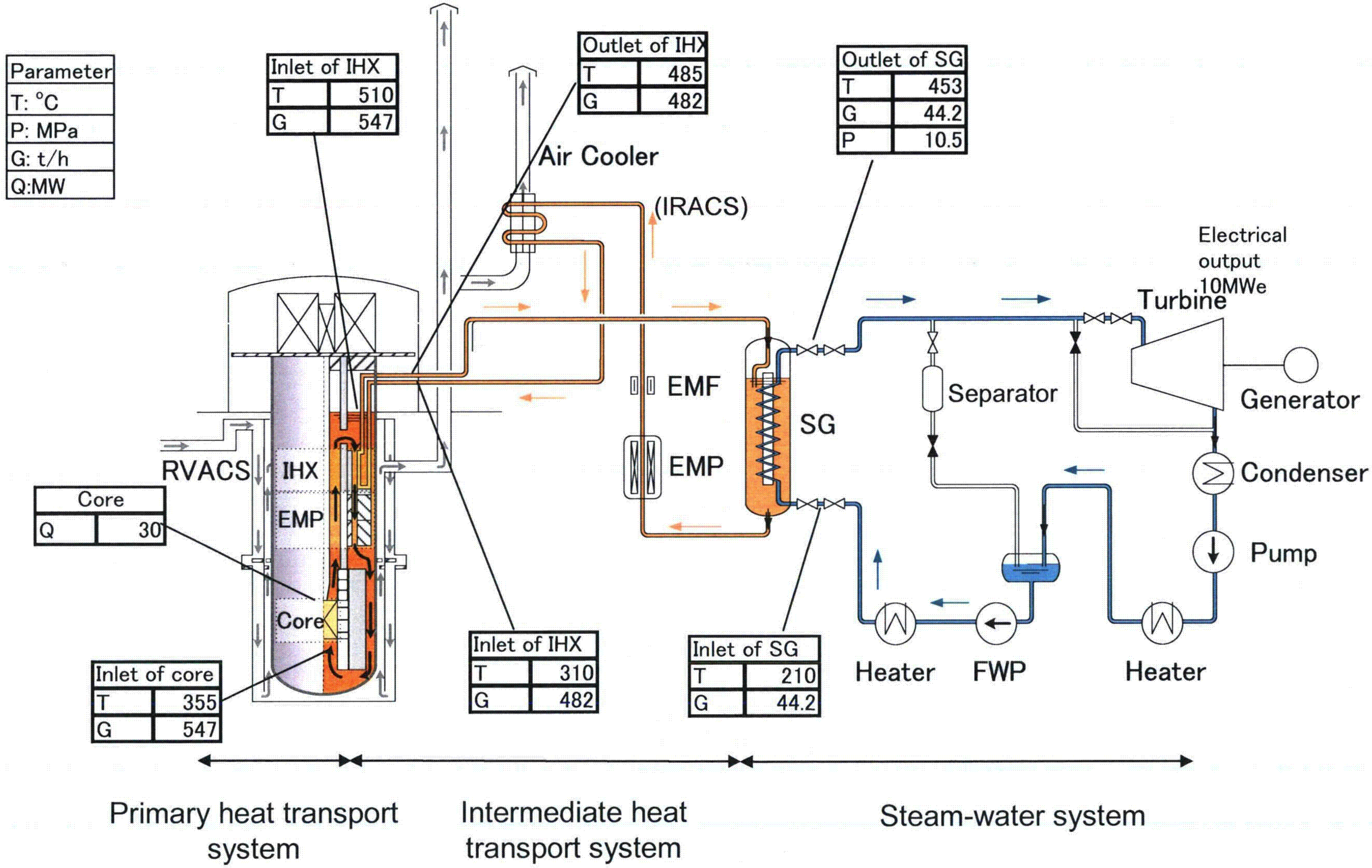

Figure 1-4 4S Heat Transport System Flow Diagram

2 PLOT PLAN AND BUILDINGS

2.1 PLOT PLAN

The main buildings of the 4S reactor site consist of the:

- Reactor building.
- Service building.
- Turbine building.

The plot plan of the 4S plant is shown in Figure 2-1.

The reactor building is below grade, and the other buildings are above grade.

The other structures (gas turbine, switchgear, and the like) are within the owner-controlled area.

2.2 BUILDINGS

A section view of the reactor building and turbine building is shown in Figure 2-2.

2.2.1 Reactor Building

The reactor building is set below grade. It contains the reactor assembly and IHTS (piping, air cooler, EMP, steam generator, and safety grade electrical and control equipment). The reactor assembly is supported from the reactor building, and it extends into the silo, which is a separate enclosure below the reactor building. A concrete-filled steel structure is used for the reactor building.

A base mat supports the reactor and other safety-related components, and a bio-shield wall shields radiation.

The reactor building is supported by horizontal seismic isolators, which are anchored to the base mat. In addition to being located where the normal radiation dose is low, the seismic isolators are protected by a shield wall and a labyrinth RVACS flow path. Space is provided around the isolators to accommodate in-service inspection and isolator maintenance.

The roof corresponds to the slabs above the ground level and includes the bio-shield plug, which is a concrete-filled steel structure removed to gain access for maintenance and refueling that is designed to withstand tornado impact. The reactor building is safety-grade and seismic Category I.

2.2.2 Service Building

The service building is above grade, and it contains the security, radiation control, and radioactive waste management (gas treatment) facilities.

The structure of this building is conventional construction.

2.2.3 Turbine Building

The turbine building is above grade, and it includes the turbine, generator, and related components for the power conversion system and auxiliary systems.

The structure of this building is conventional construction.

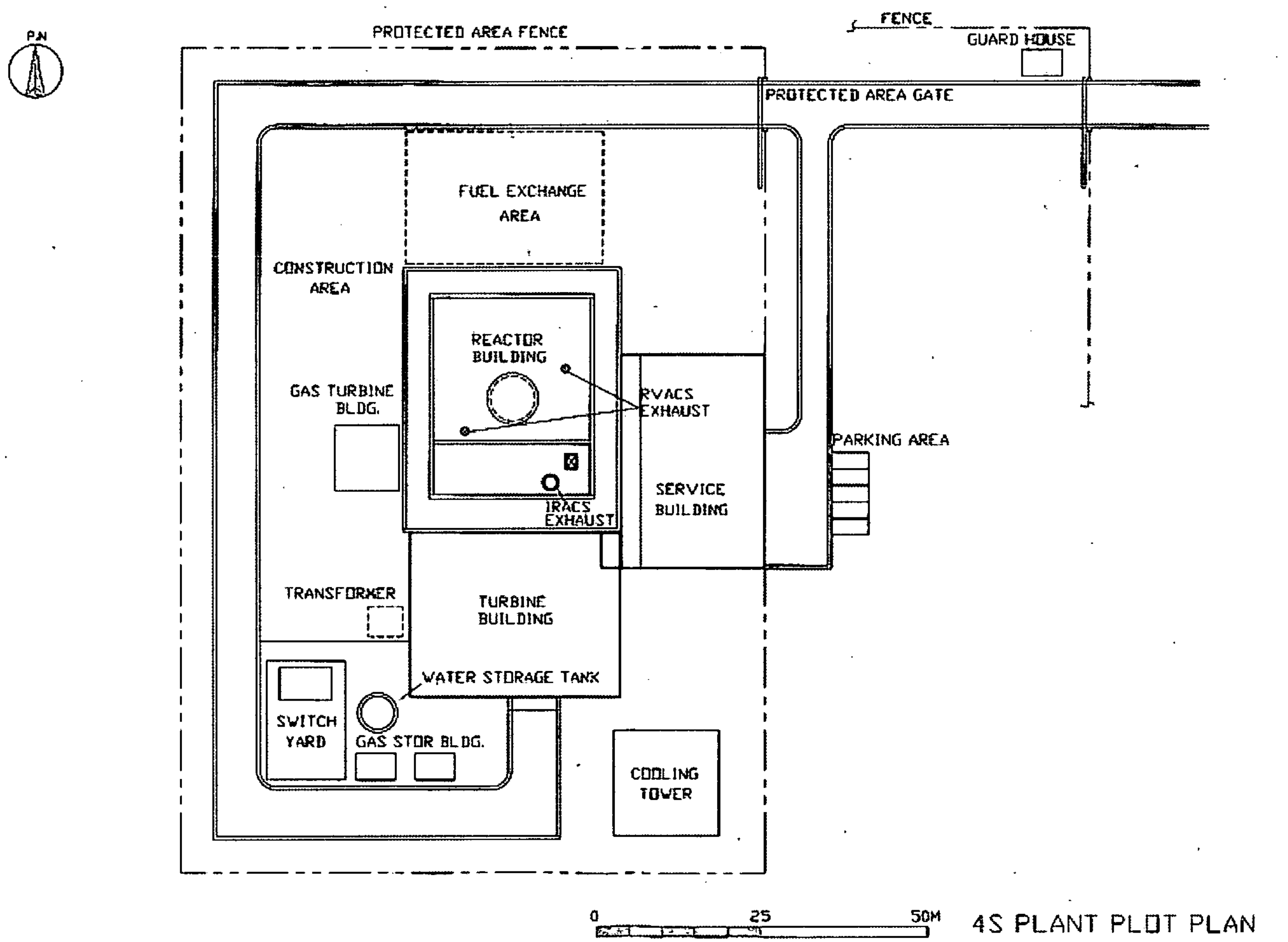

Figure 2-1 4S Plot Plan

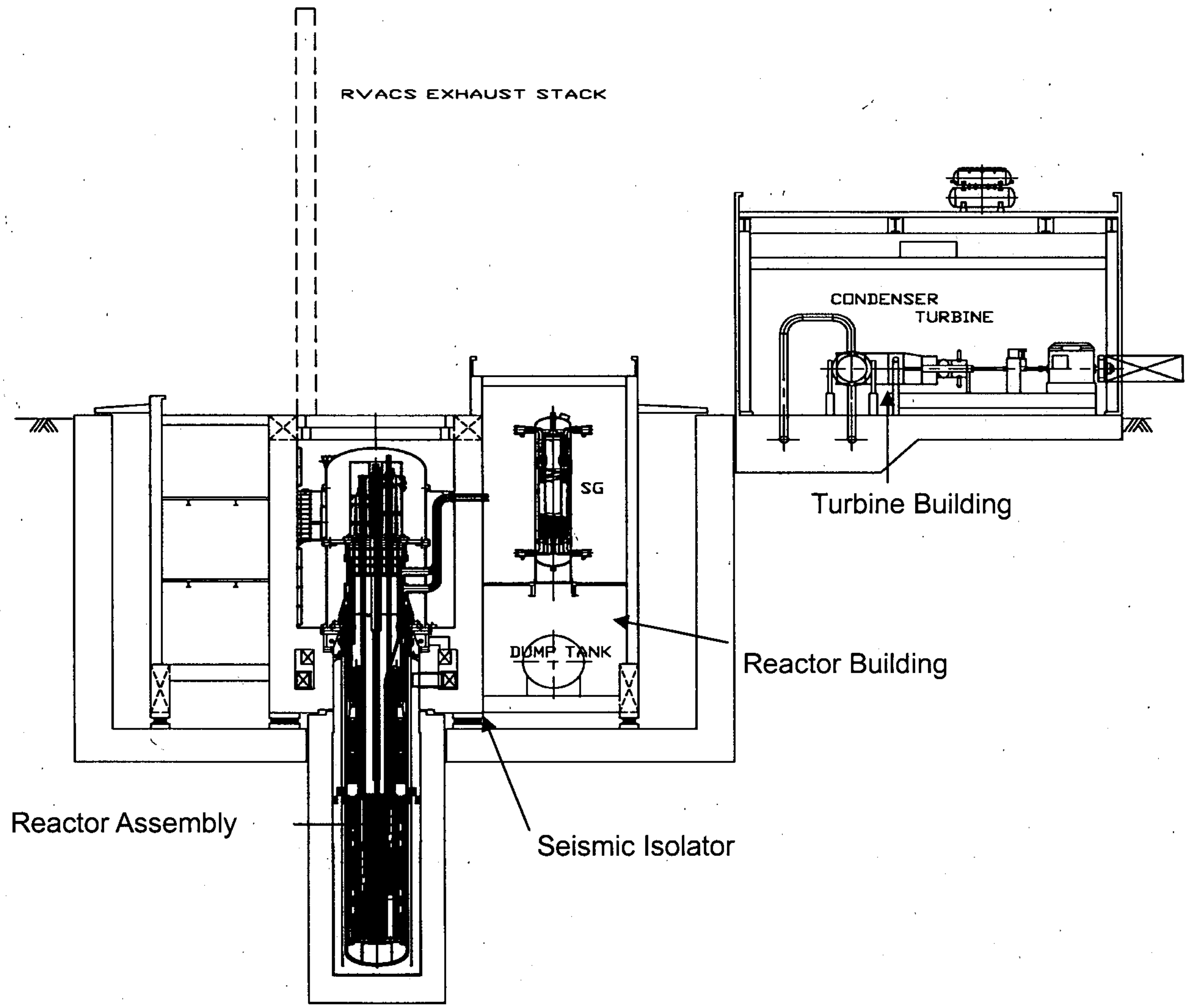

Figure 2-2 Section View of 4S Reactor Building and Turbine Building

3 REACTOR AND CORE

3.1 INTRODUCTION

The 4S core is reflector controlled. The core consists of 18 hexagonal fuel assemblies and 1 central assembly containing the shutdown rod and fixed absorber. The core is rated at 30 MWt with an average temperature rise of 155°C. The inlet temperature is 355°C, and the outlet bulk temperature is 510°C. The core height is 2.5 m. The fuel life is 30 years.

The fuel subassembly cladding and duct material is HT-9, chosen for its resistance to void swelling. The fuel alloy material is U-10%Zr. The fuel core height is 2500 mm, and the overall assembly length is 6520 mm.

The core barrel, reflector, and lower vertical shroud material is ferritic stainless steel (modified 9Cr1Mo steel).

Reactivity and power are controlled by a six-segment cylindrical reflector surrounding the core. The reflector covers the core partially to reach criticality. Lowering of the reflector to below the core region can be rapidly achieved for scram shutdown. The reflector has sufficient worth to enable shutdown without using any additional means.

In addition, the centrally located shutdown rod has sufficient worth itself to bring the core to subcriticality under cold conditions.

Figure 3-1 shows the core cross section and the reflector.

3.2 FUEL SYSTEM DESIGN

Figure 3-2 shows the fuel assembly configuration. The number of pins in one assembly is 169. The pins contain fuel columns made of U-10%Zr alloy. The grid spacers maintain gaps between the pins to prevent them from contacting each other. The fuel slug portion of each pin is 2500 mm high, and the fission gas plenum just above the fuel is 2700 mm high. The pins incorporate a sodium bond between the fuel slug and cladding. The fuel smear density inside the cladding is 78 percent of the theoretical density.

A neutron shield made of seven pins containing B_4C is installed in the upper portion of each fuel assembly.

The combination of the outer diameter of the entrance nozzle of each fuel assembly, and the inner diameter of the outlet nozzle, enables the fuel handling equipment discrimination mechanism to identify a certain fuel assembly fit to the module located in the corresponding orifice zone of the core flow distribution map.

The refueling machine loads and unloads the fuel by gripping it at the handling head.

The core fuel is restrained and supported by the core support structure.

The metallic fuel lifetime is limited by the cladding creep rupture performance. Design criteria limits that ensure the cladding integrity during steady-state operations are set based on limits that were used to ensure the safe operation of the EBR-II in the United States. The fuel pins are designed to maintain integrity for 30 years by adopting the large fission gas plenum and thick cladding wall to establish a large margin to cladding failure.

3.3 NUCLEAR DESIGN

Table 3-1 identifies the core performance parameters.

Reactivity balance for the 4S reactor is achieved by the cavity can above the reflector and the fixed absorber, which is made of hafnium and is installed at the center assembly. The cavity cans installed above the reflectors enhance the increase in neutron leakage from the steel reflectors relative to the sodium coolant. The fixed absorber enables a large excess reactivity at the beginning of the cycle, which is required to maintain criticality for 30 years.

Table 3-2 lists the reactivity control equipment.

Figure 3-3 is a graph of the 4S reactor decay heat (normalized at rated power).

3.4 THERMAL-HYDRAULIC DESIGN

There are three flow orifice zones for the fuel regions. The assembly flow is set using an orifice to adjust for the power distribution across the core. The maximum cladding temperature is maintained less than 620°C over the fuel life.

The orifice design assumes that the leakage flow ratio from the core assembly supports is approximately 1.2 percent of the total flow. The flow through the reflectors is approximately 2.5 percent of the total core flow to provide for cooling the gamma heating of the reflector.

The maximum pressure drop across the core, which includes the subassemblies and the associated modules including the flow orifice, is 0.10 MPa.

3.5 REACTIVITY CONTROL AND SHUTDOWN SYSTEM

The reactivity control system consists of the following control elements:

- Reflector
- Shutdown rod
- Fixed absorber
- Drive equipment, including drive units for each reflector, the reactor shutdown rod, and the fixed absorber

Figure 3-1 shows the core arrangement.

Six separately controllable segments combine to form a cylindrical reflector outside the core barrel. The core element at the reactor core center has a cylindrical reactor shutdown rod surrounded by six circumferentially divided, fan-shaped fixed absorbers, contained in a hexagonal wrapper tube.

The reflector is the primary shutdown system with the shutdown rod available as a backup shutdown system.

3.5.1 Reflector

Figure 3-1 includes a structural drawing of the reflector, showing the reflecting region and the cavity can region. The reflector is fabricated of laminated sheets of ferritic steel (modified 9Cr-1Mo steel) and is connected to the reflector drive unit on the shielding plug. The reflector increases reactivity when it is raised above the reactor bottom to overlap the active region of the core and lowers reactivity when it is lowered back into the reactor bottom.

Each sector of the cavity region consists of six cavity cans. The cavity region is installed above the reflecting region; its function is to enhance neutron leakage relative to the surrounding sodium coolant. Each cavity can is a cylindrical shape and filled with argon gas to prevent deformation by outside pressure.

3.5.2. Reflector Drive

The drive unit consists of three kinds of drive systems: startup and shutdown, power control, and burnup swing compensation. Each separate reflector segment drive unit is independent from each other.

Figure 3-4 shows the drive mechanisms and their movement. As described in the following paragraph, the letters in parentheses correspond to Figure 3-4.

Power cylinder (A) initiates the startup and shutdown motion of the reflector. (The power cylinder is a motor-driven gear mechanism used to raise and lower the reflector segments for fast [coarse adjustment] motion.) In the case of startup, power cylinder (A) will raise the reflector until just before criticality is reached. The mechanical rod stop (A) restricts the motion of plate (A) to limit the potential total reactivity inserted. A separate power cylinder (B) for power control continues to raise (insert) the reflector from criticality to rated power. Another mechanical rod stop (B) restricts the motion of plate (B) to limit the total reactivity inserted.

A burnup swing compensation drive incrementally raises the reflector during reactor operation to compensate for reactivity over core life. This drive system consists of a ball screw, motor, and reduction gear. The power cylinder (A) is used for rapidly lowering (withdrawing) the reflector by releasing the brake to accomplish reactor shutdown/scram in an emergency.

3.5.3 Shutdown Rod

Included in the core element at the reactor center is a cylindrical reactor shutdown rod. This rod is surrounded by a fixed absorber, which is divided into six fan-shaped pieces in a hexagonal wrapper tube.

Each control element of the reactor shutdown rod is made of a cylindrical tube filled with B_4C pellets and sealed. The control element is inserted into an upper and lower lattice board with protecting tubes to form the reactor shutdown rod.

The drive system of the shutdown rod is a motor-driven ball screw mechanism. It withdraws the shutdown rod prior to startup. The reactor shutdown rod is detached from the drive mechanism and the rod inserts by gravity in the event of a scram. In the event of a normal plant shutdown, the shutdown rod will be driven into the core by the drive mechanism.

3.5.4 Fixed Absorber

The fixed absorber is hafnium sheathed in stainless steel. In the beginning of core life, the fixed absorber remains inserted in the reactor core. At some point in the fuel life, the fixed absorber is withdrawn, adding positive reactivity to compensate for fuel burnup. This allows the reflector to control reactor power over the entire core life.

Table 3-1 Core Performance		
Item	**Unit**	**Value**
Conversion ratio	-	0.45
Average burnup	GWd/t	34
Average linear power	W/cm	39
Maximum assembly power	MW	2
Sodium void reactivity	$	0
Fast neutron flux	nvt	2E23

Table 3-2 Reactivity Breakdown for Reactivity Control Equipment			
Reactivity Breakdown	**Reflector**	**Shutdown Rod**	**Fixed Absorber**
Reactivity from cold to full power	○	○	-
Burnup compensation	○	-	○
Shutdown margin	○	-	-
One reflector stuck margin	○	-	-
Uncertainty compensation for core reactivity	○	-	○

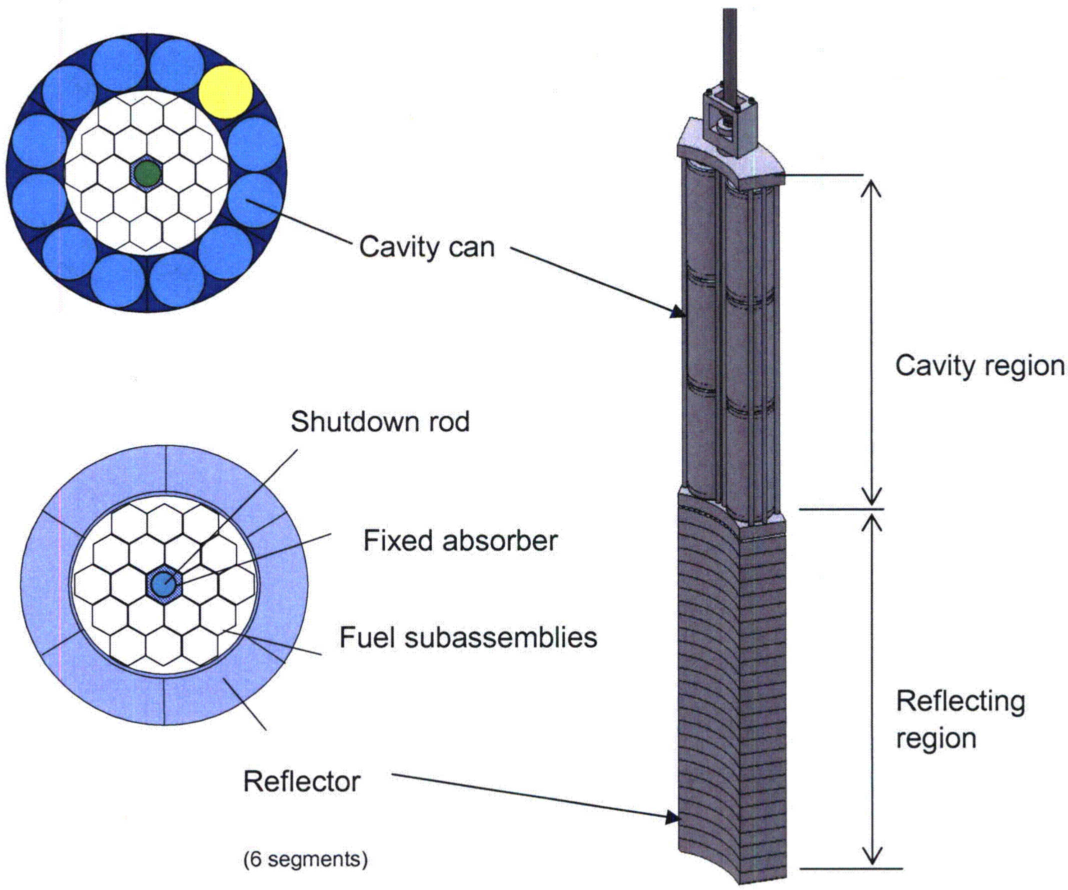

Figure 3-1 Core Layout and Reflector

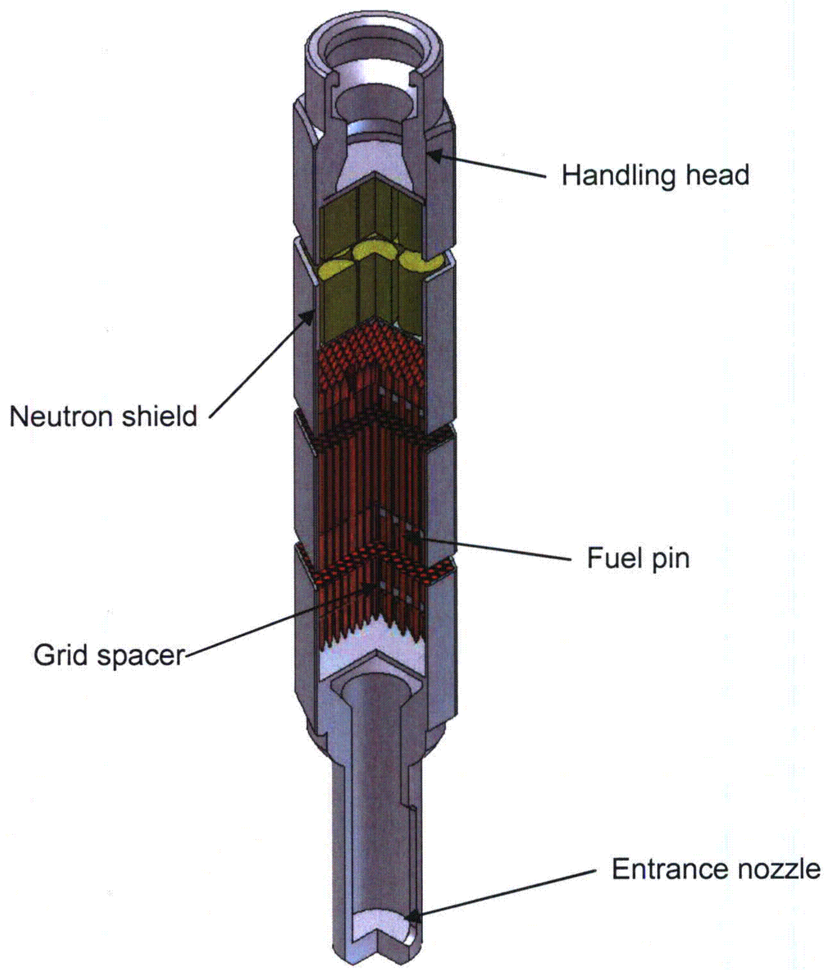

Figure 3-2 Fuel Subassembly Configuration

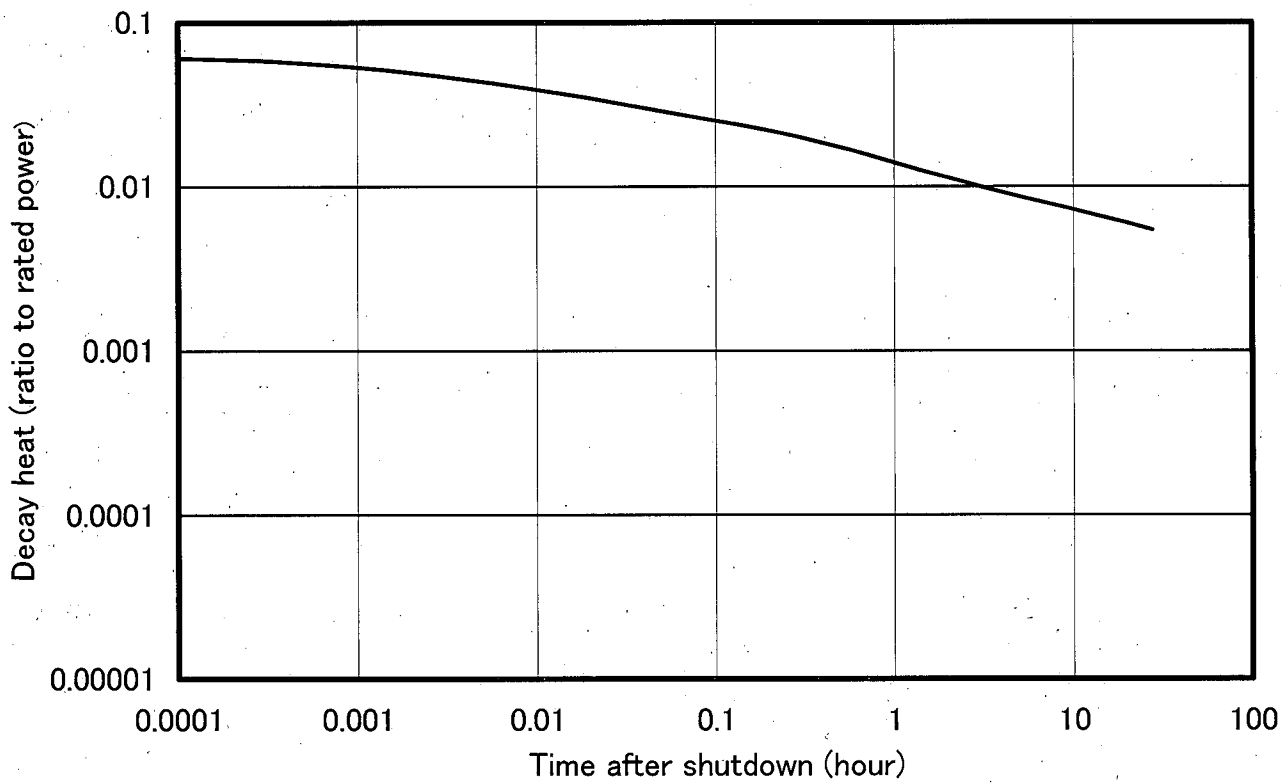

Figure 3-3 Reactor Decay Heat Graph

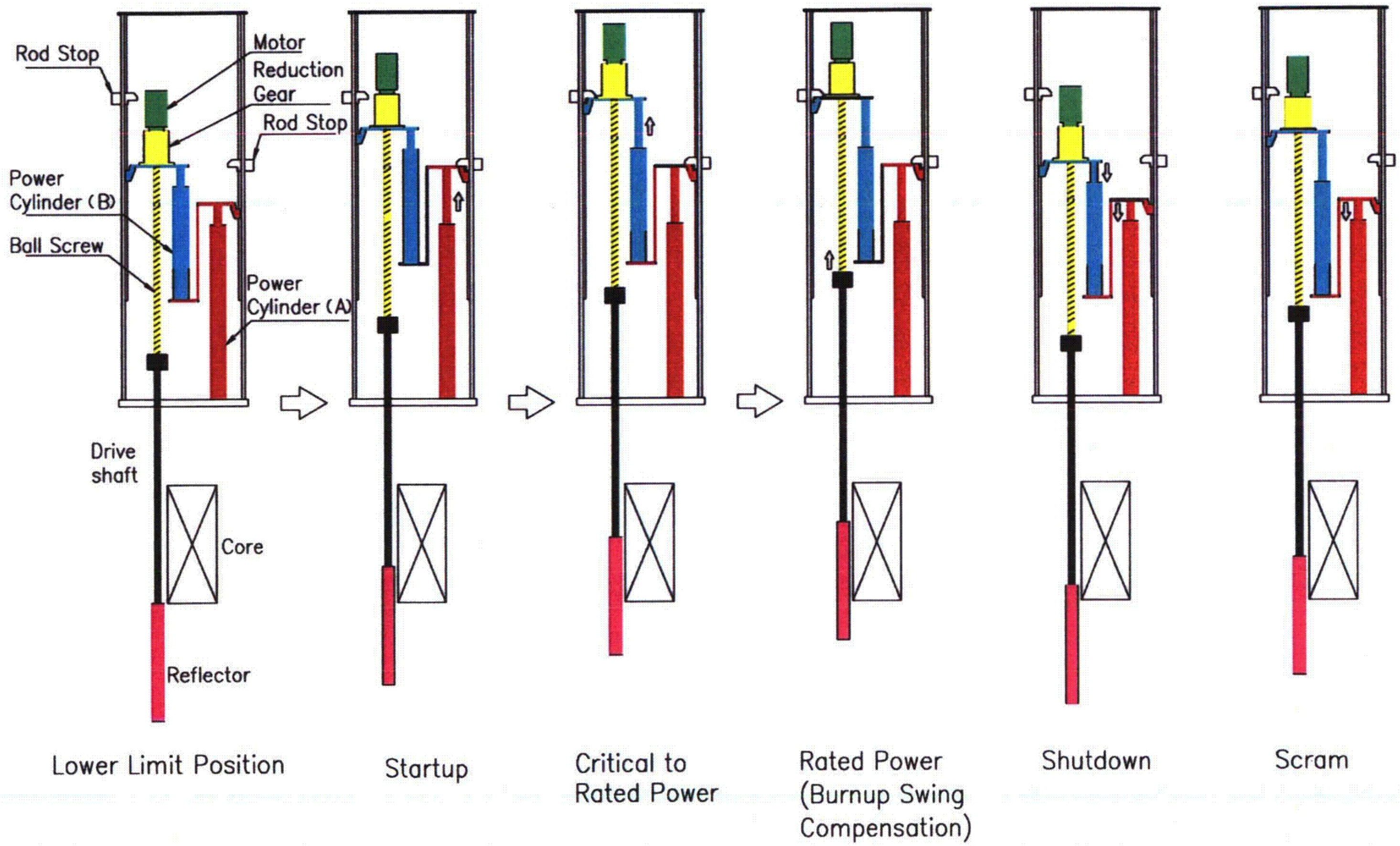

Figure 3-4 Reflector Drive Mechanism

4 REACTOR COOLANT SYSTEM AND CONNECTED SYSTEMS

4.1 INTRODUCTION

The reactor structure of the 4S is shown in Figure 4-1.

The reactor structure includes fuel assemblies, primary EMPs, an IHX, a reactor core support structure, a vertical shroud, a radial shield, a reflector, a fixed absorber, and reactor instrumentation, which are all included in the reactor vessel. The reactor is enclosed by the containment system, which consists of the guard vessel and top dome, so that cooling of the reactor core is maintained even if coolant leaks from the reactor vessel.

The primary flow circuit is shown in Figure 4-2. The coolant from the core flows up through the central part of the reactor vessel, into the IHX, and then down inside it. The coolant then reaches the primary EMPs, descends around the shield region to the lower plenum, and flows again into the core.

The IHTS consists of a steam generator, an air cooler, an EMP, an electromagnetic flow meter, piping, and associated equipment. Approximately 30 MW of heat from the primary IHX is conveyed to the steam generator during plant rated operation; decay heat is also conveyed to the steam generator during normal shutdown.

This reactor structure is installed in the reactor building; the IHTS piping penetrates the top dome and connects with the inlet/outlet header of the IHX.

4.2 REACTOR VESSEL, SHIELDING PLUG, GUARD VESSEL, AND TOP DOME

The reactor vessel and guard vessel, shielding plug, and top dome are the major components of the PHTS, which provides the shell and support structure for the reactor core, the primary sodium, and the structures within. The reactor vessel performs its support and shell functions during all temperature, pressure, and load variations that occur during the operating lifetime.

The reactor vessel is a cylindrical vertical shell fabricated from type 304 stainless steel. It has a diameter of approximately 3.5 m and a length of approximately 24 m, with an expanding conical section at the upper part. The upper flange is supported by a support cylinder on a pedestal. The sodium in the reactor vessel has a free liquid surface, above which is a cover gas space filled with inert argon gas. The coolant exits the reactor core and ascends to the central portion of the reactor vessel. It then flows through the IHX to the suction of the primary EMPs, descends the shield region, and reaches the lower plenum, from which it returns to the core. The core and the shield are supported from the lower portion of the reactor vessel.

The shielding plug is installed in the upper part of the reactor vessel at the IHX shell, completing the primary heat transfer system boundary. It shields radiation and heat from the reactor core, forms a reactor cover gas boundary, and positions/supports components mounted on the shielding plug at predetermined positions. The shielding plug, as shown in Figure 4-1, is supported on a pedestal by a shielding plug support. The lower flange of the shielding plug support is bolted onto the upper surface of the upper flange of the guard vessel. The weight of the shielding plug, reactor upper-mounted components, and shielding plug support is transmitted to the pedestal via the upper flange of the guard vessel.

The shielding plug consists of a radiation shielding layer and a heat shielding layer configured as an outer plug and an inner plug. The shielding plug incorporates redundantly sealed penetrations accommodating the following:

- Head-mounted instruments
- Reflector drive shaft
- Shutdown rod drive and fixed absorber connecting shaft

The primary EMP and the IHX are suspended from the upper support structure of the reactor vessel. Since the shield plug bears the weight load of the reflector drive mechanisms, the drive units of the shutdown rod and the fixed absorber, and the reactor instrumentation, these structures are not a weight load to the IHX.

Active components of the reflector drive mechanism, the shutdown rod, the fixed absorber drive unit, and also the electrical equipment such as nuclear instrumentation, are placed outside the nuclear reactor. This makes inspection, maintenance, and repair simpler. The reactor upper-mounted components, installed in the inner plug, such as the shutdown rod/fixed absorber drive mechanism and reflector drive mechanism, are removed for fuel charging or the unlikely event of fuel replacement. Fuel replacement is performed by removing the top dome and the inner plug, and using a temporary fuel handling facility that is not maintained at the reactor site.

The guard vessel is an engineered safety feature, which ensures the required coolant liquid level for reactor core cooling is maintained in the event of leakage from the reactor vessel. This facilitates the removal of decay heat. The guard vessel is only slightly larger than the reactor vessel, and therefore, the space between the reactor vessel and the guard vessel is limited in volume such that the liquid level in the reactor vessel can be maintained in the event of sodium leakage from the reactor vessel.

The heat collector is installed on the periphery of the guard vessel, forming an RVACS air flow path. The heat collector separates descending cold air from the inlet duct from the ascending warm air from the reactor. It also has the function of a heat sink for transmitting heat from the reactor to the atmosphere.

The top dome, as shown in Figure 4-1, is a cylindrical vertical shell supported by a pedestal at the lower flange. A half-elliptical top dome cover is fitted to the upper part of the dome. The weight of the top dome is transmitted to the pedestal via the upper flange of the guard vessel. The lower flange of the top dome and the upper flange of the guard vessel are bolted together. The compressive load applied to the upper flange of the guard vessel is effective for maintaining sealing.

The inside of the top dome is maintained as a constant nitrogen gas atmosphere. Heat removal for the top dome is provided internally by an air-conditioning system for the nitrogen and externally by heat dissipation from the top dome outside surface. The perimeter of the top dome has an air lock with a double door and cable penetrations for equipment and instrumentation installed on the shielding plug.

4.3 REACTOR INTERNAL STRUCTURES

The reactor internal structures shown in figure 4-3 consist of the following:

- Core support structures
- Upper vertical shroud
- Fixed shield
- Instrumentation and equipment support

4.3.1 Core Support Structures

The core support structures consist of reactor core support instrumentation, the reactor core barrel, and the backup core support. They support and restrain the core fuel subassemblies and the central subassembly, including the shutdown rod and fixed absorber. The core barrel and the lower vertical shroud guide the reflector segments around the core.

The reactor core support consists of an upper core support plate, a reactor core support cylinder, and a lower core support plate. The lower core support plate, fabricated from one large piece, is installed on a support base on the reactor vessel cylindrical shell, and it spans the width of the vessel. The plate is attached to the support base with long stud-bolts so that any radial position gap caused by differential thermal expansion can be accommodated. The reactor core support cylinder is fixed to the top of the lower core support plate, and the upper core support plate is fixed to the top of the reactor core support cylinder. A flow module with orifices that regulate flow to the individual fuel assemblies is also installed on the lower core support plate. A backup core support structure consists of a cylinder positioned under the lower core support plate and welded to the hemispherical section of the reactor vessel lower head.

The lower plenum, formed by the lower core support plate and the reactor-vessel bottom head, serves to redirect the sodium flow from the sides of the reactor vessel and the EMPs to the inlet of the core. In addition, the basic size is determined by the size that can guarantee the necessary rigidity for core support.

The reactor core barrel forms double cylindrical structures combined with a lower shroud, which separates the downward and upward flow of reactor coolant. The core support framework to position the fuel is installed above the upper pad of the core barrel, and the seismic pad is installed underneath that to receive the radial load of the core during an earthquake. Since the reactor core barrel and lower vertical shroud are placed near the core, the material used is modified 9Cr-1Mo steel, chosen for its resistance to irradiation-induced changes in material properties.

4.3.2 Upper Vertical Shroud

The upper vertical shroud separates the upper plenum from the IHX and the EMP, and also suppresses the amount of heat transfer from hot (510°C) sodium, which flows out of the core exit, to the sodium that flows out of the EMP at a much lower temperature (355°C).

The structure is shown in Figure 4-1. The heat insulation material is contained inside the upper support shroud, and its periphery is fully covered. The bellows accommodates the differential thermal expansion, which occurs with the temperature difference inside and outside the vertical shroud.

The reactor coolant boundary consists of the reactor vessel and the IHX. The boundary of the cover gas consists of the upper flange of the reactor vessel, the IHX and its upper flange, and the shield plug. It is a simpler structure than the rotating plug familiar to a conventional LMFBR. The reactor system is designed with no planned periodic fuel exchange; it has a simple structural boundary for the cover gas. The system does not need a purification system for the cover gas because the cover gas is sealed, and therefore, there is little opportunity for an impurity to contaminate the system.

Components, such as the IHX, the primary main EMPs, and the reflector, can be withdrawn through the upper part of the reactor for ease in replacement. The initial fuel loading is carried out through the opened inner plug using a temporary fuel-handling machine. A filling and draining system for the reactor vessel is then used to fill it with liquid sodium.

4.3.3 Fixed Shield

The radial shielding controls ductile reduction of the reactor vessel due to neutron irradiation and consists of the inner tube, which is filled with B_4C, and the outer tube, which protects the inner tube from thermal expansion and swelling of the B_4C. The radial shielding consists of several shields with differing outside diameters.

The reflector upper shielding suppresses streaming of radiation from between the reactor core barrel and the lower shroud. It is filled with B_4C. This upper shielding of the reflector is divided into six segments and is installed on the upper region of the reactor core barrel and the lower shroud, in the same circumferential pitch as the reflector.

The IHX peripheral shield is a stainless steel plate, which separates primary sodium from the tube bundle and secondary sodium inlet circulation flow path. A shielding plate decreases activation of secondary sodium in the inner wall of the tube bundle inner shroud and the upper part of the inlet circulation flow channel.

4.3.4 Instrumentation

The reactor structures provide mechanical support for in-vessel sensors and equipment required by other systems. This support for instrumentation primarily constitutes the provision for drywells with the actual instrument being provided by the requesting system. For other equipment, space in the reactor and penetrations through the shielding plug are provided. The sensors and equipment are the following:

- Reactor core outlet temperature
- Sodium level sensing
- Nuclear instrumentation system
- Neutron source
- Passive diffusion fission gas monitor

4.4 PRIMARY HEAT TRANSPORT SYSTEM

Heat generated in the reactor core is transferred to the IHTS via the IHX during normal operation. The PHTS is contained entirely inside the reactor vessel. The coolant, leaving the core, rises through the central part of the reactor vessel, is directed to the IHX, goes through the inside of the IHX tubes, and continues down to the suction of the primary EMPs. The coolant is then pumped down through the shielding, is redirected in the lower plenum, and returns to the core inlet. The flow path of the coolant is shown in Figure 4-2. The equipment is described in the following paragraphs.

Two sequential main circulating EMPs are installed in the reactor. These pumps are immersed in sodium, and circulate the primary coolant sodium. The pumps are installed in the perimeter of the core shroud near the reactor vertical center. There is shielding under the pump and the IHX above the pump. The configuration of the EMPs is shown in Figure 4-4.

The rated flow is 10.6 m^3/min, and the total rated pump head is 0.1 MPa for the two pumps in series. As shown in Figure 4-5, a motor-generator set for the EMPs serves to prolong flow coastdown when the power supply is stopped. The motor-generator set provides enough power to the pumps to support the required flow coastdown.

One IHX is installed in the nuclear reactor to transfer the heat of 30 MWt generated in the core to the IHTS. The IHX is a vertical shell and tube type heat exchanger. The primary coolant flows down inside the straight heat transfer tubes, which are arranged in several concentric circles of different diameters around the annular heat exchanger shell. The shell of the IHX is a double annular structure positioned around the entire circumference of the reactor vessel. The outer side (the reactor vessel shell side) forms the low temperature flow path of the intermediate inlet coolant, and the inner side (reactor vessel center side) forms the hot temperature flow path of the secondary outlet coolant. The IHX is hung and supported by its upper flange. The primary EMPs are connected to the lower part of the IHX.

All components of the IHX are made of austenitic stainless steel.

4.5 INTERMEDIATE HEAT TRANSPORT SYSTEM

The IHTS consists of the heat transport loop, which is formed by a steam generator, an air cooler, a main circulating EMP, an electromagnetic flow meter, piping, and associated equipment. Approximately 30 MW of heat from the primary IHX is conveyed to the steam generator during plant rated operation. The inline air cooler removes decay heat when necessary, but is in standby during normal operation.

The IHTS is located in the reactor building. The IHTS piping penetrates the top dome in order to connect with the inlet/outlet piping of the IHX.

Heat is transferred to the steam/water loop by a steam generator. The steam generator shell has a free surface of liquid sodium outside the helical tubes; the level is kept almost constant during normal operation. The steam generator level is maintained during normal operation and special evolutions, such as plant shutdown, by overflowing and pumping to/from a dump tank. The cold trap installed in the dump tank purifies the sodium. Figure 4-6 shows the steam generator structure.

The steam generator, which is a helical coil type with double wall tubes, serves as a heat exchanger from the intermediate sodium loop to the water/steam system. An EMP, which is an annular linear induction type single stator pump, is installed in the cold leg of the IHTS to provide a motive force. The diameter of the main piping is 8 inches.

The heat exchanger tubes are double wall with a wire mesh layer formed between the inner and outer surface of the double wall tube to prevent sodium/water reaction during a heat exchanger tube failure. The heat transfer tube bundle is composed of helical coils.

Sodium flows onto the top of the tube bundle through a distributing header at the top of the steam generator. While flowing down over the tube bundle, sodium exchanges heat with water and steam inside the tubes and flows out from the outlet nozzle at the bottom of the steam generator.

Water flows into the steam generator tubes from feedwater nozzles on the lower part of the steam generator. While rising through the helical tube bundle, water is heated by sodium and it becomes superheated steam. The steam then flows out from steam nozzles on the upper part of the steam generator.

The void between the inner and outer surface of the double tube is filled with helium gas, supplied to the separate plenum between the the sodium-side tube sheet and water-side tube sheet of the feedwater or the steam nozzles (see Figure 4-7). Tube leakage from the water/steam side is detected by moisture in the helium. Tube leakage from the sodium side is detected by helium in the intermediate loop sodium. If tube leakage is detected, the plant is shut down and the tube is plugged. The heat transfer area of the steam generator is designed with approximately 10-percent margin, including that for tube plugging. Figure 4-8 shows the leak detection system for the steam generator.

The IHTS is used during a normal shutdown to convey heat to the steam generator. After the plant is cooled down to 200°C, the steam generator is no longer used and the air cooler on the IHTS is used to remove decay heat.

4.6 RESIDUAL HEAT REMOVAL SYSTEMS

The reliable residual heat removal systems consist of the IRACS, which removes decay heat by using an air cooler in the IHTS (see Section 4.5) and the RVACS, which removes the decay heat with natural convection from air outside the reactor guard vessel. Figure 4-8 shows a schematic diagram of the residual heat removal systems.

The RVACS serves as a heat collector between the cylindrical underground concrete wall around the guard vessel and the reactor vessel. Ambient cold air descends between the underground cylinder wall and the heat collector, turns up at the lower end of the heat collector cylinder, and rises between the heat collector and guard vessel. Radiation heat from the reactor vessel is removed with natural convection heat transfer in the gap between the guard vessel and the heat collector. This process takes place under all plant conditions and for all design events entirely by natural phenomenon without the intervention of any active equipment.

Because the RVACS arrangement results in a streaming path of neutron and gamma rays from the core, the duct routing prevents any streaming and provides two paths for intake and exhaust air ducts. The exhaust duct is elevated approximately 13 m from the reactor core relative to the air intake. Because the estimated RVACS exhaust air temperature may exceed the allowable concrete temperature, the structure is insulated to meet the temperature limit of the building concrete.

4.7 HEAT TRANSPORT FLOW

The complete heat transport and power generation system is shown in Figure 4-9. The thermal output power of the nuclear reactor is approximately 30 MW, and the electrical output is approximately 10 MWe.

The primary coolant coming out of the core flows up the center of the reactor vessel and flows into the IHX at 510°C. The coolant then flows through the inside of the IHX to the suction of the primary EMP, and continues down through the shielding. It reaches the lower plenum, and then it is again sent to the core at 355°C. The primary coolant flow rate is 547 tons per hour.

The intermediate sodium is heated from about 310°C to about 485°C by heat exchange with the primary sodium in the IHX. The intermediate sodium heats water in the steam generator using helical coil tubes, and superheated steam of approximately 10.5 MPa and about 453°C is sent to the turbine.

The steam from the turbine exhausts to a condenser; then the water is sent to the feedwater supply line by the feedwater pump. Feedwater is heated through a low pressure heater, a deaerator, and a high pressure heater; and then is returned to the steam generator.

The generator, driven by the turbine at 3600 rpm, produces electricity. The reactor is always operated at 100-percent power. Any energy not required for the generation of the electrical load is dissipated by bypassing steam to the condenser.

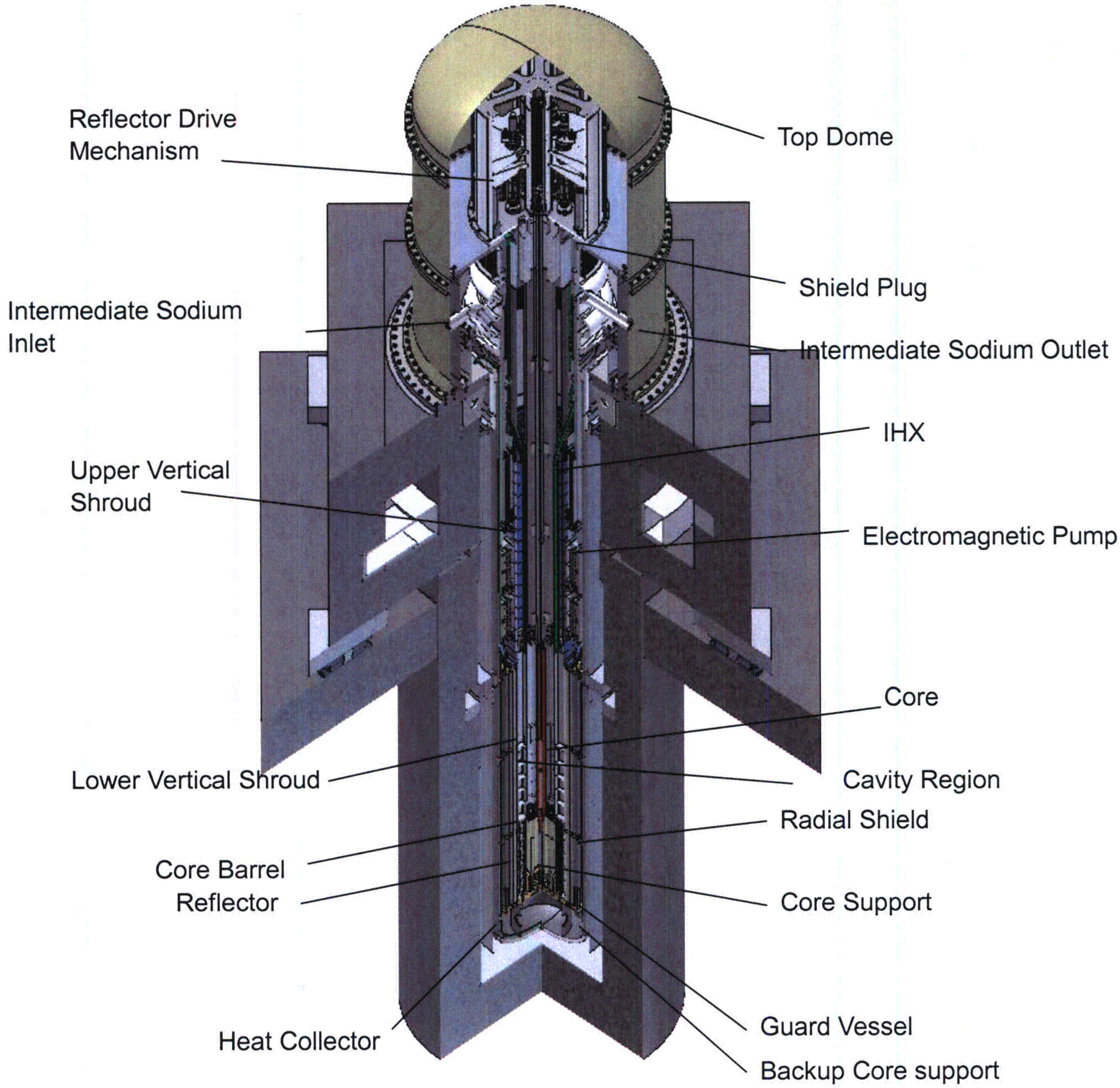

Figure 4-1 Cross Section of Reactor Assembly

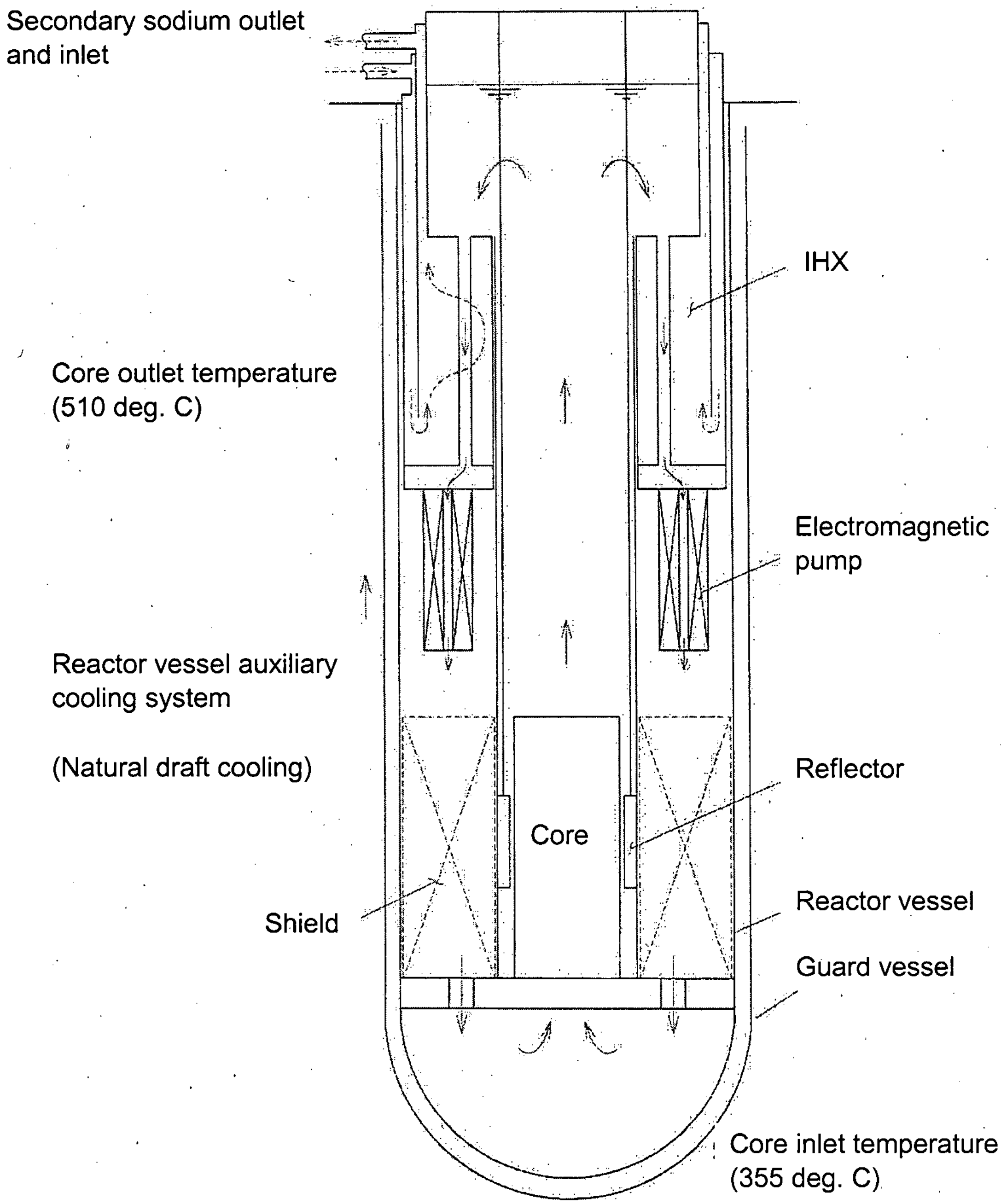

Figure 4-2 Primary Sodium Flow Circuit – Normal Operation

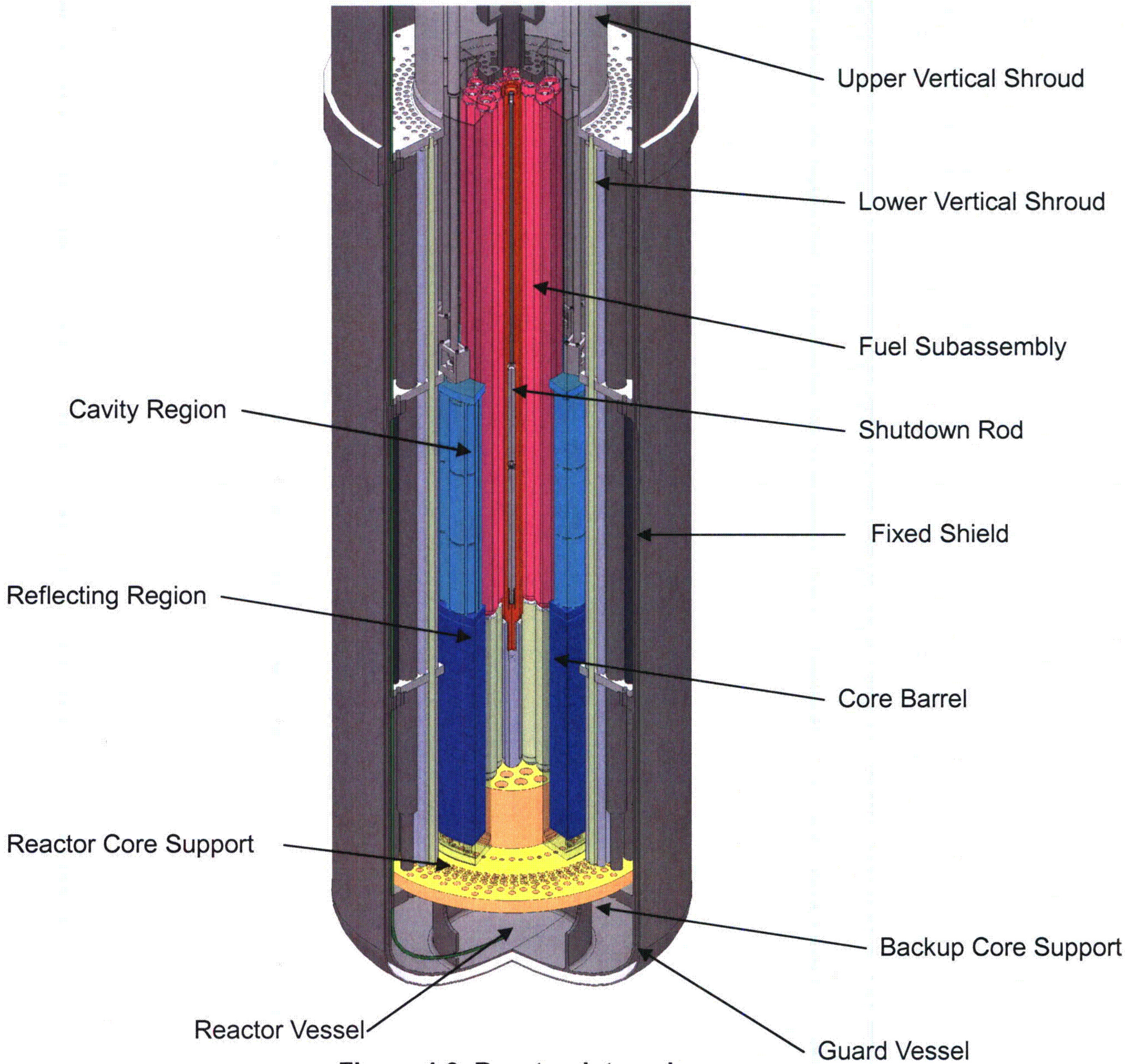

Figure 4-3 Reactor Internals

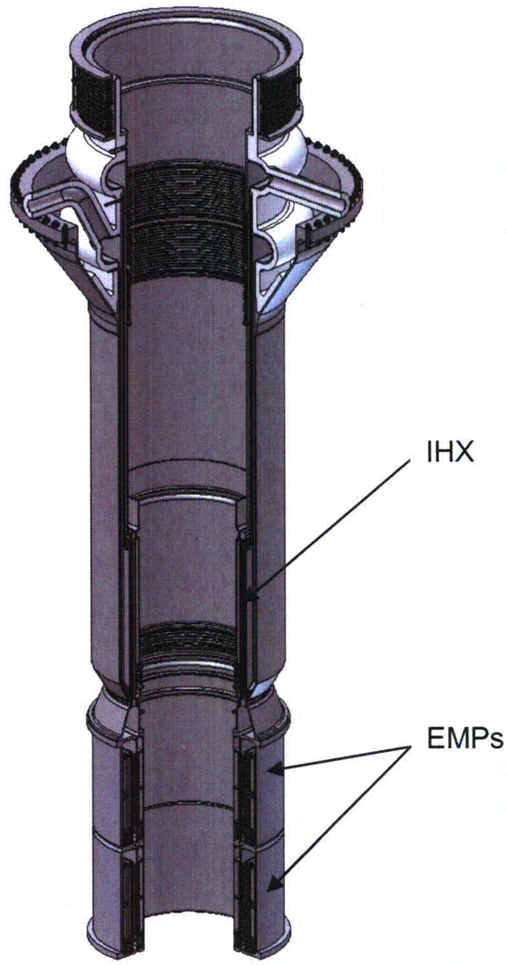

Figure 4-4 Configuration of Electromagnetic Pumps and Intermediate Heat Exchanger

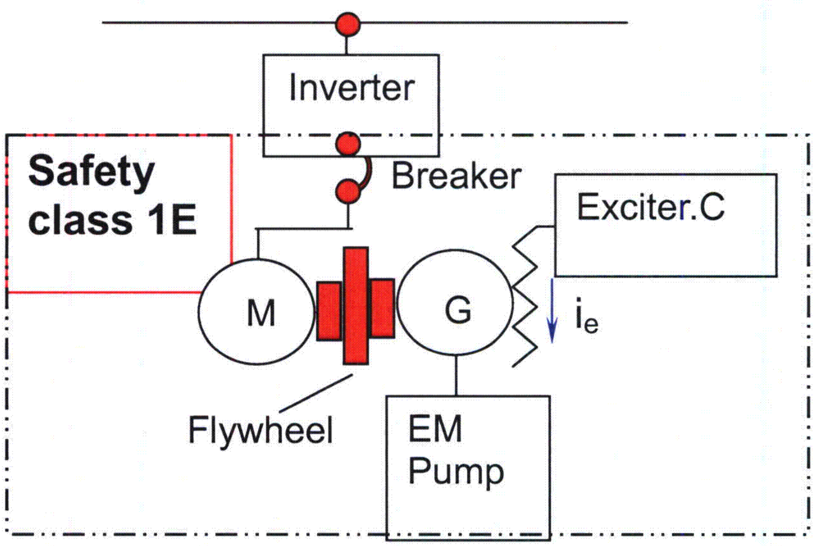

Figure 4-5 Flow Coastdown System of Electromagnetic Pump

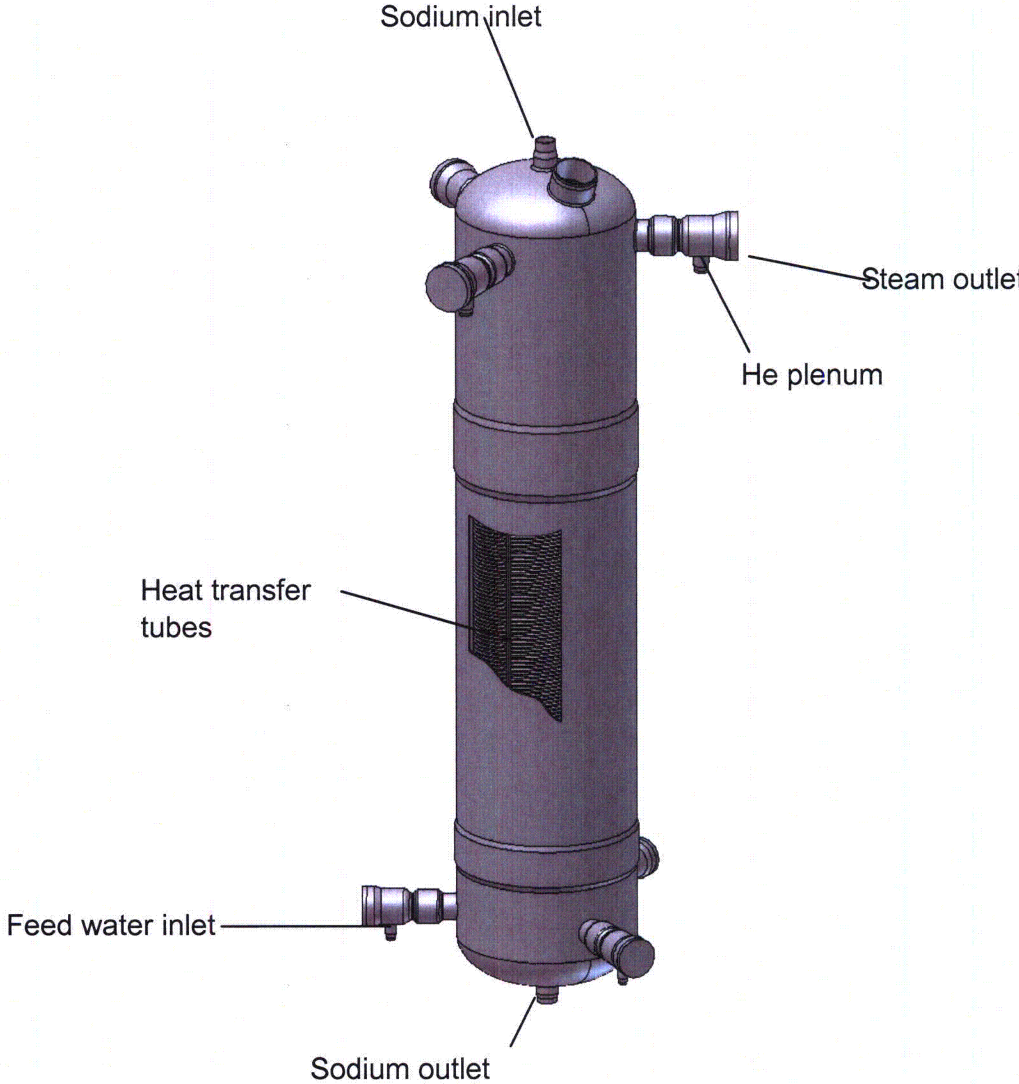

Figure 4-6 Steam Generator Configuration

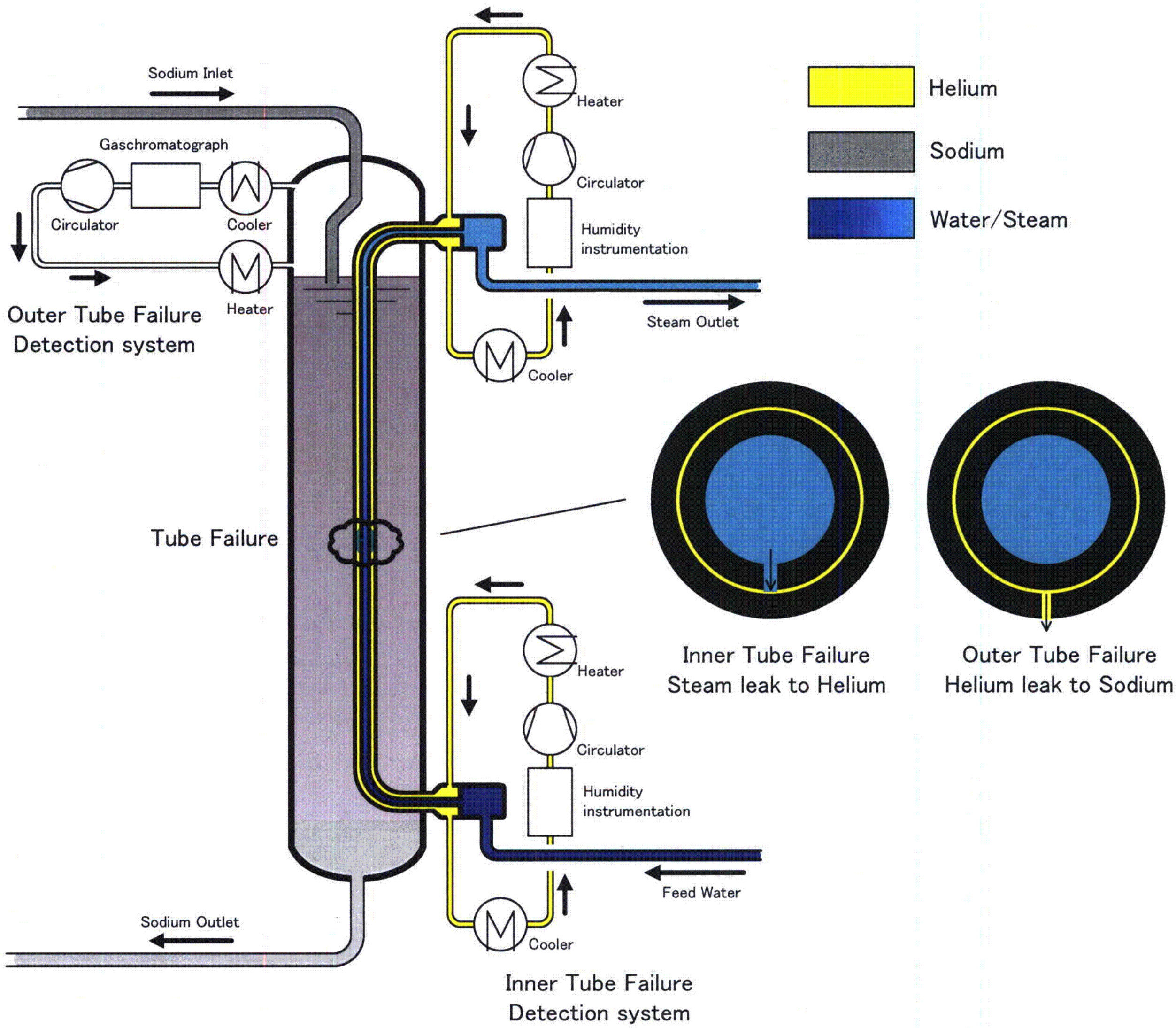

Figure 4-7 Leak Detection System of Steam Generator

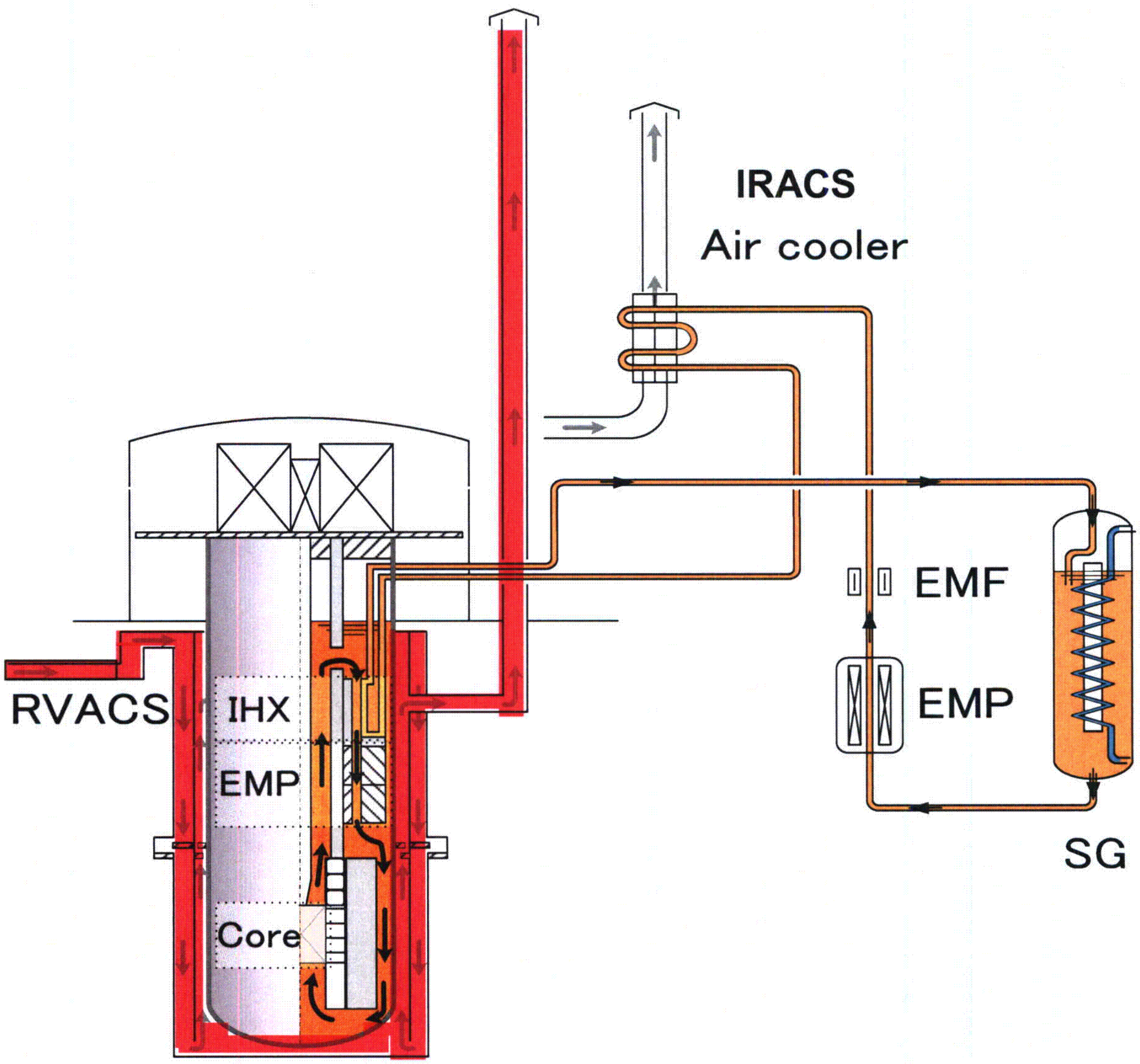

Figure 4-8 Schematic Diagram of Residual Heat Removal Systems

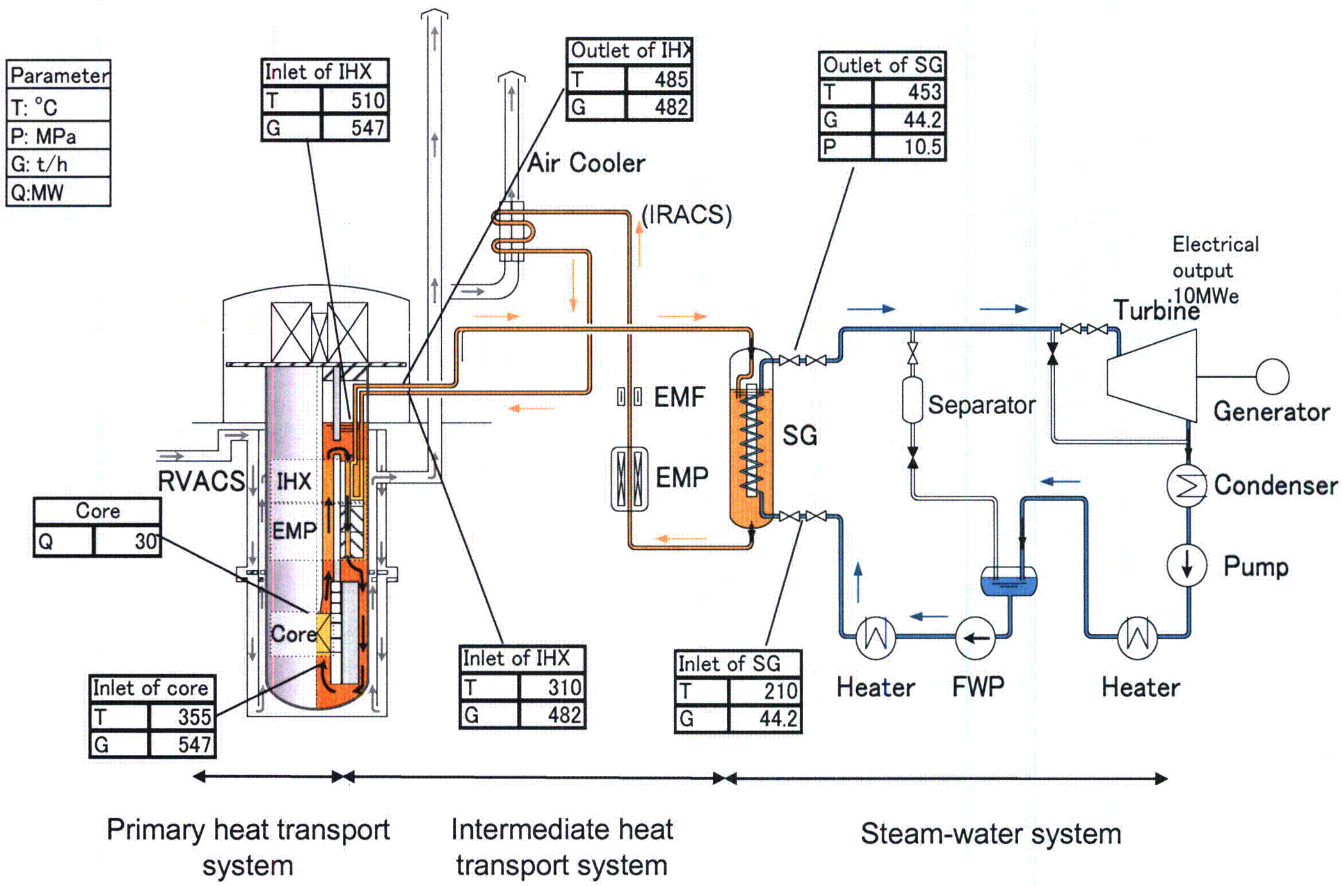

Figure 4-9 Heat Transport System Flow Diagram

5 ENGINEERED SAFETY FEATURES

Engineered safety features protect the public in the event of a potential release of radioactive fission products from the reactor system. The engineered safety features localize, control, mitigate, and terminate any such events; and maintain radiation exposure levels to the public below applicable limits and guidelines.

The following are defined as engineered safety features for the 4S reactor:

- Containment system
- Residual Heat Removal System (RHRS)

The DHRS provides a highly reliable, passive system for residual heat removal in the event of the failure of other heat transport systems. The DHRS is described in Section 4.6.

5.1 CONTAINMENT SYSTEM

The containment system consists of the guard vessel, the top dome, the airlock, the cable penetrations, and the piping penetrations, and the containment extension. The containment system is shown in Figure 5-1.

The guard vessel surrounds the reactor vessel. If the reactor vessel should leak below the sodium level, the guard vessel would retain the sodium, the core would still be immersed, and the sodium flow circuit would be maintained.

During reactor operation, the annulus between the reactor vessel and the guard vessel, and the top dome is filled with nitrogen gas.

Containment monitoring is provided by a radiation monitor in the top dome. Temperature monitors, pressure gages, and sodium leak detectors are also provided in containment to detect failures of the PHTS or IHTS.

5.2 CONTAINMENT ISOLATION

The penetrations of the containment vessel requiring automatic isolation are limited to the cooling pipe lines of the Nitrogen conditioning system for the top dome inside atmosphere. During reactor operation, the other penetration piping (reactor cover gas lines) is closed with redundant isolation valves. These valves are located outside the top dome. The IHTS piping and components which penetrate the containment vessel are designed to ASME Code Section III, Class 2 and classified as a seismic Category I system.

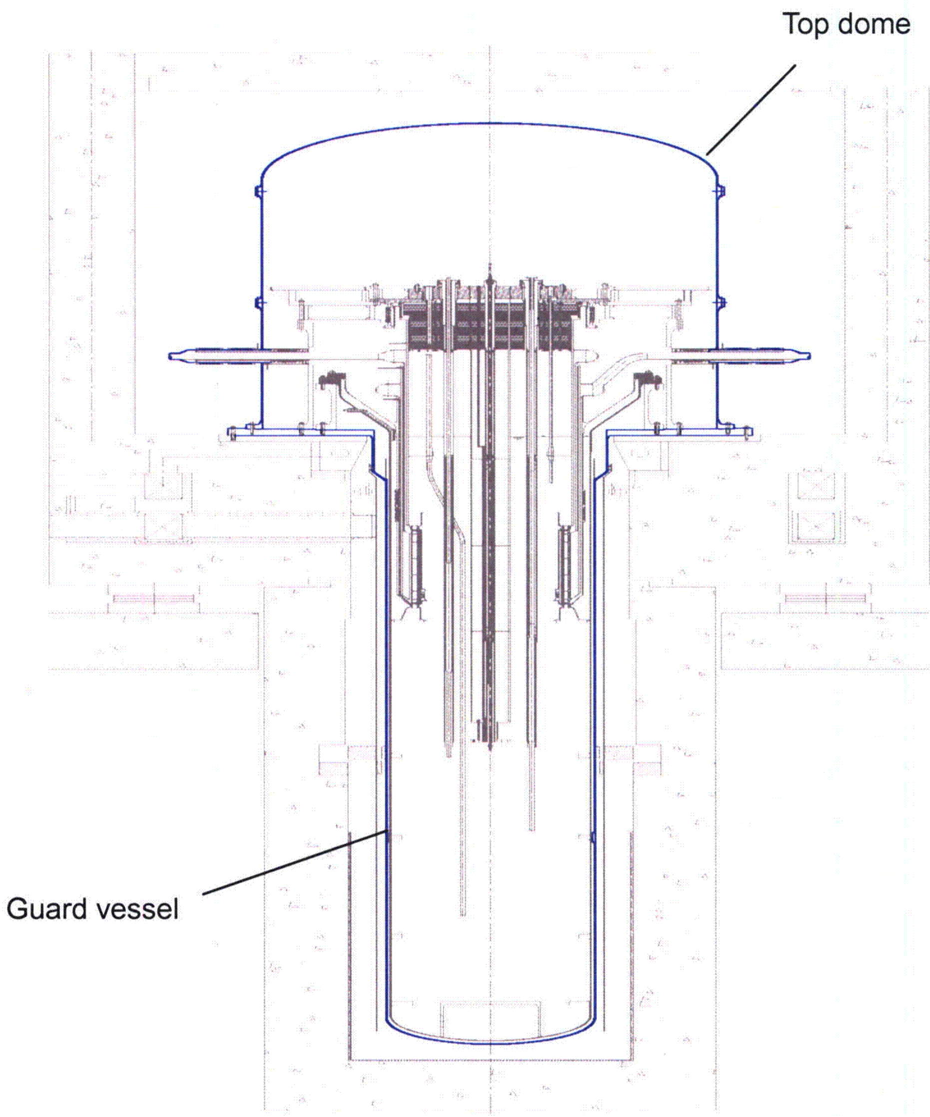

Figure 5-1 Containment Boundary

6 INSTRUMENTATION AND CONTROL

6.1 INTRODUCTION

This chapter describes the 4S instrumentation and control system, particularly the safety-related systems. These systems include the plant protection system and safety-related display instrumentation required to maintain all equipment to initiate and complete reactor heat transport and BOP shutdown, decay heat removal, and containment isolation.

This chapter provides the functional requirements, design bases, and system description, focusing on the safety-related instruments.

The safety systems related to the instrumentation and control systems described in this chapter are the following:

- Nuclear safety systems and engineered safeguards required for accidents and anticipated operational occurrences
  - Reactor protection system (RPS)
  - Core cooling systems
  - Intermediate reactor auxiliary core cooling system (IRACS)
  - Reactor vessel auxiliary cooling system (RVACS)
  - Neutron monitoring system (NMS)
- Process safety systems (required for planned operation)
  - NMS
  - Reactor vessel instrumentation

6.2 REACTOR PROTECTION SYSTEM

6.2.1 System Identification and Classification

Figure 6-1 includes an overview of the RPS. The RPS consists of sensors, logic circuits, trip breakers, and actuators, configured as three separate identical sensor and logic channels each for both the main and backup systems.

6.2.2 Initiating Circuits

The following signals will initiate RPS action:

- Neutron flux level High at reactor power range monitor
- Neutron flux increasing rate High at reactor power range monitor
- Neutron flux level Low at reactor power range monitor
- Neutron flux decreasing rate High at reactor power range monitor

- Neutron flux level High at wide power range monitor
- Neutron flux increasing rate High at wide power range monitor
- Neutron flux level Low at wide power range monitor
- Neutron flux decreasing rate High at wide power range monitor
- Primary EMP voltage and current Low
- IHX primary outlet temperature Low
- IHX primary outlet temperature High
- Reactor vessel sodium liquid level Low
- Seismic acceleration
- Manual trip actuation

The instrumentation that provides these signals is described in subsection 6.3.1.

6.2.3 Logic

The RPS has three signal sensing channels (channels I, II, and III), which are physically and electrically separated from each other. The various process signals, which are grouped into the three channels, are gathered into the separate signal conditioning panels designated for each channel. When a sensed signal exceeds its setpoint, scram signals from bi-stable circuit outputs are transmitted to the RPS voter logic panel. In the RPS voter logic panel, those scram signals are input to the two-out-of-three voter logic circuit so that if two or more signals come into this voter, reactor trip initiating signals (divided into three logic train signals that are A train logic signal, B train logic signal, and C train logic signal) are sent to the reactor trip breakers of each shutdown system. The reactor trip initiating signals are also transmitted to the primary and intermediate loop sodium coolant circulation EMP drive systems, the IRACS air cooler damper drive circuits, and the feedwater pump drive system. After the trip initiation, the reactor will shut down, the primary and intermediate loop EMPs and feedwater pumps will trip, and the IRACS air cooler dampers will open.

In addition, the reactor can be manually tripped by the operator from the control room or remote shutdown panel.

6.3 SAFETY-RELATED INSTRUMENTATION

An overview of the reactor instrumentation system is shown in Figure 6-2.

The instrumentation used for the RPS is described in this section.

The complete reactor instrumentation system consists of three subgroups:

- Reactor protection system (RPS)
- Plant control system (PCS)
- Interfacing systems' sensors

The RPS-related instrumentation consists of instrumentation that provides signals for initiating reactor trips, and instrumentation that provides information on the state of the reactor in the event of an accident. The sensors, signal conditioning equipment, and logic systems are Class 1E equipment.

The PCS and interfacing systems' sensors are not classified as Class 1E systems.

The PCS contains all sensors used for plant control and provides the information on the state of the reactor during normal operations. The PCS is described in Section 6.5.

The interfacing systems' sensors consist of the remaining monitors whose functions and requirements are defined as part of the specification of a component or subsystem. The interfacing systems' sensors are described in Section 6.4.

6.3.1 Reactor Protection System Instrumentation

The RPS is actuated when a threshold is attained by any one of the safety-function parameters as follows:

- Reactor core neutron flux
- Liquid sodium level of the reactor vessel
- Supply voltage/current of main/intermediate loop EMPs
- Primary outlet temperature of IHX
- Seismic acceleration

6.3.1.1 Neutron Flux Monitoring System

Neutron flux leaking from the core provides a measure of the core neutron flux, and it is monitored to detect both the flux level and also the rate of change in the neutron flux. Measured values are used after calibration of the reactor power obtained from a heat balance calculation.

The neutron instrumentation measures the neutron-flux level from a reactor shutdown condition up to 130 percent of the rated reactor power, initiates reactor trip signals when appropriate, and informs operators of the reactor power level during normal operation and any abnormal transients.

The source range monitoring system is installed in the reactor vessel in a well, located in the shielding plug over the reactor. Its radial position is between fuel assemblies and the core barrel. The source range monitoring system monitors the core subcritical condition during reactor shutdown and the neutron flux during reactor startup.

The wide range monitoring system and the power range monitoring system are installed outside the reactor vessel in the concrete adjacent to the RVACS flow path. The wide range monitor can monitor the neutron power from subcriticality to the power range, whereas the power range monitor is restricted to monitoring the power range only. The power monitoring system is used for the RPS signals to prevent excessive reactivity insertion and overpower in the reactor core. The axial position for both wide and power ranges is in the upper region of the fuel assemblies. The 4S design will include power range/wide range monitors installed in at least three locations.

6.3.1.2 Reactor Vessel Sodium Level Monitor

The sodium level of the reactor vessel is monitored to confirm the core cooling function. The sensor is an induction type, which uses the high conductivity of liquid sodium. The liquid sodium level indicator for the safety protection system is required to initiate a reactor trip signal when the level is reduced below a threshold as well as to measure the reactor sodium liquid level during normal operation.

6.3.1.3 Supply Voltage of Primary Main Circulation Pumps and its Electrical Current

When a low voltage power supply condition or electrical current interruption for the primary main circulation pumps is detected, a reactor trip is initiated.

6.3.1.4 Primary Outlet Temperature of Intermediate Heat Exchanger

The outlet temperature of sodium leaving the core is measured by the primary outlet temperature of the IHX. If the outlet temperature exceeds a threshold, a reactor trip is initiated.

6.3.1.5 Seismic Acceleration Monitor

Seismic acceleration monitors supply a reactor trip signal for an acceleration above a certain threshold. In addition, to determine whether the reactor facility can continue safe operation and to take appropriate measures after an earthquake, appropriate monitoring equipment (separate from that used for the RPS) is installed at locations that meet the requirements of Regulatory Guide 1.12.

6.3.2 Accident Monitoring System

The post-accident monitoring system is considered part of the 4S RPS even though it does not provide reactor trip actuation parameters. Specifically, the functions of this system are to confirm the effectiveness of the RVACS and monitor the emergency power supply.

These sensors are also classified as Class IE.

The system consists of the following subsystems:

- Trip action and function completion sensing
- Temperature monitoring
- Shutdown heat removal system monitoring
- Emergency power supply monitoring

6.4 INSTRUMENTATION AND MONITORING SYSTEMS OF INTERFACING SYSTEMS

An overview of the instrumentation systems defined by various reactor subsystems, and of monitoring systems performing specialized diagnostic functions, is included in this section.

6.4.1 Radiation Monitoring System

The radiation monitoring system monitors radiation levels during all plant operating, shutdown, abnormal, and accident conditions. The radiation monitoring systems include area monitoring, process monitoring, and environmental radiation monitoring systems; and a radiation monitoring panel. The monitors will be positioned in the areas surrounding the plant, at the site boundaries, in the head access area, and other appropriate locations.

6.4.2 Fire Protection Monitoring

Fire protection monitoring will be provided in accordance with 10 CFR 50.48 and 10 CFR 50, Appendix R.

6.4.3 Impurity Monitoring

The 4S reactor does not require refueling during its entire plant life. Normal operation is conducted with the reactor cover gas isolated. The sodium coolant is, therefore, not exposed to impurities during normal plant operation.

The primary sodium processing subsystem (see Figure 6-3) uses a cold trap for purity control and a plugging meter as a purity monitoring system. The cold trap purifies the sodium coolant by nitrogen gas cooling and excludes impurity sediments from the coolant. The primary auxiliary system purifies sodium of the PHTS during plant initial startup. When the impurity concentration in the reactor coolant decreases below the predetermined values as determined by the plugging temperature, the cold trap operation will be terminated. The cold trap is installed in the room adjacent to the containment top dome in the reactor building, and it is surrounded with a radiation shield.

An impurity monitoring system called the plugging indicator measures the sodium temperature at an orifice in the system when the orifice is being plugged by impurities in the sodium coolant, such as oxygen and hydrogen. Sodium crystallizing temperature rises with an increase in the impurities, and the empirical relationship between impurity concentration and temperature change is used to determine the impurity concentration. The plugging indicator measures the impurity concentration in the PHTS sodium, and after the sodium purity becomes high enough, purity monitoring is not continuously performed during normal operation. When the plant is subsequently shut down for maintenance requiring opening of the reactor coolant system, the plugging indicator would again be placed in service to monitor the purity of the reactor coolant.

The intermediate sodium processing subsystem (see Figure 6-4) uses a cold trap for purity control and a plugging indicator as a purity monitoring system. The cold trap purifies the sodium coolant by nitrogen gas cooling and excludes impurity sediments from the coolant. The intermediate auxiliary system purifies sodium of the IHTS during plant normal operation using the sodium overflow and make-up systems for the steam generator to and from the sodium dump tank. The impurity concentration in the IHTS coolant will be continuously monitored by the plugging indicator in the sodium make-up line. The cold trap is installed in the sodium dump tank to which the IHTS sodium overflows from the steam generator.

6.4.4 Fission Gas Monitoring

The fission gas monitor detects a fuel failure by continuously measuring the gamma rays released from noble gas fission products released to the reactor cover gas due to a comparatively small fuel pin failure (pin-hole failure) incident, and transmits the information to the operators. Fission gases in the cover gas, released from failed fuel pins, are transported from the cover gas to the detector by diffusion. The fission gas monitor samples the cover gas and measures the concentration of fission gas with a gamma ray detector. Data from the fission gas monitor is processed to inform the operator of the state of the reactor core.

Large-scale fuel failure detection is made using detectors installed outside the reactor vessel to measure the gamma radiation from noble gases in the fission products in the cover gas space.

6.5 PLANT CONTROL SYSTEM

Plant operation is directed from the control room. Normal startup and shutdown operation of major plant systems is automatically sequenced and directed between predetermined hold point by the Plant Control System (PCS), as monitored by the plant operators. An operator-controlled permissive circuit is required to be actuated to continue the sequence at each hold point.

The planned startup curve of temperature, power, and flow is shown in Figure 6-5. During plant startup and shutdown, the following parameters are monitored for controlling the start-up curve:

- Reactor power
- Primary flow rate
- Secondary flow rate
- Feedwater flow rate
- Feedwater temperature
- Steam temperature and pressure

During steady-state conditions, reactor power, primary flow rate, and intermediate flow rate are maintained at 100 percent. Load following is accomplished by diverting steam to the condenser via the turbine bypass (see Section 9). The following parameters are monitored for controlling the electrical output:

- Electrical output frequency
- Steam temperature and pressure

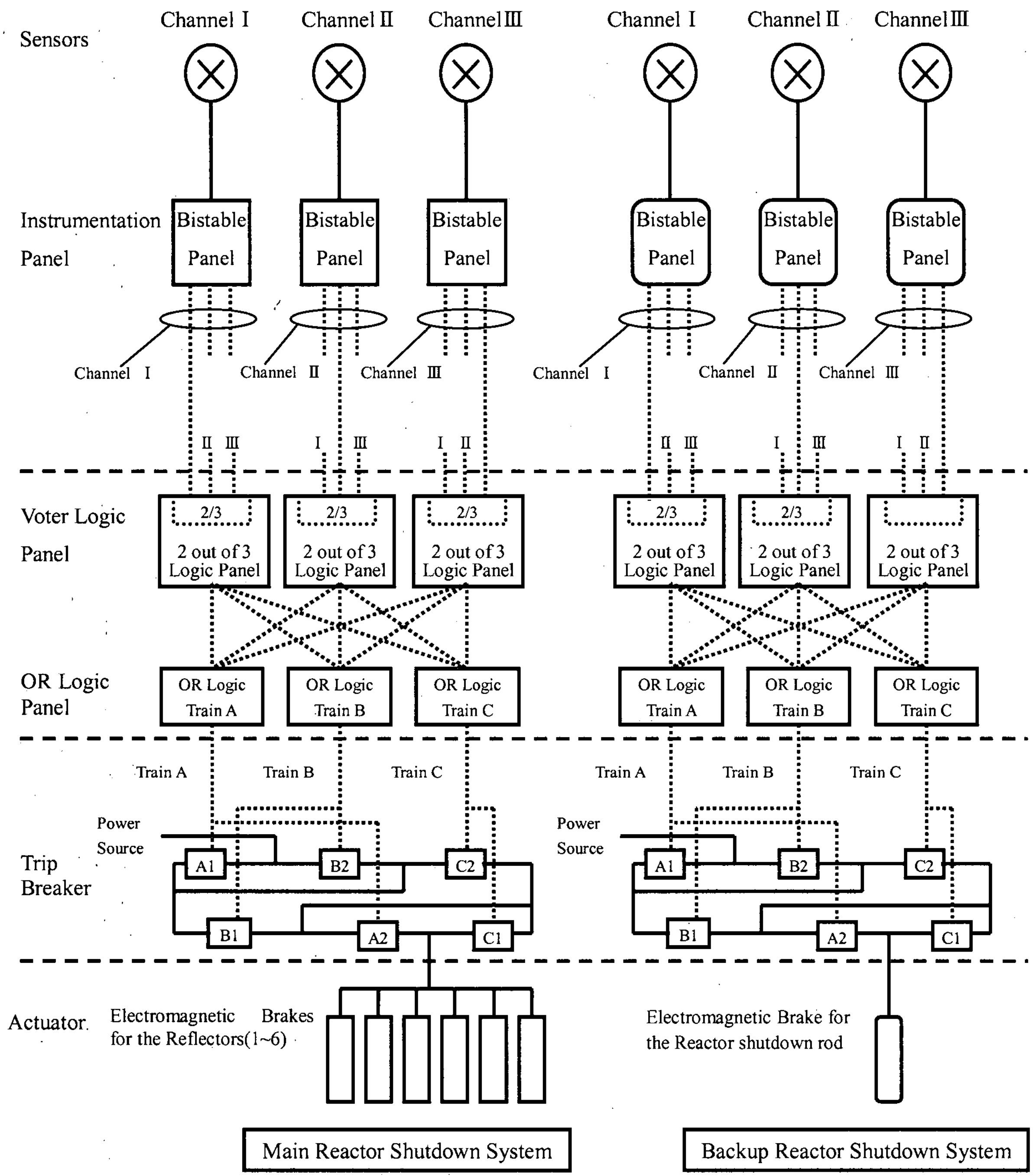

Figure 6-1 Reactor Protection System Logic Circuit

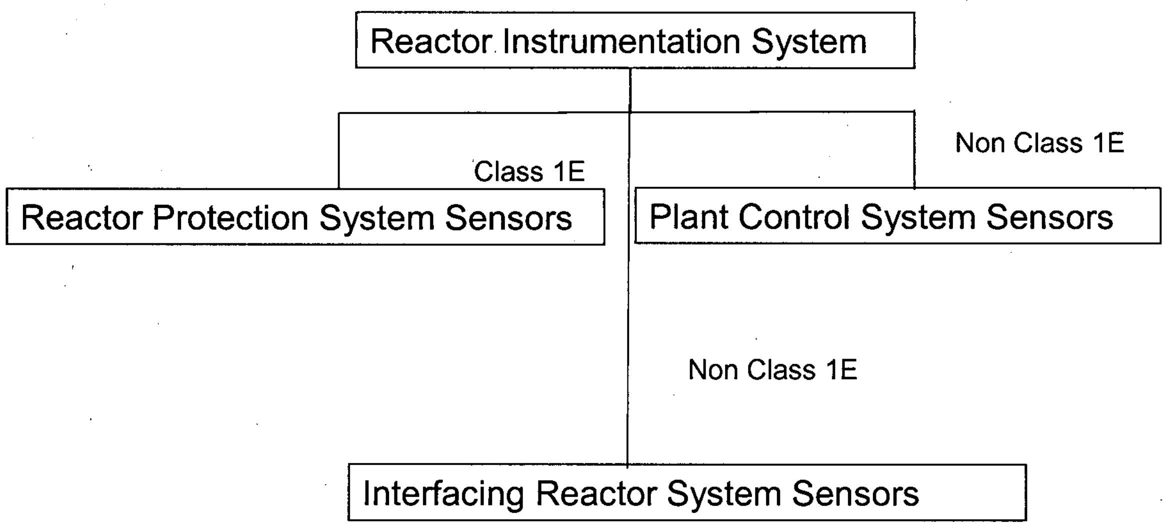

Figure 6-2 Overview of Reactor Instrumentation System

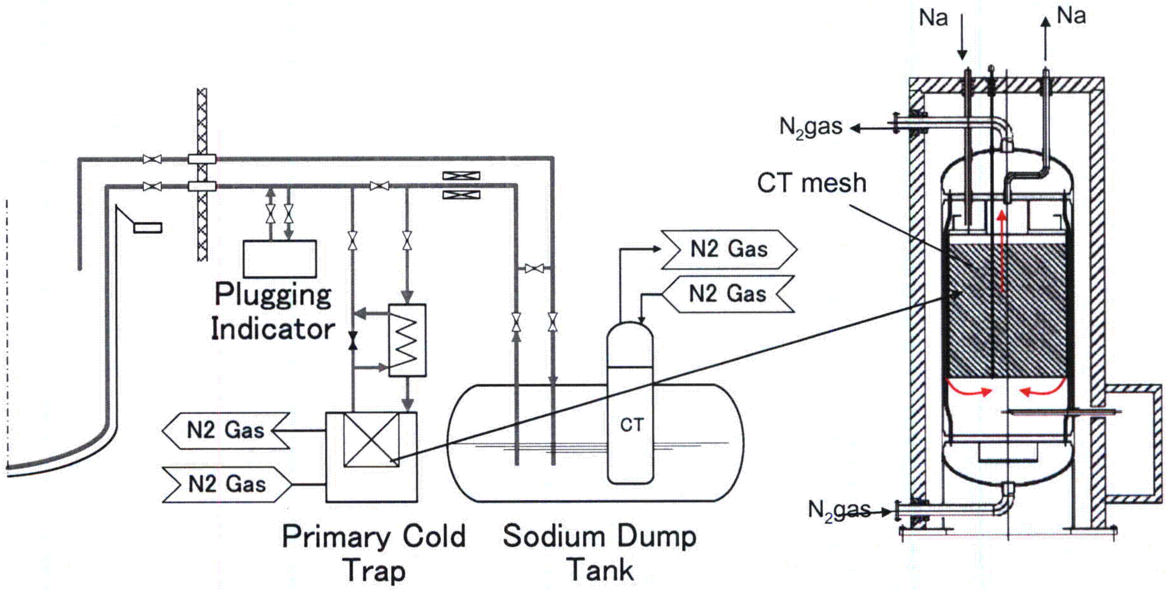

Figure 6-3 Primary Sodium Processing Subsystem

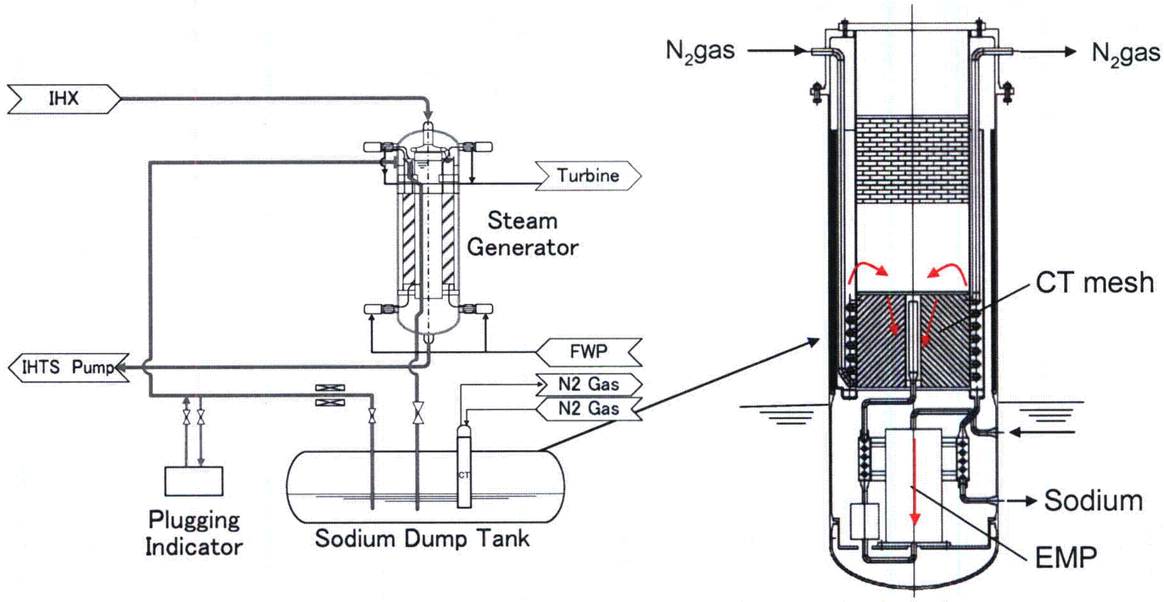

Figure 6-4 Intermediate Sodium Processing Subsystem

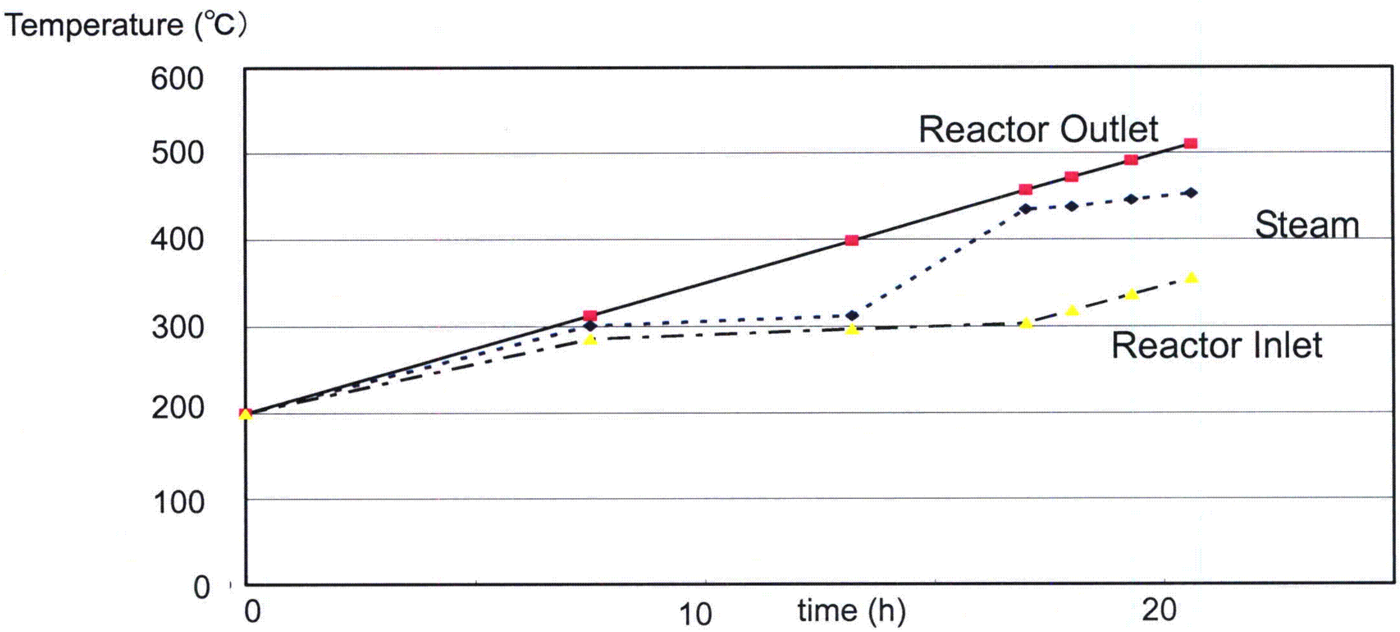

Figure 6-5 Planned Startup Curve of Temperature

7 ELECTRIC POWER

7.1 OFFSITE POWER SYSTEM

There are two power grid lines in the transmission network connected to the 4S plant.

The normally preferred power line is connected to the main power transformer and generator circuit breakers (GCB), which can isolate the fault current of the plant main generator (PMG). The grid side of the GCB terminal is also connected to the unit auxiliary transformer (UAT). The normally preferred power line and PMG can supply power to an onsite power system via the UAT. (This source is referred to as the normally preferred power source.) As the PMG and associated steam turbine system have 100-percent steam bypass capability and onsite combustion turbine generators for emergency power, the PMG can maintain generation or restart without electric power from the offsite network. Figure 7-1 shows the principal single-line diagram for the 4S electrical system.

The alternate preferred power line supplies electric power to the onsite power system via the reserved auxiliary transformer (RAT). (This source is called the alternate preferred power source.)

7.2 ONSITE POWER SYSTEM

7.2.1 AC Power Supplies

AC power supplies consist of four Non-class 1E buses. These buses contain air circuit breakers for 100 kW or larger loads and molded case circuit breakers (associated with magnetic contactors if necessary) for loads less than 100 kW.

7.2.1.1 Class 1E Power Supply

The two Class 1E buses are separated from each other and separated from the Non-Class 1E electric systems as a part of the reactor safety system configuration. Each 1E Bus is provided with a separate Emergency Diesel Generator (EDG) for backup power.

7.2.1.2 Non-class 1E Power Supply

The 4S plant has the following four Non-Class 1E buses:

- Two Non-class 1E (N1E) buses (A) and (B)
- Non-class 1E bus (C) (with combustion turbine generator backup for the sodium pre-heating system)
- Non-class 1E bus (D) for bus connection switching

Non-class 1E bus (B) and Non-class 1E-PIP (C) bus are normally tied together. The normally preferred power source usually furnishes power to the Non-class 1E buses (A), (B), and (C); however, if there is a loss of the normally preferred power source, these buses can choose the alternate preferred power source via a manual dead bus transfer.

If there is a bus voltage loss at Non-class 1E bus (C), the tie breaker to Non-class 1E bus (B) and to the RAT would be opened and the combustion turbine generator (CTG) would automatically start up and furnish power for the plant investment protection (PIP) loads, such as the pipe heating system for sodium solidification prevention, to mitigate plant transient and equipment damage.

7.2.1.3 Non-class 1E Miscellaneous Power Supply

For smaller Non-class 1E power loads and lighting fixtures, a 208/120 Vac power distribution panel with a small power distribution transformer furnishes power throughout the plant. Non-class 1E buses (A) and (B) supply the power to the power distribution transformers.

7.2.2 Instrument Power Supply

Instrument power supplies consist of 125 Vdc distribution panels with batteries and associated chargers, and 120 Vac distribution panels with uninterruptible power supplies (UPS). These distribution panels furnish power to the instrumentation and control system and computer systems in the 4S plant.

The Non-class 1E buses (A) and (B) supply the power to the Non-class 1E instrument power supply.

Class 1E bus Divisions I, II, and III furnish power to the corresponding Class 1E instrument power supplies. This Class 1E power supply is dedicated to the Class 1E loads, and each divisional power supply is designed with independence and separation from the other as a part of the reactor safety system configuration.

Division I and II instrument power supplies receive power from the corresponding 480V Class 1E bus. Division III instrument power supply receives power from the 480V Division I via the 480V Division III bus to secure the separation between Divisions I and III with two sets of serial circuit breakers.

7.2.3 Electromagnetic Pump Power Supply

The primary sodium EMP motors are supplied from Non-class 1E power supplies via adjustable speed drives and motor-generator sets. The adjustable speed drives furnish variable frequency and variable voltage power to the associated motor-generator set, and the motor-generator set supplies the corresponding frequency waveform to the EMP. Adjustable speed drives provide low frequency soft start, normal operation power, and soft shutdown to the EMP via motor-generator sets. In case of a Non-Class 1E power loss, including adjustable speed drives failure, kinetic energy from the motor-generator set flywheel is transferred to the EMP to mitigate core flow coastdown.

7.2.4 Fire Protection System for Cables

Cables in the 4S plant are designed as flame-retardant, and fire stops for raceways, including cable trays, are provided at designated penetration points for fire protection requirements.

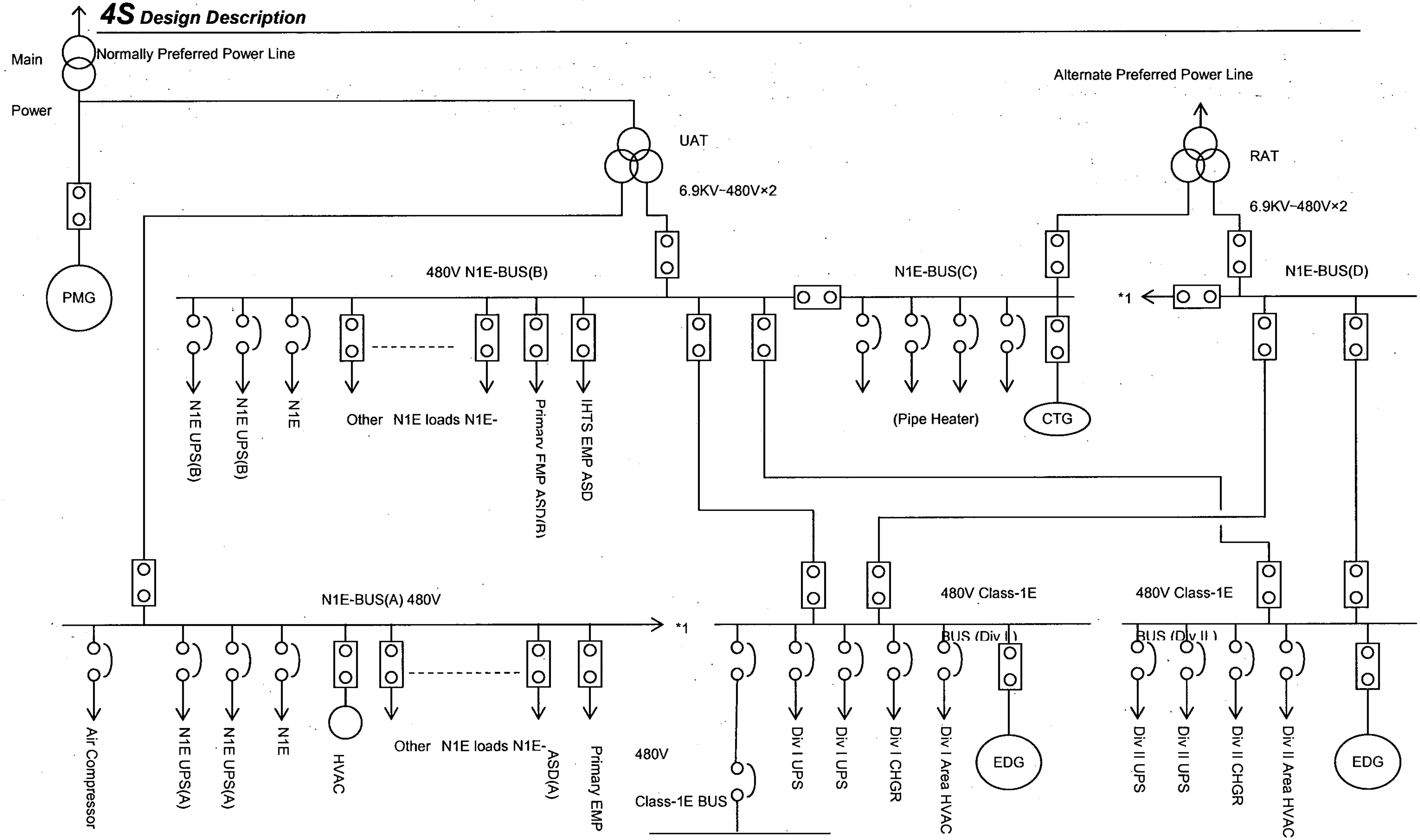

Figure 7-1 Principal Single-Line Diagram

8 AUXILIARY SYSTEMS

8.1 FUEL HANDLING SYSTEM

The fuel handling system accepts new core subassemblies and loads them in the core at initial fuel loading; it unloads the spent assemblies from the reactor after core life and transports them to the fuel cask pit. The system processes handling and storage of used fuel after the end of the 30-year core life. The system is not maintained at the reactor site, but is transported there when needed.

The fuel handling system consists of the fuel handling and transfer system, refueling enclosure, and fuel receiving and fuel shipping facility (see Figure 8-1). Figure 8-2 is a fuel movement flow diagram.

The fuel handling and transfer system consists of the fuel transfer and handling machine, and the fixed door valve set on the hatch of the reactor building. A traction locomotive moves the fuel transfer and handling machine.

The refueling enclosure encloses the work area of the upper part of the reactor building during fuel handling. The crane lifts the large equipment, such as the hatch of the reactor building and the reactivity control and shutdown system mechanisms.

The fuel receiving and fuel shipping facility includes the fuel cask pit (in the fuel exchange area) and related facilities. The fuel cask is designed considering shielding, criticality, and cooling of the fuel in the cask.

8.2 PROCESS AUXILIARIES

8.2.1 Inert Gas Receiving and Processing System

Argon (reactor cover gas) and nitrogen (containment inerting gas) supply equipment provides the required quantities of these gases to the primary argon and nitrogen gas systems. The gases are stored in liquid form.

Helium gas (steam generator leak detection) supply equipment consists of helium gas storage tanks, pressure regulatory valves, stop valves, piping, gas bottles, filters, and relief systems.

8.2.2 Impurity Monitoring and Analysis System

The impurity monitoring and analysis system provides sampling, monitoring, and analysis of the plant sodium systems and the plant nitrogen, helium, and argon gas systems. It also provides acceptance sampling and analysis of incoming sodium, argon, helium, and nitrogen. Impurities in the sodium coolant, reactor cover gas, and intermediate sodium system argon are monitored to aid the reactor operator in maintaining proper sodium and cover gas purity levels and to provide information on potential degradation of components. Impurities in the coolant cover gas can indicate the presence of leaks, tube failure, or other off-standard conditions.

8.2.3 Compressed Air Systems

The compressed air systems consist of a reciprocating air compressor, complete with intake filter-silencers, intercoolers, aftercoolers, air receiver, filter, driers, and interconnecting piping and valves to distribute the compressed air. Compressed air is used to operate valves in the steam/water system.

8.3 HEATING, VENTILATION, AND AIR-CONDITIONING SYSTEM

The plant heating, ventilation, and air-conditioning (HVAC) system maintains the environmental conditions within the design limits for the reactor and the turbine building spaces.

One of the basic features of the HVAC system is to remove heat from a wide range of sources in the building or in the compartment. This is done by circulating fresh air directly or circulating cooled air through the air-conditioning equipment. Air-conditioning is also provided to cool the nitrogen atmosphere in the top dome. In each case, the heat is released to the outside environment. Also, the HVAC system maintains the appropriate temperature range in each area of the building. For any area that cannot maintain a minimum temperature by generated heat inside, a heating unit is used. As necessary, a heating coil is installed in the duct to heat air.

The HVAC system is divided into subsystems to support each block in the reactor building and the turbine building. Subsystems for radiation controlled areas include the top dome and airlock nitrogen ventilation system for containment, the primary sodium processing subsystem room, and the Class 1E electrical equipment room. Subsystems for non-radiation controlled areas include the control room, the steam generator, and intermediate cooling system room, the turbine building, the diesel generator room, and the non-Class 1E electrical equipment room.

8.4 AUXILIARY LIQUID METAL SYSTEM

The auxiliary liquid metal system receives, transfers, and purifies all sodium used in the plant. The system furnishes the required sodium quantity at the pressure, temperature, flow rate, and purity specified by the interfacing systems. The system consists of the necessary equipment and facilities to receive, purify, and transfer the plant sodium. The system consists of the following subsystems:

- Sodium receiving and transfer subsystem
- Intermediate sodium processing subsystem (See Figure 6-4)
- Primary sodium processing subsystem (see Figure 6-3)

8.4.1 Sodium Receiving and Transfer Subsystem

The sodium receiving and transfer subsystem (SRTS) provides the initial fill of all plant sodium systems. The principal function of the subsystem is to melt the fresh sodium received for the reactor solidified in tank cars, and purify and transfer it to the IHTS, which is located in the reactor building. The SRTS is a portable system, which contains a sodium tank car (not maintained on site) or sodium drum, filter, sodium tank car unloading station, interconnecting piping, and valves.

8.4.2 Intermediate Sodium Processing Subsystem

The intermediate sodium processing subsystem (ISPS) purifies the sodium in the IHTS. The ISPS consists of an integrated cold trap with an EMP, and interconnecting piping located in the sodium dump tank. The ISPS EMP takes suction from the sodium dump tank, circulates 20 ℓ/min through the cold trap, and returns it to the sodium dump tank. The ISPS cold trap system continuously purifies IHTS sodium during startup and the first stages of plant operation. Intermediate sodium purification is terminated at this point after the desired purity specifications are reached. Connections are provided to allow for the transfer of sodium between the IHTS loop and the sodium dump tank via the overflow and makeup system of the steam generator for the purification of sodium in the IHTS loop. Before plant startup, the ISPS is temporarily connected to the reactor vessel to allow for the initial fill of fresh primary sodium from the sodium dump tank.

8.4.3 Primary Sodium Processing Subsystem

The primary sodium processing subsystem (PSPS) purifies primary sodium. The system consists of an EMP and a nitrogen-cooled cold trap, along with interconnecting piping and valves. The PSPS cold trap is connected directly to the reactor through a circulating line independent from the sodium dump tank, and the EMP provides sodium flow to the PSPS cold trap. Primary sodium purification is performed after initial sodium fill, and during the initial refueling, standby, startup, and first stages of normal operation. Primary sodium purification is terminated at this point after the desired purity specifications are reached.

8.5 SODIUM PIPING AND EQUIPMENT HEATING AND INSULATION SYSTEM

Sodium must be maintained at temperatures well above ambient to remain in the liquid metal state. The sodium piping and equipment heating and insulation system provides piping and equipment insulation and insulation hardware, electrical resistance-type heaters, heater mounting devices, electrical power controllers, temperature sensors, and temperature controlling instrumentation required to insulate and heat the sodium-containing components. This system also provides a gas heating system for preheating the reactor vessel before sodium loading, together with electrical resistance-type heaters on the bottom of the reactor vessel.

The electrical trace-heating system provides power to the mineral insulated (MI) cable heaters. The MI cable is either wrapped around the component or piping, or placed in a zigzag pattern on the surface of the component. The heat rates required by different components are controlled by thermocouples, which monitor piping and component temperatures and adjust the power supplied to the heaters by temperature controllers and solid-state relays. Electric heaters are provided for most piping and equipment that contain sodium or sodium vapor as a matter of routine operation. Some applications, such as the storage tank, require electric heat continuously during all phases of plant operation, while other applications such as the IHTS may only require electric heat infrequently.

The space containing the electric heater, between the surface of piping and/or components' inner insulation jacket, acts as an oven so that convection heating is a significant portion of the total heat transferred to the components. Heaters located on the lower portion of larger components provide the most uniform heating. For smaller piping or components, the heaters are wrapped around the component. Tanks and large component heaters are arranged in banks. Heater banks are located to provide major heating at low points to lessen the heat buildup potential.

The insulation system consists of an inner jacket of stainless steel, a layer of insulation, and an outer protective jacket of stainless steel.

The sodium piping and equipment heating and insulation system is provided backup electrical power via Non-Class 1E bus (C) from a combustion turbine generator set.

8.6 PLANT FIRE PROTECTION SYSTEM

The plant fire protection system (PFPS) consists of two subsystems:

- Sodium fire protection system (SFPS), which addresses sodium (Na) fires
- Non-sodium fire protection system (NSFPS), which addresses fires of nonalkali metal origin or involvement

The PFPS provides prevention, detection, containment, control, suppression, extinguishment, and mitigation of the consequences of plant fires.

The SFPS provides means to preclude public health hazards, as well as minimize property damage, in the event of a fire caused by the accidental leakage and exposure of sodium to an air atmosphere. Suppression of liquid sodium fires in an air atmosphere is accomplished by built-in, dedicated, passive systems for large spill fires or fires in normally unoccupied areas.

Special requirements imposed by the presence of sodium in the plant result in using special fire protection methods in the SFPS. These methods include the following:

- Passive catch pans and fire-suppression decks
- Means for restricting the smoke/aerosol
- Sodium dumping system which rapidly discharges the IHTS into a dump tank

The NSFPS minimizes property damage, increases personnel protection, and reduces the loss of power generating capability, as a result of fires in buildings and areas of the plant that do not contain alkali metals. Water-supplied firefighting systems are used in areas completely isolated from systems, equipment, and components containing sodium. Total flooding or local application systems for carbon dioxide are used for normally unoccupied electrical cable and equipment rooms.

Detection of sodium and non-sodium fires is by smoke, aerosol, and/or heat detectors. These detectors actuate alarms to alert the plant operators of the existence and location of a fire. Where appropriate, heat detectors initiate the operation of automatic suppression systems.

The effectiveness of these fire protection methods for limiting fire losses and the spread of airborne contaminants is augmented by fire barriers, fire doors, fire dampers, low-leakage penetrations, and similar isolation devices provided by the building design and by the heating and ventilation system.

The NSFPS includes the following subsystems for reactor building rooms without sodium, and for the turbine building and service building:

- Fire protection water supply subsystem
- Sprinkler, deluge, and water spray subsystems
- Wet and dry standpipe subsystems

In addition to the above-mentioned subsystems, the following specific subsystems are provided:

- Carbon dioxide subsystem for the generator room
- Foam subsystem for the fuel tanks associated with the boiler and diesel generator
- Fire extinguishers for all areas of the site as appropriate

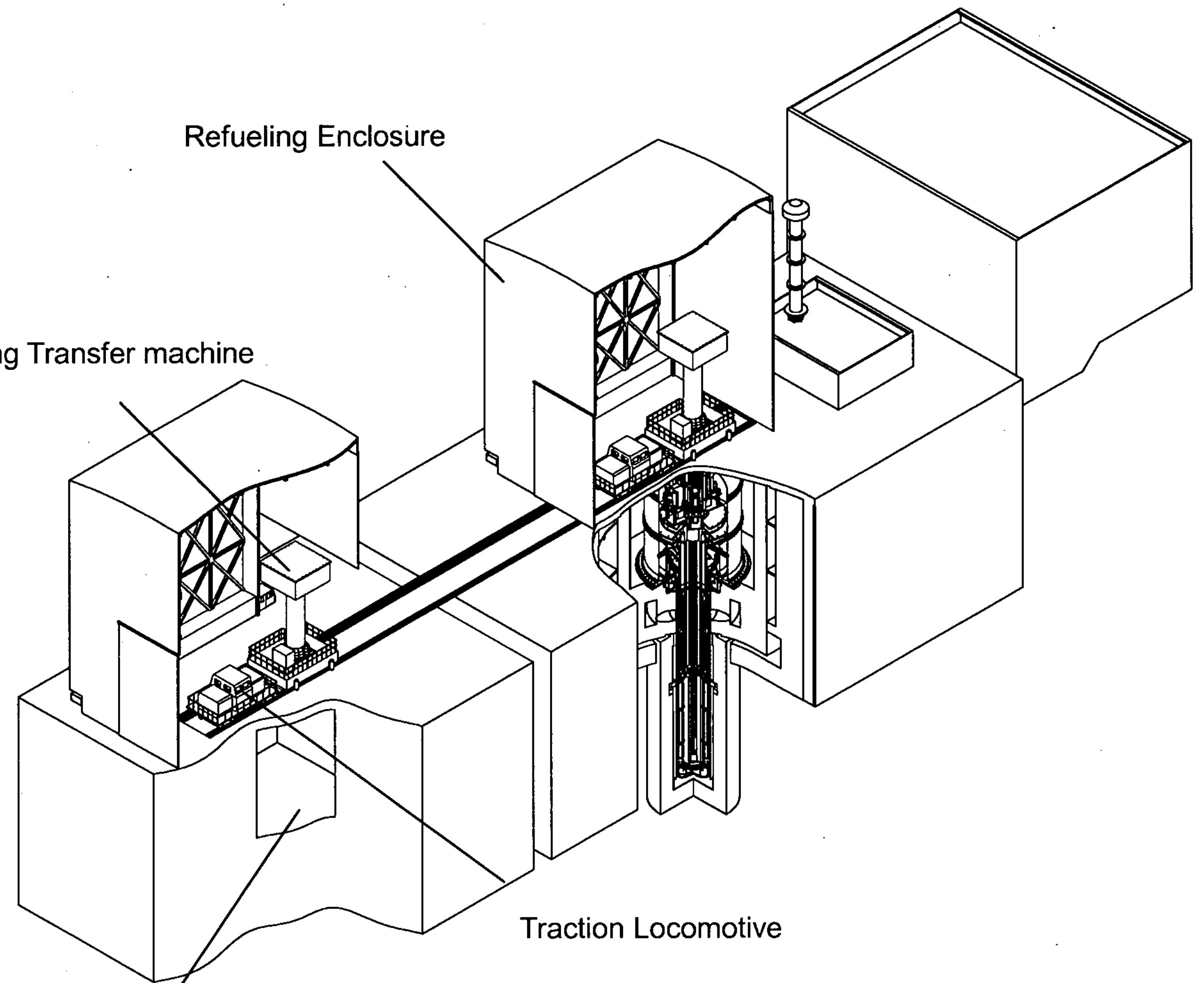

Figure 8-1 Fuel Handling System

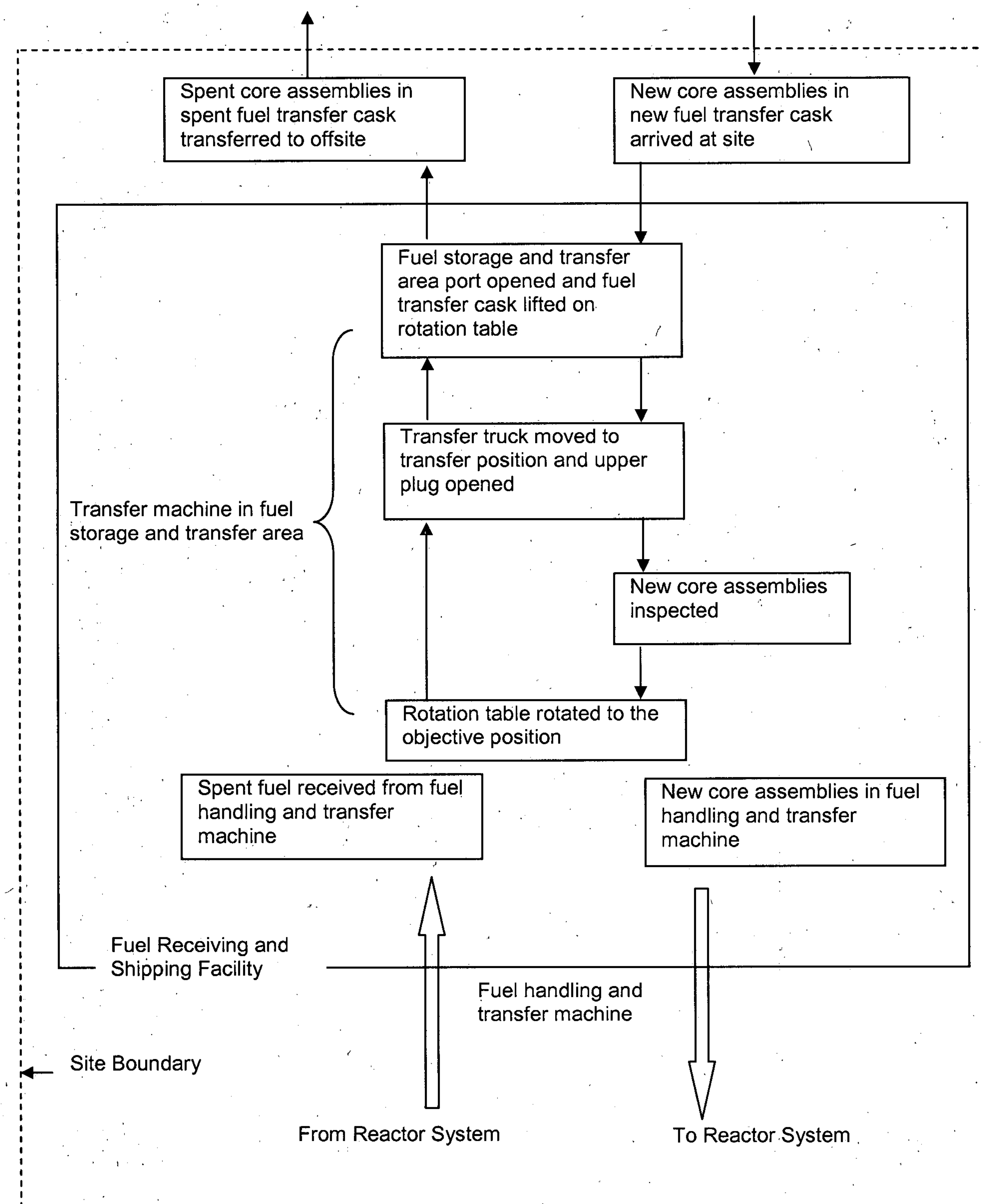

Figure 8-2 Fuel Transfer Flow Diagram

9 STEAM AND POWER CONVERSION SYSTEM

9.1 INTRODUCTION

The steam and power conversion system converts the heat produced in the reactor to electrical energy. The operation of the equipment, piping, and valves in the system do not directly affect the reactor and its safety features. The 4S plant consists of one reactor and one turbine generator system, and it generates 10 MWe of electricity.

Figure 9-1 shows a simplified flow diagram for the turbine-generator system. Superheated steam is supplied from the steam generator to the turbine. The steam is exhausted to a condenser. Condensate from the condenser is pumped by one of two 100-percent capacity condensate pumps through a low-pressure feedwater heater train consisting of two heaters in series, and is discharged to a deaerator. From the dearator, feedwater is pumped by one 100-percent capacity feedwater booster pump in series with one 100-percent capacity feedwater pump. After passing through a single high-pressure feedwater heater, it is returned to the steam generator.

9.2 TURBINE-GENERATOR

The 4S turbine plant has one turbine-generator set. The main turbine is a 3600 rpm, single-flow, non-reheat machine. The turbine consists of one integral single flow cylinder casing and a conventional steam sealing system.

Steam at 107 atg and 453°C is generated by the steam generator and led to the turbine throttle section. The steam is exhausted from the main turbine directly to the condenser.

The main turbine provides extraction steam for the high pressure feedwater heater, the deaerator, and the low pressure feedwater heaters for feedwater heating and deaeration.

A single generator is on a common shaft with the turbine rotor. The turbine-generator produces 10 MWe (gross) of electricity, exhausting to the condenser at 700 mm of mercury vacuum pressure. The condenser will typically be cooled by a circulating water system, although the plant design could rely on air cooling for the condenser instead.

The turbine-generator unit is supplied with all auxiliaries, such as instrumentation, piping, and required valving; and the following systems:

- Gland seal steam system
- Electro-hydraulic control system
- Lube oil system
- Turning gear
- All supervisory instrumentation

9.3 MAIN AND AUXILIARY STEAM SYSTEM

9.3.1 Main Steam System

The steam exhaust from the steam generator is led to a main steam header providing steam to the turbine-generator. Safety and atmospheric relief valves are included as part of the main steam header.

The atmospheric relief valves provide automatic pressure control for the main steam system to minimize any operation of the safety valves. The atmospheric relief valves can also be opened remotely by the operators. The safety valves provide Code safety overpressure protection.

At the turbine-generator, steam is distributed to control valves via one main steam stop valve. The main steam stop valve isolates the turbine-generator from the main steam header. The control valves control the main steam flow to the turbine-generator, and they can be modulated by the electro-hydraulic control system to keep the rated turbine rotation speed during the turbine normal operation. The main steam system also provides steam used in the auxiliary steam system to serve for heating and various processes throughout the plant.

9.3.2 Turbine Bypass System

The turbine bypass system provides a flow path for steam to bypass the turbine and go directly to the condenser, and has enough capacity to accept full steam flow at the rated steam generator operation. Since the 4S reactor is always operated at 100-percent power, this allows the electrical load of the turbine generator to follow demand, with the remainder of the heat being dissipated by the turbine bypass system to the condenser.

The turbine bypass system takes steam from the main steam header upstream of the main steam stop valve, bypasses the turbine, and dumps the steam directly into the condenser. The bypass valves can be modulated by the electro-hydraulic control system to keep the rated main steam pressure during plant normal operation. The bypass valve system consists of valves arranged in parallel. Each of the bypass valves directs the steam to the condenser shell. In addition, the bypass valve discharges are distributed inside the condenser to ensure that the condenser heat loads and turbine backpressure change uniformly.

9.3.3 Extraction Steam System

The turbine extraction steam is provided to the high pressure feedwater heater, the train of low pressure feedwater heaters (LP HTR No. 1 and No. 2) for feedwater heating, and the deaerator for deaerating the condensate during plant high load operation.

Each extraction steam system, in conjunction with the heater drain system, the feedwater system, and the condensate system, is designed so that no individual equipment failure in these systems will result in water entering the turbine from the feedwater heaters. The extraction lines to the feedwater heaters have motor-operated or air-operated valves for automatic shutoff on extreme high water level in the feedwater heater to prevent backflow to the turbine.

Immediately downstream of each motor-operated or air-operated valve, a fast closing bleeder trip valve (non-return valve) is used to limit turbine overspeed due to entrained energy in the extraction system. This valve also protects from water induction. The bleeder trip valve is normally closed by heater high water level or turbine trip signals.

9.3.4 Auxiliary Steam System

The auxiliary steam system consists of an auxiliary steam header, piping, and associated valves and instrumentation. The system can receive steam from either the main steam system or the auxiliary boiler.

The auxiliary steam header provides steam to the high pressure feedwater heater and the train of low pressure feedwater heaters (LP HTR No.1 and No. 2) for feedwater heating, and the deaerator for deaerating during plant startup and plant low load operation, until enough heating steam can be obtained from the extraction steam system to satisfy feedwater heating requirements. It also supplies these components during plant shutdown.

The auxiliary steam system also supplies the turbine gland system for sealing the turbine shaft.

9.3.5 Water Chemistry

Control of water chemistry minimizes corrosion of the steam generator system, particularly the steam generator, and minimizes fouling of the steam generator heat transfer surfaces. The proper water chemistry conditions are maintained by deaeration and demineralization of the feedwater. Hydrazine and ammonium hydroxide are added to the system to maintain the pH between 9.3 and 9.5.

9.3.6 Circulating Water Subsystem

The circulating water subsystem provides cooling water for the main condenser. Cold circulating water is supplied from the cooling tower basins to the condenser to condense the steam exhausted from the turbine and bypassed from the main steam header to the condenser. The hot circulating water is returned to the cooling tower where heat is released to the atmosphere. The circulating water subsystem consists of the pumps, connecting piping, valves, fittings, and cooling tower. The pumps, taking suction at the cooling tower basin, are sized to meet the requirements of the main condensers. The circulating water is screened by the stationary panel screens.

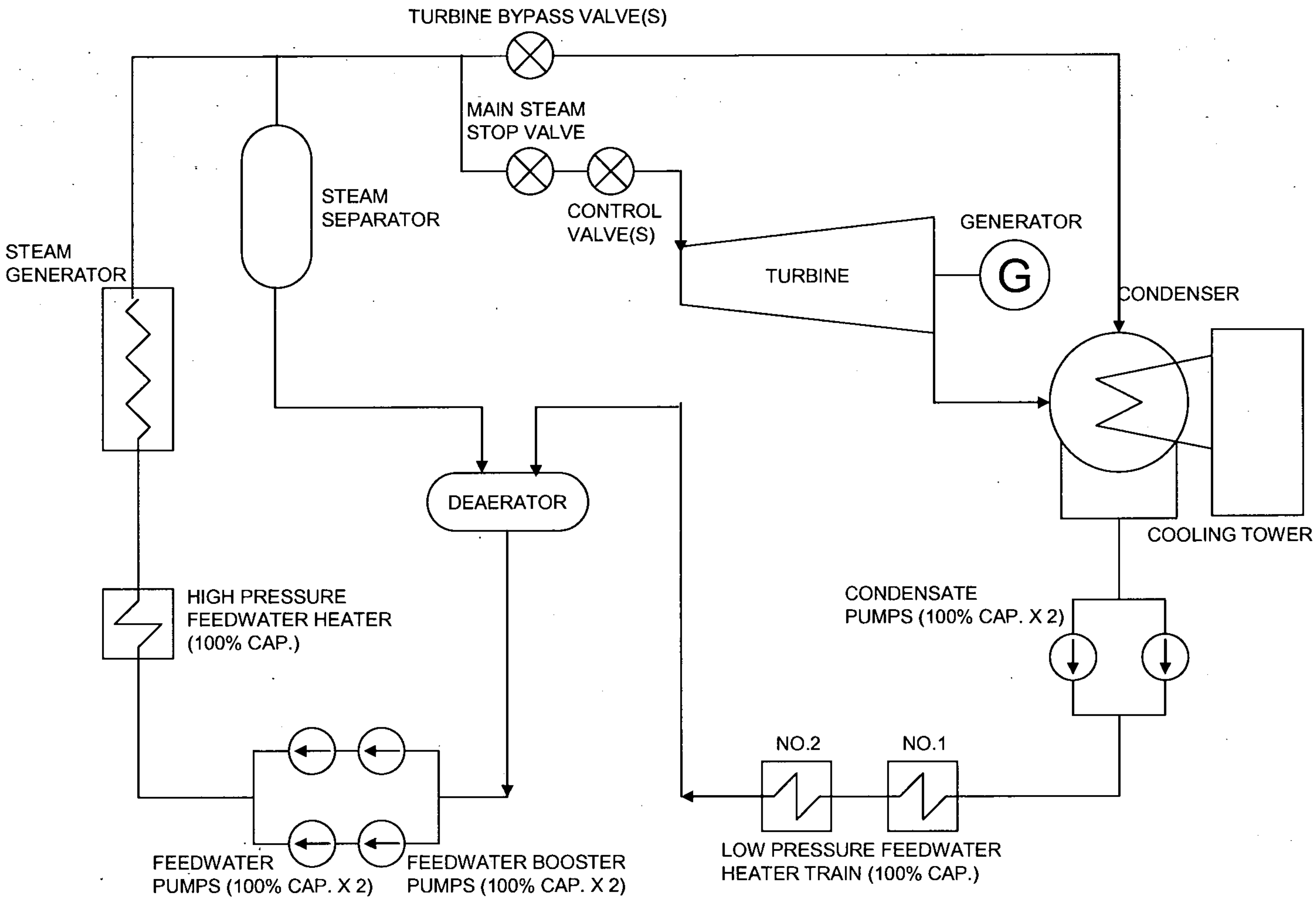

Figure 9-1 Turbine Heat Cycle Flow Diagram

10 RADIOACTIVE AND WASTE MANAGEMENT

10.1 GENERAL

The waste disposal system handles the following waste:

- Gaseous waste
- Liquid waste
- Solid waste

The primary sources of gaseous waste are the argon reactor cover gas and the nitrogen gas in the annulus between the reactor vessel and guard vessel, and in the top dome. The 4S reactor is designed not to feed/bleed these gases during operation. Following sufficient decay of the radioactivity, the waste gas is compressed, passed through a filter, and exhausted to the atmosphere.

The primary sources of liquid waste are the laundry, showers, and hand washes. After these have been collected in a liquid waste storage tank in the service building, the liquid is released to the normal plant drainage system because the concentration is less than the permissible value.

The primary sources of solid waste are spent radwaste filter cartridges, radioactive solids from equipment cleaning, and compactable solids, such as rags. These solid wastes are immediately collected and packaged for shipment to a federal or state licensed burial site.

Therefore, a liquid waste management system and solid waste management system are unnecessary in the 4S plant.

10.2 GASEOUS WASTE MANAGEMENT SYSTEM

The gaseous waste management system consists of the treatment system for the argon gas exhausted from the reactor cover gas after normal operation or during unexpected maintenance, and if necessary, for the nitrogen gas exhausted from the guard vessel and the top dome nitrogen gas systems.

A portable, vehicle-mounted, gaseous waste management system evacuates, purges, and establishes the reactor cover gas pressure. The system consists of a vacuum pump, receiver header, cooler-condenser, vapor trap, high efficiency particulate air (HEPA) filter, compressor, storage tank, dryer, and activated carbon filter.

The principal radioactive substances to be treated in the gaseous waste treatment system are argon from the reactor argon cover gas system, and fission product gas (Kr and Xe) released to the cover gas system in the unlikely event of a fuel failure. The cover gas gaseous waste is collected in a waste header and is filtered through a HEPA filter. It is then compressed and stored in a gaseous waste storage tank. Following sufficient decay of the radioactivity, the waste gas is passed through an activated carbon filter and exhausted to the atmosphere through a monitored exhaust.

Since the radioactivity of nitrogen gaseous waste is normally low, the waste is routinely passed through a high-efficiency fiberglass filter before being exhausted to the HVAC system. However, if the radioactivity concentration is high, it is diverted to the gaseous waste treatment system for processing.

10.3 PROCESS AND EFFLUENT RADIOLOGICAL MONITORING AND SAMPLING SYSTEM

The radiation monitoring system continuously monitors area radiation within accessible cells located near radiation sources and where a significant increase in a gamma radiation level could occur (indicative of a process system failure). Continuous monitoring for airborne radioactivity is conducted within the designated operating areas adjacent to potential radioactive sources.

Continuous radiation monitoring and sampling analysis of selected radioactive processes are performed. These monitors give early warning of process system malfunctions (abnormal conditions), provide a signal for process control (if required), and verify that the process product is suitable for release to the environment, if applicable.