A SUMMARY DESCRIPTION OF THE FAST FLUX TEST FACILITY

HANFORD ENGINEERING DEVELOPMENT LABORATORY OPERATED BY WESTINGHOUSE HANFORD COMPANY
A SUBSIDIARY OF WESTINGHOUSE ELECTRIC CORPORATION PREPARED FOR THE U.S. DEPARTMENT OF ENERGY UNDER CONTRACT NO. DE-AC14-76FFO2170

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DECEMBER 1980

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PREFACE

This document was prepared by the staff of Westinghouse Hanford Company to provide a single-volume technical description of the Fast Flux Test Facility. It is hoped that it will prove of value not only to the FFTF Project personnel involved in operation of the facility, but also to others interested in the design of this key facility in the U.S. program to develop LMFBF technology.

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CONTENTS

	Page
CHAPTER 1 INTRODUCTION	1-1
CHAPTER 2 SUMMARY	2-1
CHAPTER 3 REACTOR INTERNALS (SYSTEM 31)	3-1
CHAPTER 4 REACTOR ENCLOSURE (SYSTEM 32)	4-1
CHAPTER 5 REACTOR HEAT TRANSPORT (SYSTEM 51)	5-1
CHAPTER 6 REACTOR AND HEAT TRANSPORT INSTRUMENTATION AND CONTROL (SYSTEMS 15, 90, 91, 92, 93-2, 93-14, 93-15, 95 AND 99)	6-1
CHAPTER 7 SODIUM AND NaK SYSTEMS (SYSTEMS 81, 93-10 AND 93-13)	7-1
CHAPTER 8 ARGON AND NITROGEN SYSTEMS (SYSTEMS 82 AND 93-8)	8-1
CHAPTER 9 INDEPENDENTLY COOLED IRRADIATION TESTING FACILITIES (SYSTEMS 61 AND 93-3)	9-1
CHAPTER 10 SODIUM AND ARGON COVER GAS MONITORING (SYSTEMS 85, 93-9 AND 94)	10-1
CHAPTER 11 STRUCTURES (SYSTEMS 21, 27 AND 93-1)	11-1
CHAPTER 12 REACTOR REFUELING AND TEST SPECIMEN HANDLING (SYSTEM 41)	12-1
CHAPTER 13 ELECTRICAL POWER SUPPLY (SYSTEMS 11 AND 12)	13-1
CHAPTER 14 AUXILIARY SYSTEMS (SYSTEMS 23, 24, 25, 93-4, 93-5 AND 93-6)	14-1
CHAPTER 15 RADIATION MONITORING AND FIRE PROTECTION (SYSTEMS 26, 93-7 AND 96)	15-1
APPENDIX A DETAILED MAP OF FFTF CORE	A-1
APPENDIX B GLOSSARY	B-1
APPENDIX C LIST OF FIGURES AND TABLES	C-1
APPENDIX D INDEX	D-1

~~OFFICIAL USE ONLY~~ *182
2/2/12*

CHAPTER 1.
INTRODUCTION

		Page
1.1	FFTF PROGRAM SUMMARY	1-3
1.2	OBJECTIVE	1-4
1.3	FFTF PLANT SYSTEMS	1-4

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FIGURE 1-1. The Fast Flux Test Facility (FFTF) is located on the U.S. Government's Department of Energy Hanford Site near Richland, Washington.

FIGURE 1-2. FFTF Location Map.

CHAPTER 1.

INTRODUCTION

1.1 FFTF PROGRAM SUMMARY

The Fast Flux Test Facility (FFTF) (Figure 1-1) is a U.S. Government-owned 400-MWt sodium-cooled, fast-neutron flux reactor plant designed specifically for irradiation testing of nuclear reactor fuels and materials for liquid metal fast breeder reactors (LMFBRs). The FFTF is located on the Department of Energy (DOE) Hanford Site near Richland, Washington (Figure 1-2).

The FFTF plays a key role in LMFBR development and testing activities. It provides a test bed for demonstrating and evaluating the performance of future LMFBR fuel assembly and

core designs at normal conditions. It will also be used to test fuel to failure under dynamic conditions to establish ultimate fuel capability and failure modes.

In addition, the FFTF provides experience in the operation of a liquid metal fast reactor having coolant loops and components at temperatures and coolant flows typical of large LMFBR power plants.

Westinghouse Hanford Company operates the FFTF as part of the Hanford Engineering Development Laboratory (HEDL, Figure 1-3) for the U.S. Department of Energy.

FIGURE 1-3. Hanford Engineering Development Laboratory.

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Much of the work that supports FFTF operation is carried out in the HEDL laboratories. The Westinghouse Advanced Reactors Division was FFTF reactor plant designer, and the plant architect-engineer and construction manager was the Bechtel Power Corporation.

Although the FFTF, as a testing facility, is not designed to breed fuel or to produce electricity, the FFTF Program has provided valuable information for follow-on LMFBR projects and base technology programs in the areas of plant system and component design, component fabrication, prototype testing, and site construction.

1.2 OBJECTIVE

This document has been compiled and issued to provide an illustrated engineering summary description of the FFTF. The document is limited to a description of the plant and its functions, and does not cover the extensive associated programs that have been carried out in the fields of design, design analysis, safety analysis, fuels development, equipment development and testing, quality assurance, equipment fabrication, plant construction, acceptance testing, operations planning and training, and the like.

1.3 FFTF PLANT SYSTEMS

The FFTF was designed on the basis of separate "systems", as given in Table I.1. All drawings, specifications and other engineering documentation are organized by these systems. These systems are described in subsequent chapters of this document.

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2/2/12

TABLE 1-1
FFTF PLANT SYSTEMS STRUCTURE

<u>SYSTEM</u>	<u>TITLE</u>	<u>SYSTEM</u>	<u>TITLE</u>
11	Primary Electrical Power	81	Auxiliary Liquid Metal
12	Building Electrical Power	82	Inert Gas Receiving and Processing
15	Communications	85	Impurity Monitoring and Analysis
21	Reactor Support Buildings	90	Reactor Plant Control
23	Service Piping	91	Digital Data Handling and Display
24	Radioactive Waste	92	Reactor and Vessel Instrumentation
25	Heating and Ventilation	93	Process Monitoring and Control
26	Plant Fire Protection	93-1	Reactor Containment Instrumentation
27	Reactor Containment	93-2	Reactor Heat Transport Instrumentation
31	Reactor	93-3	Closed Loop Instrumentation
32	Reactor Enclosure	93-4	Service Piping Instrumentation
41	Reactor Refueling	93-5	Radioactive Waste Instrumentation
41-1	Reactor Refueling	93-6	Heating and Ventilation Instrumentation
41-2	In-Vessel Handling Machine	93-7	Plant Fire Protection Instrumentation
41-3	Closed Loop Ex-Vessel Machine and Transporter	93-8	Inert Gas Receiving and Processing Instrumentation
41-4	Loop Preparation Equipment	93-9	Impurity Monitoring and Analysis Instrumentation
41-5	Interim Decay Storage	93-10	Auxiliary Liquid Metal Instrumentation
41-6	Conditioning Stations	93-11	Reactor Refueling Instrumentation
41-7	Floor Valve	93-12	Maintenance Instrumentation
41-8	Plug Handling Fixture	93-13	Leak Detection Instrumentation
41-9	Core Component Pot	93-14	Plant Annunciator
41-10	IEM Cell Equipment	93-15	Piping and Equipment Electrical Heating Control
41-11	Bottom Loading Transfer Cask and Dolly	94	Fuel Failure Monitoring
41-12	Refueling Support Equipment	95	Neutron Flux Monitoring
41-13	Non-Irradiated Handling Equipment	96	Radiation Monitoring
51	Reactor Heat Transport	99	Plant Protection
61	Closed Loops		

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CHAPTER 2.

SUMMARY

	Page
2.1 FFTF OVERALL DESCRIPTION	2-3
2.2 REACTOR	2-6
2.2.1 Reactor Vessel, Reactor Guard Vessel and Reactor Head	2-6
2.2.2 Reactor Core	2-6
2.2.3 Above-Core In-Vessel Components	2-8
2.2.4 Ex-Vessel Neutron Flux Monitors and Surveillance Equipment	2-8
2.3 HEAT REMOVAL	2-9
2.3.1 Heat Transport System	2-9
2.3.2 Closed Loops Heat Removal	2-11
2.3.3 Sodium and NaK Processing and Monitoring	2-11
2.3.4 Argon and Nitrogen Processing and Monitoring	2-11
2.4 CONTAINMENT AND OTHER STRUCTURES	2-12
2.5 CORE COMPONENT HANDLING AND EXAMINATION	2-12
2.6 INSTRUMENTATION AND CONTROL	2-13
2.7 UTILITIES AND AUXILIARY FACILITIES	2-13
2.8 FFTF DESIGN PARAMETERS	2-13

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FIGURE 2-1. Fast Flux Test Facility.

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CHAPTER 2.

SUMMARY

2.1 FFTF OVERALL DESCRIPTION

The Fast Flux Test Facility (FFTF) is a 400-MWt, sodium-cooled, low-pressure, high-temperature, fast neutron flux, nuclear fission reactor plant designed and constructed for irradiation testing of breeder reactor fuels and materials. The reactor provides extensive capability for in-core irradiation testing, including eight core positions that may be used with independent instrumentation for the test specimens. Four of these positions may be used for independently cooled test loops.

In addition to irradiation testing capabilities, the FFTF provides long-term testing and evaluation of plant components and systems for Liquid Metal Fast Breeder Reactors.

The term FFTF includes the reactor itself, as well as equipment and structures for heat removal, containment, core component handling and examination, instrumentation and control, and for supplying utilities and other essential services, as shown in Figures 2-1 and 2-2. The FFTF is a complex array of buildings and equipment arranged around a reactor containment building. The reactor is located in a shielded cell in the center of the containment.

FIGURE 2-2. FFTF Plant Arrangement.

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Heat is removed from the reactor by liquid sodium circulated through three primary loops (including primary pumps, piping and intermediate heat exchangers) also located in cells within containment. Figure 2-3 shows the reactor location within containment, and Figure 2-4 is a cutaway of the containment building showing the location of primary pumps and intermediate heat exchangers. Secondary sodium loops transport the reactor heat from the intermediate heat exchangers to the air-cooled tubes of the dump heat exchangers. Heat from the closed loops will be removed by similar but much smaller heat transport systems when they are activated.

The FFTF includes facilities for receiving, conditioning, storing, installing in and removing from the core all routinely removable core components and test assemblies, and for storing irradiated fuel. Limited examination and packaging capabilities (for offsite shipment) are also provided.

Instrumentation and control equipment provides monitoring and automatic control of the reactor and heat removal facilities; automatic reactor shutdown (scram) if pre-set limits are exceeded; and computerized collection, handling, retrieval and processing of operating and test data.

Utilities and services include onsite emergency generation of electrical power (which drives critical equipment to cool the reactor during shutdown conditions and to operate critical control systems), heating and ventilation, radiation monitoring, fire protection, auxiliary cooling systems for cell atmospheres and some components, and the like.

Further details are given in subsequent sections of this chapter and in the chapters covering the various systems.

FIGURE 2-3. Reactor Location Within Containment.

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FIGURE 2-4. Reactor Containment Building Cutaway.

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2.2 REACTOR

The reactor is located in a shielded cell filled with nitrogen. A cutaway of the reactor is shown in Figure 2-5. This complex array consists of the following major components:

- Reactor Vessel, Reactor Guard Vessel and Reactor Head
- Reactor Core
- Above-Core In-Vessel Components
- Ex-Vessel Neutron Flux Monitors and Surveillance Equipment

2.2.1 Reactor Vessel, Reactor Guard Vessel and Reactor Head

The reactor vessel is constructed of type 304 stainless steel. It is approximately 43 ft high and 20 ft inside diameter. Its wall thickness varies from 2-3/8 in. to 2-3/4 in. A pool of liquid sodium fills the reactor vessel from the bottom to the argon cover gas zone near the top. Sodium coolant enters the reactor vessel through three 16-in. nozzles in the lower part of the vessel, flows through the core and other equipment, and then flows out through three 28-in. outlet nozzles located approximately at vessel mid-height.

The reactor vessel is suspended from its upper section and nested in a bottom-mounted type 304 stainless steel reactor guard vessel whose purpose is to assure that the reactor vessel nozzles remain submerged in sodium in the event of a leak. The reactor head is the closure for the reactor vessel and is 25 ft in diameter, about 22 in. thick and weighs 214 tons. Equipment mounted on the head

includes drive mechanisms for in-vessel components, seals and shielding for openings providing access to the vessel interior, and coolant piping for independently cooled test loops.

2.2.2 Reactor Core

The FFTF reactor core generates up to 7×10^{15} n/cm²-s of neutron flux (60 to 65% >0.1 MeV) at a power level of 400 MW.

The core consists of 199 core assemblies. The design includes 74 positions for PuO₂-UO₂ driver fuel assemblies, which generate the nuclear flux; nine boron carbide control rod absorber assemblies; and eight positions that may be used for independently instrumented tests of fuel specimens or reactor core materials. All eight independently instrumented positions may be used for open tests cooled by the reactor primary coolant system. Four of these positions may be used for independently cooled closed loops.

In these closed loops the coolant system is completely separated from the FFTF heat transport system. This permits testing of fuels and materials over a wide range of temperatures in a controlled environment.

In addition to the testing capabilities of the open tests and closed loops, the 74 positions designed for driver fuel may be used for statistical testing of fuels. These positions are cooled by the main reactor coolant. For each of these positions, coolant outlet flow and temperature are measured by instrumentation suspended above the position.

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FIGURE 2-5. Reactor Cutaway.

Nonfissioning materials may be tested in the fueled portion of the core and also in some of the 108 core positions surrounding the fueled zone. The neutron flux in these peripheral positions varies from $0.5 \times 10^{15} \text{ n/cm}^2\text{-s}$ to $4 \times 10^{15} \text{ n/cm}^2\text{-s}$. (Nominally, these 108 positions contain Inconel reflectors.)

The core periphery positions may also include a variable number (up to 15) absorber assemblies, which remain fixed in the core periphery for reactivity adjustment during a particular fuel cycle.

The other peripheral positions are occupied by Inconel reflectors, which are surrounded by radial shielding contained in a core barrel. The core barrel supports six core restraint mechanisms, which hold the core assemblies in proper orientation during nuclear operation. The core barrel is supported by a core support structure, which is welded to the reactor vessel.

2.2.3 Above-Core In-Vessel Components

Above-core in-vessel components are mounted in penetrations in the reactor head; their actuating mechanisms are located in the head compartment. The above-core components are listed in Table 2-1.

TABLE 2-1

ABOVE-CORE IN-VESSEL COMPONENTS

- 9 Control Rod Drivelines
- 3 Instrument Trees (which support flow and temperature monitoring sensors)
- 3 Temperature and Liquid Level Monitors
- 1 Outlet Temperature Monitor Plug
- 3 Low Level Neutron Flux Monitors
- 3 In-Vessel Handling Machines

2.2.4 Ex-Vessel Neutron Flux Monitors and Surveillance Equipment

Ex-vessel neutron flux monitors, which supply signals to the automatic shutdown system (Plant Protection System), are suspended between the reactor guard vessel and the reactor cavity wall. Each of the three ex-vessel flux monitoring positions consists of two thimbles installed in graphite thermal blocks in the reactor cavity. Neutron detectors covering the reactor power range from about 4 W to 500 MW are installed in the thimbles.

The plant design provides for use of closed-circuit television Surveillance and In-Service Inspection (SISI) equipment in the annulus between the reactor vessel and reactor guard vessel for remote visual examinations of the outer surface of the welds on the reactor vessel and nozzles, and of the inner surface of the welds on the reactor guard vessel. These inspections are planned for shutdown periods.

2.3 HEAT REMOVAL

The FFTF Heat Removal Facilities (Figure 2-6) consist of the Heat Transport System and two Closed Loop Heat Removal Systems.

2.3.1 Heat Transport System

The Heat Transport System has three 133-MW low-pressure, high-temperature stainless steel circuits for the sodium coolant, as shown in Figure 2-7.

FIGURE 2-6. Schematic of Heat Removal Facilities.

FIGURE 2-7. Plan View of Heat Transport System.

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Each circuit consists of a primary loop and a secondary loop (Figure 2-8). The reactor vessel and its head are part of each primary loop; additional primary loop equipment consists of a primary pump, the shell side of the Intermediate Heat Exchanger (IHX), two isolation valves, one check valve, a flow meter and necessary piping. Nominal conditions are 133 psig reactor inlet pressure, 680°F reactor inlet temperature, and 980°F reactor outlet temperature. A guard vessel surrounds each primary pump and each IHX. Each secondary loop consists of the tube side of the IHX, a secondary sodium pump, two flow meters, a sodium expansion tank and a sodium-to-air dump heat exchanger (DHX). The DHX consists of four 33-MW heat exchanger modules per loop, along with necessary piping and isolation valves.

The IHX tube bundle isolates activated primary sodium from the secondary loop; therefore, no radioactive sodium is transported out of containment. Secondary sodium components and heat dump equipment are located outside the containment structure in accessible, unshielded areas.

Heat Transport System pumps are powered by redundant Bonneville Power Administration (BPA) electrical lines. In case of the failure of BPA power, the reactor is shut down and the pumps are driven by small "pony" motors powered by FFTF onsite emergency electrical generators. In case of failure of all electrical power, the reactor is cooled by natural circulation of the sodium.

FIGURE 2-8. Elevation of One Circuit of the Heat Transport System.

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2.3.2 Closed Loops Heat Removal

Cooling systems were initially provided in the FFTF for two independently cooled test loops (closed loops). These systems are designed for 2.3-MW heat dissipation, and each can accommodate a test section in the reactor generating up to 2.0 MW. Space is provided in the FFTF for installing up to four 2.3-MW closed loop cooling systems.

Each Closed Loop System (CLS) utilizes its own coolant system with a primary and secondary loop. Each primary loop includes the Closed Loop In-Reactor Assembly (CLIRA), piping passing through and over the reactor head to the closed loop cell, two primary (electromagnetic) pumps and an intermediate heat exchanger. Each secondary loop includes a secondary pump and a sodium-to-air forced draft heat exchanger. Both loops include necessary tanks, piping, controls and auxiliary equipment.

2.3.3 Sodium and NaK Processing and Monitoring

Sodium is employed for most of the liquid metal applications in the FFTF. It is monitored continuously for purity and is also purified on-line by cold traps. These reduce the sodium temperature, causing impurities to crystallize out of solution. The sodium of the primary loops is continuously monitored to detect delayed neutrons emitted by fission products that would be released by failed fuel.

Sodium-potassium eutectic alloy (NaK) is used to cool sodium cold traps and for the secondary cooling loop of the Interim Decay Storage vessel. NaK is purified by NaK cold traps, which function in a manner similar to those used for sodium.

2.3.4 Argon and Nitrogen Processing and Monitoring

Argon is used as the cover gas for the heat removal loops and as the atmosphere for cells where reactor components are handled. For process control, argon is monitored for oxygen, hydrogen, nitrogen, methane and carbon monoxide. Argon is also monitored to detect fuel pin or absorber pin failure. (If a failure is detected, the identity of the leaking assembly is revealed by analysis of the unique "tag gas" released from the assembly.) Argon is purified by the Radioactive Argon Processing System (RAPS). RAPS employs a cryogenic process utilizing charcoal-adsorbent delay beds to retain short-lived xenon and krypton radioisotopes until they have decayed, and a reflux column to separate long-lived radionuclides. The purified argon is returned to be used as cover gas; the radionuclides are retained as stored waste.

Nitrogen is used as the atmosphere for cells and pipeways which house piping and/or equipment containing primary system sodium. The nitrogen is purified by the Cell Atmosphere Processing System (CAPS), through a cryogenic process utilizing charcoal-adsorbent delay beds to eliminate short-lived radioisotopes.

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2.4 CONTAINMENT AND OTHER STRUCTURES

The reactor and the primary heat removal cells for the Heat Transport and Closed Loops Systems are located in shielded, reinforced concrete cells within the reactor containment building. The principal feature of this building is the reactor containment vessel.

The reactor containment vessel is a steel shell 135 ft in diameter and 186 ft 8 in. high, designed for an internal pressure of 10 psig. The shell is carbon steel and was built to the ASME Pressure Vessel Code. The operating floor is at grade level, with 77 ft 10-1/2 in. of the containment below grade. Equipment enters the reactor containment building through an equipment airlock, while personnel enter this building through a personnel airlock.

Within the reactor containment building a polar gantry crane of 200-ton capacity and a jib crane provide access to all Heat Transport System and Closed Loops Systems cells through removable hatch plugs.

Support buildings surround the FFTF reactor containment building. These support buildings are concrete and steel structures. Their design reflects specific requirements to resist natural forces such as earthquakes, winds, and/or tornadoes. All support buildings are structurally independent of the reactor containment building.

2.5 CORE COMPONENT HANDLING AND EXAMINATION

The reactor core is made up of 199 removable core components (fuel, controls, test specimens, etc.) with exterior configurations in the form of hexagonal stainless steel ducts 4.715 in. across flats in their maximum dimension. Most of the core components are 12 ft long, but the independently instrumented test assemblies are 40 ft long.

The principal core component handling and examination equipment includes three conditioning stations for incoming core components, two handling machines outside the reactor vessel, three handling machines and three fuel storage modules inside the reactor vessel, an Interim Decay Storage Vessel, an Interim Examination and Maintenance Cell (IEM), a long-term storage facility for irradiated spent fuel, and a cask loadout station.

The Closed Loop Ex-Vessel Machine (CLEM) moves fuel and test specimens into and out of the reactor. The Bottom Loading Transfer Cask (BLTC) moves fuel and test specimens to stations within containment and also moves irradiated core assemblies outside of containment to the Fuel Storage Facility or Cask Loadout Station.

The IEM Cell provides a reliable means of retrieving data from irradiated fuel while maintaining controlled environmental conditions. In addition, the IEM Cell is used to process irradiated fuel for offsite shipment, and to perform limited maintenance on contaminated or radioactive plant equipment.

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The IEM cell is sealed and shielded and is equipped with manipulators, cranes, viewing windows and specialized remote handling equipment. An argon atmosphere is used.

2.6 INSTRUMENTATION AND CONTROL

Stable, reliable manual and automatic control of the reactor plant is provided through "control loops" for neutron flux, primary and secondary sodium flow, and DHX sodium bulk outlet temperature.

When abnormal plant operating conditions occur, the automatic Plant Protection System (PPS) will sense, initiate and carry to completion, immediate shutdown (scram) of the reactor, shutdown of primary and secondary pumps and DHX fan motors, and issuance of a signal for reduction of closed loop coolant flow and DHX airflow. For some abnormal conditions, the Plant Protection System will also close valves in lines and ducts leading to the reactor containment vessel. (The reactor may also be scrambled manually.)

A real-time, on-line digital-computer based system records operational and experimental data. Up to 1480 analog channels and 125 digital channels can be processed. The computer-based system is not used for control of the reactor, and the FFTF can be started up, operated and shut down without it.

Audible and visible alarms are provided in the control room to alert the operators to the existence of a system abnormality so that corrective action can be taken. Telephone equipment is employed for communications; special systems are provided for in-plant use.

2.7 UTILITIES AND AUXILIARY FACILITIES

The utilities and auxiliary facilities include electrical power, heating and ventilation, radiation monitoring, fire protection, auxiliary cooling and the like, as described in detail in later chapters of this document.

Electrical power is supplied by the Bonneville Power Administration through two separate feeder lines at 115 kV and 13.8 kV, respectively. The voltage is stepped down at FFTF to 2400 volts for the motors of the Heat Transport System main pumps and DHX fans, and to 480 volts for other plant services.

If the offsite power supply is lost, a single gas turbine generator currently being installed can supply 3000 kW, and the two FFTF emergency diesel generators together can supply a total of 2200 kW for a week before requiring refueling. In case the emergency generators are also lost, batteries and battery-driven systems will supply sufficient electrical power to critical systems to assure safe shutdown and control of reactor decay heat removal.

Auxiliary cooling of primary system cells and of some components is required because of the high operating temperatures of the reactor and Heat Transport System. Heat lost from these systems is transported to cooling towers and released to the atmosphere.

2.8 FFTF DESIGN PARAMETERS

Major design parameters for the FFTF are given in Table 2-2.

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TABLE 2-2

FFTF DESIGN PARAMETERS

REACTOR CONTAINMENT VESSEL

Material	Carbon steel
Diameter	135 ft 0 in.
Overall Height	186 ft 8 in.
Depth Below Operating Floor	77 ft 10-1/2 in.
Wall Thickness Above Grade	1 to 1-3/8 in.
Internal Design Pressure	10 psig

REACTOR VESSEL

Material	304 stainless steel
Internal Diameter	243 in. (about 20 ft)
Height	517 in. (about 43 ft)
Wall Thickness	2-3/8 to 2-3/4 in.
Vessel Liner Internal Diameter	19 ft 10-1/2 in.

REACTOR GUARD VESSEL

Material	304 stainless steel
Wall Thickness	1 to 2-1/2 in.
Annulus Between Reactor Vessel and Reactor Guard Vessel	8-in.

REACTOR VESSEL HEAD

Material	Low carbon alloy steel
Diameter	25 ft
Thickness	about 22 in. (plus shielding plates)
Weight	214 tons

GENERAL

Power, Excluding Closed Loops	400 MW
Closed Loops Capability	4 at 2.3 MW each

NUCLEAR CONTROLS

Type of Absorber	B ₄ C Pellets
Boron-10 per Assembly	1.16 to 1.28 kg
Pins per Assembly	61
Pin Cladding - OD	0.474 in.
- Thickness	0.051 in.
Pellet Diameter	0.362 in.
Duct - Wall Thickness	0.120 in.
- Length	12 ft
- Material	316 SS 20% CW
Cladding Material	316 SS 20% CW
Wire Wrap Material	316 SS 17% CW

HEAT REMOVAL - MAIN HEAT TRANSPORT SYSTEM

Circuits	3
Rating per Circuit	133 MW
DHX Modules	12
Rating per DHX Module	33 MW
Sodium Flow Rate	43,500 gal/min
Reactor Vessel	680°F nominal
- Inlet Temperature	980°F nominal
- Outlet Temperature	133 psig nominal
- Inlet Pressure	

TABLE 2-2 (Cont'd)

FFTF DESIGN PARAMETERS

CORE CONFIGURATION

Core Positions	- Rows 1-6 (Fueled Zone)	91
	- Rows 7-9 (Reflector Zone)	108
	- Total Positions	199
Core Assembly	- Shape	Hexagonal
	- Dimension Across Load Pads	4.715 in.
	- Length (for Most)	12 ft
Active Core	- Fueled Height	36 in.
	- Equivalent Diameter	47.2 in.
	- Volume	1034 liters
Positions for Driver Fuel Assemblies		74
Primary Control Rods (Boron Carbide)		3
Secondary Control Rods (Boron Carbide)		6
Fixed Peripheral Absorber Assemblies		0-15
Positions for 40-ft Independently Instrumented Test Assemblies		8

CORE PHYSICS

Total Fissile Mass	563 kg
Neutron Flux (Peak)	7×10^{15} n/cm ² -s
0.1 MeV	60 to 65%
Conversion Ratio	0.43
Fuel Cycle, Nominal	100 Full Power Days
Average Discharge Burnup	45 MWd/kg
Limiting Peak Burnup	80 MWd/kg
Power Density	0.39 MW/liter
Doppler Coefficient	-0.005
Delayed Neutron Fraction	0.003

DRIVER FUEL

Fuel Assembly Power	3 to 7 MW
Assembly Width at Load Pads	4.715 in.
Assembly Length	12 ft
Fuel Pin Linear Average Power	7.3 kW/ft
Driver Fuel Assembly Average Coolant Flow	18.7×10^4 lb/hr
Initial Core Average Coolant Velocity	21 ft/s
Fuel Type	PuO ₂ -UO ₂
Pu % (of Pu and U) - Rows 1-4	about 22.4%
Pu % (of Pu and U) - Rows 5-6	about 27.4%
Pu Fissile Content (²³⁹ Pu + ²⁴¹ Pu)	88 wt%
Uranium Type	Natural
Duct Wall Thickness	0.120 in.
Duct Material	316 SS 20% CW
Fuel Pins per Fuel Assembly	217
Fuel Pin Cladding	- OD
	- Thickness
	- Material
Fuel Pin Wire Wrap	- Diameter
	- Material
Fuel Pellets per Pin	about 150
Fuel Pin	- Length
	- Fueled Length

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CHAPTER 3. **REACTOR INTERNALS (SYSTEM 31)**

	Page
3.1 SYSTEM 31 SUMMARY DESCRIPTION	3-3
3.1.1 Reactor Core	3-3
3.1.2 Instrument Trees and Control Rod Drives	3-4
3.1.3 Core Support Structure, Core Barrel and Radial Shield	3-6
3.1.4 Core Restraint	3-7
3.1.5 Horizontal Baffle	3-7
3.1.6 In-Vessel Storage Modules	3-8
3.1.7 Low Level Flux Monitors	3-8
3.2 REACTOR CORE	3-9
3.2.1 Summary Description of Core	3-9
3.2.2 Core Arrangement	3-10
3.2.3 Driver Fuel Assemblies	3-13
3.2.4 Fuels Open Test Assemblies (FOTA)	3-14
3.2.5 Materials Open Test Assemblies (MOTA)	3-16
3.2.6 Neutron Absorbers	3-18
Absorber Assemblies	3-18
Absorber Pins	3-19
3.2.7 Radial Reflectors	3-20
3.2.8 Other Core Assemblies	3-20
In-Core Shim Assemblies	3-20
Simulated Core Assemblies	3-20
3.3 INSTRUMENT TREES	3-21
3.4 CONTROL ROD DRIVE MECHANISMS	3-22
3.5 REACTOR OPERATION	3-24
3.5.1 Nuclear Operation	3-24
Power and Flux	3-24
Reactivity Control	3-26
Reactor Startup	3-26
3.5.2 Reactor Thermal Hydraulics	3-26
Flow Patterns	3-26
Core Cooling	3-27
Cooling In-Vessel Storage Modules	3-27

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FIGURE 3-1. Components of System 31.

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CHAPTER 3.

REACTOR INTERNALS (SYSTEM 31)

In the FFTF Systems Structure, the FFTF reactor is divided into two major systems. System 31, which is described in this chapter, includes most of the internal components of the reactor. System 32, which is described in Chapter 4, includes the Reactor Vessel, Reactor Guard Vessel and Reactor Head.

3.1 SYSTEM 31 SUMMARY DESCRIPTION

System 31 consists of the reactor core; three instrument trees which support flow and temperature measuring instruments over the core, nine nuclear control drive mechanisms, radial shielding around the core, a core support structure, a core barrel that contains the core, six core restraint mechanisms, a horizontal baffle and seal to control sodium flow in the reactor vessel, three low level flux monitor thimbles, and three in-vessel storage modules.

The locations of these components are shown in Figure 3-1.

The System 31 reactor core and other reactor internals are immersed in a pool of liquid sodium that fills the free volume inside the System 32 reactor vessel from the bottom to a cover gas zone near the top of the vessel. The sodium coolant enters the reactor vessel through three 16-inch inlet nozzles, flows through the core and other equipment, and flows out through three 28-inch outlet nozzles.

3.1.1 Reactor Core

The 400-MW reactor core consists of a vertical array of 199 replaceable hexagonal core assemblies, each measuring 4.715 in. across flats. Fast neutron flux is supplied by $\text{PuO}_2\text{-UO}_2$ driver fuel assemblies. Nuclear control is maintained by nine boron carbide control rod absorber assemblies (which contain neutron absorber sections that are moved vertically in and out of the core) plus a variable number of "fixed shim absorber assemblies" that remain fixed in the core during a particular fuel cycle. Inconel reflectors are used to minimize neutron leakage from the fueled zone of the core.

Each driver fuel assembly, which consists of 217 individual fuel pins, can be used for statistical testing of fuel pins under actual operating conditions. Each assembly can also be used for operational testing of alternative designs and materials for the nonfissioning components of fuel assemblies.

The core will also accommodate up to eight independently instrumented test assemblies which may be used for testing either fissioning materials (i.e., advanced fuels) or nonfissioning materials. The independently instrumented test assemblies may include up to four independently cooled closed loop in-reactor assemblies. The independently instrumented test assemblies are 40 ft long. The other core assemblies are 12 ft long (except for some slightly shorter reflectors).

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3.1.2 Instrument Trees and Control Rod Drives

The three instrument trees (Figure 3-2) are a unique feature of the FFTF. Since they cover the core, the control rod drives (Figure 3-3) pass through guide tubes in the instrument trees.

To obtain access to the core for refueling, the instrument trees must be rotated away from the core into a stored position. Before such rotation, the control rod drivelines must be disconnected remotely at the top and bottom of the instrument tree guide tubes. The actual nuclear control absorber assemblies remain in the core.

FIGURE 3-2. Instrument Tree Schematic.

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FIGURE 3-3. Nuclear Control System.

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The core support structure (Figure 3-4) positions the core components within the reactor vessel. The support structure is welded to the reactor vessel.

Different sizes and shapes of receptacles are used to assure that the core assemblies are placed in their proper locations.

The core barrel is a type 304 stainless steel cylinder approximately 10 ft high and 11-1/2 ft in diameter. The core barrel surrounds the radial shield of the core and is supported by, and welded to, the core support structure.

The radial shield consists of six inner blocks and six outer shield blocks arranged around the periphery of the radial reflector region. The inner and outer shield blocks are composed of vertical standing type 304 stainless steel plates. The radial shielding is supported by the core support structure.

3.1.4 Core Restraint

The core restraint mechanisms (see Figure 3-5) apply radial forces to the load pads of the core assemblies to hold them in position for power operation. The core restraint mechanisms are mounted on the core barrel. Six mechanisms are equally spaced around the periphery of the core and are actuated by shafts extending through the reactor head.

3.1.5 Horizontal Baffle

The horizontal baffle, mounted at the upper end of the core barrel, acts as a thermal insulator and flow barrier between the hot outlet plenum of the reactor vessel and the relatively cool inlet plenum. The baffle is sealed to the reactor vessel liner (see Chapter 4) by the baffle/liner interface seal.

FIGURE 3-5. Arrangement of Core Restraint Mechanisms Around Core.

3.1.6 In-Vessel Storage Modules

In-vessel storage modules are provided in three sections of the annular region between the core barrel and the reactor vessel thermal liner. Each storage module (Figure 3-6) provides 19 natural-convection-cooled type 304 stainless steel receptacles for core components and one transfer port position for the core component pot (see Chapter 12).

Assemblies for material surveillance samples are also installed in the in-vessel storage modules. During reactor operations, these samples are exposed to the sodium, thermal and radiation environment. Figure 3-8 on the following page shows the locations of two of the in-vessel storage modules.

3.1.7 Low Level Flux Monitors

The Low Level Flux Monitoring (LLFM) instrumentation for determining the reactivity status of the reactor during subcritical and low-power conditions consists of three

FIGURE 3-6. In-Vessel Storage Module.

assemblies located 120 degrees apart in the reactor vessel. Each assembly (Figure 3-7) is made up of a composite thimble, a sensor drive unit, a sensor (System 95) with cable and a nitrogen gas cooling system (System 25) that maintains the neutron sensor and its cabling below 300°F.

The drive mechanism, mounted above the vessel head, positions the neutron sensor axially within the thimble. The sensor is located at the core midplane during reactor shutdown and startup operations and is retracted to a higher elevation prior to full-power operation.

FIGURE 3-7. Low Level Flux Monitor Assembly.

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3.2 REACTOR CORE

3.2.1 Summary Description of Core

The FFTF core contains $\text{PuO}_2\text{-UO}_2$ driver fuel assemblies, positions for independently instrumented open test assemblies, positions for independently instrumented and independently cooled "closed loop" assemblies (see Chapter 9), boron carbide neutron

absorbers for nuclear control, and Inconel reflectors.

While the general design of all 199 core assemblies is similar, details of the handling sockets and nozzles differ to assure proper location of various types of assemblies in the core.

FIGURE 3-8. Locations of In-Vessel Storage Modules.

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3.2.2 Core Arrangement

Since FFTF is an irradiation test reactor, the composition and arrangement of the core are subject to change to meet varying testing requirements. A typical core arrangement (that presented in the FFTF Final Safety Analysis Report) is shown in Table 3-1 and Figure 3-9. (A more detailed map is shown in Appendix A).

The core is arranged in the form of concentric hexagonal rings of assemblies surrounding a central assembly. The central assembly is known as "Row 1." The first ring surrounding the central assembly is known as "Row 2," and so on for a total of nine rows.

The first four rows are known as the "inner enrichment zone," and Rows 5 and 6 are known as the "outer enrichment zone." These first six rows constitute the core's fueled (active) zone, which is 3 ft in axial length and 47.2 in. in equivalent diameter. The first six rows contain the driver fuel assemblies, nine control rod assemblies, and up to eight independently instrumented test assemblies.

The active zone of the core is surrounded by three rows (Rows 7, 8 and 9) of assemblies (108 total) consisting of reflectors and fixed shim absorber assemblies. Rows 7, 8 and 9 are surrounded by segmented radial shielding.

TABLE 3-1

TYPICAL CORE ARRANGEMENT										
Type of Assembly	Row									Total
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	
Driver Fuel Positions	1	4	9	15	18	27	--	--	--	74
Primary Control Rod	--	--	3	--	--	--	--	--	--	3
Secondary Control Rod	--	--	--	--	6	--	--	--	--	6
Potential Control Rod Positions	--	--	--	--	--	--	9	--	--	9
Fixed Shim Absorber Positions	--	--	--	--	--	--	6	--	--	6
Reflector Positions	--	--	--	--	--	--	21	42	30	93
Open Test Positions	--	1	--	1	--	2	--	--	--	4
Closed Loop Positions	--	1	--	2	--	1	--	--	--	4
Total	<u>1</u>	<u>6</u>	<u>12</u>	<u>18</u>	<u>24</u>	<u>30</u>	<u>36</u>	<u>42</u>	<u>30</u>	<u>199</u>

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202
2/2/72

1-9: ROW NUMBER FOR CORE ASSEMBLY. ROWS 1-6 ARE THE FUELED ZONE; ROWS 7-9 ARE THE REFLECTOR ZONE.

CL - CLOSED LOOP POSITION.

SCR - SECONDARY CONTROL ROD ABSORBER POSITION. SIX ASSEMBLIES WERE INSTALLED INITIALLY.

OT - OPEN TEST ASSEMBLY POSITION.

PC - POSITIONS IN WHICH CONTROL RODS MAY BE INSTALLED.

PFS - PERIPHERAL FIXED SHIM ABSORBERS.

PCR - PRIMARY CONTROL RODS. THREE RODS WERE INSTALLED INITIALLY.

FIGURE 3-9. Core Map Showing Typical Arrangement.

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Figure 3-10 is a construction view of the top of the core, loaded with simulated core assemblies that were used for system testing and sodium cleanup.

The core is surrounded by the core restraint mechanisms and by the horizontal baffle. Two of the three instrument trees are shown in place.

FIGURE 3-10. Construction View of the Top of the Core Loaded with Simulated Core Assemblies.

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3.2.3 Driver Fuel Assemblies

FFTF driver fuel assemblies (Figure 3-11) are hexagonally shaped components, 4.715 in. across outside load pad flats and 12 ft long. The assembly is composed of a bundle of 217 fuel pins, 0.230-in. OD, and containing mixed oxide ($\text{PuO}_2\text{-UO}_2$) pellets; a surrounding duct, 4.715 in. across load pad flats; and lower and upper end hardware.

The driver fuel assemblies for Cores 1 and 2 are composed of mixed plutonium-uranium oxides ($\text{PuO}_2\text{-UO}_2$), with compositions of 22.43 and 27.37 wt% Pu/(U+Pu) for the core's inner and outer enrichment zones, respectively. The plutonium has a fissile content of approximately 88 wt% ($^{239}\text{Pu} + ^{241}\text{Pu}$). Natural uranium is used. Future reload driver fuel may deviate from these compositions because of changing operational requirements and feed material assays.

FIGURE 3-11. Driver Fuel Assembly.

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The driver fuel pins (Figure 3-12) are approximately 94 in. long, positioned in a hexagonal array. They are spaced by 0.056-in. diameter helical wrapped wires. Design of the pin end caps assures that pins of the proper enrichment are placed in each fuel assembly.

Each pin contains a "tag gas" capsule. (See Chapter 10.) Inside the tag gas capsule is a penetrator, which is magnetically actuated to permit the tag gas to escape into the plenum after the clad tube has been sealed.

3.2.4 Fuels Open Test Assemblies (FOTA)

The FOTA allows irradiation of highly instrumented fuel assemblies in reactor coolant. Sodium exit temperature can be approximately 120° higher than the sodium exit temperature from adjacent fuel assemblies. Flow is controlled with an inlet orifice. The FOTA uses a standard driver fuel duct and an attached "stalk"; the assembly is 40 feet long. (See Figure 3-13.)

FIGURE 3-12. Driver Fuel Pin.

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FIGURE 3-13. Fuels Open Test Assembly (FOTA).

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Parameters such as sodium temperature within the fuel bundle, cladding temperature, duct temperature, fuel centerline temperature and fission gas pressure within the pin can be monitored. Transducers can also be used to measure differential pressure within the fuel bundle. Fifty-one leads for pressure, temperature and electrical connections may be used.

When a FOTA is removed from the core, the instrumentation leads are severed. However, the specimens may be re-inserted in the core in a Post-Irradiation Open Test Assembly (PIOTA), which provides measurements of coolant outlet flow and temperature. (See Figure 3-14.)

3.2.5 Materials Open Test Assemblies (MOTA)

The highly instrumented Materials Open Test Assembly (MOTA) (Figure 3-15) is designed to eliminate many problems associated with evaluating the irradiation behavior of structural materials. The MOTA provides detailed temperature control and measurement during irradiation as well as density and dimensional measurements on test specimens during reactor shutdown. The MOTA contains 48 specimen canisters, 30 of which have independent temperature control. In its current configuration, the MOTA contains up to 2500 cm^3 of specimen space for in-core irradiation. Eighty-two leads for pressure, temperature and electrical connections may be used.

The MOTA is limited to nonfissioning materials. The MOTA test section is a standard FFTF duct with a "stalk," or upper assembly, mechanically attached to the duct assembly. This arrangement permits the direct removal of the entire assembly from the reactor by use of the Closed Loop Ex-Vessel Machine (Chapter 12). The MOTA is designed so that the experiment can be removed from the core at the end of an operating cycle, the test specimens can be examined and the experiment can be reinserted into the core for the start of the next cycle. This rapid turnaround capability further enhances the value of the large irradiation test volume.

FIGURE 3-14. Post-Irradiation Open Test Assembly (PIOTA).

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FIGURE 3-15. Materials Open Test Assembly (MOTA).

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3.2.6 Neutron Absorbers

Absorber Assemblies — Neutron flux in the FFTF core is adjusted by use of neutron absorber assemblies containing pins loaded with boron carbide.

Control rod absorber assemblies are used for the nine control rods of the FFTF. The control rod absorber assembly contains boron carbide in a movable pin bundle assembly (known as a "control rod"), which provides adjustable control of the local neutron flux by axial movement of the pin bundle.

The control rod absorber assembly is a hexagonally shaped component (see Figure 3-16) consisting of an orifice assembly, duct tube, load pads, handling socket and pin bundle.

The pin bundle is mounted in an inner duct that may be attached to or detached from the drive mechanisms through the absorber coupling at the top of the absorber assembly. This permits uncoupling prior to refueling operations and recoupling of these components to resume reactor operation. (The disconnected pin bundle remains in the core after the disconnect operation.)

FIGURE 3-16. Control Rod Absorber Assembly.

The fixed shim absorber assembly is similar to the control rod absorber assembly. However, the pin bundle is not movable; and since the fixed shim absorber assembly is not adjustable during operation, it does not have a coupling section.

Absorber Pins — The control rod absorber pins (Figure 3-17) are 63.63 in. long including the end caps. The cladding is 0.474 in. nominal OD by 0.051 in. thick for the reference design and is 20% cold drawn 316 stainless steel. Each absorber pin is helically wrapped with 0.024-in. diameter wire for lateral spacing.

The portion of the control rod pin containing absorber material consists of a stack of boron carbide pellets ($92 \pm 2\%$ theoretical density) 36 in. long. The nominal absorber pellet stack consists of 60 pellets, each 0.6 in. long and 0.362 in. in diameter, of hot pressed and sintered boron carbide produced by a solid-state process. The boron enrichment is that of natural boron ($19.78\% {}^{10}\text{B}$).

A gas plenum with an effective length of 21.24 in. is provided in the absorber pin to limit internal gas pressure buildup caused by helium generation. Within the upper plenum are a spacer, a tag gas capsule and a spring to keep the boron carbide pellets and lower plenum spacer compressed during handling prior to installation in the reactor.

The pins for fixed shim absorbers are generally similar to the control rod absorber pins but are 95.83 inches long.

FIGURE 3-17. Control Rod Absorber Pin.

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3.2.7 Radial Reflectors

Radial reflectors consist of hexagonal reflector assemblies in Rows 7, 8 and 9. The inner assemblies are supported by the core basket. The outer assemblies are supported by the inner radial shield assembly. Reflector assemblies are composed of a section of Inconel 600 and upper and lower shield sections of type 316 stainless steel. The Inconel section and the upper shield sections consist of blocks stacked on a vertical array of parallel coolant and structural tubes (see Figure 3-18).

3.2.8 Other Core Assemblies

In-Core Shim Assemblies — The in-core shim assemblies are nonfueled assemblies that may be installed in the core as substitutes for fuel or test assemblies during reactor operation. An in-core shim assembly is a stainless steel, hexagonally shaped component, 4.715 in. across load pad flats and 12 ft long. Stainless steel simulated fuel pins are used. These assemblies were used at initial startup to compensate for the excess reactivity that would otherwise have existed in the initial core, and they may be used from time to time in the future as required.

Simulated Core Assemblies — The simulated core assemblies are nonfueled assemblies that were installed as initial units in-core for use during hot functional testing and system cleanup.

Each assembly is 12 ft long and contains a filter/trap unit and an orifice unit. After completion of functional testing and system cleanup, the simulated core assemblies were removed from the core and replaced by normal core components.

FIGURE 3-18. Radial Reflector Assembly.

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3.3 INSTRUMENT TREES

The FFTF has three instrument trees (Figure 3-19), each covering a 120° section of the core. Each instrument tree is approximately 33 feet high and weighs about 30 tons. An instrument tree performs the following functions:

- Provides space and support for reactor core and reflector instrumentation assemblies. The instrumentation measures flow and temperature.
- Directs the coolant flow from the in-core assemblies to the instrumentation.
- Provides secondary hold-down for the fuel, reflector and control rod absorber duct assemblies. In the event of a complete or partial failure of the primary hydraulic hold-down system (see Section 3.5.2), the upward movement of the in-core assemblies is restrained by the lower instrument tree frame and is limited to an axial movement of two inches.
- Provides support, location and translation to the control rod driveline disconnect (CRDD) assemblies.

Each instrument tree contains guide tubes for six control rod drivelines. Three guide tubes are presently used in each instrument tree. The additional guide tubes may be used in the future to accommodate additional control rods. Under refueling conditions, the control rod disconnect drivelines are nested in and supported by the instrument tree guide tubes when the instrument trees are lifted and rotated to storage positions.

FIGURE 3-19. Instrument Tree.

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Figure 3-20 shows installation of an instrument tree in the reactor.

Each instrument tree includes its own mechanism for raising and lowering the tree with respect to the reactor core. The lift and rotational drives are designed to lift the tree 15 in. vertically (16.75 in. for removal) at a nominal rate of 1.8 in./min, and rotate the tree 184 degrees at a nominal rate of 11.4 degrees per minute. The radius of rotation is 65.142 in.

The instrument tree control and instrumentation system includes instrument tree status indicators in the control room and a control console in containment.

The instrument tree argon system consists of an argon distribution cabinet and distribution lines that route the argon to various points on the instrument tree for seal inflation, seal buffering, xenon contamination control and annulus purging for maintenance purposes.

3.4 CONTROL ROD DRIVE MECHANISMS

The control rod drive mechanism (CRDM) (see Figure 3-3) is an electro-mechanical roller-nut actuating device that moves and positions the control rod absorber pin bundle (i.e., "control rod") within the active core in response to commands by the Reactor Plant Control System (System 90). The CRDM also drops the control rod into the core upon the direction of the Plant Protection System (System 99). The CRDM is cooled by nitrogen provided by System 25.

The CRDM consists of three subassemblies separately installed into the reactor vessel head nozzle and connected to the control rod driveline assembly. These subassemblies are the lower CRDM assembly, the rotor assembly and the stator assembly.

The CRDM is operated by signals from the reactor control room, which cause roller nuts on the rotor to engage the threaded portion of the leadscrew on the lower CRDM assembly. Rotation of the electrical field of the stator causes rotation of the roller nuts with respect to the leadscrew and raises or lowers the leadscrew to any desired position. De-energizing the stator causes the roller nuts to disengage the leadscrew and allows the leadscrew to fall. This action, under spring-assisted gravity forces, drops the control rods into the core and shuts down the nuclear fission reaction. A bellows on the CRDM prevents penetration of sodium vapor to the roller-nut mechanism. The shafts of this system are hollow to permit insertion of tools for connecting and disconnecting control rod absorber pin bundle assemblies with control rod drivelines. (See also Sections 3.1.2 and 3.3.)

Eighteen penetrations were provided in the head for control rod assemblies. Nine penetrations were used for control rod assemblies, and nine were plugged for initial operation. CRDM shield plugs and vacant nozzle shield plugs provide thermal and radiation shielding. A closure cap provides a gas seal at the top of each vacant CRDM nozzle and completes the primary barrier required of the vacant CRDM nozzles.

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FIGURE 3-20. Instrument Tree Being Installed in Reactor.

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3.5 REACTOR OPERATION

The reactor is designed to contain a critical assembly of fuel, to control the fission rate and to remove the fission energy that is generated.

3.5.1 Nuclear Operation

Power and Flux — The reactor is designed to operate at a constant power of 400 MW throughout each driver fuel irradiation cycle (100 full power days); about 30% of the core is replaced at refueling shutdown between cycles. Nominal total neutron flux profiles in the radial and axial directions for full-power conditions are shown in Figures 3-21 and 3-22.

A small systematic change in flux distribution occurs during an operating cycle due to depletion of fuel and withdrawal of the Row 5 control rods, as illustrated by the two curves shown for beginning-of-cycle (BOC) and end-of-cycle (EOC) conditions. Such perturbations are most pronounced in positions adjacent to control rods.

The reactor neutron energy spectrum is typical of oxide-fueled fast reactors. Approximately 60% to 65% of the total neutron flux in the fueled regions of the core exceeds an energy of 0.1 MeV (see Figure 3-23). The nickel-rich radial reflectors surrounding the core and the axial reflector segments contained in the driver fuel pins produce a locally softened spectrum near the core boundaries.

FIGURE 3-21. Radial Total Flux Profile at Core Midplane at Full Power.

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FIGURE 3-22. Axial Total Flux Profile Through Core Centerline at Full Power.

FIGURE 3-23. Neutron Flux Energy Spectrum at Center of Core.

Reactivity Control -- The core is designed with reactivity coefficients that will provide for stable, safe and predictable operation over the full range of reactor power.

Reactivity control during reactor operation is provided by the movable full-length B_4C absorber rods, operated by individual control rod drive mechanisms. In addition, the core reactivity is adjusted to fall within the proper range for each irradiation cycle by prepositioning the in-core (nonfueled) and the peripheral (absorber) shim assemblies as necessary before startup. The shim assemblies are not movable and remain in their fixed positions during the irradiation cycle. They are placed in the desired core locations by the fuel handling equipment during fuel handling shutdowns.

Primary and secondary movable control rod systems are provided. Each system has its own independent scram initiation circuitry. The primary system consists of the three rods located in the third hexagonal row of the core.

The secondary control rod system consists of the six rods in the fifth hexagonal row of the core. The secondary control rods provide operational reactivity control, including startup and shutdown, power ascent, and burnup reactivity compensation.

Either control system can shut down and maintain the reactor in a subcritical status independently of the other control system. If abnormal conditions were to occur, the automatic Plant Protection System would trip and shut the reactor down safely.

Reactor Startup -- After shutdown operations and reactor checkouts are completed, the three primary control rods are withdrawn one at a time. At this point, the reactor remains subcritical. The secondary rods are then withdrawn in such a way that they will have the desired rod configuration at criticality. When criticality has been achieved, the actual critical rod positions attained are checked against theoretical and administrative limits prior to power ascent. Following low-power tests and checkouts, the reactor is brought to full power and temperature by further withdrawal of the secondary control rods, on a schedule consistent with heatup rate limitations. As full power is approached, the secondary rods are realigned into the desired configuration for power operation. During steady-power operation, the position of a selected rod may be adjusted by the automatic control system or by operator manual control action from time to time to realign rods to compensate for fuel burnup.

3.5.2 Reactor Thermal Hydraulics

Flow Patterns -- The flow rate is 17.48×10^6 lb/hr of sodium; the distribution of sodium coolant flow in the reactor is summarized in Table 3-2.

Hydraulic balance is the primary method of hold-down of fuel and control assemblies within the core. The system relies on differential pressure between the high-pressure inlet plenum and the low-pressure region below the core support basket.

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TABLE 3-2

SODIUM FLOW DISTRIBUTION IN REACTOR	
	% of Flow
Core Component Assemblies	88.4
Peripheral Plenum (Between Reactor Vessel and Liner)	7.7
Shield Blocks and Outer Reflectors	3.5
Gaps Between Core Assemblies, etc.	0.3
Other	0.1
	100.0

The hydraulic balance system negates the upward drag force due to pressure drop, so that the net downward force on any hydraulically balanced assembly is approximately equal to its weight in sodium.

Core Cooling -- When the reactor is at full power (400 MW) with a nominal coolant temperature rise of 300°F, the average sodium velocity past the fuel assemblies is about 21 ft/s. Orificing is used to cause the flow rate in all assemblies to be greater or less than the average. In high-flow assemblies, the velocity of fluid flowing parallel to the fuel pins is approximately 23 ft/s. The flow rates in the control assemblies are reduced by orificing to provide a maximum velocity of flow parallel to the control rod pins of less than 6 ft/s.

Above the core, the vessel contains a large volume of sodium. This large volume of

sodium assures that thermal transients at the core outlet will be significantly attenuated before they affect the vessel outlet nozzles.

Adequate sodium is provided to fill the guard vessel; even in the unlikely event of a sodium leak in the reactor vessel, the reactor coolant level will remain above the minimum safe level.

Cooling In-Vessel Storage Modules --

During refueling of the reactor, fuel assemblies (and in some instances, test assemblies) are removed from the core and placed in sodium-cooled storage modules within the vessel.

The spent fuel and test assemblies are allowed to remain in the in-vessel storage modules until their radioactive decay heating rates have fallen to 10 kWt, the level at which they can be handled by the CLEM. Two criteria related to assembly cooling in storage must be satisfied. First, the temperature of the cladding on pins within all fuel assemblies must be maintained low enough to prevent additional cladding strain resulting from creep. Second, the temperature of the cladding on fuel pins (for driver fuel and test assemblies) must always be kept below the at-power operating temperature at all positions along the length of the fuel pins. In certain instances, keeping the cladding well below its at-power temperature may be desired.

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CHAPTER 4.
REACTOR ENCLOSURE (SYSTEM 32)

	Page
4.1 REACTOR ENCLOSURE SUMMARY DESCRIPTION	4-3
4.2 REACTOR VESSEL	4-3
4.3 REACTOR GUARD VESSEL	4-5
4.4 REACTOR HEAD	4-5
4.5 HEAD COMPARTMENT EQUIPMENT	4-8
4.5.1 Center Island Enclosure	4-10
4.5.2 Temperature and Liquid Level Monitor Assemblies	4-11
4.5.3 Proximity Test Plug	4-11
4.5.4 Fuel and Test Handling Equipment	4-11
4.5.5 Access for Visual Inspection of Vessels	4-13
4.5.6 Maintenance Floor and Operating Deck	4-13
4.5.7 Temperature Control Systems	4-13
4.5.8 Other Head Compartment Equipment	4-14
4.6 REACTOR CAVITY EQUIPMENT	4-14
4.6.1 Reactor Cavity Shielding	4-15
4.6.2 Ex-Vessel Flux Monitors	4-15

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FIGURE 4-1. Components of System 32.

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CHAPTER 4.

REACTOR ENCLOSURE (SYSTEM 32)

4.1 REACTOR ENCLOSURE SUMMARY DESCRIPTION

The major components of the Reactor Enclosure System (Figure 4-1) include the reactor vessel, main support structure, reactor guard vessel and reactor head. Other System 32 components are located in the head compartment and in the reactor cavity.

4.2 REACTOR VESSEL

The Reactor Vessel (Figure 4-2) is constructed of type 304 stainless steel. The vessel is approximately 43 ft high and 20 ft inside diameter, and the wall thickness varies from 2-3/8 in. to 2-3/4 in. The vessel is classified as Class "A", in accordance with Section III of the ASME Code for pressure vessels.

A vessel liner (19 ft 10-1/2 in. ID) protects the vessel wall from severe temperature transients. The annulus between the vessel and liner is approximately 1-1/4 in. Bypass inlet coolant is diverted to this annulus to cool the vessel walls.

Flow from the three primary heat transport system loops enters the reactor through three 16-in. inlet nozzles located 120 degrees apart in the inlet plenum of the reactor vessel.

Three 28-in. outlet nozzles for outflow of core coolant are located 120 degrees apart at approximately the mid-height of the vessel.

FIGURE 4-2. Reactor Vessel.

Nozzles are provided in the upper portion of the vessel for sodium makeup and sodium overflow (System 81) and sodium sampling (System 85).

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The reactor vessel is suspended by 30 support arms (Figure 4-3) welded to the vessel. The support arms are bolted to the main support structure (Figure 4-4), which is in turn supported by a concrete ledge on the adjacent reactor cavity wall. (See Chapter 11.)

Ninety-six load-bearing pads are provided to enable the main support structure to slide with respect to the concrete to allow for thermal expansion of the vessel and main support structure.

Figure 4-5 shows the reactor vessel being installed in FFTF.

FIGURE 4-3. Reactor Vessel Support Arm.

FIGURE 4-4. Main Support Structure Readied for Installation.

FIGURE 4-5. Reactor Vessel Installation.

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4.3 REACTOR GUARD VESSEL

The reactor vessel is surrounded by a bottom-mounted reactor guard vessel. The purpose of this vessel is to provide an 8-in. annulus to assure that reactor vessel nozzles remain submerged in sodium in the unlikely event of a leak in the nozzles, piping or piping connections.

The guard vessel is constructed of type 304 stainless steel and is designed to Section III, Class A requirements of the ASME Code for pressure vessels. The material thickness varies from 1 to 2.5 in. to provide structural integrity

at its design temperature (1050°F) with a full head of sodium coolant. The guard vessel is insulated on the outer surface to protect the reactor cavity walls and to reduce heat loads to the heating and ventilating system.

4.4 REACTOR HEAD

The reactor head is the closure for the reactor vessel. It is 25 ft in diameter and about 22 in. thick; it weighs 214 tons. It was fabricated (Figure 4-6) from two SA-508, Class 2 forgings (low-alloy carbon steel) that were butt-welded together as a Class A vessel.

FIGURE 4-6. Machining the Reactor Head.

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The under-the-head shielding is composed of four thick metallic shield plates, thermal and radiation shielding and a gas entrainment suppressor plate. The shield plates consist of two 4-in. carbon steel plates, one 4-in. type 410 stainless steel plate, and one 5-in. Inconel 600 plate. Below the shield plates are eight type 304 stainless steel thermal reflectors, and a segmented gas entrainment suppressor plate made of type 316 stainless steel.

The head assembly is supported (Figure 4-7) by the main vessel support structure through an I-ring member, and is secured by 82 peripheral hold-down stud bolts on a 291.5-in. diameter bolt circle. Sealing is accomplished by an SB-168 Inconel omega seal welded both to the upper flange of the reactor vessel and to the I-ring, as well as by two concentric metallic O-rings (copper-plated Inconel 600) between the head and the I-ring.

The reactor head contains 50 major penetrations (Table 4-1) and 84 peripheral bolt holes. All penetrations are sealed through use of equipment, plugs or similar means. Figure 4-8 shows the locations of these penetrations. Twenty-seven of the penetrations are within the shielded center island section of the head compartment.

TABLE 4-1

REACTOR HEAD MAJOR PENETRATIONS

Quantity	Purpose
3	Instrument Tree
9*	Control Rod Mechanism
9*	Control Rod Spare Standpipe
8*	Test Position Spoolpiece
3	Low-Level Flux Monitor
6	Core Radial Restraint
3	In-Vessel Handling Machine
3	Fuel Transfer Port
1	Cover Gas Inlet Line
1	Cover Gas Outlet Line
3	Temperature/Liquid Level Monitor
1*	Proximity Test Plug

* In Center Island

FIGURE 4-7. Reactor Head Support.

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CGE - Cover Gas Equalization Port (1)
 CGF - Cover Gas Feed Port (1)
 CI - Center Island Area (27 penetrations)
 CR - Core Restraint (6)
 FTP - Fuel Transfer Port (3)

HB - Head Bolt Penetrations (84)
 IT - Instrument Tree (3)
 IVHM - In-Vessel Handling Machine (3)
 LLFM - Low Level Flux Monitor (3)
 TLLM - Temperature/Liquid Level Monitor (3)

FIGURE 4-8. Reactor Head Penetrations.

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4.5 HEAD COMPARTMENT EQUIPMENT

The head compartment is the area located directly above, and including the upper surface of, the reactor head. The compartment is 36 ft by 36 ft by 12 ft 7 in. high (Figure 4-9).

Most of the equipment is located over the 50 major penetrations in the reactor head, but some items (i.e., Ex-Vessel Flux Monitors and plugs for Reactor Cavity access) are located over the reactor cavity outside the reactor head (Figure 4-10).

FIGURE 4-9. Head Compartment Arrangement.

LEGEND:

BAPS - BRANCH ARM PIPING SHIELD
 CGPS - COVER GAS PIPING SHIELD
 EVFM - EX-VESSEL FLUX MONITOR
 FTP - FUEL TRANSFER PORT
 HTCS - HEAD TEMPERATURE CONTROL SYSTEM
 IT - INSTRUMENT TREE
 IVHM - IN-VESSEL HANDLING MACHINE
 LLFM - LOW LEVEL FLUX MONITOR
 RCA - REACTOR CAVITY ACCESS

FIGURE 4-10. Head Compartment Plan View.

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The head compartment provides space for reactor equipment above the head and has an air atmosphere to permit direct personnel access for operations and maintenance. Extensive local shielding is provided around all radioactive sources to protect personnel. Cooling and ventilation are provided by the heating and ventilation system (System 25), as well as by air circulated from the reactor containment above.

The branch arm piping connects the vertical closed loop spool pieces to the piping running to the closed loop cells (see Chapter 9). The branch arm piping carries the sodium coolant. The piping is completely contained in separate, shielded nitrogen-filled sheet metal enclosures.

4.5.1 Center Island Enclosure

The center island enclosure in the middle of the reactor head is directly over the 27 head penetrations above the reactor core. These penetrations are fitted with 18 standpipes (5.4 in. ID and 87.47 in. long) for the control rods and 8 spool pieces (5.6 in. ID and 87.12 in. long) for the closed loop and open test positions. One test position penetration is sealed by the Proximity Test Plug (PTP, see Section 4.5.3). The center island shielding and enclosure shields the standpipes, spoolpieces, control rod drive mechanisms and the PTP. Horizontal extensions shield the branch arm piping for closed loops (Figure 4-11). The center island shield assembly consists of a shield deck, attached shielding and a shield vessel—an irregular, thick-walled steel cylinder that bolts to the reactor head (Figure 4-12). Nitrogen cooling is used for the center island enclosure.

FIGURE 4-11. Center Island Shielding.

FIGURE 4-12. Center Island Shielding Details.

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4.5.2 Temperature and Liquid Level Monitor Assemblies

The temperature and liquid level monitor assembly (TLLM) consists of a plug and accessories (see Section 6.5). Three such assemblies are located in penetrations of the reactor head. The TLLM plug is a flanged tube approximately 240 in. long and 8 in. in diameter, weighing approximately 1400 pounds (Figure 4-13).

The 8-in. diameter tube extends approximately 213 in. below the reactor head, 163 in. into the reactor coolant. Within this tube are located the various instrument guide tubes that contain the instruments provided by System 92. These instruments measure coolant outlet temperature and coolant level.

FIGURE 4-13. Temperature and Liquid Level Monitor Assembly.

4.5.3 Proximity Test Plug

The proximity test plug (PTP) assembly (Figure 4-14) consists of a flange, plug, seals, drywells, thermocouples, fittings and attaching hardware. This assembly houses the instrumentation supplied by System 92, which measures coolant outlet temperature for the Plant Protection System and also monitors temperatures of the reactor head.

4.5.4 Fuel and Test Handling Equipment

System 32 includes the fuel transfer port assemblies, floor valve adapters and test transfer port assembly used in core component handling (Chapter 12).

FIGURE 4-14. Proximity Test Plug.

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Three fuel transfer ports (FTP) are provided in the reactor vessel head, one for each IVHM. Each fuel transfer port consists of a nozzle, a sleeve, a plug, a nozzle cover and local shielding surrounding the nozzles (Figure 4-15). The ports are mounted on standpipes approximately 13-3/4 in. high.

FIGURE 4-15. Fuel Transfer Port Assembly.

Two floor valve adapters (FTP/FVA) (Figure 4-16) are provided. These adapters, when positioned over a particular Fuel Transfer Port nozzle, create a sealed passageway from the vessel to the floor valve on the operating deck for transfer of core components. The floor valve is described in Chapter 12.

The test transfer port assembly (TTP) and shielding are shown in Figure 4-17. The top face of this assembly is designed to interface with the underside of the floor valve. The bottom of the assembly fits onto the spoolpiece for the test position.

FIGURE 4-16. Floor Valve Adapter (FTP/FVA).

FIGURE 4-17. Test Transfer Port Assembly.

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4.5.5 Access for Visual Inspection of Vessels

Reactor Cavity access openings (see Figure 4-10) are provided in the Head Compartment for the use of closed circuit TV equipment to inspect the outer surface of the welds on the reactor vessel and nozzles, and the inner surface of the welds on the reactor guard vessel and the vessel support arms, during reactor shutdown periods.

4.5.6 Maintenance Floor and Operating Deck

The maintenance floor is located 43.5 in. above the level of the head compartment floor. The walking surfaces are removable for access to equipment under the maintenance floor.

The operating deck is a fabricated carbon steel structure that covers the entire 36-ft square head compartment and provides a working surface over the compartment at the same elevation as the containment building operating floor (Figure 4-18). The 62-ton, 14-inch-thick carbon steel component contains openings to permit transfer of Closed Loop In-Reactor Assemblies (CLIRAs) and in-core assemblies, as well as openings for replacing removable instrument assemblies in the three FFTF instrument trees. It also has a removable inner section.

4.5.7 Temperature Control Systems

The head compartment contains the temperature control systems for the head, the head compartment and the reactor enclosure preheat systems.

FIGURE 4-18. Operating Deck Being Installed.

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Electrical heaters placed on the reactor head under the head insulation add heat as required to maintain head temperature at approximately 400°F during operation and to maintain acceptable thermal gradients during startup. The heaters are automatically controlled, based on head-mounted thermocouple signals, to maintain an acceptable outer head temperature distribution for all operating conditions.

4.5.8 Other Head Compartment Equipment

In addition to the equipment described above, the head compartment contains argon piping, shielding, gas service lines, instrumentation wiring and equipment, power wiring and equipment, and instrumentation provided by Systems 92 and 93-13. (See Chapters 6 and 7.)

4.6 REACTOR CAVITY EQUIPMENT

The reactor cavity houses the reactor vessel and guard vessel. System 32 equipment in the reactor cavity also includes the reactor cavity shielding and ex-vessel flux monitors.

Figure 4-19 is a schematic of the reactor enclosure preheat systems. The nitrogen preheat system circulates temperature-controlled gas through the reactor vessel/guard vessel annulus. The argon preheat system circulates temperature-controlled argon through the reactor internals.

FIGURE 4-19. Reactor Enclosure Preheat Systems.

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4.6.1 Reactor Cavity Shielding

The reactor cavity shielding attenuates radiation upward from the reactor vessel. As indicated in Figure 4-20, this shielding consists of two collars: a B_4C collar supported from the guard vessel top flange and a reactor cavity shield collar supported from the reactor cavity wall.

4.6.2 Ex-Vessel Flux Monitors

Three ex-vessel flux monitors (EVFM) are located in three penetrations in the head compartment floor between the reactor guard vessel and the reactor cavity wall. Each of the three ex-vessel flux monitors includes two thimbles in the reactor cavity approximately midway between the three stored fuel locations. One thimble contains a wide-range channel and the other contains a secondary channel, both part of System 95. (See Chapter 6.)

FIGURE 4-20. Reactor Cavity Shielding.

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CHAPTER 5.
REACTOR HEAT TRANSPORT (SYSTEM 51)

	Page
5.1 REACTOR HEAT TRANSPORT SYSTEM SUMMARY DESCRIPTION	5-3
5.2 HTS PRIMARY LOOPS	5-4
5.2.1 HTS Primary Valves	5-6
HTS Isolation Valves	5-6
HTS Check Valves	5-6
5.2.2 HTS Primary Pumps	5-6
5.2.3 HTS Intermediate Heat Exchangers	5-8
5.3 HTS SECONDARY LOOPS	5-10
5.3.1 HTS Secondary Pumps	5-11
5.3.2 HTS Dump Heat Exchangers	5-12
5.3.3 HTS Secondary Loop Expansion Tanks	5-14
5.3.4 HTS Secondary System Component Location and Protection	5-14
5.4 HTS PIPING	5-14
5.5 HTS SYSTEM OPERATION AND CONTROL	5-15
5.5.1 HTS Normal Operation	5-15
5.5.2 HTS Two-Circuit Operation	5-16
5.5.3 HTS Natural Circulation Cooling	5-16
5.5.4 HTS System Control	5-16
5.6 REACTOR HEAT TRANSPORT SYSTEM DESIGN PARAMETERS	5-16

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FIGURE 5-1. Reactor Heat Transport System (HTS) Schematic.

FIGURE 5-2. Reactor Heat Transport System Arrangement.

CHAPTER 5.

REACTOR HEAT TRANSPORT (SYSTEM 51)

5.1 REACTOR HEAT TRANSPORT SYSTEM SUMMARY DESCRIPTION

Heat generated by the 400-MW FFTF reactor is removed via the Heat Transport System (HTS) (Figures 5-1 and 5-2) by pumping 43,500 gal/min of sodium through the reactor vessel, at a nominal inlet temperature of 680°F, an inlet pressure of about 133 psig, and a nominal outlet temperature of 980°F. The actual inlet and outlet temperatures depend on the operating conditions selected.

Dry argon cover gas is used to blanket the sodium in the reactor vessel and throughout the Heat Transport System, to avoid contact between sodium and air. The Heat Transport System has three 133-MW stainless steel circuits (Figure 5-3). Each circuit consists of both a primary (radioactive) loop and a secondary

(nonradioactive) loop. The reactor vessel and its head are part of each primary loop; additional loop equipment consists of a primary pump with two motors, two isolation valves, one check valve, required piping, and the shell side of the Intermediate Heat Exchanger (IHX). The IHX isolates radioactive primary sodium from the secondary loop.

Each main component and each vertical run of piping in the primary loops is provided with a guard vessel.

Each secondary loop consists of the tube side of the IHX, a secondary sodium pump with two motors, an expansion tank and a sodium-to-air Dump Heat Exchanger (DHX). The DHX consists of four 33-MW heat exchanger modules per loop, along with required piping and isolation valving.

FIGURE 5-3. One of the Three Cooling Circuits of the Heat Transport System.

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5.2 HTS PRIMARY LOOPS

The primary loops transport reactor heat to the intermediate heat exchangers, which thermally link the primary and secondary loops. The three primary loops have common flow paths through the reactor vessel but are otherwise independent in operation, except for a cover gas equalization line common to all three loops, linking all primary pumps with the reactor vessel. The sodium coolant enters the reactor vessel below the bottom of the core, flows up through the core and reactor internals, and flows out slightly above the midplane of the reactor vessel (Figure 5-4).

Heated sodium flows (Figure 5-5) from the reactor outlet nozzle through the hot leg isolation valve to the suction of a centrifugal, free-surface pump. Sodium from the pump discharge is circulated to the shell side of the intermediate heat exchanger, where the heat is transferred to secondary sodium. From the intermediate heat exchanger outlet, the primary sodium flows through a check valve and a cold leg isolation valve, then to the reactor vessel inlet and through the reactor, thus completing the flow cycle. Covered guard vessels around each primary pump and IHX retain the sodium in the unlikely event of a leak.

FIGURE 5-4. Sodium Flow Through FFTF Reactor Vessel.

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The piping from the reactor vessel to the pump section is 28-in. OD; the remaining piping from the pump discharge to the reactor vessel inlet nozzle is 16-in. OD. The choice of the size of the 28-in. reactor vessel outlet pipe was governed mainly by the frictional pressure losses in this line.

The sodium flow rate is measured by a permanent magnetic flowmeter located downstream from the IHX outlet; flow is adjustable by a variable-speed drive pump. Maximum fluid

velocity is less than 30 ft/s to limit coolant cavitation, pipe erosion and pipe vibration.

The primary hot leg piping (i.e., reactor to IHX) is of type 316H stainless steel. The cold leg (i.e. IHX to reactor) piping and components are of type 304H stainless steel.

Equipment and piping containing primary sodium are installed inside steel-lined, shielded cells. These cells contain inert gas (nitrogen) during normal reactor operation (see Chapter 8).

FIGURE 5-5. HTS Primary Loop Piping Schematic.

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5.2.1 HTS Primary Valves

HTS Isolation Valves — A remotely operated isolation valve (Figure 5-6) is installed in both the hot and cold leg piping of each primary loop in the HTS near the reactor vessel. These valves are intended for plant maintenance purposes.

FIGURE 5-6. HTS Primary Isolation Valve Installed.

HTS Check Valves — A check valve of the tilting-disk type (Figure 5-7) is located in the HTS cold leg piping of each primary loop downstream from the IHX and upstream from the cold leg isolation valve. The function of this check valve is to avoid flow reversal in a primary loop in the event of a pump failure or loss of power.

FIGURE 5-7. HTS Primary Cold Leg Check Valve.

5.2.2 HTS Primary Pumps

Each primary pump (Figure 5-8) is a vertical, single-stage, single-suction, controlled-inlet, free-surface centrifugal pump located in the primary hot leg piping. The suction nozzle is 28 in. diam. and the discharge nozzle is 16 in. diam.

The pump is driven by a 2400-volt a-c wound rotor induction motor and controlled by a liquid rheostat variable-speed control. An auxiliary 480-volt a-c pony motor on each primary pump provides low-flow decay heat removal capability at low power and standby conditions.

The pony motors are driven by the FFTF emergency generators if normal power fails (see Chapter 13).

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FIGURE 5-8. HTS Primary Pump with Guard Vessel.

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Typical primary coolant pump design features are:

- A design flow of 14,500 gal/min sodium at 500-ft head (180 psig) and 1050°F
- A variable speed ratio of 2.3 to 1, which provides flow control over a range of about 50% to 100% of design flow
- A stable head capacity curve between flows of 7,000 gal/min and 18,000 gal/min at design speed, with drawdown of five feet or less at design flow
- A seal system to prevent escape of radioactive argon from the primary system or inflow of lubricants or fluids into the pump
- Optimized coastdown characteristics to minimize thermal transients and provide adequate reactor core cooling following a scram
- Pony motor drive to provide about 7-1/2% of design flow at 4-ft head with automatic takeover from main motor to pony motor during coastdown to prevent any flow interruption
- The system is completely drainable

A lubrication circulation system is provided for each HTS pump to carry away the heat generated by frictional losses in the seals and bearings.

5.2.3 HTS Intermediate Heat Exchangers

The Intermediate Heat Exchanger (IHX) (Figure 5-9) is of vertical counterflow design transferring reactor heat from the primary loop to the secondary loop via primary flow outside the tubes and secondary flow inside the tubes.

Primary sodium enters the IHX below the top of the upper tube sheet and is directed circumferentially around the tube bundle down along the outside of the tubes. A small percentage of flow (about 1%) is continuously returned to the primary pump tank through a 2-in. orificed line to prevent gas collection in the upper regions of the primary (shell) side of the IHX. The primary sodium leaves the bundle area just above the bottom tube sheet and flows into the annulus between the shell and bottom plenum and out the nozzle in the shell hemisphere.

Secondary sodium enters at the top of the unit, flows down through the central downcomer into the lower hemispherical plenum, then upward through the inside of the tubes into the upper plenum area. The secondary flow then leaves the IHX through the horizontal outlet nozzle.

One IHX is located in each of the three Heat Transport System circuits downstream from the primary pump and ahead of the check valve.

To meet the system operating requirements, typical design features in the IHX are:

- Design pressure of 225 psig on the primary side and 250 psig on the secondary side
- Maximum pressure drop of 10 psi on the primary side and 15 psi on the secondary side at design flow rate
- Effective tube length geometric center of at least 15 ft above the reactor core geometric center to ensure adequate thermal driving head for natural convection cooling

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FIGURE 5-9. HTS Intermediate Heat Exchanger (IHX) and Guard Vessel.

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5.3 HTS SECONDARY LOOPS

The three secondary loops (Figure 5-10) circulate nonradioactive sodium coolant to transport heat from the tube side of the IHX to the air-cooled Dump Heat Exchangers (DHXs). No direct sodium interconnections exist among the loops.

Heated secondary sodium leaving the IHX flows to the air-cooled DHX through 16-in. diam piping via a containment penetration. Near the DHX, the piping branches and reduces to 8 in. diam and connects to an 8-in. diam hot leg DHX isolation valve. From this valve, the pipe connects to the inlet header of an individual DHX module (of which there are four to each secondary loop, 12 total for the Heat Transport System).

Cooled sodium from the outlet of each module flows through an 8-in. diam cold leg DHX isolation valve; the piping then expands from 8 in. to 16 in. and finally connects to the 28-in. diam suction line of the secondary pump. From the pump discharge, the sodium piping enters the HTS cell through a penetration in the reactor containment building and then connects to the IHX to complete the flow path.

Sodium flow rate is measured by a permanent magnetic flow meter located downstream from the pump discharge. The flow rate is adjustable by a variable-speed pump drive. A Venturi flow meter located upstream from the secondary pump is used for flow calibration of the secondary loop permanent magnetic flow meter.

FIGURE 5-10. HTS Secondary Loop Schematic.

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The 16-in. diam secondary hot leg piping and the section of 28-in. cold leg piping at the inlet to the secondary pump are of type 316H stainless steel. The 16-in. cold leg, as well as the 8-in. piping and components, are of type 304H stainless steel.

The secondary piping loops are designed for a pressure of 250 psig throughout. This design pressure allows the secondary loop to operate at a higher pressure in the IHX, so that if a leak occurs in the IHX tubing the leakage would be from nonradioactive sodium of the secondary loop into the primary loop.

An expansion tank having a surge volume filled with argon gas is provided in each secondary loop to accommodate sodium thermal expansion and to pressurize the system. Secondary loop sodium pressure at the intermediate heat exchangers is always maintained above the primary loop pressure.

5.3.1 HTS Secondary Pumps

Each secondary sodium coolant pump (Figure 5-11) is a vertical, single-stage, single-suction, controlled-inlet, free-surface centrifugal pump. Its design is similar to that of the primary pump, except that the secondary pump has a shorter, smaller shaft and a slightly smaller impeller. Similar main motors and pony motors are used. The secondary pump is located in the secondary cold leg piping between the DHX and the IHX.

The secondary sodium pump is designed for 14,500 gal/min sodium flow at 830°F and 400-ft head (144 psig). It is designed for a variable-speed ratio of 2.3 to 1, which provides flow control over a range of about 50% to 100% of design flow and accommodates a sodium level change of 3 ft caused by secondary loop sodium volume change.

The pony motor drive provides 10% of design flow at 3-ft head, with automatic takeover from main motor to pony motor during coastdown to give uninterrupted flow.

FIGURE 5-11. HTS Secondary Pump.

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5.3.2 HTS Dump Heat Exchangers

Dump Heat Exchangers (DHXs) are sodium-to-air exchangers that transfer heat from the secondary loop sodium to the ambient air (Figures 5-12 and 5-13). One DHX unit of four modules is located in each of the three secondary loops. Each DHX module is equipped with a fan with variable inlet vanes, fan drive motor, fine and coarse control dampers, isolation gates, manual and automatic controls, tube bundle, oil-fired preheater, ducting, stack, and airflow turning vanes.

The nominal thermal rating of a DHX module is 33 MW, with 90°F inlet air.

The DHX tube bundle is made up of a bank of 66 four-pass serpentine tubes located between horizontal upper and lower headers.

The four-pass serpentine tubes consist of 30-ft long finned sections joined by bare U-tube return bends. Suitable baffling at the sides and ends minimizes bypass of air. Turning vanes are provided to assure uniform air flow over the tube bundles.

The air supply system consists of a double width/double inlet centrifugal fan with air flow control provided by a variable-speed coupling (to vary fan speed) and by variable-inlet guide vanes. The fan is driven by a 1250-hp electric motor and provides air flow of 2.25×10^6 lb/hr with air side pressure drop of 11.0 in. of water.

Other design features incorporated into the DHX to meet the system operating requirements include:

FIGURE 5-12. HTS Dump Heat Exchanger Module.

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FIGURE 5-13. HTS DHX Air Flow Diagram.

- DHX tube bundle geometric center 30 ft above the IHX geometric center to ensure adequate thermal driving head for natural convection cooling, if required
- Sufficient air natural draft provided through the tube bundle to dissipate a minimum of 10% of design power
- Instrumentation provided to detect any sodium leakage

Each DHX bundle is preheated through a circulation system with air heated by an oil-fired burner. These heaters establish or maintain a temperature of 400°F during standby when sufficient decay or pump heat is not available.

The DHX isolation valves are angle-globe valves (see Figure 5-14) located at the inlet and outlet connections of each DHX module. Their primary function is to provide the capability for isolating a module in the event of a leak.

FIGURE 5-14. HTS DHX Isolation Valve.

5.3.3 HTS Secondary Loop Expansion Tanks

An expansion tank is provided in each secondary loop to meet the following heat transport system design and operational requirements:

- To accommodate sodium volume changes due to thermal expansion over the entire operating range
- To contain the argon cover gas for secondary loop pressurization

5.3.4 HTS Secondary System Component Location and Protection

Except for the secondary side of the IHX and adjacent piping, which is situated inside the reactor containment building, the secondary system components are located in accessible, unshielded areas outside containment. The expansion tanks, secondary pumps and associated equipment are located in reinforced concrete cells within the HTS service buildings; this provides weather, wind, tornado, and tornado missile protection for these components.

Secondary loop piping between the HTS service building and the DHX cruciform area (the cross-shaped area between the DHX modules) is located in pipeways that provide weather and fire protection for all loops. The cruciform area has a roof for weather protection of the DHX inlet and outlet valves and piping. A roof for weather protection is also provided over the DHX fans and drives.

Smoke detectors are provided throughout the secondary sodium areas to signal the presence of any sodium fire.

To the maximum extent feasible, all secondary sodium piping and components are installed in cells or pipeways that can be isolated (except in the DHX cruciform areas) so that fires would be self-extinguishing. Nitrogen lines are available to provide an inert atmosphere. These cells and pipeways contain segmented steel catch pans to contain any leaking sodium and prevent its spread.

Each DHX module is equipped with isolation gates and outlet dampers that can be closed in the event of a sodium leak to suppress and minimize the effects of a fire. After isolation, modules may be flooded with inert gas for fire control. Sodium-tight basins at the lower end of each module would receive and contain all sodium that might leak.

All DHX modules, including the stack, are designed for tornado wind loads. In addition, tornado-missile protection is provided for the secondary piping in HTS DHX-East. (See Chapter 11). In this DHX the portion of the DHX modules below the top of the control dampers is also protected from tornado missiles by the DHX enclosure.

5.4 HTS PIPING

Piping constitutes a major portion of the Heat Transport System. For the 16- and 28-inch sizes, all-welded 3/8-inch wall seamless austenitic types 304H and 316H stainless steel pipe are used.

Special pipe hangers support the piping. The clamp portion of the hanger is fitted with load-bearing insulation, which supports the pipe while insulating the pipe wall from the metal clamp.

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Insulation is provided for all HTS components and piping containing liquid sodium or sodium vapors, except where the application of insulation would interfere with proper equipment functioning.

All HTS components and piping are fitted with heaters to prevent sodium freezing during shutdown conditions. (Pure sodium freezes at about 208°F.) Except for the DHX tubes, which are heated by an oil-burning heater, tubular, Incoloy-sheathed electrical heater elements are used for HTS piping (Figure 5-15).

The electrical heaters are supported around the components by a prefabricated stainless steel standoff assembly, which is covered by stainless steel sheeting. This sheeting forms a one-inch annulus between the component outer surface and the insulation inner surface. An outer wrapper of stainless steel is applied over the insulation and banded in place.

5.5 HTS SYSTEM OPERATION AND CONTROL

5.5.1 HTS Normal Operation

Each Heat Transport System circuit is designed on a unit basis, which permits it to operate independently of the other two circuits. Virtually complete isolation has been provided among the three circuits. A fault in one circuit will not jeopardize the operational capability of the remaining two.

During three-circuit operation, each circuit dissipates one-third of the heat generated in the reactor, with equal flows in each primary loop. Because of density and specific heat differences caused by lower secondary temperatures, the secondary loop flow is slightly lower than that of the primary loop.

FIGURE 5-15. Typical HTS Piping Trace Heating and Insulation.

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5.5.2 HTS Two-Circuit Operation

Two-circuit operation may be used to allow limited plant operation if repairs or corrective actions for a fault in the HTS cannot be performed for an extended period of time.

The HTS is designed for two-circuit operation at nominally two-thirds of reactor power. HTS Circuit 1, which includes HTS DHX-East, is completely hardened against tornado damage as well as earthquake damage, and must always be one of the two operating circuits. The transition from three-loop to two-loop operation can be made only when the reactor is shut down.

5.5.3 HTS Natural Circulation Cooling

Should all electrical power be lost, the reactor will be shut down; and the decay heat will be removed by natural circulation of sodium in the three cooling circuits. The hydraulic profile of each of these circuits is designed to maintain natural circulation, and special vernier dampers in the DHXs provide control of natural draft air flow during such heat removal.

A sodium inventory of 3600 ft^3 (26,392 gal) is held in the reactor vessel above the vessel outlet nozzles to assure that an adequate reserve of sodium is maintained for cooling the reactor.

5.5.4 HTS System Control

The HTS is controlled automatically by System 90. In addition, the automatic Plant

Protection System (PPS) trips to shut down the reactor safely if abnormal conditions occur (see Chapter 6).

5.6 REACTOR HEAT TRANSPORT SYSTEM DESIGN PARAMETERS

Typical design parameters for the Heat Transport System are presented in Table 5-1.

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TABLE 5-1
REACTOR HEAT TRANSPORT SYSTEM
DESIGN PARAMETERS

GENERAL PARAMETERS

Loops - Number	3
Primary Flow per Loop (Design)	14,500 gal/min
Capacity per Loop	133 MW

MAIN COOLANT PUMPS

Primary Pumps - Number	3
- Structural Design Temp	1050°F
Secondary Pumps - Number	3
- Structural Design Temp	830°F
Sodium Flow Rate - All Pumps (Design)	14,500 gal/min each
Speed - All Pumps	1100 r/min
Speed Control Range - All Pumps	2.3/1
Pony Motor Flow Capability	
- Primary at 4-ft Head	7.5%
- Secondary at 3-ft Head	10%

INTERMEDIATE HEAT EXCHANGERS

Number	3
Structural Design Temp	1050°F
Capacity - Each	133 MW
Coolant Tubes - Each (0.875 in. OD)	1540
Material	304 SS

DUMP HEAT EXCHANGER MODULES

Number	12
Capacity - Each	33 MW
Sodium Flow - Each (Design)	3625 gal/min
Tube Side - Structural Design Temp	1000°F
Fan - Rated Power	1250 hp
Air Flow (Design)	2.25 x 10 ⁶ lb/hr

PRIMARY PIPING

Hot Leg - Reactor to Pump - OD	28 in.
- Pump to IHX - OD	16 in.
- Structural Design Temp	1050°F
- Material	316H SS
Cold Leg - IHX to Reactor - OD	16 in.
- Structural Design Temp	830°F
- Material	304H SS

SECONDARY PIPING

Main Piping - OD	16 in.
DHX Branch Piping - OD	8 in.
IHX to DHX - Structural Design Temp	1000°F
DHX to IHX - Structural Design Temp	830°F
Material - Hot Leg	316H SS
- Cold Leg	304H SS

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CHAPTER 6.

REACTOR AND HEAT TRANSPORT INSTRUMENTATION AND CONTROL (SYSTEMS 15, 90, 91, 91, 93-2, 93-14, 93-15, 95 AND 99)

	Page
6.1 SUMMARY DESCRIPTION	6-3
6.2 REACTOR PLANT CONTROL (SYSTEM 90)	6-4
6.2.1 Neutron Flux Control	6-4
6.2.2 Sodium Flow Control	6-6
6.2.3 Dump Heat Exchanger Control	6-6
6.2.4 Decay Heat Removal Control	6-8
6.2.5 Reactor Control Room	6-8
6.3 PLANT PROTECTION (SYSTEM 99)	6-9
6.3.1 Purpose of PPS	6-9
6.3.2 Scope of PPS	6-9
6.3.3 PPS Equipment Characteristics	6-10
6.3.4 PPS Power Supply	6-10
6.3.5 Reactor Shutdown Systems	6-10
RSS Description	6-10
RSS Functions	6-12
Manual Scram	6-13
6.3.6 Engineered Safety Features	6-13
6.3.7 Containment Isolation System	6-14
6.4 NEUTRON FLUX MONITORING (SYSTEM 95)	6-14
6.4.1 In-Vessel Flux Monitoring System	6-16
6.4.2 Ex-Vessel Flux Monitoring System	6-17
Primary Flux Monitoring System	6-17
Secondary Flux Monitoring System	6-18
6.5 REACTOR AND VESSEL INSTRUMENTATION (SYSTEM 92)	6-18
6.5.1 Driver Fuel Instrumentation	6-19
6.5.2 Control Rod and Potential Fixed Shim Absorber Assembly Instrumentation	6-20
6.5.3 Open Test Assembly Instrumentation	6-22
6.5.4 Closed Loop Process Instrumentation	6-22
6.5.5 Reflector Instrumentation	6-22
6.5.6 Coolant Level Instrumentation	6-22
6.5.7 Reactor Coolant Outlet Temperature Instrumentation	6-23
6.5.8 Reactor Head Temperature Instrumentation	6-23
6.5.9 Reactor Vessel Temperature Instrumentation	6-23

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CHAPTER 6. (Cont'd)

REACTOR AND HEAT TRANSPORT INSTRUMENTATION AND CONTROL (SYSTEMS 15, 90, 91, 92, 93-2, 93-14, 93-15, 95 AND 99)

	Page
6.6 REACTOR HEAT TRANSPORT INSTRUMENTATION (SYSTEM 93-2)	6-23
6.6.1 Measurement of Process Variables	6-24
Process Temperature Measurements	6-24
Process Flow Measurements	6-25
Process Pressure Measurements	6-26
Sodium Level Measurements	6-26
Rotational Speed Measurements	6-26
Position Measurements	6-26
6.6.2 Monitoring and Interlocking Instrumentation	6-27
6.7 DIGITAL DATA HANDLING AND DISPLAY (SYSTEM 91)	6-27
6.7.1 Plant Data System	6-28
6.7.2 Experimenter's Data System	6-28
6.8 ANNUNCIATION AND COMMUNICATIONS	6-28
6.8.1 Plant Annunciator (System 93-14)	6-28
6.8.2 Communications (System 15)	6-29
6.9 PIPING AND EQUIPMENT ELECTRICAL HEATING CONTROL (SYSTEM 93-15)	6-29

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CHAPTER 6.

REACTOR AND HEAT TRANSPORT INSTRUMENTATION AND CONTROL (SYSTEMS 15, 90, 91, 92, 93-2, 93-14, 93-15, 95 AND 99)

6.1 SUMMARY DESCRIPTION

System 90, the Reactor Plant Control System, provides equipment for stable, reliable manual and automatic control of the Reactor System and the Heat Transport System during normal operation. Figure 6-1 shows a typical view in the FFTF Control Room.

The Plant Protection System (System 99) automatically shuts down (scrams) the reactor when required, by releasing (tripping) the nine control rods. The Plant Protection System also closes lines and ducts leading to and from containment if radiation level limits are exceeded.

Systems 90 and 99 function separately to assure safe and reliable operation of the FFTF at all times.

Systems 95, 92 and 93-2 provide signals (flux, flow and temperature) to Systems 90 and 99 as well as to System 91. System 91 provides computerized recording and retrieval of plant operating data and experimenter's test data.

System 93-14 provides annunciation and identification of off-normal conditions. System 93-15 controls the electrical heating of sodium piping and equipment. System 15 provides onsite and offsite telephone communications.

FIGURE 6-1. Typical View of FFTF Control Room.

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6.2 REACTOR PLANT CONTROL (SYSTEM 90)

The Reactor Plant Control System (System 90) provides controls for routine normal operation, including removal of decay heat during reactor shutdown. It provides a neutron flux control system and control systems for coolant flow and DHX bulk sodium outlet temperature for each of the three Heat Transport System cooling circuits. (Table 6.1 and Figure 6-2.)

6.2.1 Neutron Flux Control

The neutron flux control system (Figure 6-3) operates the three primary control rods and the six secondary control rods. In normal operation, the three primary rods are fully withdrawn, while the secondary rods are used for control. The three primary rods and the six secondary rods have separate control equipment.

The flux controller provides stable automatic control of reactor power by operating the secondary control rods using flux as the feedback signal. The power setpoint is adjusted by the operator to set the desired reactor power. The feedback signal is the auctioneered high of the three secondary power range nuclear signals (see Section 6.4). This controller also provides secondary rod withdrawal stops based on high flux and high flux/flow ratio, causing all secondary rods to be blocked for withdrawal if the allowable flux or flux/flow ratio is exceeded.

The control rod selection logic assures that only one control rod in the primary system or one in the secondary system can be manually withdrawn at one time, and that the automatic control can operate only one secondary rod at a time. Rod position is measured and indicated by two completely independent methods, a relative rod position indicator and an absolute rod position indicator.

TABLE 6-1

SYSTEM 90 CONTROL FUNCTIONS			
Function	Controlled Variable	Sensor	Actuator
Flux Control	Neutron Flux	Compensated Ion Chamber	Control Rod
Primary Flow Control	Primary Loop Sodium Flow	Magnetic Flow Meter	Liquid Rheostat of Primary Pump Motor
Secondary Flow Control	Secondary Loop Sodium Flow	Magnetic Flow Meter	Liquid Rheostat of Secondary Pump Motor
Secondary Cold Leg Temperature Control	DHX Bulk Sodium Outlet Temperature	Thermocouple	Air Flow (Fan Speed and/or Damper Position)

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882
2/2/12

FIGURE 6-2. Reactor Plant Control System.

FIGURE 6-3. FFTF Neutron Flux Control System.

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The major elements of the system are the flux controller, the control rod selection logic, the rod position indicators, the motor-generator (MG) set and the control rod drive mechanism (CRDM) controllers, and the power supplies.

Separate motor generator (MG) sets, circuit breakers, and 3- to 6-phase transformers are provided for the primary control rod system and for the secondary control rod system. The MG sets provide 3-phase power for input to the 3- to 6-phase transformers, which in turn provide the power sources for the CRDM controllers (Figure 6-4). These controllers supply pulsed dc to energize the CRDM stator coils. (The CRDM motor is a 6-coil, 6-phase "stepping" type that requires dc to energize the coils.)

6.2.2 Sodium Flow Control

The sodium flow control system includes all equipment necessary to provide stable control of sodium flow in each HTS loop during all modes of operation by varying the pump speed by the use of liquid rheostats.

The system includes six control subloops, one for each pump (Figure 6-5) and a flow setpoint generator. Feedback signals are derived from the loop flow instrumentation.

The flow controller output drives the liquid rheostat position control system. The liquid rheostat provides the capability to vary the rotor resistance of the wound rotor motor, thereby changing motor speed. A speed range of approximately 2.3 to 1 is available.

6.2.3 Dump Heat Exchanger Control

The DHX control system consists of equipment to provide stable control of air flow, thereby maintaining the DHX sodium outlet temperature within limits. Included are interlocks and equipment required to rapidly reduce air flow after reactor scram.

Each of the 12 DHX modules has a control subloop (Figure 6-6) to operate the variable speed control of the fan and the controllable outlet dampers (coarse control damper with six blades and fine control damper with two blades).

FIGURE 6-4. Block Diagram of CRDM Controller and Power Train.

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802
2/2/12

FIGURE 6-5. FFTF Sodium Flow Control System Subloop.

FIGURE 6-6. FFTF DHX Control System Subloop.

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6.2.4 Decay Heat Removal Control

The reactor plant control system provides an integrated design to monitor, control and coordinate the decay heat removal process for plant shutdown operations. Following a scram or shutdown to refueling temperature, the decay heat of the reactor and stored heat in the HTS are dissipated by the primary and secondary loops at pony motor (see Chapter 5) flow conditions; the DHX modules (Figure 6-7) are cooled by natural air circulation.

The reactor plant control system also provides the monitoring control and coordination functions necessary to assure decay heat removal under completely natural circulation conditions, if all electrical power (offsite power and onsite emergency power) were lost (see Chapter 13). Special instrumentation, separate from the normal control system, is operated from a Class 1E battery power source. Manual control of the fine damper is provided from the control room for each of the 12 modules; the DHX outlet temperature for each module is displayed adjacent to the manual controller.

6.2.5 Reactor Control Room

The control room is the central complex where all important reactor, heat transport, closed loop and other supporting system parameter readouts (flux, rod position, flows, temperatures, pressures, etc.) and controls are brought together for plant operation. Equipment for monitoring these parameters is arranged for operational efficiency in coordinating and controlling the plant during shutdown, startup, power emergency and accident conditions, including isolation of containment (see System 99).

FIGURE 6-7. DHX Module.

The control room is 35 ft by 78 ft at ground floor elevation in the control building. It is divided into two areas based on activity. In the manned area, equipment is designed and arranged to give the operators direct view of instrumentation and ease of control manipulation (Figure 6-8). The second area of equipment racks provides easy access to the equipment, although not a direct operator view.

Annunciators (provided by System 93-14) provide visible/audible alarms of off-normal conditions. Telephones and public address systems (System 15) provide communications.

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2/2/12

FIGURE 6-8. General Arrangement of Manned Portion of Control Room.

The control room, its equipment and furnishings are designed so that the likelihood is extremely remote that fire or other conditions could render the control room inaccessible. However, emergency controls for reactor and HTS prime mover shutdown, containment isolation and decay heat removal are provided at remote locations, such as the Emergency Shutdown Station in the Primary CRDM Cabinet Room. These provisions assure that the reactor can be shut down and maintained in a safe condition even if access to the control room is lost.

6.3 PLANT PROTECTION (SYSTEM 99)

6.3.1 Purpose of PPS

The purpose of the Plant Protection System (PPS, System 99) is to take automatically

the necessary actions required to protect the public and the plant when abnormal operating conditions occur. The PPS acts regardless of any action, or lack of action, taken by the Reactor Plant Control System (System 90).

6.3.2 Scope of PPS

The PPS consists primarily of two Reactor Shutdown Systems, engineered safety features, and a Containment Isolation System. Functionally, the PPS includes all instrumentation channels, power supplies, logic device elements and actuators associated with these systems and subsystems, even though much of this equipment is supplied by other systems in conformance with specifications defined by the PPS.

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82
2/2/12

6.3.3 PPS Equipment Characteristics

All equipment that is part of the PPS, whether supplied by System 99 or another system, is designed and installed to meet stringent requirements for reliability, redundancy, separation (electrical and physical), and protection from the effects of earthquakes and tornados.

All inter-rack PPS wiring is in rigid steel conduits with wiring for redundant channels run in separate conduits. Wiring for redundant channels is brought through separate penetrations, with only PPS wiring brought through these penetrations. Instrumentation equipment associated with redundant channels is mounted in separate racks (or in metal compartments). Only PPS channel instrumentation is mounted in these racks.

The PPS is separated mechanically and electrically from the control system (System 90), with the exception of some instrumentation sharing through buffer amplifiers for the secondary power range flux monitors and the HTS primary and secondary flow meters. These buffers provide isolation so that equipment failures on the control side of the buffer are not reflected back to the PPS side and thus do not cause degradation of PPS performance. PPS equipment has its own enclosures mechanically separated from the control system modules. The PPS has also been designed to operate at temperatures greater than will result from failure of the Heating and Ventilation System.

6.3.4 PPS Power Supply

The PPS has been designed to operate or fail to a safe condition during the loss of electrical power. The main a-c power is backed by three onsite electrical generators and two battery-supported Zero Time Outage (ZTO) buses (see Chapter 13). Two channels of the PPS are operated from separate ZTO buses, and the third channel is operated from a regulated instrument bus. Following loss of offsite electrical power, the PPS shuts the plant down safely.

6.3.5 Reactor Shutdown Systems

RSS Description — The two independent Reactor Shutdown Systems (RSS) consist of the Primary Reactor Shutdown System and the Secondary Reactor Shutdown System (Figure 6-9). The Primary RSS causes the three primary control rods in Row 3 to drop into the reactor, and the Secondary RSS causes the six secondary control rods in Row 5 to drop into the reactor. These control rods (System 31) will terminate the results of anticipated transients even if the most reactive rod is not inserted. Also, each RSS will shut down the HTS prime movers (primary and secondary pumps and DHX fans).

If either RSS loses power or if inter-connecting wiring is disconnected or shorted so that the voltage drops to zero, a trip condition will result.

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FIGURE 6-9. Reactor Primary and Secondary Shutdown Systems.

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To assure that the two shutdown systems are independent, the two systems are mechanically and electrically isolated from one another; separate wiring, conduits, penetrations and racks are used. Each shutdown system is designed as if it were the only one providing protection. Each shutdown system has been designed to include sufficient redundancy to assure that single internal random failures will not cause degradation of protection.

Each shutdown system includes:

- Three instrument channels for each shutdown system parameter. Any two of the three in the tripped state will cause a reactor scram and HTS prime mover trip.
- Two logic trains, either of which in the tripped state will cause a reactor scram and a prime mover trip. The primary Reactor Shutdown System uses solid-state, bi-polar, monolithic integrated circuits as the basic logic switching scheme for each of the two trains. The secondary Reactor Shutdown System uses solid-state, discrete components as the basic logic switching elements in a hybrid general/local coincidence logic scheme for each of the two logic trains.
- Two circuit breakers in series which trip and thereby interrupt power to the control rod drive mechanisms. Opening either breaker drops the rods and initiates an HTS prime mover trip.

- Two sets of HTS prime mover trip initiation circuitry. Either set is capable of tripping all the HTS prime movers.
- Testing, monitoring and annunciation circuits.

RSS Functions -- The RSS shuts down (scrams) the reactor, along with the primary and secondary pumps and DHX fan motors, and issues a signal to reduce closed loop coolant flow and DHX airflow, when any of the following abnormal plant operating conditions (Table 6-2) occur:

- Nuclear power excursion (up or down)
- Insufficient heat removal in either the reactor plant system or a CLS
- Significant imbalance between the heat removal capabilities of the primary and secondary of any HTS loop
- Loss of offsite electrical power
- Manual scram of reactor

Signals from the experimenter's instrumentation can initiate shutdown, if required.

The two systems are actuated by different plant variables except for experiment-associated trip functions and manual scram.

TABLE 6-2

TRIP INPUTS FOR REACTOR SHUTDOWN SYSTEMS	
PRIMARY SHUTDOWN SYSTEM	SECONDARY SHUTDOWN SYSTEM
Primary Power Range Nuclear High Flux	Secondary Flux/Total Flow
Primary Power Range Nuclear Low Setting	Secondary Flux-Increasing Delayed Flux
High Startup Flux	Secondary Flux-Decreasing Delayed Flux
Primary Flux-Decreasing Delayed Flux	Low Primary Loop Flow
Primary Flux ² /Loop Pressure	High Primary Loop Flow
IHX Primary Outlet Temperature	Low Secondary Flow
Reactor Vessel Coolant Level	Loss of Offsite Power
Flux/Primary Closed Loop Flow	Reactor Outlet Plenum Temperature
Closed Loop IHX Primary Outlet Temperature	Closed Loop Outlet Temperature
Experiment-Associated Trip Functions	Experiment-Associated Trip Functions
Primary Flux-Increasing Delayed Flux	Flux/Closed Loop Flow
Pressure Permissive	High Closed Loop Flow
Manual Scram	Power Permissive
	Manual Scram

Manual Scram — A manual scram is initiated from the operator's control room console by a remote manual scram switch, which breaks the connection between the scram breakers and the logic trains of the protective logic. The remote manual scram switch has four separate contacts, each of which simultaneously operates relays to disconnect the logic trains from the corresponding scram breakers in both the primary and secondary RSS. Local manual scram switches are also located in the primary and secondary control rod cabinet rooms. Contacts of the switch located in the primary control rod cabinet room connect in series with the contacts of the remote manual scram switch and trip the primary rods. The switch in the secondary control rod cabinet room trips the secondary rods.

6.3.6 Engineered Safety Features

Engineered safety features are provided by the PPS for use in case all offsite electrical power is lost and no power is available from the onsite electric generators. The PPS provides instrumentation and controls to assure operation of System 25 facilities for emergency cooling of the IDS (see Chapter 14). For natural convection reactor decay heat removal, the PPS includes the manually-operated remote controls in System 90 for the DHX fine dampers.

The PPS also provides monitors for reactor outlet plenum sodium temperature, DHX outlet sodium temperature, IDS sodium temperature, and containment pressure, temperature and exhaust radiation.

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88A
2/2/12

6.3.7 Containment Isolation System

FFTF containment is necessarily penetrated by heating and ventilating ducts and process piping. The Containment Isolation System (CIS) automatically closes the isolation valves on those penetrations if radiation levels above limits are detected (by System 96) in the containment vessel exhaust duct or head compartment exhaust. Closure of heating and ventilating ducts takes place at lower radiation levels than closure of isolation valves on process piping.

Table 6-3 lists the locations of the automatically-actuated Containment Isolation System valves.

The CIS also provides closure of gas lines (for air, nitrogen and argon) entering the containment vessel when gas line pressure falls to a level near the containment design pressure. This closure, which prevents flow of cell gas outside of containment, is accomplished by local automatic valves and is independent of the automatic systems actuated by the radiation monitors.

6.4 NEUTRON FLUX MONITORING (SYSTEM 95)

The Neutron Flux Monitoring System for the FFTF reactor measures neutron flux, which is proportional to reactor power. The system provides signals used by FFTF personnel to safely operate the reactor. The signals are also supplied to System 90 for automatic control of reactor flux and associated power load, to System 93-3 for Closed Loop System control, and to System 99 for automatic shutdown (scram) of the reactor, if needed.

TABLE 6-3

LOCATIONS OF AUTOMATICALLY ACTUATED CONTAINMENT ISOLATION SYSTEM VALVES*	
SYSTEM	IDENTIFICATION
25	Central H&V Exhaust Duct
25	Central H&V Supply Duct
85	HTS Primary Sodium Sample Lines (2)
85	Closed Loop No. 1 Primary Sodium Sample Lines (2)
85	Closed Loop No. 2 Primary Sodium Sample Lines (2)
25	Atmospheric Pressure Reference Line
85	Closed Loop No. 3 Primary Sodium Sample Lines**
85	Closed Loop No. 4 Primary Sodium Sample Lines**
82	CAPS Collection Header
82	CAPS Header Extension into HTS Service Building South
82	RAPS Collection Header
85	HTS Argon Cover Gas Sample Line (Out)
85	HTS Argon Cover Gas Sample Line (In)
85	Closed Loop No. 1 Argon Sample Lines (2)
85	Closed Loop No. 2 Argon Sample Lines (2)
85	Closed Loop No. 3 Argon Sample Lines**
85	Closed Loop No. 4 Argon Sample Lines**
82	Low Pressure Nitrogen Distribution Header

* The two Mobiltherm*** Isolation Valves and eight in-containment chilled water isolation valves in System 23 fail automatically "as-is" on loss of power; no signal from the Containment Isolation System is required.

** Planned for the future.

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The Neutron Flux Monitoring System accurately and reliably measures the neutron flux over a wide range from shutdown to above full power operation. To perform this function, this system comprises both an in-vessel flux monitoring system and an ex-vessel flux monitoring system, which consists of primary and secondary systems. The design ranges of these flux monitoring systems overlap to assure safe coverage of all reactor conditions, as shown in Figure 6-10.

The Flux Monitoring System also provides for insertion and withdrawal of passive and/or active dosimeters (self-powered detectors, and activation wires and foils) used to determine neutron flux, fluence and spectrum in-core for mapping both radial and axial coordinates. Readout of activation packets such as wires and foils is accomplished in a counting room provided by System 21.

The in-vessel flux monitoring system described in this section is also known as the "Low Level Flux Monitoring System" (LLFM).

FIGURE 6-10. Neutron Flux Monitoring System Design Ranges.

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6.4.1 In-Vessel Flux Monitoring System

The in-vessel flux monitoring system (Figure 6-11) consists of three redundant channels to monitor the neutron flux level of the reactor core in the source range from approximately 25 milliwatts to 250 watts. (Reactor power at criticality is approximately 5 watts.) The measurements are performed at the reactor midplane by three retractable ^{235}U fission counters located in cooled thimbles 120 degrees apart and spaced around the periphery of the removable reactor shield subassemblies at a radius of 44.5 in. from the center of the core. This measurement is the equivalent thermal neutron flux. The cooled thimbles and retraction mechanisms for the in-vessel system are supplied by System 31 (see Chapter 3).

The system continuously displays neutron flux in the source range in the form of counts per second on a six-decade logarithmic scale

from 1 to 10^6 counts per second. The system also computes flux change rate and displays this on a linear scale from -1 to +3 decades per minute.

The system provides outputs for display, recording and annunciation, and to the computer, but does not routinely provide outputs to the Plant Control System or to the Plant Protection System.

To indicate flux level during refueling operations, an audible count rate system and a linear count rate indication system are provided. A front panel switch allows the operator to select the channel to be monitored at a particular time.

When the reactor is at full power, the flux at the midplane location is too high for the fission counters; hence, they are retracted approximately 5 ft up into the shield.

FIGURE 6-11. In-Vessel Nuclear Channel Block Diagram.

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18A
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6.4.2 Ex-Vessel Flux Monitoring System

The Ex-Vessel Flux Monitoring System consists of a primary "wide-range" flux monitoring system and a secondary flux monitoring system. Each of these systems consists of three redundant channels. The sensors are installed in thimbles in graphite thermal blocks in the reactor cavity, spaced evenly around the reactor approximately midway between the stored fuel locations (Figure 6-12). The primary system employs three ^{235}U fission detectors, and the secondary system employs three boron-lined compensated ion chambers (CIC). These systems are designed to monitor the flux level of the reactor core from approximately 4 watts (10 watts with stored fuel in reactor) to 500 MW.

This range overlaps the in-vessel source range by better than one decade.

Primary Flux Monitoring System -- Each primary flux monitoring channel consists of one ^{235}U detector providing outputs to three parallel ranges: a log count rate range, a logarithmic mean square voltage (MSV) power range and a linear d-c current primary power range. The logarithmic count rate portion of each channel covers the range from about 4 watts (10 watts with stored fuel in reactor) to approximately 4 MW. The logarithmic MSV portion of the channel covers the range from about 4 kW to 500 MW. The linear d-c current portion of the channel covers the range from about 4 MW to 500 MW.

FIGURE 6-12. Ex-Vessel Flux Monitoring System Thimble Locations.

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Each channel (count rate, MSV and linear d-c current) of the system provides outputs (Figure 6-13) for the primary Reactor Shutdown System and for annunciation, recording, display and the computer.

Secondary Flux Monitoring System — Each secondary flux monitoring channel consists of a ^{10}B gamma-compensated ion chamber providing detector current outputs which are proportional to the flux level. The secondary channels cover the range from about 4 MW to 500 MW and supply output to the Plant Control System and the Secondary Reactor Shutdown System, as well as for annunciation, recording, display and the computer (see Figure 6-14).

6.5 REACTOR AND VESSEL INSTRUMENTATION (SYSTEM 92)

The Reactor and Vessel Instrumentation System provides the sensors, signal conditioners and amplifiers for all required reactor and vessel parameters except for flux monitoring and fuel failure. This system provides inputs to the Plant Protection System (99), the Digital Data Handling and Display System (91), and the Reactor Plant Control System (90). No control loops are provided by this system.

FIGURE 6-13. Ex-Vessel Primary "Wide Range" Flux Monitoring System Block Diagram.

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100
2/2/12

FIGURE 6-14. Ex-Vessel Secondary Flux Monitoring System Block Diagram.

Instrumentation supplied by System 92 is as follows:

- Coolant outlet temperature and flow for driver fuel assemblies and selected reflector assemblies
- Control rod coolant outlet temperature
- Open test outlet temperature
- Closed loop outlet temperature (for input to Plant Protection System, System 99)
- Open test flow (and capability for experimenter's instrumentation)
- Coolant level (provides input to Plant Protection System, System 99)
- Reactor outlet plenum sodium temperature (provides input to Plant Protection System, System 99)
- Temperatures for selected reflectors, vessel wall and reactor head

System 99 will scram the reactor if any pre-set value of closed loop outlet temperature, coolant level, or reactor outlet plenum sodium temperature is exceeded.

6.5.1 Driver Fuel Instrumentation

Flow and temperature instrumentation provides data monitoring and recording capability for each driver fuel position in the FFTF and hence provides accurate data (not available in other reactors) on the actual operating conditions for each assembly. This instrumentation makes it possible to use driver fuel positions as test positions for a wide variety of fuels and materials tests (subject to conformance of the test assemblies to operational and safety requirements).

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Each driver fuel position is instrumented with three thermocouples and an eddy current sodium flow meter. The thermocouples and the flow meter, along with their mechanical support, shield, signal leads and connector, constitute a Flow-Temperature Removable Instrument Assembly (FTRIA).

Figures 6-15, 6-16 and 6-17 show the basic configuration of the driver fuel instrumentation. The FTRIA is inserted into an instrument tree guide tube (System 3I); the sensor leads terminate at a FTRIA connector at the top of the instrument tree column. During reactor operation, the instrument tree instrument tube positions the sensor directly above the driver fuel assembly to measure the assembly coolant temperature and flow. The flow guide tube directs the sodium output from the driver fuel assembly to the instrument tube.

6.5.2 Control Rod and Potential Fixed Shim Absorber Assembly Instrumentation

Each control rod position, potential movable control rod position and potential fixed shim absorber position is instrumented with one or two thermocouples (see Table 6-4) to measure coolant outlet temperature. This information is needed to assure that the neutron absorber assemblies are being properly cooled.

The thermocouples are mounted in a Temperature Removable Instrument Assembly (TRIA). The TRIA employs a 1/16-inch wire-wrapped, chromel-alumel, ungrounded thermocouple.

Each TRIA is inserted in an instrument tree instrument guide tube that positions the thermocouple.

TABLE 6-4

ABSORBER POSITION TEMPERATURE INSTRUMENTATION			
Function	No. of Channels	Core Location	No. of Thermocouples per Channel
Primary Control Rod	3	Row 3	2
Secondary Control Rod	6	Row 5	2
Potential Movable Control Rod or Fixed Shim Absorber	9	Row 7	2
Potential Fixed Shim Absorber	6	Row 7	1

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88A
2/2/12

FIGURE 6-15. Removable Assemblies for Measurement of Outlet Temperature and Flow of Core Components.

FIGURE 6-16. Basic Configuration of Driver Fuel Instrumentation (FTRIA).

FIGURE 6-17. Simplified Diagram of Eddy Current Flow Meter.

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98A
2/2/12

6.5.3 Open Test Assembly Instrumentation

Open Test Assemblies are instrumented by FTRIAs similar to those used for driver fuel. Three thermocouples and one eddy current sodium flow meter are installed in the Open Test Assembly (OTA) instrument tube to measure coolant outlet temperature and flow and to provide required data on test conditions.

In addition to the three thermocouples and the flowmeter, the OTA provides capabilities for extensive contact instrumentation by experimenters (see Chapter 3). Each OTA provides space for the exit of the experimenter's leads to the center island on the reactor head.

6.5.4 Closed Loop Process Instrumentation

Process instrumentation sensors for each Closed Loop In-Reactor Assembly (CLIRA) include three thermocouples to measure the closed loop outlet temperature. These three channels of closed loop outlet temperature measurement are required by the Plant Protection System (PPS). If the closed loop outlet temperature exceeds pre-set limits, the PPS automatically scrams the reactor. PPS separation requirements apply to the three sets of thermocouple leads. Buffered signals from the three coolant outlet thermocouples are made available to the experimenter and to the Closed Loop System process control instrumentation.

6.5.5 Reflector Instrumentation

Twelve reflector Row 7 positions are instrumented with three thermocouples and an

eddy current sodium flow meter installed in an instrument tree guide tube located directly above the position to measure assembly coolant outlet temperature and flow. Signals are transmitted to the Digital Data Handling and Display System (DDH&DS) for the information of the reactor operators.

Twelve Row 8 reflector positions are instrumented with one thermocouple each. The temperature measured by the thermocouple is read by a portable device at a jack panel in the head compartment wall terminal box, when required.

6.5.6 Coolant Level Instrumentation

Reactor coolant level must be maintained at a pre-set level to assure adequate cooling of the core in case of emergencies. If coolant level falls below the set-point, the reactor is scrammed by the Plant Protection System.

Measurements of coolant level in the reactor vessel are performed by induction coil level sensors. The sensor and support equipment, consisting of leads, shield, support structure and seal, comprise a Level Removable Instrument Assembly (LRIA). Five LRIAs are provided: three for PPS, one for operating and one for a minimum safe level.

Each LRIA is contained in a separate dry thimble. The LRIA thimbles are in three temperature/liquid level monitors (T/LLM) evenly spaced about the reactor, near the liner, at 120-degree intervals (see Chapter 4).

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For PPS signals, three LRIA inductive probes, one contained in each T/LLM, monitor sodium level in the reactor vessel. The instrument channel range is from 6 in. above to 14 in. below the normal operating level.

One T/LLM contains an LRIA inductive probe that measures sodium level in the reactor vessel from 6 in. above to 4 ft 6 in. below the normal operating level. Another measures sodium level from 6 in. above to 12 ft 6 in. below the normal operating level.

6.5.7 Reactor Coolant Outlet Temperature Instrumentation

The reactor coolant outlet temperature is measured in the vessel outlet plenum to supply signals to the Plant Protection System (PPS).

The coolant temperature in the outlet plenum is measured for the Plant Protection System by three thermocouples in the Proximity Test Plug (PTP) in the reactor vessel head. (See Chapter 4.) Separate dry thimbles are located near the core radial center line below the suppressor plate. These ungrounded chromel/alumel thermocouples are placed in separate dry thimbles. Signals provided to the Plant Protection System are used by this system to scram the reactor if the temperature exceeds pre-set limits.

The coolant temperature is also measured for the Plant Protection System by thermocouples at T/LLM locations in the reactor vessel head. These thermocouples are located near coolant outlet nozzles and, therefore, measure the mixed mean outlet plenum

temperature. Each thermocouple is in a separate dry thimble with a connector on top. These sensors are used to measure decay heat removal and are part of the engineered safety features.

6.5.8 Reactor Head Temperature Instrumentation

Ninety thermocouples in 45 locations are provided for the Reactor Enclosure System (System 32) for the head heating and cooling system. One thermocouple in each of 45 locations is used by the head heating and cooling system to control head temperature. The remaining 45 thermocouples are installed spares. Also, four thermocouples in the Proximity Test Plug (PTP) provide an axial temperature distribution of the reactor head.

6.5.9 Reactor Vessel Temperature Instrumentation

Thermocouples are provided for measuring reactor vessel nozzle temperatures of the three outlet nozzles and the sodium makeup and overflow nozzles. These thermocouple leads are routed to head compartment wall terminal boxes; the thermocouples are replaceable. A number of nonreplaceable thermocouples are provided for measuring reactor vessel wall OD temperature.

6.6 REACTOR HEAT TRANSPORT INSTRUMENTATION (SYSTEM 93-2)

System 93-2, the Reactor Heat Transport Instrumentation System, provides instrumentation required for measuring heat transport

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2/2/12

system process variables; equipment for monitoring performance of critical equipment; and interlocks and controls required for operating pumps, valves and similar equipment. This instrumentation also satisfies surveillance needs and in-service inspection requirements.

All major parameters of the Heat Transport System are indicated, alarmed and controlled from the control room.

5.6.1 Measurement of Process Variables

The process variables of sodium temperature, flow, pressure and level are measured, as well as pump speed and position of DHX dampers. Applicable signals are provided to the following systems:

- Reactor Plant Control System (System 90) for plant control functions
- Plant Protection System (System 99) to initiate appropriate protective action
- Digital Data Handling and Display System (System 91) for recording and display. (A voltage signal is provided from each analog channel for input to the computer multiplexer.)

Process Temperature Measurements — Resistance Temperature Detectors (RTDs) are used in thermowells (Figure 6-18) to measure temperatures of the hot and cold legs in the primary and secondary systems.

Thermocouples are used to measure IHX primary outlet temperature, DHX module outlet temperature and the temperature of the secondary expansion tank.

The IHX primary outlet temperature measurement is made by three chromel/alumel thermocouples per loop installed in thermowells

in the elevated section of the HTS cold leg piping nearest the IHX primary outlet. The thermocouples are 1/8-in. insulated junctions swaged to 1/16-in. at the tip to provide a time response of less than 5 seconds.

The DHX sodium outlet temperature measurement is made by three chromel/alumel thermocouples per module installed in thermowells in branch arm piping near the DHX module outlet. The arrangement is similar to that used for the IHX primary outlet temperature. Also two PPS chromel/alumel thermocouples per module are strapped onto the pipe surface adjacent to the other DHX thermocouples and used for control of decay heat removal.

FIGURE 6-18. Thermowell Assembly.

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002
2/2/12

Process Flow Measurements — Process flow measurements are made for primary loop flow, secondary loop flow and IHX recirculation line flow. The primary loop flow measurement is made by a permanent magnet flow meter installed around the HTS piping between the IHX primary outlet and the check valve. The magnet assembly is in the shape of an inverted "U", which is suspended around the pipe (see Figure 6-19). A thermocouple is installed in the magnet structure to monitor the magnet temperature and permit manual corrections of flow meter calibration as necessary.

For secondary loop flow measurement, both a magnetic flow meter and a Venturi meter are employed. The permanent magnet flow meter has a rapid response time but is not completely accurate. The Venturi meter has high inherent accuracy, but the response time is too slow for use in the control system and PPS. With both flow meters installed in the loop, the Venturi meter may be used for in-place calibration of the permanent magnet flow meter.

FIGURE 6-19. Permanent Magnet Flow Meter Schematic.

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Process Pressure Measurements --

Process pressure is measured for the primary loops, for primary and secondary pump discharge and for the secondary expansion tank. A typical pressure sensor installation is given in Figure 6-20.

Sodium Level Measurements --

Sodium level is measured in the primary and secondary pump tanks and in the secondary expansion tanks to confirm proper operation of the pumps, loops and expansion tanks, and to provide warning of sodium loss from the secondary loop. Sodium level is measured by an inductive level probe installed in a dry thimble (1-in. Schedule 40 fully annealed SS).

Rotational Speed Measurements --

Rotational speed is measured for primary and secondary pumps and DHX fans. The measurements are made by a tachometer attached to the shaft. This tachometer supplies a d-c voltage signal proportional to the shaft speed.

Position Measurements --

Position measurements are made for the liquid rheostat electrodes and for the DHX fine and coarse dampers; these measurements are used by the Reactor Plant Control System (System 90) to assist in maintaining stable plant operation. Position measurements are also made for the DHX vanes and isolation doors.

FIGURE 6-20. Pressure Sensor Installation.

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6.6.2 Monitoring and Interlocking Instrumentation

The HTS Instrumentation System provides the instrumentation equipment necessary to monitor the operation of HTS components such as pumps, valves, motors, liquid rheostats and DHXs, and to provide required interlocking.

6.7 DIGITAL DATA HANDLING AND DISPLAY (SYSTEM 91)

The Digital Data Handling and Display System (DDH&DS) (Figure 6-21) is a real-time on-line digital computer-based system that serves the primary purpose of recording plant operational and experimental data. Up to 1480 analog channels and 125 digital channels can be processed. The DDH&DS is divided into a plant data system and an experimenter's data system.

The DDH&DS system may be modified and/or reprogrammed as required to meet changing test conditions.

Three computers with associated disk units and magnetic tape drives are provided. Plant and experimental data are recorded on 9-track magnetic tape so that the data may be subsequently processed and analyzed. (One of the major outputs of the FFTF is plant and experimental data, used to analyze FFTF performance and to determine the response of test materials and assemblies to the FFTF test environments.)

The DDH&DS also provides calculational and display support to plant operators and experimenters, although operation of the FFTF is not dependent on these functions. The FFTF can be started up, operated and shut down without the DDH&DS.

FIGURE 6-21. Digital Data Handling and Display System (DDH & DS) Schematic.

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2/2/12

6.7.1 Plant Data System

The computer for the DDH&DS plant data system is a 16-bit Modcomp* III minicomputer with 64K words of core and a MAX-III operating system. The Modcomp III is equipped with a power fail-safe feature that protects the contents of core memory upon loss of power.

The plant data system contains two 262K-word high-speed disk units. These units provide primary on-line storage for system programs and data files. The storage functions of each disk are completely separate.

The DDH&DS contains three 9-track magnetic tape units. These units are used to record the FFTF data for subsequent analysis and for historical records. They are also used for tape copying, tape listing and program development.

Other peripheral equipment includes three teletypes, a line printer, a card reader, a paper tape punch, a paper tape reader, three data acquisition controllers, one multiplexer in the computer room and three multiplexers within the containment vessel.

6.7.2 Experimenter's Data System

The experimenter's data system is built around two additional computers. The multiplexers that acquire experimenter's data are controlled by a Hewlett Packard H-P 1000 computer system with 128K words of memory, two magnetic tape drives, a 2-megabyte disk and a graphics terminal.

* Registered trademark of Modular Computer Systems, Inc.

A DEC PDP 11/34 system is available for making on-line calculations for experimenters. It is in communication with both the HP-1000 and the Modcomp and has all plant and experimenters' data available for any necessary on-line manipulations.

The PDP 11/34 has two tape drives, a 14-megabyte disk drive, a CRT terminal and a line printer.

6.8 ANNUNCIATION AND COMMUNICATIONS

6.8.1 Plant Annunciator (System 93-14)

The Plant Annunciator System provides audible and visual alarms in the control room to fulfill the following functions:

- Alert the operator to the existence of a system or control abnormality so that required corrective action can be initiated
- Provide sufficient information to direct the operator to the instrument or control panel at which confirmation and evaluation of the abnormality may be made

The Plant Annunciator System receives signals from control and monitoring systems throughout the plant. It is powered from the emergency power system. System design includes redundant lamps and power supplies to provide reliable alarms. Specific inputs to the annunciator system are described in the chapters of this document devoted to various instrumentation and control systems.

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100
2/2/72

6.8.2 Communications (System 15)

The Communications System employs standard telephone equipment for internal and external plant communications. Five sub-systems are provided:

- Operations System
- Public Address System
- Private Automatic Exchange System
- IEM Cell System
- General Plant Telephones

All but the last of these systems are powered by the emergency power system. This power source is backed up for each system by a separate battery that can supply power for a minimum of four hours after the loss of offsite and onsite-generated power sources.

6.9 PIPING AND EQUIPMENT ELECTRICAL HEATING CONTROL (SYSTEM 93-15)

The Piping and Equipment Electrical Heating Control System provides instrumentation to monitor and control (Figure 6-22) electrical heating of sodium piping and equipment during normal plant operating conditions. The system is powered from the normal offsite power system. No portion of System 93-15 is required for operation of the PPS (System 99).

Localized control stations are provided for regulation of heater power, which is adjusted automatically to obtain the desired temperature. Piping and equipment temperatures are monitored with a multiplexer alarm system. All temperatures are compared with predetermined high and low alarm values at localized stations. Signals are provided to the Plant Annunciator System (System 93-14) for the control room alarm in the event of local high or low temperatures.

FIGURE 6-22. Typical Control Channel Block Diagram for System 93-15.

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CHAPTER 7.

SODIUM AND NaK SYSTEMS (SYSTEMS 81, 93-10 AND 93-13)

	Page
7.1 AUXILIARY LIQUID METAL SYSTEM (SYSTEM 81)	7-3
7.1.1 Components in System 81	7-4
7.1.2 Sodium Receiving and Unloading System	7-4
7.1.3 Reactor Primary Sodium Processing System	7-6
7.1.4 Reactor Secondary Sodium Processing System	7-8
7.1.5 IDS and Primary Sodium Storage Processing System	7-9
7.1.6 NaK IDS Cooling System	7-10
7.1.7 NaK Cold Trap Cooling System	7-10
7.1.8 Liquid Metal Valves	7-12
7.1.9 Pipe Heating	7-12
7.2 AUXILIARY LIQUID METAL INSTRUMENTATION (SYSTEM 93-10)	7-12
7.2.1 Monitoring Functions	7-12
Temperature	7-13
Level	7-13
Flow	7-13
Pressure	7-13
7.2.2 Control Functions	7-13
7.3 LEAK DETECTION INSTRUMENTATION (SYSTEM 93-13)	7-13
7.3.1 Aerosol Leak Detection	7-13
7.3.2 Electrical Contact Leak Detectors	7-14

~~OFFICIAL USE ONLY~~

18A
2/2/12

VESSEL OD 12 ft 0 in.
 VESSEL LENGTH 38 ft 1/8 in.

FIGURE 7-1. FFTF Secondary Sodium Storage Vessel.

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CHAPTER 7.

SODIUM AND NaK SYSTEMS (SYSTEMS 81, 93-10 AND 93-13)

7.1 AUXILIARY LIQUID METAL SYSTEM (SYSTEM 81)

The Auxiliary Liquid Metal System (System 81) for the FFTF provides the equipment and facilities to store and control the liquid metal inventory for all liquid metal systems (see Table 7-1). It also provides purification capabilities for the reactor, Heat Transport System, Interim Decay Storage System (System 41) and two self-contained NaK cooling systems.

Equipment and piping are of stainless steel. Equipment containing radioactive sodium is located in steel-lined shielded cells to prevent sodium-concrete reaction in case of sodium leaks. All radioactive system components are provided with biological shielding. Such shielding reduces personnel radiation exposure during normal operation to the whole body limits set by DOE. Figure 7-1 shows a typical component, the FFTF Secondary Sodium Storage Vessel.

TABLE 7-1

FFTF LIQUID METAL INVENTORY		
System	Component/System	Volume (ft ³)*
32	Reactor Vessel	10694.0
51	3 HTS Primary Loops	5712.3
51	3 HTS Secondary Loops	7227.0
61	4 CLS Primary Loops	402.1
61	4 CLS Secondary Loops	481.9
81	Reactor Primary Sodium Processing System	750.2
81	IDS and Primary Sodium Storage Processing System	2619.4
81	Reactor Secondary Sodium Processing System	536.3
85	Impurity Monitoring and Analysis System	20.0
All	Total Sodium Inventory	<u>28,443.2</u>
81	Total NaK Inventory	65.7

*Sodium at 400°F; NaK at 70°F

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The Auxiliary Liquid Metal System is made up of the following: Sodium Receiving and Unloading System, Reactor Primary Sodium Processing System, Reactor Secondary Sodium Processing System, IDS and Primary Sodium Storage Processing System; NaK IDS Cooling System; and NaK Cold Trap Cooling System.

7.1.1 Components in System 81

Major components in System 81 consist of vessels, cold traps, pumps and heat exchangers. Table 7-2 lists this equipment. Design pressures range from 1 in. (water gage) to 250 psig, depending on the type of service.

7.1.2 Sodium Receiving and Unloading System

The Sodium Receiving and Unloading System provides the equipment to melt the contents of a sodium tank car and transfer the sodium to the system storage vessels, T-42, T-43 and T-44 (Figure 7-2).

A portable tank car receiving station is provided with an oil-fired Tank Car Oil Heater that circulates hot oil through the channels in the tank car to melt the sodium.

TABLE 7-2

MAJOR EQUIPMENT IN SYSTEM 81			
Equipment Piece No.	Name	Equipment Piece No.	Name
T-42	Primary Sodium Overflow Vessel	P-39	Primary Sodium System Makeup Pump
T-43	Primary Sodium Storage Vessel	P-40	Primary Sodium IDS Pump
T-44	Secondary Sodium Storage Vessel	P-41	Primary Sodium Storage Tank Pump
T-88	EM Pump Drain Vessel	P-57	Secondary Sodium Cold Trap Pump
T-89	EM Pump Drain Vessel	P-58	Secondary Sodium Cold Trap Pump
T-98	NaK Vessel	P-105	NaK IDS System Pump
T-99	NaK Vessel	P-106	NaK Cold Trap System Pump
N-5*	Primary Sodium Cold Trap	E-79	IDS Sodium Primary Cooler
N-7	Secondary Sodium Cold Trap	E-133	NaK IDS System Regenerative Exchanger Heat
N-40	Secondary Sodium Cold Trap	E-134	NaK IDS System Cooler
P-38	Primary Sodium System Makeup Pump	E-137	NaK Cold Trap System Cooler

*Space is available for installation of another cold trap (N-6) if needed in the future.

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88a
2/2/72

When the sodium has been melted, it is transferred to the applicable FFTF sodium storage vessels by pressurizing the tank car with argon (up to 12 psig) to establish and maintain flow as required.

During transfer, the sodium is filtered by one of two parallel filters to remove any particulate matter in the sodium.

Also, a Fresh Sodium Drum Unloading Station is located just south of the HTS Service Building - South to supply fresh sodium to the primary closed loop systems via the System 85 primary sodium sample supply lines.

FIGURE 7-2. FFTF Sodium Fill System.

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7.1.3 Reactor Primary Sodium Processing System

The Reactor Primary Sodium Processing System, shown schematically in Figure 7-3, provides sodium purification for the reactor and the primary heat transport system, sodium storage for maintenance operations, and level control for the reactor vessel during operation.

Sodium is circulated by electromagnetic pumps (Figure 7-4) through the processing system at a nominal flow rate of 60 gal/min. The sodium overflows from the reactor vessel into the Primary Sodium Overflow Vessel.

It then is circulated through the primary cold trap and/or through the cold trap bypass. The cold trap flow and cold trap bypass flow are combined and circulated back to the reactor vessel.

The HTS primary cold trap (Figure 7-5) provides a means of purifying the sodium by removing sodium oxide and other impurities by crystallization at a temperature significantly below the main-stream sodium temperature. The sodium cold trap is cooled by NaK (sodium-potassium eutectic alloy). One cold trap (N-5) was installed initially.

FIGURE 7-3. Reactor Primary Sodium Processing System.

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182
2/2/12

FIGURE 7-4. Electromagnetic Pump Schematic for System 81 Pumps.

FIGURE 7-5. HTS Primary Sodium Cold Trap.

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38A
2/2/12

7.1.4 Reactor Secondary Sodium Processing System

The Reactor Secondary Sodium Processing System (Figure 7-6) provides sodium purification for the secondary HTS and sodium storage for maintenance operations. The largest piece of equipment is the Secondary Sodium Storage Vessel. Each secondary HTS Loop is provided with an independent cold trap loop.

During reactor operation, sodium is circulated from each secondary HTS loop at a nominal flow rate of 18 gal/min. The sodium flows from the loop cold leg to the EM Pump, then through the air-cooled Secondary Cold Trap (Figure 7-7) and back to the Secondary HTS Loop Expansion Vessel. A cold trap bypass sample (approximately 3 gal/min) is circulated through a sampling package (System 85—see Chapter 10).

FIGURE 7-7. Air-Cooled Cold Trap.

FIGURE 7-6. Reactor Secondary Sodium Processing System Schematic Showing One of Three Cold Trap Circuits.

7.1.5 IDS and Primary Sodium Storage Processing System

The IDS and Primary Sodium Storage Processing System is shown schematically in Figure 7-8. This system provides: 1) the Primary Sodium Storage Vessel, 2) cooling of the Interim Decay Storage Vessel, and 3) a nitrogen-cooled cold trap for purifying the sodium in the system.

During normal operations, sodium is circulated at a nominal rate of 30 gal/min

through the primary cooling loop for the IDS Vessel. The sodium flows from the IDS vessel down to the pump and back up through the NaK-cooled heat exchanger to the IDS vessel. A bypass flow of 15 gal/min is circulated through the nitrogen-cooled cold trap (similar to the cold trap shown in Figure 7-7) to maintain IDS sodium purity within acceptable limits, and a flow of 3 gal/min is circulated through an auxiliary plugging temperature indicator (see System 85).

FIGURE 7-8. IDS and Primary Sodium Storage Processing System.

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18A
2/2/12

7.1.6 NaK IDS Cooling System

The NaK IDS Cooling System (Figure 7-9) provides cooling for the IDS vessel primary cooling loop and NaK storage for the two NaK systems (i.e., the Primary Cold Trap and the IDS). During operation, the NaK normally circulates at approximately 15 gal/min. The NaK flows from the NaK IDS system pump to the IDS Na/NaK heat exchanger. From there, it passes through the NaK Regenerative Heat Exchanger into the shell-and-tube, Mobiltherm-cooled NaK IDS System Heat Exchanger (Figure 7-10) and then back through the regenerative heat exchanger to the storage vessel. The oxide level of the NaK is controlled by the nitrogen-cooled Diffusion Cold Trap shown in Figure 7-11.

FIGURE 7-9. NaK IDS Cooling System.

7.1.7 NaK Cold Trap Cooling System

The NaK Cold Trap Cooling System, shown schematically in Figure 7-12, provides cooling, storage and purification for NaK used for cooling the Primary Sodium Cold Trap.

During normal operation, NaK is circulated through the cooling loop at approximately 80 gal/min. The NaK flows from the NaK Cold Trap System Overflow and Storage Vessel through the pump and up through the jacket of the Primary Sodium Cold Trap. From there, it passes down through the Mobiltherm-cooled heat exchanger and back to the storage vessel. The oxide level of the NaK is controlled by use of a diffusion cold trap.

FIGURE 7-10. NaK/Mobiltherm Heat Exchanger.

FIGURE 7-11. NaK Diffusion Cold Trap.

FIGURE 7-12. NaK Cold Trap Cooling System.

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7.1.8 Liquid Metal Valves

Pneumatic (Figure 7-13) and electric motor operators are used to drive remotely controlled valves. All sodium valves in the system are provided with trace heating and temperature indication on the body and bonnet.

7.1.9 Pipe Heating

All sodium piping and components in the Auxiliary Liquid Metal System are provided with electrical trace heaters. (Heating of NaK piping is not required.) Heater design consists of a nickel-chromium resistance element insulated with magnesia and a covered nickel-iron-chromium alloy heater sheath.

7.2 AUXILIARY LIQUID METAL INSTRUMENTATION (SYSTEM 93-10)

The Auxiliary Liquid Metal Instrumentation System (System 93-10) provides monitoring and control instrumentation for the Auxiliary Liquid Metal System (System 81).

7.2.1 Monitoring Functions

The primary monitoring functions performed by System 93-10 are the monitoring of temperature, level, flow and pressure for sodium components and NaK components. The more important signals are indicated or alarmed in the main control room and/or recorded by System 91.

FIGURE 7-13. Pneumatic Valve Operator Attached to Small Sodium Valve.

Temperature -- Surface-mounted ungrounded thermocouples are used for measuring temperatures in the Auxiliary Liquid Metal System except in the cold traps. The cold trap crystallizer internal temperatures are measured with probe-type thermocouples inserted in thermowells.

Level -- Level probes used are of the mutual inductance type, consisting of a bifilar winding continuously wound on a stainless steel former. The probes are inserted in stainless steel thimbles. The enveloping liquid metal reduces the mutual inductance between the sensor windings.

Flow -- Permanent magnet-type flow meters are used for measurement of flow in the sodium and NaK lines. The permanent magnet temperature is not monitored; however, a surface-mounted thermocouple is provided for periodic checks and calibration.

Pressure -- Transducers that generate an electrical signal proportional to differential or static pressure are used for differential and static pressure indication, alarming and pump interlock.

7.2.2 Control Functions

System 93-10 provides all control functions for System 81; no control functions are provided by System 90 or 91. The System 93-10 control functions are applied to pumps, cold traps, valves and portions of the Mobiltherm system.

Operation of pumps is controlled in accordance with requirements of the component/

system serviced by the pump. Interlocks are provided to prevent opposite flow, i.e., one pump in forward flow control position and the other in reverse flow control position. To protect the pumps, automatic pump shutdown is typically provided should any designated abnormal conditions arise.

Trapping temperatures in the cold traps are automatically regulated by control of the coolant streams.

7.3 LEAK DETECTION INSTRUMENTATION (SYSTEM 93-13)

Piping and vessels containing NaK or sodium are monitored for leaks by the Leak Detection Instrumentation System. The system provides alarm functions only. The primary method of monitoring is by detection of sodium or NaK aerosols in gas samples. Contact detectors are used as backup in selected locations.

7.3.1 Aerosol Leak Detection

Detection of sodium aerosols in the nitrogen atmosphere is used to monitor leaks in the reactor vessel/guard vessel annulus, the HTS cells, the reactor cavity and valve cells, and the closed loop cells. Ionization detectors and filters are provided to monitor gas from the reactor vessel/guard vessel annulus; filters alone are used on the other applications.

The reactor vessel/guard vessel annulus is sampled by three sample tubes, one under each primary sodium inlet nozzle. The gas samples are passed over a heated filament in an ionization detector.

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2/2/72

Sodium and sodium compounds are ionized, and the ions are attracted by a collector electrode. A sensible ion current is produced by sodium concentrations of 10^{-12} to 10^{-10} g/cm³. A detector circuit measures the ion current and provides indication and alarm.

The sample gas is also drawn through a replaceable submicron filter. An alarm, activated by the pressure drop across this filter, provides effective notification of relatively large leaks. To detect small leaks (on the order of 100 g/hr), the filter is removed and chemically analyzed for sodium and sodium reaction products. The filter is also analyzed for radioactivity, since radioactivity analysis provides the most sensitive leak detection method when the reactor is operating at power.

Filters used for the other aerosol monitoring applications are similar to those used in the annulus system.

7.3.2 Electrical Contact Leak Detectors

Electrical contact detectors consist of two electrodes extended to a gap at a location where leaking sodium may be expected to collect. Leaking sodium will cause a short circuit between the two electrodes, which is converted by associated circuitry into an alarm.

These electrical contact detectors are used chiefly as a backup to the more sensitive aerosol detectors. In a typical application, a contact detector is located in the reactor vessel/guard vessel annulus under each of the three auxiliary (sampling, overflow and make-up) nozzles. Each of the three contact leak detectors is installed in a separate guide tube and each guide tube terminates in a junction box on the head compartment floor. Figure 7-14 shows the relationship between the two types of detectors for the reactor vessel/reactor guard vessel annulus.

FIGURE 7-14. Leak Detection for Reactor Vessel/Reactor Guard Vessel Annulus.

2/2/72

CHAPTER 8.

ARGON AND NITROGEN SYSTEMS (SYSTEMS 82 AND 93-8)

	Page
8.1 INERT GAS RECEIVING AND PROCESSING (SYSTEM 82)	8-3
8.1.1 Argon System	8-3
8.1.2 Nitrogen System	8-5
8.1.3 Radioactive Argon Processing System	8-6
8.1.4 Cell Atmosphere Processing System	8-8
8.1.5 Vacuum System	8-10
8.2 INERT GAS RECEIVING AND PROCESSING INSTRUMENTATION (SYSTEM 93-8)	8-10
8.2.1 Argon Supply and Pressurization Instrumentation	8-10
Reactor and Primary Pumps Cover Gas Pressure Control	8-10
Control of Argon for Other Equipment	8-10
8.2.2 Nitrogen Supply and Pressurization Instrumentation	8-10
Pressure Control	8-10
Cell Gas Monitoring	8-11
Oxygen Control	8-11
Other Nitrogen Controls	8-11
8.2.3 Radioactive Argon Processing System Instrumentation	8-11
8.2.4 Cell Atmosphere Processing System Instrumentation	8-11

FIGURE 8-1. Reactor and Primary HTS Argon Cover Gas System.

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CHAPTER 8.

ARGON AND NITROGEN SYSTEMS (SYSTEMS 82 AND 93-8)

8.1 INERT GAS RECEIVING AND PROCESSING (SYSTEM 82)

The Inert Gas Receiving and Processing System provides argon and nitrogen inert gas services and pressure control for liquid metal systems and inert atmosphere facilities. It also provides controlled processing of radioactive gases.

The system is divided into the following subsystems:

- Argon System
- Nitrogen System
- Radioactive Argon Processing System (RAPS)
- Cell Atmosphere Processing System (CAPS)
- Vacuum System

8.1.1 Argon System

The Argon System supplies and controls argon gas for the following purposes:

- Providing an inert atmosphere and pressure control for liquid metal-gas interfaces
- Providing pressurized inert gas services for buffered and inflatable seals
- Purging and pressure control for liquid metal and gas sampling operations

- Purging and providing atmosphere and pressure control for fuel preparation, examination and storage areas and for fuel handling equipment
- Purging and supplying fresh gas for liquid metal system equipment maintenance
- Purging and pressurizing liquid metal vessels and lines for filling and draining

Argon gas, derived from liquid argon storage vessels (Dewars), is distributed by way of pressure-controlled stainless steel supply lines to all liquid metal systems for use as cover gas. The reactor cover gas space consists of the gas volume in the primary HTS pumps, the reactor vessel, the Primary Sodium Overflow Vessel (T-42) and the interconnecting lines (Figure 8-1). The reactor vessel and Sodium Overflow Vessel are interconnected by a 3-in. gas equalization line. The primary HTS pump cover gas spaces are connected to this 3-in. line by 2-in. equalization lines. In addition, the argon is used to service pressure-buffered seals, fuel handling equipment and argon atmosphere cells. Argon pressures are regulated by pressure control systems. Overpressure protection is provided as required by the ASME code by pressure relief valves, which discharge into inert atmosphere cells for in-containment systems and to the atmosphere for ex-containment systems.

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Vapor traps and aerosol filters (Figure 8-2) are provided to prevent liquid metal vapors and particulates from contaminating the argon supply system. Freeze vents are designed to form a barrier against inadvertent flooding of the gas system and/or inadvertent pressurizing of the liquid sodium system.

FIGURE 8-2. Sodium Aerosol Filter.

Argon applications within containment are given in Table 8-1. Argon applications outside containment are given in Table 8-2.

TABLE 8-1

**ARGON SYSTEM APPLICATIONS
WITHIN CONTAINMENT**

- Reactor Cover Gas Space (Reactor Vessel, Primary HTS Pumps, Primary Sodium Overflow Vessel T-42 and Interconnecting Lines)
- Interim Examination and Maintenance Cell
- Test Assembly Conditioning Station
- Core Component Conditioning Stations (2)
- Interim Decay Storage Vessel
- Primary Sodium Storage Vessel T-43
- Primary Closed Loops
- Primary Sodium Drain Vessels T-88 and T-89
- Seals for Reactor, IVHM (3), Instrument Tree (3), Primary Pump Shafts (3), and Reactor Head Compartment
- Lube Oil Systems for Primary Pumps
- System 4I Shield Stations and Floor Service Stations
- Piping Vents for Primary HTS Cold Traps and Primary Sodium Storage/Makeup
- NaK Piping Vent for Primary HTS Cold Traps
- NaK Storage Vessels T-98 and T-99
- NaK Cold Trap System Overflow
- NaK IDS Cooling System Piping Vents

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The argon cover gas is analyzed by Systems 85 and 94 (see Chapter 10). A nominal 1.0 std ft³/min gas sample is drawn continuously from the cover gas system for analysis.

TABLE 8-2

**ARGON SYSTEM APPLICATIONS
OUTSIDE CONTAINMENT**

- HTS Secondary Pumps (3) Including Shaft Seals and Lube Oil Systems
- Secondary Sodium Storage Vessel T-44
- Secondary HTS Expansion Vessels
- Valves and Freeze Vents, HTS Dump Heat Exchangers and Secondary Cold Traps
- CLS Secondary Surge Tanks and Piping Vents
- Makeup for Recycle Cover Gas Storage Vessel
- IEM Cell Sodium Removal Station
- Floor Service Stations
- Tank Car Station

8.1.2 Nitrogen System

The nitrogen system supplies nitrogen at controlled pressures and flow rates to provide:

- Inert atmosphere for process cells
- Nitrogen-type cooling systems

- Actuation of pneumatically operated valves in inert spaces
- Inert atmosphere purity control
- Nitrogen flooding for secondary sodium fire protection (System 26).

Nitrogen gas is derived from liquid nitrogen storage Dewars and distributed by way of pressure-controlled carbon steel supply lines. Nitrogen pressures are controlled by pressure control systems.

A sampling and analysis subsystem is used to measure and record the oxygen, hydrogen, moisture and radioactivity of the nitrogen atmosphere in each inert cell at approximately 20-minute intervals. If a high oxygen content (i.e., over 1.2% by volume) is detected, the cell atmosphere is purged automatically with pure nitrogen until the oxygen concentration is brought within specified limits. Detection of hydrogen, moisture and radioactivity is alarmed to permit the operator to take corrective action.

The nitrogen system is purified by the Cell Atmosphere Processing System (CAPS). Liquid nitrogen used as the coolant for the Radioactive Argon Processing System and for the Cell Atmosphere Processing System is stored in the Reactor Service Building in Cell 235 and is a source separate from the main nitrogen supply Dewars.

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8.1.3 Radioactive Argon Processing System (RAPS)

The Radioactive Argon Processing System (RAPS) processes contaminated argon from the reactor and the primary closed loop systems, to remove krypton and xenon isotopes. Leakproof diaphragm compressors force the argon into a large surge tank, which is designed to allow short-lived isotopes in the contaminated argon to decay. The contaminated gas effluent from the surge tank is purified by a cryogenic process system utilizing charcoal adsorbent delay beds (to eliminate short-lived xenon and krypton radionuclides) and an argon distillation column (to remove long-lived xenon and krypton radionuclides). The purified argon is returned to be used as the reactor cover gas.

The flow diagram for RAPS is shown in Figure 8-3. Radioactive argon, collected in vacuum tank T-51, flows through filters, compressors, a surge and delay tank (T-49) and radiation monitors into the cryogenic "cold box" (U-497). The cold box discharge is checked for radiation activity level. If activity level is less than $10^{-3} \mu\text{Ci}/\text{cm}^3$, it is directed to the Recycle Cover Gas Storage Tank T-95. If it is greater than $10^{-3} \mu\text{Ci}/\text{cm}^3$, it is routed to the CAPS for processing. (See also 15.1.4).

The RAPS cryogenic "cold box" (Figure 8-4) receives argon gas from the surge and delay tank (T-49) at a flow rate varying from 0 to 25 std ft³/min. This stream is mixed with sufficient gas recycled within the unit to maintain a constant 25 std ft³/min flow rate through the processing components.

FIGURE 8-3. RAPS Flow Diagram.

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The inlet stream is cooled from ambient temperature to -165°F by heat transfer from the effluent stream in a counterflow regenerative heat exchanger, E-150. The cooled stream flows through the charcoal delay beds and the associated heat exchangers, E-151, E-152 and E-153. Essentially all radioactive xenon and most of the short-lived radioactive krypton are eliminated in the delay beds.

The feed stream is then introduced into column T-110 where the cold argon stream flowing up through the packing is refluxed by liquid argon, which is condensed by the liquid nitrogen cooling coils at the top of the column in

the condenser section. The liquid argon reflux continuously strips out the xenon and krypton as well as other impurities (such as methane) from the feed stream and collects them in liquid form at the bottom of the column in the reboiler.

During RAPS operation, the concentration of noble gases in the distillation column reboiler will increase to a point where they should be removed, as determined either by solubility considerations or by operational convenience. About once each year, the 1.5 ft^3 of cryogenic noble gases will be drained, vaporized and transferred to storage tank T-111 or directly to shipping casks.

FIGURE 8-4. RAPS Cryogenic Processing System Flow Diagram.

8.1.4 Cell Atmosphere Processing System (CAPS)

The Cell Atmosphere Processing System (CAPS) is designed to purify potentially contaminated nitrogen, air or argon and discharge it to the atmosphere through the heating and ventilation system. The gases are purified by a cryogenic process utilizing charcoal adsorbent delay beds. Cell atmosphere purges are the primary source of gas to the CAPS, although several other sources contribute intermittent input to this system. The gas processed by the CAPS normally has only trace quantities of radioisotopes ($<10^{-7} \mu\text{Ci/cm}^3$).

The flow diagram for CAPS is given in Figure 8-5. The gas mixture (N_2 , air and argon) enters through a collection header and flows through filters, compressors and after-coolers to Surge and Delay Tank T-113. From the delay tank the gas flows through the dryers (Figure 8-6) to the cold box (U-498). After processing in the cold box (Figure 8-7), the gas is checked by radiation monitors and released to the Heating and Ventilation System. If the CAPS effluent radioactive concentration exceeds the allowable value, radiation monitors automatically divert the effluent to the CAPS intake for reprocessing. (See also 15.1.4).

FIGURE 8-5. CAPS Flow Diagram.

FIGURE 8-6. CAPS Dryers Installed.

FIGURE 8-7. CAPS Cold Box Flow Diagram.

8.1.5 Vacuum System

The vacuum system consists of eight vacuum pumping units located throughout the FFTF plant; the system aids in obtaining inert gas purity levels and assists in sodium fill and drain operations.

The vacuum system is designed to produce a vacuum of 10^{-1} torr with an effective unit pumping speed range of $65 \text{ ft}^3/\text{min}$ to $80 \text{ ft}^3/\text{min}$.

8.2 INERT GAS RECEIVING AND PROCESSING INSTRUMENTATION (SYSTEM 93-8)

The Inert Gas Receiving and Processing Instrumentation System provides monitoring and control instrumentation for argon supply and pressurization, nitrogen supply and pressurization, radioactive argon processing and cell atmosphere processing.

8.2.1 Argon Supply and Pressurization Instrumentation

Reactor and Primary Pumps Cover Gas Pressure Control -- Pressure control of reactor cover gas and the interconnected primary pumps cover gas is accomplished by an automatic feed and bleed system with inlet flow rate limiting. Cover gas pressure is measured with NaK capillary pressure sensors located on the argon inlet and discharge piping. These sensors are of the same design as those used in the PPS.

Control of Argon for Other Equipment --

Cover gas pressure of secondary HTS pumps and expansion tanks is controlled in the same manner as reactor cover gas pressure, except that the inlet flow is not limited. Cover gas pressure control of the CLS surge tanks, the IDS, IEM cell and the Auxiliary Liquid Metal System tanks also employs a feed and bleed system without inlet flow limiting. Primary HTS pump argon seal pressure and lube oil argon pressure are controlled in a manner similar to that described above. Control of argon supply pressure to reactor seals is accomplished with a conventional pressure feedback control system. Control of secondary HTS, IDS, CLS and Auxiliary Liquid Metal System argon supply is provided at local control stations. The liquid argon level in argon storage Dewars, and the argon distribution header pressures, are indicated in the control room. Conventional instruments are used for these measurements.

8.2.2 Nitrogen Supply and Pressurization Instrumentation

Pressure Control -- Cell gas pressure control is accomplished by use of a feed and bleed control scheme similar to that used for reactor cover gas pressure control. Cell differential pressure is sensed, with respect to reactor containment pressure or ambient atmospheric pressure, by a conventional differential pressure transmitter.

Instrumentation for nitrogen supply and pressurization is designed to monitor and control nitrogen service supply to inert gas cells.

Cell Gas Monitoring -- Cell gas oxygen content, radiation level, humidity and hydrogen content are monitored and recorded sequentially for each cell.

Leaking sodium will react with the small moisture content present in inert cell atmospheres to form gaseous hydrogen. The hydrogen analyzer is capable of detecting hydrogen in quantities as small as 10 parts per million. Radioactive noble gases escaping to the cell atmosphere will be detected by the radiation detectors. Conventional instruments are used for gas impurity detection; the Radiation Monitoring System (System 96) provides radiation detection.

Oxygen Control -- Cell gas oxygen content is automatically controlled by opening a second nitrogen feed valve in parallel with the pressure-controlled feed valve when high oxygen content is sensed. The purge valve remains open until the oxygen content decreases to an acceptable level.

Other Nitrogen Controls -- Conventional instruments are used to measure nitrogen distribution header pressures, liquid nitrogen Dewar levels and the nitrogen supply pressure of the Low-Level Flux Monitor (LLFM) and Control Rod Drive Mechanism (CRDM).

8.2.3 Radioactive Argon Processing System Instrumentation

Conventional pressure, temperature and flow instruments are provided for control and monitoring of the RAPS. System parameters and complete system control capabilities are indicated in the control room. The RAPS is powered from the emergency power system.

8.2.4 Cell Atmosphere Processing System Instrumentation

Conventional pressure, temperature and flow instruments are provided for control and monitoring of the CAPS. Parameters and complete system control capabilities are indicated in the control room. The CAPS is powered from the normal a-c power system.

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CHAPTER 9.
INDEPENDENTLY COOLED IRRADIATION TESTING FACILITIES
(SYSTEMS 61 AND 93-3)

	Page
9.1 CLOSED LOOPS (SYSTEM 61)	9-3
9.1.1 Summary Description	9-3
9.1.2 CLS Primary Cooling Systems	9-4
CLIRA	9-4
CLS Primary Module	9-6
CLS Primary Purification System	9-8
CLS Primary Cover Gas System	9-8
CLIRA Operating Conditions	9-8
9.1.3 CLS Secondary Cooling Systems	9-8
CLS Secondary Cold Traps	9-9
CLS Dump Heat Exchangers	9-10
9.1.4 CLS Valves	9-11
9.1.5 CLS Piping and Component Heating	9-11
9.1.6 CLS Sodium Leak Detection	9-11
9.1.7 CLS Sodium Purity Control	9-11
9.1.8 CLS Argon Cover Gas Purity Control	9-11
9.2 CLOSED LOOP INSTRUMENTATION (SYSTEM 93-3)	9-12
9.2.1 Functions	9-12
Process Measurements	9-12
Automatic Control	9-12
9.2.2 Sensors Used	9-12

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FIGURE 9-1. The Two 2.3-MW Heat Dumps for the FFTF Closed Loops.

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CHAPTER 9.

INDEPENDENTLY COOLED IRRADIATION TESTING FACILITIES (SYSTEMS 61 AND 93-3)

9.1 CLOSED LOOPS (SYSTEM 61)

9.1.1 Summary Description

Space is provided in the FFTF for installing up to four 2.3-MW independently cooled "closed loop" irradiation testing systems. Since each closed loop system (CLS) utilizes its own coolant systems, the purity, flow and temperature of the sodium coolant in each loop can be controlled independently of the FFTF Main Heat Transport System.

A CLS consists of a Closed Loop In-Reactor Assembly (CLIRA) that contains the irradiation test specimen, a primary cooling system and a secondary cooling system (Figures 9-1 and 9-2). Argon is used as cover gas.

Initially, primary and secondary cooling systems were installed for two closed loops, and several CLIRA were provided for these loops.

FIGURE 9-2. Closed Loop System Schematic.

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9.1.2 CLS Primary Cooling Systems

Operationally, each CLS primary cooling system (Figure 9-3) consists of: 1) a CLIRA; 2) branch arm piping (BAP); 3) a primary module containing parallel electromagnetic primary pumps, intermediate heat exchanger, tanks, piping and valving; and 4) a sampling pump and cold trap. Types 316 and 316H stainless steel are used for the primary system piping and components.

Within the primary system, BAP extends across the top of the reactor in the head compartment to transfer high-temperature sodium coolant between the CLIRA and the primary module. The entire primary system is located within containment.

All loops have provisions to detect fuel failures in the primary coolant. The Delayed

Neutron (DN) Monitor (System 94) contains the DN detectors, which count the delayed neutrons given off in the primary sodium by fuel particles (from fuel failures).

CLIRA — Figure 9-4 gives details of the CLIRA, which penetrates the vessel head (System 32) and extends down into the core support structure (System 31).

In the CLIRA, the test section outside diameter can be as large as 2.75 inches. Twenty-six instrument channels are provided for monitoring test section variables such as pressure, temperature, flux, strain, and the like. The CLIRA experiments can be re-instrumented following interim examinations.

Cold leg and hot leg nozzles in the spool piece on the reactor head connect the CLIRA to the BAP of the primary system.

FIGURE 9-3. CLS Primary Cooling System Schematic.

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From the cold leg nozzle, sodium flows down the CLIRA annulus between the flow and pressure tubes to the test section inlet. Coolant flow moves up through the test section; details of the test section vary depending upon the experiment installed.

Sodium leaves the CLIRA through the 3-in. outlet nozzle in the spool piece to the BAP hot leg at the 541-ft level. It is then carried across the reactor head to the head compartment wall in the hot leg 3-in. pipe of the BAP, and thence to the primary module.

FIGURE 9-4. Closed Loop In-Reactor Assembly (CLIRA).

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CLS Primary Module -- The CLS Primary Module contains CLS primary heat removal components. The module (Figure 9-5) is 28.5 ft high by 9 ft 6 in. by 9 ft 10 in. The module support structure is designed to be installed and removed from the closed loop cell as a unit, utilizing the reactor containment polar gantry crane.

After entering the primary module, the sodium passes through an electromagnetic flow meter and rises to the Intermediate Heat Exchanger (IHX) inlet (Figure 9-6) at the 544-ft level. (The IHX is located as high as possible in the cell to promote coolant circulation by natural convection between the CLIRA and the IHX.) Primary system sodium flows down through the 17 tubes of the IHX and exits at the 533-ft level.

FIGURE 9-5. Closed Loop Primary Module Schematic.

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FIGURE 9-6. CLS Intermediate Heat Exchanger.

A flow of 13 gpm for sampling and purification is withdrawn. The main IHX outlet line carries the sodium to the primary surge tank, which in turn supplies the main and auxiliary electromagnetic pumps that provide the driving force for coolant circulation. During normal operation, each pump provides one-half of the flow; this redundancy allows flow to continue even if one pump fails. Outputs from the main and auxiliary pumps join downstream from the pumps at the mixing component. Sodium flows from the mixing component out of the module and back to the CLIRA.

The primary pumps (Figure 9-7) are helical induction electromagnetic pumps, chosen for high reliability and low maintenance. (There are no moving parts or bearing surfaces.) Pump windings are designed for easy replacement. The pumps have a design life of ten years.

FIGURE 9-7. CLS Primary Pump and Secondary Pump.

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CLS Primary Purification System —

Primary sodium purification is accomplished with the primary cold trap system, located in the HTS Service Building - South. The cold trap (Figure 9-8) is in its own shielded, inerted cell. The cold trap is cooled with nitrogen and is divided into a separate economizer on top and a crystallizer tank, containing a stainless-steel crystallizer element (single-filament wire mesh) in the trapping volume.

CLS Primary Cover Gas System —

The primary cover gas system consists of a loop through which the argon cover gas is circulated between the primary surge tank and the sampling system (System 85); inlet and outlet connections through which argon is added to or evacuated from the system (System 82); and vents for the drain tank and drain system.

CLIRA Operating Conditions —

CLIRA operating conditions are given in Table 9-1.

9.1.3 CLS Secondary Cooling Systems

Each Closed Loop Secondary Cooling System (Figure 9-9) consists of a coolant loop which circulates sodium between the IHX and the Sodium-To-Air Dump Heat Exchanger (DHX), where the heat is transferred to the atmosphere by forced convection. The driving force for the sodium flow is provided by an electromagnetic pump in the cold leg of the system. In addition to the main coolant loop, a sampling loop supplies sodium to a cold trap and to a secondary surge tank. A secondary cover gas system provides argon cover gas.

FIGURE 9-8. CLS Primary Cold Trap Schematic.

TABLE 9-1

CLIRA OPERATING CONDITIONS	
Flow	1.14×10^4 to 1.31×10^5 lb/hr
Coolant Temperature	760°C (1400°F) Max*
Pressure Drop Test Section	100 lb/in. ²
Test Section Heat Removal	2 MW
Test Section Maximum OD	2.75 in.
Test Section Length	36 in.
Test ΔT	400°F Max
Test Train Length	12 ft
Neutron Flux	7×10^{15} n/cm ² -s

* Test section outlet temperature, which is above allowable maximum mean mixed outlet temperature of 1200°F for the closed loop CLIRA

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FIGURE 9-9. CLS Secondary Cooling System Schematic.

The major portion of the secondary loop is located outside the reactor containment building and is connected by piping to the IHX in the closed loop cell. The IHX provides physical separation between the primary and secondary systems. The secondary system is operated at a higher pressure than the primary system so that, in the event of an IHX tube failure, any leakage flow will be in such a direction that the secondary system will not become contaminated with radioactive sodium from the primary system. The DHX is located above the IHX to promote coolant circulation by natural convection in the event of a loss of pumping power.

The secondary sodium electromagnetic (EM) pump is identical to those in the primary

system. Because the head requirements for the two loops are not the same, the secondary pump is operated at reduced power.

The secondary cooling system supplies a bypass stream of sodium to a plugging meter and to a bypass sampler. The stream is monitored for plugging temperature to prevent plugging in the IHX and DHX.

CLS Secondary Cold Traps — Each secondary sampling system includes a cold trap system. The secondary cold trap system is identical to the primary cold trap system except for the substitution of a forced air cooling system consisting of a blower and associated duct work.

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102
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CLS Dump Heat Exchangers — The principal components of the closed loop dump heat exchangers (Figure 9-10) are two motor-driven centrifugal fans, a fin-tube heat exchanger, fan discharge and stack outlet dampers, and a hot-air exhaust stack. Hot sodium is circulated through the tubes while ambient air is forced across the tubes to cool the sodium.

Air circulation is provided by two variable-speed centrifugal fans. The fan housings are arranged with a bottom, horizontal discharge nozzle from which air is ducted and directed upward across the tube bundle. Air leaving the tube bundle continues upward through the exhaust stack, mounted directly above the tube bundle. Air flow is controlled by fan speed and damper position.

Sodium enters the cross-counter-flow serpentine coil tube bundle (18 rows wide by 6 rows deep) through a manifold at the top of the bundle. The sodium then flows downward to another manifold at the bottom of the bundle. The thermal design sizing condition data are 620°F and 420°F sodium inlet and outlet temperatures, respectively, at 1.31×10^5 lb/hr sodium flow. The tube bundle material is type 316H stainless steel with a minimum carbon content of 0.06%.

An electrical preheater system, consisting of an electrical heater, blowers, manifolds, dampers and control system, is used to maintain tube bundle temperature during standby conditions. The heater has a rating of 130 kW.

FIGURE 9-10. Schematic of Closed Loop Dump Heat Exchanger.

9.1.4 CLS Valves

The closed loop design employs valves for the following applications:

- check valves to prevent reverse flow through primary loop sodium pumps
- pneumatically operated valves for auxiliary systems such as purification and drain systems
- manually operated valves (with mechanical extensions) for infrequent drainage, venting, or isolation of a system

CLS valves are type 316H stainless steel with a minimum carbon content of 0.06%. They are bellows-seal, butt-weld valves rated for sodium service at 1220°F and 375 psig.

9.1.5 CLS Piping and Component Heating

All piping and components containing sodium are heated with standoff electrical heaters. The heaters can maintain a sodium temperature of 400°F to 500°F without any reactor power.

9.1.6 CLS Sodium Leak Detection

The Sodium Leak and Smoke Detection and Inert Gas Analyzer Systems are parts of the Leak Detection Instrumentation System (System 93-13), the Plant Fire Protection System (System 26), and the Inert Gas Receiving and Processing System (System 82). These systems detect and verify CLS sodium leaks.

9.1.7 CLS Sodium Purity Control

Sodium sampling and monitoring capability is provided by the Impurity Monitoring and Analysis System (System 85). A Plugging Temperature Indicator (PTI) for each

primary and secondary system for each loop provides continuous monitoring. The PTI determines the temperature at which the sodium freezes, based on the impurities in the sodium at a given time. A plugging temperature in excess of 280°F (330°F when sodium temperature is below 800°F) actuates a control room alarm.

The concentrations of the impurities in the primary and secondary sodium are controlled at the levels given in Table 9-2.

TABLE 9-2

CLS SODIUM IMPURITY CONTROL CAUTION LEVELS	
	(ppm)
Oxygen	2.0
Hydrogen	0.20
Uranium, Plutonium	0.001
Other	10

9.1.8 CLS Argon Cover Gas Purity Control

The concentrations in the argon cover gas of the impurities listed in Table 9-3 are monitored continuously. Impurity concentrations in excess of the caution level actuate a control room alarm.

TABLE 9-3

CLS ARGON CAUTION LEVELS	
	(ppm)
Oxygen	2
Hydrogen	4
Nitrogen	30
Carbonaceous Gases	5

9.2 CLOSED LOOP INSTRUMENTATION (SYSTEM 93-3)

9.2.1 Functions

Each Closed Loop Instrumentation and Control System (Figure 9-11) is designed to provide the maximum availability of the test loop and FFTF plant and at the same time provide flexibility to the experimenter.

Process Measurements -- Process measurements include flow, pressure, temperature, sodium level, DHX fan speeds and valve positions. Experimenters may use extensive special instrumentation.

Signals-requiring permanent recording are transmitted to the Digital Data Handling and Display System (System 91). Certain critical signals (primary loop flow, loop outlet sodium temperature, and IHX primary sodium outlet temperature) are input to the Plant Protection System (System 99) for automatic FFTF plant shutdown if the signal does not conform to pre-set limits.

Since closed loop test section heating (and related cooling requirements) are a function of FFTF reactor neutron flux, System 95 supplies neutron flux level signals to the Closed Loop Instrumentation and Control System. System 99 provides scram signals.

Automatic Control -- Automatic control is provided with manual override. The system monitors three principal closed loop variables (primary sodium flow, secondary sodium flow, and DHX sodium outlet temperature) and controls the CLS operating conditions.

Setpoints for the loop flows and the DHX outlet temperature controllers are provided at the control console in the FFTF control room.

Each primary and secondary closed loop flow controller adjusts the pump voltage to keep the loop flow at the setpoint. The flow setpoint varies as a programmed function of reactor neutron flux above 75% power level, so there is automatic compensation for variation in energy input to the CLS. The sodium flow control system allows operators to trim loop flows and transfer flow control in each loop from automatic to manual control.

In addition to control of overall CLS processes, the control system automatically controls cold trap temperature in both the primary and secondary loops of the CLS.

The closed loop control system design also incorporates interlocks to inhibit unsafe operator actions and an extensive system of monitoring and deviation alarms to alert the operator audibly and visually to existing or incipient out-of-limit conditions.

9.2.2 Sensors Used

Temperature measurements are made with type K thermocouples located in wells or attached to surfaces. These thermocouples have magnesium-oxide insulated chromel/alumel temperature junctions and are sheathed in austenitic stainless steel.

The pressure sensors consist of a NaK-filled pressure-sensitive element, a thin-film strain gage transducer and a transmitter.

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FIGURE 9-11. Principal Elements of CLS Control System.

Sodium level is measured with induction-type coils in thimbles. Two coils are wound on a single form, so that the two are linked by the magnetic field generated by the excitation of one coil. The presence of sodium surrounding the probe thimble disrupts this magnetic field, causing variations in the voltage induced in the other coil. Included as a part of the level sensor are the associated electronics for sensor excitation, conversion of the process variable signal to a standard instrumentation signal, and transmission.

Flow is measured by permanent magnet flow meters installed around the CLS piping.

The magnet assembly is in the shape of a "U" suspended below the pipe. The magnet assembly is attached to the cell structure and is physically separated from the pipe.

Attached to the pipe within the flow meter are four independent pairs of electrodes, which are of the same material lot as the pipe so that thermal potentials are minimized.

Chromel/alumel thermocouples are installed in the magnet structure to monitor the magnet temperature. These permit corrections in the flow meter calibration curve.

100
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CHAPTER 10.

SODIUM AND ARGON COVER GAS MONITORING (SYSTEMS 85, 93-9 AND 94)

	Page
10.1 SUMMARY	10-3
10.1.1 Sodium Monitoring	10-3
10.1.2 Argon Cover Gas Monitoring	10-3
10.2 SODIUM MONITORING	10-3
10.2.1 Sodium Monitoring by System 85	10-3
Primary Sodium	10-3
Secondary Sodium	10-4
Plugging Temperature Indicator	10-4
Multipurpose Sampler	10-5
10.2.2 Sodium Analysis	10-6
10.2.3 Sodium Monitoring by System 94	10-6
Monitoring Heat Transport System Sodium	10-6
Monitoring Closed Loop Sodium	10-7
10.2.4 Electrical Heating of Sodium Monitoring Equipment	10-7
10.3 ARGON COVER GAS MONITORING	10-7
10.3.1 Argon Cover Gas Monitoring by System 85	10-7
Primary Systems Equipment	10-7
Secondary Systems Equipment	10-7
10.3.2 Argon Cover Gas Monitoring by System 94	10-8
On-Line Monitoring	10-8
Fuel Failure Location	10-8
10.4 INSTRUMENTATION (SYSTEM 93-9)	10-8

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98a
2/2/12

FIGURE 10-1. Laboratory Analysis of Sodium.

FIGURE 10-2. Reactor Primary Sodium Sampling and Monitoring System.

CHAPTER 10.

SODIUM AND ARGON COVER GAS MONITORING (SYSTEMS 85, 93-9 AND 94)

10.1 SUMMARY

Monitoring of FFTF coolant sodium and FFTF argon cover gas is provided both by System 85 (Impurity Monitoring and Analysis) and by System 94 (Fuel Failure Monitoring).

10.1.1 Sodium Monitoring

System 85 monitors all coolant sodium in the Heat Transport System and closed loops to detect gross levels of impurities. System 94 monitors primary sodium systems to detect any leaking fuel pins or test pins. For definitive analysis of sodium, samples are taken for laboratory analysis (Figure 10-1).

10.1.2 Argon Cover Gas Monitoring

System 85 monitors argon cover gas for process control and detection of absorber pin leakage. System 94 monitors cover gas to detect any fuel pin, test pin, or absorber pin leakage. Upon detection of a leaking pin, samples of cover gas are taken to the laboratory and analyzed to identify the exact fuel assembly, test assembly, or absorber assembly that contains the leaking pin.

10.2 SODIUM MONITORING

10.2.1 Sodium Monitoring by System 85

System 85 provides equipment to monitor saturation temperatures of all sodium

systems with on-line plugging temperature indicators (to measure gross impurity levels) and with multipurpose samplers to sample sodium for laboratory analysis.

Primary Sodium -- The reactor primary sodium monitoring and sampling system (Figure 10-2) consists of a primary sodium sampling loop that withdraws sodium from the reactor vessel, a plugging temperature indicator (PTI), two multipurpose samplers (MPS), and an associated distribution loop. An electromagnetic pump rated at 10 gal/min and total developed head of 31 psig is used for sodium circulation. Similar equipment is used for each of the closed loop primary systems.

The primary sodium monitoring and sampling areas are located in the Heat Transport System (HTS) Service Building - South in a compact and self-contained arrangement. Each primary sodium sampling line is provided with automatic containment isolation valves actuated by the Plant Protection System (System 99). (See Table 6-3 in Chapter 6.)

Two auxiliary PTI units are also provided within containment. One monitors the impurity level of the sodium in the Reactor Primary Processing System; the other PTI monitors the Reactor Primary Storage Processing System and the Interim Decay Storage System.

Secondary Sodium — A Sodium Sampling Package (SSP) (Figure 10-3) is provided for each secondary loop in the Heat Transport System and Closed Loop Systems. The SSP includes the following:

- Distribution Loop
- Plugging Temperature Indicator (PTI)
- Multipurpose Sampler (MPS) Welded to the Distribution Loop

Components of the Secondary Sodium Sampling Packages are similar to those used for primary sodium. The stations for monitoring

and sampling secondary sodium are located adjacent to the respective secondary loops.

Plugging Temperature Indicator -- The Plugging Temperature Indicator (PTI), shown in Figure 10-4, is used to measure gross impurity levels in sodium. It consists of three concentric tubes. An orifice is located at the lower end of the center tube. Sodium flows down the center tube through the four-hole orifice plate (with 0.052-in. diameter holes). Forced air flow between the outer and intermediate tube cools incoming sodium until soluble impurity precipitates form on the orifice, partially blocking flow.

FIGURE 10-3. Secondary Sodium Sampling Package.

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The sodium temperature at which the soluble impurities crystallize out of the sodium indicates the sodium purity, although results are not specific for any given impurity.

The PTI is packaged in a module that includes the sodium piping, flow control valve, flow meter, heaters, coolers, and economizer required for operation of the PTI.

Multipurpose Sampler — The Multipurpose Sampler (MPS) for sodium, shown in Figure 10-5, is a vertical section of 2-inch pipe with an economizer (heat exchanger) in the lower section and a sample chamber in the upper section. The upper section also includes a freeze vent that connects to the vacuum and purge gas systems. Sample holders are inserted into the chamber through the top opening of the MPS and mechanically connected to seal the system.

Flowing sodium enters the lower section of the MPS and flows up through the counterflow heat exchanger and through an annulus in the upper section. The sodium then discharges through wall ports at the top of the annulus and passes downward through the sample section before leaving the MPS. A multiple-section furnace encloses the MPS and is used to heat the sodium to about 1400°F before passing through the sample section.

The MPS can also be operated as an equilibration device, where equilibration specimens, consisting of wires or other material forms, are exposed to flowing sodium in the MPS and are then analyzed to measure concentrations of impurities absorbed by the wires. Vanadium, scandium and iron alloy are used for oxygen, hydrogen and carbon determinations, respectively. Materials for nitrogen determination are being evaluated.

FIGURE 10-4. Plugging Temperature Indicator.

FIGURE 10-5. Multipurpose Sampler for Sodium.

10.2.2 Sodium Analysis

Concentrations of impurities in the primary sodium of the HTS and closed loops are determined by laboratory analysis of sodium samples (Figure 10-1). Sodium samples of 30 to 40 grams are taken in the multipurpose sampler.

In case of fuel pin cladding failure, the concentration of fuel isotopes in the primary sodium will also be determined by laboratory analysis of sodium samples. In this process, the sample is vacuum-distilled to remove the sodium. The residue is analyzed for total alpha activity, then for concentrations of uranium and plutonium isotopes, if warranted. Comparison of these results with previous analyses indicates the amount of fuel that has escaped from the failed fuel pin.

10.2.3 Sodium Monitoring by System 94

The reactor heat transport and closed loop primary sodium systems are continuously monitored by System 94 BF_3 neutron detector tubes for delayed neutrons emitted by fission products released from failed fuel. The monitors activate an annunciator in the control room whenever the delayed neutron activity in any pipe exceeds a predetermined level.

A delayed neutron annunciation accompanying or following a rise in the fission gas activity (see Section 10.3.2.) indicates that a cladding failure has exposed fuel to the sodium coolant. After such an annunciation, the sodium may be sampled and analyzed to characterize the cladding failure.

Monitoring Heat Transport System

Sodium — Identical instrumentation channels containing signal conditioning, display and alarm equipment are provided for each of the three HTS primary loops. The detection system (Figure 10-6) for each loop consists of an electrostatically shielded assembly of three BF_3 -filled gas proportional neutron detectors mounted in the shielding and a moderator assembly adjacent to the hot leg pipe in the HTS cell, approximately 4 ft upstream from the first bend.

FIGURE 10-6. HTS Delayed Neutron Monitoring System.

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2/2/12

Maximum transport time of the sodium from the core to the pipe section where the delayed neutron monitors are located is 55 seconds at full flow.

System sensitivity depends on the signal-to-background ratio. The minimum detectable fuel escape is calculated to be 2.5 grams. The delayed neutron monitoring system can also detect fuel exposed to the primary sodium following cladding failure without any fuel release, since the recoil of fission products directly into the coolant can be detected, provided the breach uncovers at least 3.00 cm^2 of the outer fuel pin surface.

Monitoring Closed Loop Sodium — The closed loop delayed neutron monitoring system is almost identical to that of the HTS; the detectors are located adjacent to a hot leg pipe between the closed loop in-reactor assembly (CLIRA) and the closed loop cell.

10.2.4 Electrical Heating of Sodium Monitoring Equipment

All piping and components for monitoring sodium are heated with tubular electrical resistance heating elements to maintain the sodium in the liquid state. The heaters are capable of maintaining an isothermal system temperature of $1200^\circ\text{F} \pm 25^\circ\text{F}$ in an ambient temperature of 70°F . Thermal insulation is applied to heated surfaces as required to minimize heat loss.

10.3 ARGON COVER GAS MONITORING

10.3.1 Argon Cover Gas Monitoring by System 85

Equipment provided by System 85 is used to perform the following argon monitoring and sampling functions:

- Continuous monitoring of concentrations of oxygen, hydrogen, nitrogen, methane and carbon monoxide in all primary argon cover gas systems, with on-line gas chromatographs for process control
- Monitoring concentrations of helium in the primary Heat Transport System (the presence of significant quantities of helium at nominal zero reactor power would indicate an absorber pin leak)
- Providing argon to System 94 for on-line fuel failure monitoring
- Obtaining periodic bulk samples of argon cover gas from the primary and secondary Heat Transport and Closed Loop Systems for laboratory analysis.

Primary Systems Equipment -- The argon cover gas for the primary coolant systems is directly sampled from the gas equalization line connecting the reactor vessel and the sodium overflow vessel, and from each primary CLS surge tank. A continuous closed loop circulating flow is provided to a gas chromatograph, which is located in the HTS Service Building - South. The chromatograph sampling head selects each gas sequentially for analysis. Argon compressors circulate the sample gas.

Pneumatically operated isolation valves are automatically closed by the Plant Protection System (System 99) when required to assure containment isolation of lines from the primary systems (see Table 6-3).

Secondary Systems Equipment — Argon cover gas in the secondary systems is sampled manually from the HTS secondary expansion tanks and the CLS secondary surge tanks, using "grab sample" cylinders.

10.3.2 Argon Cover Gas Monitoring by System 94

System 94 provides: 1) on-line monitoring to detect the escape of fission gas from a

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leaking fuel assembly into the cover gas, or the escape of activated tag gas from a leaking absorber assembly, and 2) sampling equipment and analytical procedures to locate the leaking assembly.

On-Line Monitoring — Cover gas for the reactor heat transport primary system is scanned continuously with a thin pure germanium (Ge) diode gamma detector. Fission gas isotopes are monitored to detect fuel failures; and ^{125}Xe is monitored to detect an absorber pin failure when the reactor is at power. An alarm is activated in the reactor control room if an abnormal activity level is detected for any of these isotopes.

The level of activity detected by the monitor varies from 1 to 10 counts per second for the background case to as high as 10^5 counts per second during a rapid gas escape.

The cover gas is monitored in the Cover Gas Monitor Module by passing a continuous controlled flow through a small, liquid-nitrogen cooled, activated charcoal sample column adjacent to the gamma-sensitive germanium diode. Use of the sample column and thin detector permits accurate monitoring under conditions of high background radiation.

Fuel Failure Location — The technique for locating a failed fuel (or absorber) assembly is based on the use of unique mixtures of xenon and krypton in fuel and absorber pins. These tag gas mixtures are loaded into the pins at the time of fabrication.

All individual pins of a given fuel assembly contain the same unique isotopic mixture consisting of one std cc of xenon and one

std cc of krypton. All individual pins of a given absorber assembly contain the same unique isotopic mixture consisting of 2 std cc of xenon and 2 std cc of krypton. Over 106 unique mixtures will be used for the driver, open test and absorber assemblies of the core. Each time a fuel or absorber pin failure is detected, cover gas samples will be obtained with a tag gas sampling trap.

The failed assembly will be identified by matching the results of a mass spectrometer analysis with previously determined analyses of all tag gas mixtures in the reactor, suitably corrected for burnup and background.

10.4 INSTRUMENTATION (SYSTEM 93-9)

In support of System 85, System 93-9 (Impurity Monitoring and Analysis Instrumentation) provides instruments, controls, panels and related accessories.

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88a
2/2/72

CHAPTER 11.
STRUCTURES (SYSTEMS 21, 27 AND 93-1)

	Page
11.1 STRUCTURES SUMMARY DESCRIPTION	11-3
11.2 REACTOR CONTAINMENT (SYSTEM 27)	11-4
11.2.1 Reactor Containment Vessel	11-5
Vacuum Relief Valves	11-5
Containment Vessel Penetrations	11-5
11.2.2 Cells and Pipeways	11-6
Reactor Cavity	11-6
Heat Transport System Cells	11-6
Closed Loop System Cells	11-6
Interim Examination and Maintenance Cell	11-8
Cell Penetrations	11-8
Cell Access Closures	11-8
Equipment and Personnel Access	11-9
11.2.3 Polar Gantry Crane	11-9
11.3 REACTOR SUPPORT BUILDINGS (SYSTEM 21)	11-9
11.3.1 Reactor Service Building	11-10
11.3.2 Fuel Storage Building	11-10
11.3.3 Auxiliary Equipment Building - East	11-10
11.3.4 Control Building	11-10
11.3.5 Auxiliary Equipment Building - West	11-11
11.3.6 HTS Service Buildings - East and West	11-11
11.3.7 HTS Service Building - South	11-11
11.3.8 HTS Dump Heat Exchanger Structures	11-11
11.3.9 Closed Loop System Dump Heat Exchanger Structures	11-12
11.4 REACTOR CONTAINMENT INSTRUMENTATION (SYSTEM 93-1)	11-12

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2/2/12

FIGURE 11-1. Aerial View of the FFTF. (Building Numbers are Shown - See Table 11-1)

CHAPTER 11. **STRUCTURES (SYSTEMS 21, 27 AND 93-1)**

11.1 STRUCTURES SUMMARY DESCRIPTION

The principal FFTF structures consist of: 1) the Reactor Containment Building, 2) the Reactor Support Buildings surrounding the Reactor Containment Building, and 3) heat dump structures for the Heat Transport and Closed Loop Systems. These structures are listed in Table 11-1, and their locations are shown in Figure 11-1.

The FFTF complex also includes a number of auxiliary structures, such as electrical substations, pads for outdoor equipment, shops, offices, guard houses, the FFTF Visitor Center, and the like.

Normal functions of the FFTF structures are to house plant equipment and personnel and to provide shielding against radiation. The structures are also designed and constructed to provide safety to the public and to the plant in the event of abnormal operating conditions, earthquakes, or tornados.

The containment structure is designed to retain radioactive material that might be present in the unlikely event of equipment failure.

TABLE 11-1

PRINCIPAL FFTF STRUCTURES	
Building No.	Building Name
403	Fuel Storage Building
405	Reactor Containment Building
408-A	HTS Heat Dump Exchanger - East (HTS Loop 1)
408-B	HTS Heat Dump Exchanger - South (HTS Loop 2)
408-C	HTS Heat Dump Exchanger - West (HTS Loop 3)
409-A	Closed Loop System Dump Heat Exchanger (CLS 2)
409-B	Closed Loop System Dump Heat Exchanger (CLS 1)
491-E	HTS Service Building - East
491-W	HTS Service Building - West
491-S	HTS Service Building - South
4621-E	Auxiliary Equipment Building - East
4621-W	Auxiliary Equipment Building - West
4703	Control Building
4717	Reactor Service Building

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11.2 REACTOR CONTAINMENT (SYSTEM 27)

The Reactor Containment System consists of a cylindrical carbon steel reactor containment vessel 186 ft 8 in. high by 135 ft in diameter (Figure 11-2), along with several principal structures and equipment pieces within the vessel.

Steel-lined reinforced concrete cells occupy the lower portion of the containment vessel from grade level to approximately 78 ft below grade.

In the operating area a shielded operating floor is located at grade level (elevation 550 ft 0 in.).

The central portion of the operating floor is occupied by a steel operating deck (System 32), which is directly above the reactor head compartment. A large fuel handling machine (CLEM) provided by System 41 is located on the operating floor.

Above the perimeter of the operating floor is a structural steel mezzanine at elevation 570 ft 0 in. The mezzanine provides additional work area plus space for heating and ventilation equipment and a number of control panels.

Above the mezzanine, a 200-ton polar gantry crane and a jib crane are provided to satisfy hoisting requirements.

FIGURE 11-2. FFTF Containment Vessel.

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982
2/2/12

11.2.1 Reactor Containment Vessel

Design parameters for the reactor containment vessel are given in Table 11-2. Figure 11-3 gives a construction view of the vessel.

TABLE 11-2

REACTOR CONTAINMENT VESSEL DESIGN PARAMETERS	
Diameter	135 ft 0 in.
Overall Height	186 ft 8 in.
Internal Design Pressure	10 psig
External Design Pressure	0.2 psig
Design High Temperature	250°F
Design Low Temperature	-10°F
Allowable Leakage Rate at 10 psig(ambient temp)	0.1% vol/ 24 hr
Maximum Vacuum Relief Capacity at 4.5 in. H ₂ O	114,330 std ft ³ /hr
Design Life	20 yr
Operating Floor Elevation	550 ft 0 in.
Depth Below Operating Floor	77 ft 10 1/2 in.

Vacuum Relief Valves — The containment vessel is provided with two independent vacuum relief systems, each sized for the full relief capacity. Each system consists of two series-connected self-activated 16-in. diameter vacuum relief valves. These valves are a safety feature to prevent collapse of the containment vessel in the unlikely event of depressurization.

Containment Vessel Penetrations —

Penetrations are designed and tested for leaktightness to meet the overall leak rate requirement of the containment vessel. Penetrations of the unitized header plate type are used for all electrical conductors passing through the containment vessel. All pipes penetrating the containment vessel are anchored and sealed to the vessel. Lines and ducts that penetrate containment and that are normally in use but are not necessary to maintain the reactor in a safe condition are equipped with two isolation valves on each line, one located on either side of the containment vessel. These valves are closed automatically (see Table 6-3 in Chapter 6) if conditions arise that require assurance of containment integrity.

FIGURE 11-3. Placing Top on FFTF Containment Vessel.

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2/7/72

11.2.2 Cells and Pipeways

Below the operating floor are the cells and pipeways (Figures 11-4 and 11-5). These internal structures are made of reinforced concrete. Cells and pipeways that house piping and/or equipment containing primary system sodium are provided with an inert nitrogen gas atmosphere. Steel liners contain the inert atmosphere and protect the concrete from exposure to sodium in case of a spill. Cells containing large quantities of sodium are designed with liners backed with insulating brick.

The reactor cavity, located in the center of the containment vessel, houses the reactor vessel, the guard vessel, the main reactor support structure and associated shielding, and reactor piping. The cavity is insulated and temperature-controlled to maintain allowable temperatures for concrete.

The three HTS cells, which house the primary sodium pumps and intermediate heat exchangers along with associated equipment, piping and instrumentation for each of the three primary heat transport system loops, are adjacent to the reactor cavity on the east, south and west sides.

Four closed loop system (CLS) cells and associated pipeways are located between the east and south HTS cells and between the west and south HTS cells. The CLS cells are designed to contain pumps, heat exchangers, piping, equipment and instrumentation associated with the CLS primary heat removal systems.

The northwest quadrant of the containment, below the operating floor, is the location for the Interim Decay Storage (IDS) Vessel Cell and cells for the auxiliary liquid metal system equipment, piping and valves.

Reactor Cavity -- The reactor cavity is a 36-ft diameter cylinder located in the center of the containment vessel, 42 ft 1-13/16 in. high, with floor elevation at 489 ft 0 in. The reactor vessel and reactor vessel head are supported on a concrete ledge extending from the reactor cavity wall.

Heat Transport System Cells -- The three HTS Cells, one for each loop, are reinforced concrete structures approximately 37 ft wide by 35 ft radially. About half of each cell has a depth of 19 ft and the remaining area, nearest the reactor, has a depth of 43 ft to accommodate the primary pumps and intermediate heat exchangers.

Six monitoring accesses are provided through the operating floor to the top of the liner over HTS Cell 3 and its isolation valve area. When not in use, the access holes are filled with shielding plugs.

Closed Loop System Cells -- Each of the CLS cells is approximately 10 ft by 12 ft by 29 ft high and will contain a CLS primary module. Access to the cells is through access plugs, which contain sealed penetrations that may be used for surveillance periscopes.

FIGURE 11-4. Typical Plan of Internal Structures Within the Containment Vessel.

FIGURE 11-5. Typical Cross Section of Internal Structures Within the Containment Vessel.

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Interim Examination and Maintenance Cell — The IEM Cell is lined with stainless steel and has an argon atmosphere. Operation of the cell is performed from the top at elevation 550 ft 0 in. and in the shielded IEM Cell operating area from galleries with operating floors at elevations 532 ft 5 in., 516 ft. 0 in., 503 ft 3 in., and 495 ft 0 in. (See Chapter 12.)

Cell Penetrations — Piping that penetrates inert atmosphere cells is sealed to the steel cell liner. Two connection configurations are used; the first is a fully-rigid welded connection, and the second a flexible or bellows-type connection. Figure 11-6 shows a typical cell penetration with bellows expansion joints.

The cell liner penetrations for electrical conduits for power, control and instrumentation circuits consist of radiation-resistant wires pulled through embedded conduits designed to maintain the shielding integrity of the cell wall. Penetrations are confined to the low-temperature areas of the cell liners.

Surveillance periscope penetrations are small steel-lined circular stepped shield plugs, which are sealed to the cell liner by means of a compression seal; these provide access for inspection of piping, equipment and spaces.

The radiation surveillance penetrations are steel-lined, stepped tubes that go down to but not through the liner of HTS Cell 3 and its associated isolation valve area.

Three Reactor Cavity Access Penetrations are provided (see Figure 4-10). These permit use of closed-circuit TV equipment to inspect the Reactor Vessel exterior and reactor guard vessel interior during shutdown periods.

Cell Access Closures — Cell access closures consist of shielding access plugs, rolling shield plugs and steel shielding doors, soft shielding plugs, or shielding blocks, as applicable.

FIGURE 11-6. Typical Bellows-Type Piping Penetration of Inert Atmosphere Cell.

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Shielding access plugs are steel-lined (sides and bottom), tapered and stepped concrete plugs that fit into an embedded steel frame in the cell or pipeway ceilings. These plugs are equipped with seals to contain the inert cell atmosphere.

Rolling shield plugs are steel-lined, tapered and stepped concrete plugs mounted on wheels that roll on tracks in the floor. Cells utilizing rolling plugs have bulkhead-type gas-tight doors behind the plugs to contain the inert cell atmosphere.

Soft shielding plugs are made of concrete cast into a steel plug frame in a cell wall. The soft plug is removed by breaking up the concrete mechanically and is replaced by casting new concrete in place. The cell liner is continuous and must be cut out in order to secure cell entry. Soft plugs provide for future access to areas that have no present requirement for maintenance access.

Equipment and Personnel Access — An equipment airlock and two personnel airlocks are provided for access. Each lock has two doors in series. Each door is equipped with redundant seals and a pressure-equalizing valve. Interlocks are provided so that neither a door nor its equalizing valve can be opened unless the other door is locked and sealed. Also, a welded construction "hardpatch" on the containment vessel can be cut open if needed.

The equipment airlock is used for all transfers of fuel into and out of containment. It will also be used for transfer of large equipment, if such is needed for maintenance.

The equipment airlock is approximately 25 ft in diameter with doors at opposite ends,

each with a clear opening 11 ft wide by 16 ft 10 1/2 in. high. An emergency escape hatch in the airlock provides a 24-in. diameter opening. This airlock extends into the Reactor Service Building.

The personnel airlock is 10 ft in diameter and 12 ft long, with doors 6 ft 8 in. high and 3 ft 6 in. wide. This airlock extends into the Auxiliary Equipment Building - East in an area convenient to the control room.

The emergency airlock is 6 ft in diameter and 12 ft long, with doors 2 ft 6 in. in diameter. This airlock extends into the HTS Service Building - West, below grade level.

11.2.3 Polar Gantry Crane

The polar gantry crane is a massive steel frame structure with 16 wheels as its base. The crane moves around a circular rail track located on top of the box girder of the supporting structure at elevation 590 ft 6 in.

The bottom of the bridge on the polar gantry crane has a clearance of 65 ft above the operating floor. The main hook has a 200-ton capacity with a hook coverage radius of 53 ft 8 in. An auxiliary hook of 20-ton capacity has a coverage radius of 55 ft 7 in.

11.3 REACTOR SUPPORT BUILDINGS (SYSTEM 21)

The Reactor Support Buildings are the major buildings and structures (Figure 11-1) surrounding the reactor containment building. The reactor support buildings are concrete and steel structures. Their design reflects specific requirements to resist natural forces such as earthquakes, winds and tornadoes.

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892
2/2/72

All support buildings are structurally independent of the Reactor Containment Building and most of them are similarly independent of each other because of thermal and seismic requirements as well as functional and access requirements.

Exterior walls are generally made of sheet metal siding on steel frames, and roofs are generally sheet metal decking with insulated built-up roofing. Concrete walls or roofs are used when needed to meet special requirements.

Heating and ventilation barriers are provided throughout the Reactor Support Buildings to prevent fire propagation or gas leakage. Nitrogen flooding capability is provided in the secondary pump room for each HTS Service Building.

11.3.1 Reactor Service Building

The Reactor Service Building (No. 4717) is a structurally independent building with underground cells for offsite cask loading and for storage and processing of radioactive gases and waste. These cells include cell atmosphere processing system cells and pipeways as well as radioactive argon processing system cells and pipeways. The building's superstructure provides access for trucks and railroad cars to the equipment airlock. It contains a 100-ton bridge crane with an auxiliary 25-ton hook for handling equipment and materials. The bottom loading transfer cask, (see Chapter 12) is stored in this building.

11.3.2 Fuel Storage Building

The Fuel Storage Building (No. 403), under construction at the time this document was prepared, is adjacent to the Reactor Service Building. The principal equipment in the Fuel Storage Building is a below-ground cell containing a carbon steel storage vessel approximately 21 ft in diameter and 24 ft deep for storing up to 466 FFTF spent fuel assemblies in liquid sodium. (See Chapter 12.)

11.3.3 Auxiliary Equipment Building - East

The Auxiliary Equipment Building - East (No. 4621-E) is a two-story building with a full basement. It is structurally connected to the Control Building (No. 4703). The two buildings provide an integrated arrangement of plant control, auxiliary equipment, radiation monitoring, and controlled access to both the Reactor Containment and the Reactor Service Building. The Auxiliary Equipment Building - East contains diesel generator room No. 1, the personnel airlock access way, and a variety of auxiliary equipment.

11.3.4 Control Building

The Control Building (No. 4703) is a one-story building with a full basement. The building is designed to provide protection under emergency conditions to personnel who operate the reactor and its coolant system.

The control room within this building is a tornado-hardened, reinforced concrete structure with 3 ft 3 in. and 3 ft thick walls on the

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822
2/2/72

south and west sides, respectively, (closest to the reactor area) and 1 ft 3 in. thick walls on the north and east sides. The roof of the control room is 3-ft thick concrete. The control room floor is 1-ft thick and is supported on reinforced concrete beams.

11.3.5 Auxiliary Equipment Building - West

The Auxiliary Equipment Building - West (No. 4621-W) contains electrical distribution and switchgear areas, auxiliary electrical equipment rooms, and diesel generator room No. 2. It is a two-story building with a tornado-hardened basement.

11.3.6 HTS Service Buildings - East and West

The Heat Transport System Service Buildings - East (No. 491-E) and West (No. 491-W) are structurally connected and contain the secondary sodium pumps and piping as well as other portions of the Heat Transport System and Closed Loop System sodium equipment, switchgear, controls and electrical equipment.

Building 491-E provides access to the containment hardpatch area. Building 491-W provides access to the emergency airlock. Both are two-story buildings with concrete walls for the tornado-hardened secondary pump cells. The basements are also tornado-hardened.

Portions of the buildings containing sodium are of concrete, fire-resistant construction. Fire barriers are also provided, as well as steel cell liners and sodium catchpans (for retention of any possible sodium leaks).

11.3.7 HTS Service Building - South

The HTS Service Building - South (No. 491-S) contains the equipment for primary sodium sampling, closed loop sampling, cover gas monitoring and sampling, decontamination, and building inert gas cooling. The building is one-story with a basement.

11.3.8 HTS Dump Heat Exchanger Structures

Each HTS DHX pit is a concrete structure with a floor at 530 ft elevation; the top of the walls are at 554 ft elevation. The four DHX modules are tied together with structural steel framing in the form of a cross (referred to as the cruciform area). The cruciform area has a metal roof and siding part way to the floor to protect the pipe insulation and control cabinets from weather. The sodium piping to the cruciform area is protected by a pipeway enclosure. Sodium catch pans extending to the adjacent HTS Service Building are provided to protect the enclosure concrete from sodium leaks. At the ends of the HTS DHX structures, a slightly sloped roof just above the top of the walls provides weather protection for the DHX fans and fan motors.

Four dump heat exchanger 33-MW modules (DHXs) are located in each of three HTS DHX structures (No. 408-A, 408-B and 408-C). These are referred to as HTS DHX-East, South and West, respectively.

HTS DHX - East (No. 408-A) is tornado-hardened, with 1/2 in. steel plate on a structural steel frame located just outside the cruciform area to provide tornado protection for the DHX units below 580 ft elevation. The pipeway

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enclosure in this area is also tornado-hardened with 1/2 in. steel plate. (Only the HTS DHX - East is required for safe cooling of the shutdown reactor in the event of a tornado.)

11.3.9 Closed Loop System Dump Heat Exchanger Structures

The Closed Loop System Dump Heat Exchangers for CLS 1 and 2 are small-scale, single-module, 2.3-MW heat dumps. These structures are near grade level and are not tornado-hardened. The pipeways are provided with sodium catchpans to limit sodium-concrete reaction in case of a leak.

11.4 REACTOR CONTAINMENT INSTRUMENTATION (SYSTEM 93-1)

The Reactor Containment Instrumentation System provides instrumentation to perform the following major functions:

- Measure containment pressure and temperature
- Monitor position of containment isolation valves and provide the manual actuation capability for closing individual containment isolation valves

- Monitor position status of reactor containment airlock doors
- Periodically measure containment leak rate
- Measure and record any containment seismic activity
- Receive a signal from the Plant Protection System (System 99) to alarm when principal containment has been activated (i.e., when all valves are closed) (See Chapter 6.)
- Measure the temperature of the Interim Decay Storage (IDS) sodium pool (See Chapter 7)
- Measure the temperature gradients in the concrete support ledge for the reactor vessel

The containment atmosphere monitoring instruments and IDS temperature monitoring instruments are powered from the emergency power system.

Containment isolation valve position indicating instruments, pilot solenoids and electric operators are powered by the 125-V d-c battery system.

The seismic monitoring instrumentation requiring electrical power is supplied from self-contained batteries continuously maintained at design charge by the normal power system.

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2/2/12

CHAPTER 12.

REACTOR REFUELING AND TEST SPECIMEN HANDLING (SYSTEM 41)

	Page
12.1 SUMMARY DESCRIPTION	12-3
12.1.1 Ex-Reactor Components	12-3
12.1.2 In-Reactor Components	12-3
12.1.3 System Functions	12-4
Handling of 12-Foot Assemblies	12-4
Handling of Fuels Open Test Assemblies	12-6
Handling of Post-Irradiation Open Test Assemblies	12-6
Handling of CLIRA and MOTA	12-7
Use of Floor Valves and Adapters	12-7
Inventory Control	12-7
12.2 COMPONENTS	12-8
12.2.1 Closed Loop Ex-Vessel Machine	12-8
12.2.2 Bottom Loading Transfer Cask	12-10
12.2.3 Core Component Conditioning Stations	12-11
12.2.4 Test Assembly Conditioning Station	12-11
12.2.5 Interim Decay Storage	12-12
12.2.6 Fuel Storage Facility	12-13
12.2.7 Interim Examination and Maintenance Cell	12-14
12.2.8 In-Vessel Handling Machines	12-14
12.2.9 Shield Plug Handling and Storage	12-18
Plug Handling Fixture	12-18
Shield Plug Storage Station	12-18
12.2.10 Refueling Support Equipment	12-18

FIGURE 12-1. General Arrangement of Reactor Refueling Facilities.

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CHAPTER 12.

REACTOR REFUELING AND TEST SPECIMEN HANDLING (SYSTEM 41)

12.1 SUMMARY DESCRIPTION

The Reactor Refueling System includes facilities for the receipt, conditioning, storage, installation in and removal from the core of all core components and test assemblies that are routinely removable. Limited examination and packaging capabilities are also provided. All the principal equipment incorporates an inert argon gas environment for the fuel and test assemblies. The Reactor Refueling System includes components both inside and outside the reactor (Figure 12-1).

12.1.1 Ex-Reactor Components

The principal ex-reactor component is the Closed Loop Ex-Vessel Machine (CLEM) shown in Figure 12-2. The CLEM loads all components into the reactor and removes all components from the reactor.

Other principal ex-reactor components include two Core Component Conditioning Stations, a Test Assembly Conditioning Station, a Bottom Loading Transfer Cask, an Interim Decay Storage Vessel, an Interim Examination and Maintenance Cell, a Fuel Storage Facility and a Cask Loadout Station.

The Reactor Refueling System also employs the three Fuel Transfer Ports, eight test position spoolpieces, two floor valve adapters and the Test Transfer Port provided by System 32, and the Reactor Containment Building Cranes.

12.1.2 In-Reactor Components

The in-reactor components consist of three In-Vessel Handling Machines plus the three In-Vessel Storage Modules provided by System 32.

FIGURE 12-2. Closed Loop Ex-Vessel Machine (CLEM).

12.1.3 System Functions

The Reactor Refueling System handles three types of core assemblies: 12-ft assemblies such as Driver Fuel; 40-ft assemblies such as Fuels Open Test Assemblies (FOTA), which are loaded into the reactor full-length but are cut into two sections before removal; and 40-ft assemblies such as Materials Open Test Assemblies (MOTA) and Closed Loop In-Reactor Assemblies (CLIRA), which are loaded into and removed from the reactor as full-length sections. (See Chapters 3 and 9.) Typical sequences for each type of handling operation are summarized below, along with brief descriptions of contamination control and inventory control practices.

Handling of 12-Foot Assemblies — In the handling of twelve-foot assemblies such as driver fuel (Figures 12-3 and 12-4), an incoming assembly is first lowered by the crane into one of the two Core Component Conditioning Stations. In this station, the assembly is flooded with argon and heated to approximately 450°F. The assembly is then picked up by the Bottom Loading Transfer Cask and is transported, in an argon atmosphere, to the Interim Decay Storage Vessel. The assembly is then lowered into a sodium-filled Core Component Pot in the Interim Decay Storage Vessel. The assembly is held in Interim Decay Storage in liquid sodium at 500°F to 600°F until the reactor is shut down for refueling.

At the reactor, the plug is removed from the Fuel Transfer Port and an adapter and

floor valve are installed on the port. The control rod drive shafts are also disconnected, and the Instrument Trees are moved to their stored positions.

The CLEM then picks up the Core Component Pot containing the assembly and lowers it into an in-vessel storage module through the Fuel Transfer Port.

The next objective in the handling sequence is placing the assembly into the reactor core. First, the In-Vessel Handling Machine (IVHM) removes a spent assembly from the core and places it into an in-vessel storage module position. The IVHM then removes the new assembly from the Core Component Pot and places the new assembly into the core. Finally, it removes a spent assembly from the in-vessel storage module and places it into the Core Component Pot.

The CLEM then picks up the Core Component Pot and its contained spent assembly and places the Core Component Pot into the Interim Decay Storage Vessel. After a suitable decay period, the Bottom Loading Transfer Cask picks up the spent assembly and transfers it out of containment to the Fuel Storage Facility.

Before reactor startup, the In-Vessel Handling Machines are placed in their "stored" positions in the reactor. The Instrument Trees and Control Rod Shafts are restored to power-operation status, the adapter and floor valve are removed and the Fuel Transfer Port is sealed with its plug.

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FIGURE 12-3. Driver Fuel Handling Sequence.

FIGURE 12-4. Driver Fuel Handling Sequence Between Interim Decay Storage and Reactor Vessel.

Handling of Fuels Open Test Assemblies

— The 40-ft Fuels Open Test Assembly (FOTA) is placed by the crane into the Test Assembly Conditioning Station, where it is flooded with argon and preheated to 450°F.

The CLEM then places the assembly into the shutdown reactor, lowering it through the floor valve, Test Transfer Port, test position spoolpiece (in the center island) and then into one of the eight positions in the reactor core which accommodate 40-ft independently instrumented test assemblies.

When the test is completed, the 12-ft fuel assembly section is sheared from the FOTA instrument stalk assembly (Figure 12-5). The instrument stalk assembly is removed through the Test Transfer Port by the CLEM and is transported to the Interim Maintenance and Examination Cell. In this cell, the stalk is disassembled and loaded into a solid waste cask for disposal.

The Fuel Test Section is moved by the In-Vessel Handling Machine to a Core Component Pot under a Fuel Transfer Port. The CLEM then moves the Core Component Pot to the Interim Decay Storage Vessel. After decay, the CLEM moves the test section to the IEM Cell for examination.

Handling of Post-Irradiation Open Test Assemblies — If it is desired to reinsert an irradiated assembly as a Post-Irradiation Open Test Assembly (PIOTA), the test section is reinserted in the same manner as a driver fuel assembly. A modified type of instrument "stalk" (containing a flow meter and thermocouples) is inserted through the Test Transfer Port by the CLEM. The reverse sequence is followed for removal.

FIGURE 12-5. Removal of Fuels Open Test Assembly from the Reactor.

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Handling of CLIRA and MOTA — Handling of the Closed Loop In-Reactor Assembly (CLIRA) and the Materials Open Test Assembly (MOTA) is initially similar to handling of the FOTA.

After immersion in a Test Assembly Conditioning Station, the CLIRA or MOTA is loaded into the reactor core via a Test Transfer Port by the CLEM. When the assembly is to be moved, it is not necessary to sever the instrument stalk. Hence, the CLIRA and the MOTA are removed from the reactor core by the CLEM, via the Test Transfer Port. Movement is then by the CLEM to the Interim Examination and Maintenance Cell; in some cases, it may be necessary to go through an interim storage step in the Interim Decay Storage Vessel.

Use of Floor Valves and Adapters — The confinement of fission gases and contaminants is of special importance in all areas of fuel handling. Access to all the inerted or potentially contaminated facilities requires the use of equipment such as floor valves (Figure 12-6) and adapters unique to the particular facility or port involved. The most important adapters are the two Floor Valve Adapters and the Test Transfer Port. These adapters are part of System 32 (Chapter 4.)

Inventory Control — Because of the quantity of assemblies, the many possible variations in assembly types and the lack of direct observation at most residence or transfer points, an inventory system is provided. The control system traces all core assemblies, core component pots, etc. by location and also records the status of all storage locations.

FIGURE 12-6. Floor Valve.

12.2 COMPONENTS

12.2.1 Closed Loop Ex-Vessel Machine

The function of the Closed Loop Ex-Vessel Machine (CLEM) is to transfer reactor core components and test assemblies (which may be up to 40 ft long) between the various FFTF refueling stations. The CLEM has a 10-kWt heat removal capability and handles one component at a time.

The CLEM is 61 ft high and weighs 217 tons (Figure 12-7). It moves on a 40-ft wide transporter on tracks in the operating deck.

The temperature of the CLEM is controlled by a cold-wall cooling system and an electrical heating system. The cold-wall cooling system consists of an 8-in. pipe, having an array of straight fins attached to the outside. The normal cooling mode for the CLEM is by internal radiation of fuel assembly decay heat to the cold wall, which is externally cooled by ambient air circulated over the fins. During normal core component handling operations, the fuel pin cladding temperature of the driver fuel is limited to 1000°F.

The CLEM operator controls all machine operations from the control console in the cab mounted on the transporter trolley. The control of CLEM is semiautomatic, i.e., operations are performed automatically after the operator initiates a command. Interlocks to control the machine's operations have been incorporated into the design to meet safety requirements.

Manual overrides are also provided to permit the operator to take control if necessary. The grapple speed and push-pull load requirements in handling fuel are controlled through all modes of operation. Indexing of the CLEM to a refueling station is accomplished by manually operated controls.

The CLEM is hermetically sealed to a refueling station by lowering the movable closure valve which mates with a floor valve. Sealing this interface is accomplished by two inflatable seals (providing a double barrier), which engage the floor valve. The air trapped between the movable closure valve and floor valve is purged by the plant argon supply and vent system through hose connections made after the CLEM is indexed to a Fuel Transfer Port or Test Transfer Port.

Electrical and instrumentation connections are also made at each refueling station to control and monitor the operation of the floor valve and provide the interlock connections to assure safe operation, e.g., CLEM and the In-Vessel Handling Machine (IVHM) are interlocked at the reactor to prevent simultaneous operation in their common operating space.

The major subassemblies of the CLEM include: the grapple drive system, cask body modules, service platforms, a movable closure valve that mates with the floor valve, the cold-wall assembly, and a seal monitoring system.

FIGURE 12.7 Schematic of Closed Loop Ex-Vessel Machine (CLEM) and Transporter.

12.2.2 Bottom Loading Transfer Cask

The Bottom Loading Transfer Cask (BLTC) (Figure 12-8) transfers core components up to 13.5 ft long between transfer stations inside and outside the FFTF Containment Building. The BLTC is a single-barrel, internally cooled machine that travels on rails through the equipment airlock and in line with the Core Component Conditioning Stations and Interim Decay Storage. The BLTC grapple reaches through a floor valve on the operating floor and into each transfer station or cell to install or remove a core component for transfer to another station. The BLTC is about 10 ft wide by 22 ft long by 19 ft high. It is made up of three main parts: the cask, the dolly and the control system. The total weight is 72.5 tons.

The cask provides the shielding, inert environment, confinement, component grapping and 1.4-kWt cooling capability required to handle sodium-wetted, irradiated core components. It is about 8 in. inside diameter. The dolly provides traverse drive, cask elevation and seismic restraint functions. The control system provides the control consoles, motor control equipment and all interconnecting cable. Control of the BLTC is semiautomatic; key operations are automatically performed after the operator initiates a command. Interlocks are incorporated to meet safety requirements. Status lights indicate the exact machine conditions during all operations. Manual overrides permit the operator to complete key operations in case of a control system failure.

FIGURE 12-8. Bottom Loading Transfer Cask Schematic.

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The BLTC's normal cooling mode is by forced argon gas circulated through a closed system. The circulating gas transfers heat from the core component to the cask shielding wall.

12.2.3 Core Component Conditioning Stations

The function of the two Core Component Conditioning Stations (Figure 12-9) is to prepare 12-ft long core components for operation in liquid sodium at elevated temperatures. The components are immersed in an argon atmosphere and heated to 450°F.

Cooling nitrogen from System 25 is supplied to the exterior of the separate cells, up through the vaults, to maintain 100°F average cell wall temperature throughout the station.

Each station contains a heater-getter cell for heating the argon and an inerting and preheating cell. One station also contains a transfer cell that permits transfer of up to 13.5-ft long components between the Closed Loop Ex-Vessel Machine (CLEM) and the Bottom Loading Transfer Cask (BLTC).

12.2.4 Test Assembly Conditioning Station

The Test Assembly Conditioning Station provides argon flooding and preheating to 450°F for 27 40-ft long test assemblies. Space is also provided for storage of radioactive test assemblies, recycled closed loop in-reactor assemblies and shield plugs. All storage spaces will accommodate 40-ft assemblies. Design is generally similar to that of the Core Component Conditioning Stations.

FIGURE 12-9. Core Component Conditioning Stations.

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12.2.5 Interim Decay Storage

The primary function of the Interim Decay Storage (IDS) (Figure 12-10) is to provide a passive, controlled liquid sodium environment for damage-free temporary storage for new components en route to the reactor and for irradiated core components and test assemblies removed from the reactor. Sodium temperature is held between 500°F and 600°F. The IDS facility is located between the Closed Loop Ex-Vessel Machine (CLEM) rails, in a rectangular steel-lined shielded concrete cell lying entirely below the operating floor, with the top flush with the operating floor. The Bottom-Loading Transfer Cask (BLTC) rails traverse the IDS cover. The IDS consists of a rotatable storage basket submerged in liquid sodium in a stainless steel tank surrounded by a guard vessel.

Storage positions are provided for 112 core components 12 feet long in the upper section of the IDS storage basket. Ten storage tubes are included near the center of the basket to store the 40-ft test assemblies such as the FOTAs and CLIRAs.

During normal operation, two independent cooling systems are available. The IDS Sodium Cooling System circulates sodium from the IDS to an intermediate sodium NaK heat exchanger. The NaK is in turn cooled by a mobiltherm cooler. This sodium cooling system is part of System 81 (Chapter 7).

If it is necessary to remove the primary sodium cooling system from service for any reason, a backup nitrogen gas cooling system and an emergency natural convection air cooling system (provided by System 25) may be utilized (Chapter 14).

FIGURE 12-10. Interim Decay Storage.

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12.2.6 Fuel Storage Facility

The Fuel Storage Facility (FSF, Figure 12-11) was designed as a separate project after the FFTF design was completed. The project includes a main 12,200-ft² Fuel Storage Facility building and a 72 ft by 72 ft extension of the Reactor Service Building (RSB). It is designed to handle fuel for the first five years of FFTF operation. The fuel storage vessel, 21 ft in diameter and 24 ft deep, contains

liquid sodium for cooling spent fuel from the FFTF. It is surrounded by a guard tank. Two heat exchanger systems dissipate decay heat from the irradiated fuel elements immersed in the sodium for storage.

The 62-ft high RSB extension provides an enclosure for movement of fuel between the FFTF and FSF. The building extension also contains a cask loadout station below ground, where spent fuel elements can be placed in casks for offsite shipment.

FIGURE 12-11. Fuel Storage Facility Under Construction.

12.2.7 Interim Examination and Maintenance Cell

The Interim Examination and Maintenance (IEM) Cell is a shielded hot-cell complex that provides a reliable means of conducting nondestructive examinations of test assemblies and core components under controlled argon atmosphere conditions.

The IEM Cell contains equipment necessary for disassembly, reassembly and requalification of test assemblies and components. Nondestructive examinations that can be performed include dimensional checks, weighing, gamma scanning, visual inspections and photography.

The IEM Cell can also be used to perform limited maintenance of plant equipment, or to prepare plant equipment for transfer to other maintenance facilities. Cell ceiling valves and an access plug are provided over the cell for transfer of all core components and maintenance equipment in and out of the IEM Cell. Sodium removal facilities are included in the cell.

Four levels of operating galleries, which encompass the cell operating face along the north and east walls, provide visual access for remotely operating the in-cell equipment.

The operating galleries are provided with shielded viewing windows, masterslave manipulators, communication equipment, in-cell viewing aids, and consoles and controls necessary for performing cell functions. The operating galleries also include the transfer locks, entrance plugs, interconnection plugs and

associated equipment, and other support equipment and systems necessary to perform in-cell operations.

Primary control of measuring equipment for component positioning, data acquisition, reduction, storage and readout is accomplished with a computer system and its associated peripheral equipment. Manual control is also provided for selected operations from a console at the operating station.

Service cells containing process equipment for support of in-cell sodium removal equipment are located in the Reactor Service Building. This process equipment consists of tankage, valves, heat exchangers, blowers, piping, etc. When operated with the in-cell equipment as a closed system, it is an extension of containment.

12.2.8 In-Vessel Handling Machines

The function of the three In-Vessel Handling Machines (Figure 12-12) is to move 12-ft core assemblies back and forth between the reactor core and the In-Vessel Storage Modules, and between the storage locations in the modules and the Core Component Pots located beneath the Fuel Transfer Ports. All movements are under sodium.

These movements supplement the functions of the CLEM, which operates through the three Fuel Transfer Ports to place Core Component Pots into the In-Vessel Storage Modules and to remove the pots.

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FIGURE 12-12. In-Vessel Handling Machine.

Each of the three IVHMs services its own 120-degree sector of the reactor core. Figure 12-13 is a plan view showing the locations of the In-Vessel Handling Machines and the In-Vessel Storage Modules. Figure 12-14 is an elevation view showing one of the In-Vessel Handling Machines in its position in the reactor.

Each IVHM includes a large plug (known as the Reactor Refueling Plug) installed in the reactor head. Eccentrically mounted on the plug, inside the vessel, is an arm structure. Attached to this structure is a grappling device used to grasp core components. Both the plug and arm structure can be rotated by independent ex-vessel drive systems and the arm structure can be raised or lowered.

The coordinated movement of the plug and arm structure allows operators to place the grappling device over any core or storage location within the IVHM's trisector.

The control console employs a computer programmed by a tape containing the sequence of moves for each component being handled.

The core component identification technique is based on use of notches on the outside of the core component handling socket; these notches are positioned geometrically to represent the serial number in binary count.

During reactor operation, the IVHM arm is stored radially adjacent to the core, near the vessel wall.

FIGURE 12-13. Plan View Showing Locations of In-Vessel Handling Machines.

FIGURE 12-14. Reactor Cutaway Showing In-Vessel Handling Machine.

12.2.9 Shield Plug Handling and Storage

Plug Handling Fixture -- A Plug Handling Fixture (Figure 12-15) removes, transports and replaces the FFTF shield plugs. The Plug Handling Fixture is a portable machine with a winch assembly and grapple enclosed in an airtight container. It is moved by the cranes in the FFTF Containment Building and is normally stored in the Containment Building over the Shield Plug Storage Station. The Plug Handling Fixture is nominally 6 ft in diameter, 13 ft high, and weighs 17 tons. The control mode is manual with automatic override shutoff at safety or operational setpoints.

Shield Plug Storage Station -- A shield plug storage station vault is located west of the reactor, just south of primary sodium pump No.3. The argon-filled section of the vault contains storage positions for various types of shield plugs. Air cells are provided for general purpose storage. A valve pit area, located east of and adjacent to the shield plug storage station, houses the piping and manually operated valves that control the argon atmosphere in the vault.

12.2.10 Refueling Support Equipment

Refueling support equipment includes facilities for handling nonirradiated fuel, a solid waste cask and other handling equipment.

FIGURE 12-15. Plug Handling Fixture.

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CHAPTER 13.

ELECTRICAL POWER SUPPLY (SYSTEMS 11 AND 12)

	Page
13.1 PRIMARY ELECTRICAL POWER (SYSTEM 11)	13-3
13.1.1 Main Preferred Electrical Service	13-3
13.1.2 Alternate Preferred Electrical Service	13-4
13.2 BUILDING ELECTRICAL POWER (SYSTEM 12)	13-4
13.2.1 Main Heat Transport System Power System	13-4
13.2.2 Plant Power System	13-6
13.2.3 FFTF Emergency Power System	13-6
Emergency Power Systems 1 and 2	13-6
Emergency Power Systems 3, 4 and 5	13-6
13.2.4 Safety Power Systems	13-8
Batteries	13-9
ZTO Systems	13-9
Inverters	13-10
13.2.5 Emergency Lighting	13-10
13.2.6 Special Features of System 12	13-10
Wire and Cable	13-10
Penetrations	13-11
Grounding System	13-11
System Separation	13-12
Electrical System Annunciation	13-12
Cathodic Protection	13-12

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FIGURE 13-1. Simplified BPA Transmission Line Map for FFTF Interties.

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CHAPTER 13.

ELECTRICAL POWER SUPPLY (SYSTEMS 11 AND 12)

13.1 PRIMARY ELECTRICAL POWER (SYSTEM 11)

The Primary Electrical Power System provides 13.8-kV electrical power services at the FFTF Site from the Bonneville Power Administration (BPA) lines.

Figure 13-1 is a map of the FFTF Site and vicinity showing transmission lines and substations. (A number of circuits have been omitted for clarity.)

Two electrical services are provided to FFTF by the primary electrical power system:

- A main preferred service from a connection to the BPA network at the Benton Switching Station. This service includes the main power transformer to step the BPA utility voltage (115 kV) down to the FFTF utilization voltage (13.8 kV).
- An alternate preferred service from a separate connection to the network to provide (13.8-kV) emergency power for conditions when the main preferred service is not available. The alternate preferred service connects the FFTF to the 300 Area 13.8-kV system.

The two FFTF power services are independent. The incoming circuit breakers that connect the two services to the FFTF 13.8-kV buses are interlocked to prevent interconnection of the main preferred and alternate preferred services through these buses.

The power services are designed, constructed and equipped with protection in accordance with industry standards for environmental and operational transient conditions including wind, ice loading, temperature, lightning, flooding, seismic disturbances and switching surges.

13.1.1 Main Preferred Electrical Service

Design parameters of the main preferred electrical service are given in Table 13-1. The design basis load is 47 MVA.

TABLE 13-1

MAIN PREFERRED ELECTRICAL SERVICE DESIGN PARAMETERS	
• Voltages* at 115 kV level:	
Nominal	115 kV
Minimum	113.5 kV
Maximum	120 kV
• Voltages* at 13.8 kV level, with 30 MVA demand:	
Nominal	13.8 kV
Minimum	13.11 kV
Maximum	14.52 kV
• Frequency:	
Nominal	60 Hz
• Capacity, transmission line:	
	119 MVA
• Capacity, substation transformer:	
	50 MVA

*Range expected 95% of the time.

13.1.2 Alternate Preferred Electrical Service

Design parameters of the alternate preferred electrical service are given in Table 13-2. This service provides 3 MVA of 13.8-kV power from the 300 Area.

TABLE 13-2

ALTERNATE PREFERRED ELECTRICAL SERVICE DESIGN PARAMETERS	
• Voltage:	
Nominal	13.8 kV
Minimum	13.11 kV
Maximum	14.52 kV
• Frequency:	
Nominal	60 Hz
• Capacity, transmission line:	
3 MVA	

13.2 BUILDING ELECTRICAL POWER (SYSTEM 12)

The Building Electrical Power System (System 12) distributes and controls electrical energy for the FFTF. This system consists of the Main Heat Transport System (MHTS)* Power System (24 MVA load), the Plant Power System, and the FFTF Emergency Power System (which consists of five emergency Power Systems and two Safety Power Systems (Figure 13-2).

The power received by System 12 from the Main Preferred Service passes through 13.8-kV circuit breakers and is stepped down via transformers (Figure 13-3) to supply 2400 volts to the MHTS Power System, and 480 volts to the Plant Power System and to the FFTF Emergency Power System.

*The Main Heat Transport System (MHTS) is the same as the Heat Transport System (HTS).

Power received by System 12 from the Alternate Preferred Service passes through 13.8-kV circuit breakers and 13.8-kV/480-V transformers. This power is supplied to the FFTF Emergency Power System only.

13.2.1 Main Heat Transport System Power System

The MHTS Power System operates only when power is available from the Main Preferred Service.

The loads of the MHTS Power System are equally divided between three load centers and include the three primary pump main motors, three secondary pump main motors and twelve DHX fan motors, all operating at 2400 volts a-c. To provide pump shutdown and/or reactor scram upon signal from the Plant Protection System (PPS), two series-connected, independent circuit breakers that trip open upon signal from the PPS are provided between the main preferred power supply and each MHTS load center. Each of the two PPS breakers has two independent trip coils powered from separate 125-V d-c supplies.

In addition, the switchgear contains a fused disconnect switch in the line that provides power to the motor of the primary control rod drive mechanism MG Set. Through this arrangement, a complete loss of primary MHTS pumping power will result in reactor scram. An undervoltage relay is also provided for each primary pump main motor. The relay sends a signal to the Plant Protection System (PPS) to scram the reactor when power is lost to any primary pump.

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FIGURE 13-2. FFTF Building Electrical Power System Block Diagram.

FIGURE 13-3. 13.8-kV Transformers Ready for Installation.

13.2.2 Plant Power System

Loads supplied by the Plant Power System are loads that can be deprived of 480-V a-c power for extended periods without impact on the safety of the facility and without significant economic loss.

13.2.3 FFTF Emergency Power System

The FFTF Emergency Power System consists of five Emergency Power Systems and two Class IE Safety Power Systems (Figure 13-4) at the 480-V level. Loads supplied through the FFTF Emergency Power System are loads that require continued power after loss of the Main Preferred Service.

When both preferred electrical services are available, the power supplied to the FFTF Emergency Power System comes from the main preferred electrical service. If the main preferred electrical service is lost for longer than two seconds, the Plant Power System automatically disconnects the main preferred electrical feed, drops all loads except the FFTF Emergency Power System and connects the alternate preferred power electrical feed to the FFTF Emergency Power System.

If alternate preferred electrical service is lost for longer than six seconds following the loss of main preferred electrical service, the FFTF Emergency Power System is disconnected and operates alone, supplying power produced by its two diesel generators, its turbine generator and its storage batteries.

In case the emergency generators are lost also, the batteries and battery-driven systems within the FFTF Emergency Power System supply sufficient electrical power to the Plant Protection System (Chapter 6) and other critical systems to assure safe shutdown of the reactor.

Emergency Power Systems 1 and 2 --

Emergency Power Systems 1 and 2 are similar and provide redundant power to the same plant loads. Each includes a safety power system, emergency lighting, 125-V d-c supply, and a diesel engine generator set that supplies 1100 kW at 480 volts (Figure 13-5). Starting of the engine is normally automatic, initiated by the undervoltage relay on the associated emergency load center bus; loading is controlled by a load sequencer.

Emergency Power Systems 1 and 2 are physically and electrically separated to minimize the probability that a single event could cause loss of function in both systems.

Emergency Power Systems 3, 4 and 5 --

Emergency Power System 3 is powered from either Emergency Power System 1, 2 or 4 and supplies certain important emergency loads such as the pony motors for the primary and secondary pumps of HTS Loop 1.

Emergency Power System 4 is an onsite emergency power supply and distribution system. The onsite power supply is a single, seismically qualified 3-MW gas turbine generator set with auxiliaries. The gas turbine generator is being installed as this document goes to press.

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FIGURE 13-4. Simplified Single Line Diagram of FFTF Emergency Power System Incorporating Gas Turbine Generator.

FIGURE 13-5. Diesel Engine Generator Set.

182
2/2/12

The generator set and auxiliaries are located in a tornado-hardened building and are adequately sized to supply power to Emergency Power Systems 1, 2 and 3, as well as to Emergency Power System 4 loads if the main and alternate preferred electrical services are lost.

Emergency Power System 5 is a distribution system that does not have its own onsite power source.

13.2.4 Safety Power Systems

There are two Safety Power Systems in the FFTF. Safety Power System 1 (part of

Emergency Power System 1) provides power to safety-related loads that provide critical plant control and monitoring functions. Safety Power System 2 (in Emergency Power System 2) is similar and provides an independent, redundant supply to these loads.

Each Safety Power System contains a battery, battery charger, distribution panels, d-c motor control centers, Zero Time Outage (ZTO)* and inverter 120-V a-c systems, associated metering and protective relaying, and raceway and cable (Figure 13-6).

*FFTF plans call for replacement of the ZTO systems with Class 1E inverters.

FIGURE 13-6. One of the Two Safety Power Systems.

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In design, construction and installation, Safety Power Systems meet the requirements for Class IE power supplies as defined by IEEE Standard 308. All equipment and the associated raceway is classified as Seismic Category I and is tornado-hardened.

During normal plant operation, energy for the Safety Power Systems is supplied by the main preferred electrical service. In the event of loss of that offsite power, the plant is shut down and power from the offsite alternate preferred service supplies the Safety Power Systems. When both offsite services are lost, the onsite diesel generators and the turbine generator provide power to the Safety Power Systems. In case all a-c power is lost, the Class IE batteries within the systems provide the energy for necessary surveillance, control and monitoring (Table 13-3).

Batteries — Each storage battery is of 60-cell, 125-V, lead acid type. The battery is rated for 830 ampere hours at 77°F and an 8-hour cell discharge, with cell voltage to be 1.75 V or higher (105 V for the total battery).

ZTO Systems — Each Zero Time Outage (ZTO) MG Set has a 35-hp, 480-V a-c 1800-rpm induction motor, a 25-hp d-c motor, a 15-kW, 120-V a-c single-phase generator and a flywheel mounted on a common shaft.

The ZTO MG Set provides continuous power to instrumentation loads. With 480-V a-c power available from the Emergency Power System, the ZTO MG Set is driven by the induction motor. The generator output is 120-V a-c, regulated to within 1% with a nominal frequency of 60 Hz. When a-c drive power from the Emergency Power System is lost, the d-c motor automatically takes over to drive the generator.

Due to the regulating action of the control system and the inertial properties of the flywheel, the generator voltage and frequency do not significantly change during this transfer, thus producing no undesired effect on the PPS or other instrumentation supplied by the ZTO system.

TABLE 13-3

**SAFETY POWER SYSTEM BATTERY LOADS
FOR 7-DAY PERIOD
FOLLOWING LOSS OF ALL A-C POWER**

Short-Term Loads After Start of Outage

- Zero Time Outage MG Set with 100% load on generator
- MHTS power circuit breaker tripping and containment isolation valve switching control
- Mobiltherm isolation motor-operated valves
- DHX fine control damper buffers
- DHX manual control for dampers
- Miscellaneous d-c loads

Intermittent Loads During 7-Day Period

- Ex-vessel neutron flux monitoring
- In-containment radiation monitoring
- IDS cooling valve control

Continuous Loads for the 7-Day Period

- Continuous measurement and readout for containment pressure and for temperatures in containment, IDS, primary hot and cold legs, secondary cold leg, and DHX outlet
- Emergency portable control room lighting
- Metering instruments for d-c and inverter output
- Battery leakage resistance

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Inverters -- Each Safety Power System includes an inverter system to convert 125-V d-c power from the batteries to 120-V a-c power to supply selected Class IE and surveillance loads in the event that a-c power from offsite sources and from the emergency system is not available. The inverter system also supplies a-c power to a few loads during normal plant operation. The inverter system consists of two inverters (one rated at 250 VA and the other at 500 VA), two transfer switches and associated metering, protective relaying, raceways and wiring.

13.2.5 Emergency Lighting

Emergency lighting is supplied by the FFTF Emergency Power System. Four types of emergency lighting are employed. The first and most prevalent type uses selected lamps from the normal power multi-lamp fluorescent fixtures throughout the plant.

The second type of emergency lighting has a system of battery-inverter 120-V supplies that power all exit lights except those in the head compartment and a few selected control room and stairwell lights. If power is not available to operate these supplies through their battery chargers, the battery capacity is sufficient to power the lights for 90 minutes.

The third type of emergency lighting consists of fixed and portable wall-mounted lights with integral batteries.

In addition to the above, a small amount of control room lighting is provided as a Class IE load powered by the Safety Power Systems. Four special control room outlets, two for each safety system, are provided for extension-cord-type lighting.

13.2.6 Special Features of System 12

Wire and Cable -- All wire and cable were specified and selected to be flame-retardant and to perform for the expected lifetime of the plant in the anticipated environments. Cable specifications were categorized according to voltage level and environmental duty.

Adverse-environment-type wires and cables are insulated and jacketed with polyimide compounds. Halogen-related materials are not used. The cables will endure a twenty-year integrated radiation dosage of 2×10^{10} rads, and are capable of carrying current continuously at a maximum conductor temperature of 125°C with a 50°C maximum ambient temperature. The 600-V power and control cables pass the flame-resistance test of IPCEA S-61-402, Section 6.5. The 300-V instrumentation cables pass the ASTM D2633, Section 30 flame test.

Nonadverse-environment-type wires and cables are also flame resistant, in accordance with IPCEA S-19-81, Section 6.19.6.

Penetrations — Electrical penetration assemblies (Figure 13-7) are installed in the containment vessel wall to provide electrical circuit continuity into containment while maintaining the leak-tight integrity of the vessel. Most of the penetration assemblies consist of a 12-inch carbon or stainless steel header plate drilled with several holes. Each header plate is bolted to a nozzle flange, which in turn is welded to a containment wall nozzle. A double seal arrangement is provided. Inner barrier penetrations are used to seal conduits that terminate in cells having a closed or inert atmosphere. Two types of penetration seals are used: connector box seals and conduit seals.

Grounding System — A ground grid is installed throughout the plant, both indoors and outdoors, to facilitate system and equipment grounding. The ground grid is composed of three primary components:

- Three grounding wells and two water wells with a water line forming a loop around the perimeter of the ground grid
- A main ground grid of 5/8-inch diameter steel cables grounded to the water line loop at 100-foot intervals
- Building ground grids consisting of two 5/8-inch diameter steel cables a minimum of 18 inches below grade around the perimeter of each building and copper conductors within the buildings connected to the main ground grid.

FIGURE 13-7. Typical Electrical Penetration.

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System Separation — The electrical system is separated by systems and voltage levels for the purposes of:

- Preventing loss of capability to perform a function vital to safe plant shutdown, post-shutdown cooling and monitoring, or important to avert major economic damage to plant or equipment as the result of a single occurrence
- Minimizing inadvertent scrams or shutdowns and thereby maintaining maximum plant availability
- Protecting plant personnel from accidental contact with hazardous high voltage
- Reducing the risk of spreading a fire originating from a short circuit or overload in a high-energy circuit
- Minimizing introduction of electrical noise into sensitive low-level instrumentation circuits.

Redundant system circuits are routed through conduits or cable trays specifically designated for an individual channel of a system.

Electrical System Annunciation -- Annunciation of trouble conditions for important parts of the Building Electrical Power System is provided by System 93-14, Plant Annunciator System.

Cathodic Protection — System 12 also provides cathodic corrosion protection for six underground FFTF tanks.

CHAPTER 14.
AUXILIARY SYSTEMS
(SYSTEMS 23, 24, 25, 93-4, 93-5 AND 93-6)

	Page
14.1 HEATING AND VENTILATION (SYSTEM 25)	14-3
14.1.1 Reactor Containment Building Air Conditioning Supply and Filtered Exhaust System	14-3
14.1.2 Control Area Heating and Ventilating Systems	14-3
Control Area Central Air Conditioning System	14-3
Control Area Life Support System	14-4
14.1.3 Local Air Conditioning and Supply Systems	14-5
14.1.4 Cell Gas Cooling Systems	14-5
14.1.5 RAPS and CAPS Cell Cooling and Atmosphere Pressure Control Systems	14-5
14.1.6 Reactor Component Cooling Systems	14-6
14.1.7 IDS Special Cooling Systems	14-6
14.1.8 Cell Purge Exhaust Systems	14-7
14.2 HEATING AND VENTILATION INSTRUMENTATION (SYSTEM 93-6)	14-7
14.3 SERVICE PIPING (SYSTEM 23)	14-7
14.3.1 Sanitary Water and Related Systems	14-7
14.3.2 Coolant Fluid System	14-8
In-Containment Chilled Water System	14-9
Ex-Containment Chilled Water System	14-10
Standby Chilled Water System	14-10
Mobiltherm System	14-11
Cooling Water System	14-11
14.3.3 Compressed Air System	14-12
14.3.4 Other Systems	14-12
Fuel Oil Distribution System	14-12
Diesel Generator Auxiliary Service Systems	14-13
Sewer Systems	14-13
Acid Waste System	14-13
Atmospheric Pressure Reference System	14-13
14.4 SERVICE PIPING INSTRUMENTATION (SYSTEM 93-4)	14-13
14.5 RADIOACTIVE WASTE (SYSTEM 24)	14-13
14.5.1 Radioactive Liquid Waste System	14-14
14.5.2 Radioactive Solid Waste System	14-14
14.6 RADIOACTIVE WASTE INSTRUMENTATION (SYSTEM 93-5)	14-14

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FIGURE 14-1. Reactor Containment Building Air Conditioning Supply and Filtered Exhaust System.

CHAPTER 14.

AUXILIARY SYSTEMS (SYSTEMS 23, 24, 25, 93-4, 93-5 AND 93-6)

14.1 HEATING AND VENTILATION (SYSTEM 25)

The Heating and Ventilation system performs multiple functions which include: 1) providing atmospheric temperature, humidity and cleanliness control within FFTF for personnel comfort and for proper operation of instruments, 2) providing recirculating gas cooling services to cells and reactor components requiring gas cooling to avoid excessive temperatures due to heat losses from sodium-cooled equipment, and 3) preventing the release of airborne radioactivity to the outside environs in response to signals from the operator, the Plant Protection System (System 99) or the Radiation Monitoring System (System 96).

14.1.1 Reactor Containment Building Air Conditioning Supply and Filtered Exhaust System

Figure 14-1 is a schematic of the Reactor Containment Building air conditioning supply and filtered exhaust system.

The Reactor Containment Building central air conditioning supply system consists of two 100% capacity air conditioning units and a duct system that distributes conditioned air to the Reactor Containment Building. The containment filtered exhaust system consists of two 100% capacity exhaust fan units and a 100% capacity high-efficiency particulate filter. The particulate filter is bypassed in normal operation and is used only for abnormal conditions.

This filter provides a minimum particulate removal efficiency of 99.97%, based on a nondestructive test with a homogeneous aerosol of 0.30-micron diameter particles determined according to Mil Std 282 Method 102.91.

The central air supply and exhaust penetrations through the containment vessel are equipped with two automatic isolation valves, one on each side of the vessel wall, so that the possible failure of one valve to close would not result in loss of isolation.

Exhaust air from containment is continuously monitored by radiation detectors provided by the Radiation Monitoring System (System 96) prior to discharge to the outside environment. The double isolation valves in supply and the exhaust lines are controlled by the Containment Isolation System of the Plant Protection System (System 99) and are automatically closed should radioactivity above allowable limits be detected in the exhaust air.

Six seconds are required for the exhaust gas to flow from the monitoring point to the containment isolation valve; this provides time to close the valve and prevent release of radioactivity.

14.1.2 Control Area Heating and Ventilating Systems

Control Area Central Air Conditioning System — This system consists of two 100% capacity air conditioning supply units, one 100%

capacity return/exhaust fan and a duct system that distributes conditioned air to the control room, computer room and adjacent areas of the control room.

Control Area Life Support System —

The life support system consists of two 100% capacity outside air supply filter-fan units, a duct system to the control area, and an air conditioning unit with two 100% capacity supply fans (one is redundant). (See Figure 14-2.)

If a signal is received indicating high levels of radiation or sodium oxide (or chlorine from a possible accident at another Hanford location) the Control Area Air Conditioning System is stopped, and all air intakes to the shielded portion of the control building are automatically closed.

The life support system automatically starts in a recirculation mode. The appropriate air intake to this life support system is manually selected later from the control room, after assessment of the outside meteorological and radiological conditions.

Upon loss of normal plant electrical power, the life support system is operated in place of the Control Area Air Conditioning System to maintain ambient temperatures in the Control Area and ZTO MG Set Room No. 1 at a maximum of 100°F. The system is automatically restarted on emergency power within two minutes after loss of normal plant electrical power.

FIGURE 14-2. Control Area Life Support System.

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14.1.3 Local Air Conditioning and Supply Systems

Local air conditioning units are provided as necessary to circulate outside air for ventilating and cooling. Recirculating air coolers are provided in areas where supplemental cooling is required because of high local heat loads. Local heaters are provided where supplementary heating is required in winter. Several important local air conditioning and supply systems are discussed below.

The HTS Service Building - South Air Conditioning System operates continuously during normal plant operation. Normally, the exhaust air does not contain any radioactive contaminants. Therefore, the air is discharged directly to the outdoors without any need for filtering. A filter-fan unit is isolated from the normal exhaust air stream and is in a standby condition. A high efficiency particulate filter unit is automatically valved into the exhaust stream upon receipt of a signal from the duct radiation monitor.

The two Diesel Generator Room Supply Fan Systems are operated automatically and are started up by the emergency load sequencer within 10 minutes after loss of normal plant electrical power. Each system is composed of two supply fan units, each rated at 50% of system capacity. Each system contains a thermostat that indicates room temperature and controls the position of the return and outside air dampers on the fan units to maintain the room temperature between 60°F and 120°F.

The Reactor Service Building H&V System maintains pressure control, cooling and

heating of the work areas in the Reactor Service Building. The pressure control function maintains all Reactor Service Building work areas at positive pressures with respect to all potentially contaminated areas to minimize the possibility of contamination migration into the work areas. The exhaust air from the work areas is continuously monitored by the Radiation Monitoring System (System 96) to alarm if any radioactivity is detected in the exhaust air.

The heating and ventilating system for the Closed Loop Systems outside the Reactor Containment Building includes air-conditioning units, exhaust fans, booster blowers, and ducts ranging in width from six inches to three feet.

14.1.4 Cell Gas Cooling Systems

The cell gas cooling systems consist of recirculating gas coolers piped in closed gas-tight cooling circuits. The coolers use chilled water coolant from the Service Piping System (System 23) and serve to cool gas supplied by the Inert Gas Receiving and Processing System (System 82).

14.1.5 RAPS and CAPS Cell Cooling and Atmosphere Pressure Control Systems

The Radioactive Argon Processing System (RAPS) Cell Pressure Control System serves the RAPS steel-lined cells, which house RAPS components potentially containing high levels of radioactivity. This system prevents the spread of airborne contamination in the Reactor Service Building lined cells by maintaining the cell pressure below that of the adjacent work areas.

The RAPS, CAPS and Radioactive Liquid Waste Cells Cooling and Pressure Control Systems serve the unlined cells of the RAPS, CAPS and Radioactive Liquid Waste Systems. The cells are interconnected with the pipeways that serve as the common exhaust path to the Containment Exhaust System. Local recirculating air coolers are placed in cells having high heat loads. This system prevents the spread of airborne contamination in the Reactor Service Building unlined cells by maintaining a negative cell pressure relative to the building work areas.

Radioactive gases in these cells have a very low potential for leakage. However, the exhaust line to the Containment Exhaust System is monitored for radiation (System 96); and upon detection of significant radiation levels, the cell exhaust is automatically diverted to the Cell Atmosphere Processing System.

14.1.6 Reactor Component Cooling Systems

The Control Rod Drive Mechanism Cooling System, the Low Level Flux Monitor Gas Cooling System and the Center Island Gas Cooling System are individual nitrogen gas cooling systems having 100% redundant cooler/blower sets. Pressurized gas is used to improve performance in the Control Rod Drive Mechanism and Low Level Flux Monitor Gas Cooling Systems.

14.1.7 IDS Special Cooling Systems

An IDS Vessel N_2 Backup Cooling System and an IDS Vessel Emergency Cooling System (Air) are provided (Figure 14-3).

FIGURE 14-3. IDS Vessel N_2 Backup Gas Cooling System and IDS Emergency Cooling System.

The IDS Vessel N₂ Backup Cooling System is the backup unit to the IDS Vessel Sodium Cooling System (System 81). It consists of one recirculating inert gas cooler piped in a closed cooling circuit with the IDS Cell. Within the IDS Cell, the backup cooling system connects to a cooling annulus formed between the outside surface of the IDS Guard Tank and the insulation assembly.

The IDS Vessel Emergency Cooling System utilizes a part of the IDS Vessel Nitrogen Backup Cooling System piping and ducts to provide a flow path for the circulation of air by natural convection between the IDS vessel cooling annulus and the containment atmosphere. A control system operable from the control room utilizes Class IE electric power from the emergency power system to open valves in the convection flow path.

14.1.8 Cell Purge Exhaust Systems

Portable filter and exhaust fan units are provided for air-purging inerted spaces within containment. The discharge of these units is to the atmosphere through the Containment Exhaust System. Similar systems are provided for the gas or air atmosphere cells outside containment.

14.2 HEATING AND VENTILATION INSTRUMENTATION (SYSTEM 93-6)

The Heating and Ventilation Instrumentation System provides instruments and controls to perform the following functions for all System 25 equipment:

- Measure process system variables
- Provide operating status indication of each major piece of air conditioning equipment
- Provide alarms to alert operating personnel when normal operating limits are exceeded or a system malfunction has occurred
- Control temperature, pressure, flow and dewpoint regulating equipment
- Provide oxygen concentration monitors in cells

The Heating and Ventilation Instrumentation System also provides control signals to System 93-4 to control the operation of the chilled water valves in System 23 as required to meet cell gas cooling needs of System 25. No portion of the Heating and Ventilation Instrumentation System is required for operation of the Plant Protection System (System 99).

14.3 SERVICE PIPING (SYSTEM 23)

The FFTF Service Piping System provides sanitary water, cooling of auxiliary process equipment, compressed air, sewers, fuel oil and similar services during reactor startup, normal operations and shutdown.

14.3.1 Sanitary Water and Related Systems

The plant water requirements are supplied by the Sanitary Water System. Water is provided from two onsite wells. Two electric motor-driven vertical turbine pumps, rated at approximately 180 gal/min each, deliver water to two separate water storage tanks (T-58 and T-87) with a capacity of 218,000 gallons each.

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These tanks supply the sanitary water distribution system through pumps P-19 and P-29, and supply the Fire Protection System (System 26) through pumps P-27 and P-28. In tank T-87 180,000 gallons of water are reserved exclusively for fire protection service.

The Demineralized Water System located in the Reactor Service Building and is supplied with water from the Sanitary Loop. The demineralizer is a 5-gal/min capacity, two-resin-bed duplex type with automatic change-over and regeneration controlled by conductivity instruments. The demineralizer unit is equipped with a prefilter, pressure regulator, chlorine filter and backflow preventer in the supply line. The pH of the

regeneration effluent is adjusted before discharge to the process sewer.

The Humidification System consists of two electric steam generators each rated at 600 lb/hr. The generators supply two humidifiers, which inject the steam into the System 25 ducts when moisture is needed to maintain desired humidity levels.

14.3.2 Coolant Fluid System

The Coolant Fluid System (Figure 14-4) provides heat removal for H&V coolers and air conditioning units (System 25), heat exchangers (System 81), compressors (Systems 23 and 82), electrical components (System 51) and other equipment in Systems 41 and 82.

FIGURE 14-4. Coolant Fluid System.

The Coolant Fluid System consists of several cooling systems as follows:

- In-Containment Chilled Water System
- Ex-Containment Chilled Water System
- Standby Chilled Water System
- Mobiltherm* System
- Cooling Water System

*Trademark of the Mobil Oil Corporation

The Chilled Water Systems collect heat from heating, ventilating and other equipment, and transfer this heat to freon refrigerant in "chiller" components; in turn, this heat is transferred by the freon to the Cooling Water System.

The Mobiltherm System collects heat from the NaK heat exchangers of System 81 and transfers this heat to the Cooling Water System.

The Cooling Water System picks up heat from all the other systems and releases it to the atmosphere in the FFTF Cooling Towers. The Cooling Water System also provides cooling to compressed air equipment, RAPS and CAPS compressors and aftercoolers in System 82, and the liquid rheostats of System 51.

Upon loss of offsite power, critical components of the coolant fluid system are operated by the emergency power system.

In-Containment Chilled Water System

The heat from inert gas and in-containment air coolers in System 25 is removed by transferring the heat in the air and gas to the water-glycol fluid of the In-Containment Chilled Water System. This system consists of four chillers, each including a compressor, condenser and evaporator (Figure 14-5), two chilled water expansion tanks, and four chilled water pumps

FIGURE 14-5. Chilled Water Refrigerator Units for In-Containment Chilled Water System.

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(all located on a concrete pad near the Reactor Service Building), five booster pumps for in-containment air coolers, and eight electric-motor-actuated fail-as-is isolation valves powered by Class 1E power. The valves are located on the ex-containment side of each penetration and are remotely actuated from the control room or manually overridden locally. Each chiller is rated at 400 tons (i.e., 4,800,000 Btu/hr).

Each chiller and pump is sized for one-third of the system capacity. Three chillers handle the normal cooling load. The fourth chiller, with its associated pump, acts as a spare unit. The condensers on the In-Containment Chilled Water System chillers are cooled by water from the cooling water system.

The nominal composition of the coolant fluid is 45% inhibited ethylene glycol and 55% water. The fluid enters the chillers at 45°F and exits at 35°F. Flow rate per chiller is 1237 gal/min.

Equipment serviced includes 20 gas coolers, the five containment work area air coolers and the IDS System Cooler (all in System 25). Piping sizes range from 1 inch to 16 inches.

Ex-Containment Chilled Water System

The heat from ex-containment air conditioning units (System 25) and other specific equipment (Systems 41 and 82) is removed by transferring it to a chilled water system, which employs a mixture of 45% inhibited ethylene glycol and 55% water as a coolant medium.

The major portion of the system consists of four main water chillers. Each water chiller includes a compressor, condenser, and evaporator, two chilled water expansion tanks, and four chilled water pumps, all located in the Reactor Service Building. Each chiller and pump is sized for 1/3 of the system capacity. Each chiller is rated at 400 tons; flow rate is 1100 gal/min per chiller. This system services 44 air conditioners/coolers.

Two small secondary (35-ton) chilled water loops are also provided to cool the System 41 Sodium Removal System and the System 82 CAPS condenser (E-270). Since the potential exists to contaminate this chilled water with radioactivity if a leak occurred in the System 41 or 82 equipment, the chilled water in these loops is separated from the main chilled water system by chilled water auxiliary heat exchangers. The loops consist of the two chilled water heat exchangers, two secondary chilled water pumps, and one expansion tank, all located in the Reactor Service Building. Each of the loops is sized to handle 100% of the cooling requirements.

Standby Chilled Water System — The Standby Chilled Water System, a closed cooling system completely independent of the Chilled Water System, provides necessary cooling to designated equipment during periods of emergency power operation.

This system consists of two completely redundant loops each having a 20-ton water chiller, a pump, and an expansion tank. Flow rate is 54 gal/min. The Standby Chilled Water System operates on emergency power only.

Mobiltherm System — Mobiltherm is used for cooling the two NaK Systems (see Chapter 7), since Mobiltherm would not exothermally react with NaK in case of accidental contact between these fluids.

The Mobiltherm system consists principally of one cooling water/Mobiltherm heat exchanger (E-1000), which supplies 96 tons of cooling, one Mobiltherm pump (P-400) rated at 400 gal/min, one air separator (U-700) and one expansion vessel (T-300), all located on a concrete pad along the pipeway of the Auxiliary Equipment Building - West, plus two electric-motor-actuated fail-as-is Containment Isolation Valves powered by Class 1E power. The valves

are located on the ex-containment side of each Mobiltherm penetration and are remotely actuated from the control room or manually overridden locally. Leak alarms are provided.

Cooling Water System — The cooling water system discharges approximately 12 MW of heat to the atmosphere through forced-draft evaporatively cooled cooling water towers (Figure 14-6). The cooling water enters at 95°F, flows inside the tubes of the towers and exits at 85°F. Treated water is sprayed on the outside of the tubes. Cooling air is forced over the external tube surfaces by blowers, and the resultant warm moist air is discharged vertically.

FIGURE 14-6. Cooling Water Towers.

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The cooling water system includes eight cooling towers, eight associated cooling water pumps, two cooling water expansion tanks, interconnected piping, and a spray water treatment system employing two pumps and a chemical injection system.

The cooling towers, pumps and expansion tanks are located outdoors at grade level northwest of the containment building. Each cooling tower and pump is sized for 14.3% of the system capacity. Seven cooling towers and pumps will operate the normal cooling load of 3380 tons of cooling at 10,598 gal/min of cooled water. (Each tower is rated at 482 tons cooling load at 1534 gal/min.) The eighth unit (cooling tower and pump) acts as a spare.

Cooling load during emergencies is 553 tons at 1873 gal/min; two towers are operated by the emergency power system under emergency conditions.

The cooling water used in this system contains 45% ethylene glycol (to prevent freezing) and also rust inhibitors.

14.3.3 Compressed Air System

The Compressed Air System is designed to provide all compressed air requirements for instrument air, breathing air and utility air.

Three compressors (each rated at 50% of total design requirements) supply total air requirements of 800 std ft³/min through a pipe distribution system with the required controls and instrumentation. A water-cooled after-cooler and a water separator with an automatic water condensate trap are located downstream from each compressor.

The compressed air supply services are capable of continuously supplying instrument air after loss of normal electrical power. Emergency power is made available to the compressors during power failure by the Emergency Power System. The compressors may be started on emergency power at the option of the control room operators. In addition, in order to assure continued supply to important air systems on loss of air pressure, backup air cylinder supplies are automatically activated to provide instrument air to in-containment equipment, Closed Loop System and Main Heat Transport System DHXs, equipment airlock doors and other important equipment.

Breathing air is provided to the personnel, emergency and equipment air locks and at all use points by breathing air manifolds and outlets.

Utility air, at sufficient pressure (100 psig) and flow rates, is supplied to all serviced systems to satisfy their operational and maintenance requirements.

14.3.4 Other Systems

Fuel Oil Distribution System — The Fuel Oil Distribution System provides fuel for the following equipment:

- Emergency diesel-driven fire pump (System 26)
- Sodium preheaters for HTS Dump Heat Exchangers 1, 2 and 3 (System 51)

The diesel engine fire pump is supplied with fuel from the diesel supply tank, located below grade adjacent to the pump house. Flow is maintained by the fuel pump on the engine.

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The HTS Dump Heat Exchanger preheaters are supplied with fuel oil from three underground storage tanks, with pressure on the supply piping maintained by three transfer pumps. Three additional transfer pumps are provided in parallel for system redundancy. These 10-gal/min positive displacement preheater fuel transfer pumps are connected to the emergency power system to assure heat dump operation during emergencies.

Diesel Generator Auxiliary Service Systems -- The Diesel Generator Auxiliary Service Systems supply diesel fuel, starting air, cooling water, lube oil, air supply and exhaust, and oily waste systems for each diesel-driven emergency generator.

Each diesel generator is gravity fed by a 1300-gallon day tank, which is sufficient to operate the diesel engine for 16 hours at full-load fuel consumption of 80 gallons per hour. Diesel Fuel Oil No. 2 is used. Two underground fuel oil storage tanks of 20,000-gallon capacity each supplement the day tank.

Sufficient stored pressurized air is provided to crank the diesel engine for five 10-second starts. Compressors are also provided to restore this air supply.

Sewer Systems -- The Sanitary Sewer System provides for the collection of solid and liquid sewage from the reactor support buildings. The Process Sewer System provides for the collection of nonradioactive waste water from all systems to which sanitary water is provided, but which are not served by the Sanitary Sewer System. Both systems feed into site disposal facilities.

Acid Waste System -- The Acid Waste System neutralizes battery acid waste and delivers it to the process sewer system.

Atmospheric Pressure Reference System -- The Atmospheric Pressure Reference System provides the outside air (atmospheric) pressure reference for systems that must maintain pressure differentials between enclosed spaces and the outside atmosphere. The system consists of a 6-inch OD cylindrical reference chamber exposed to the outside air. (The containment penetration is in System 25.)

14.4 SERVICE PIPING INSTRUMENTATION (SYSTEM 93-4)

The Service Piping Instrumentation System (System 93-4) provides instrumentation for the Service Piping System (System 23) to monitor and control system functions. No portion of the Service Piping Instrumentation System is required by the Plant Protection System (System 99). System malfunctions are alarmed locally and in the control room.

Portions of the instrumentation system required for emergency operation of inert gas and air heat removal equipment are powered from the emergency power system. Fuel oil and air system controls required to operate the emergency diesel power system are powered from the 125-V d-c battery system.

14.5 RADIOACTIVE WASTE (SYSTEM 24)

The design of the Radioactive Waste System is predicated upon the goal of as-low-as-practicable release of radiation.

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All radioactive liquid wastes are collected by the Radioactive Liquid Waste System and sent to the Hanford 200 Area for disposition. All radioactive solid wastes are packaged via the Radioactive Solid Waste System and sent to the Hanford 200 Area for disposition.

All handling, storage and transportation of radioactive wastes is carefully controlled in accordance with DOE-approved procedures to assure safety of plant personnel and the public.

14.5.1 Radioactive Liquid Waste System

The Radioactive Liquid Waste System provides equipment and facilities for collection, temporary storage and transfer of radioactive liquid wastes. The system also provides for monitoring and sampling of the liquid wastes. The system is primarily designed to process low/intermediate-level liquid wastes (waste activity concentration of $1.0 \mu\text{Ci/ml}$ or less).

Radioactive liquid wastes are collected by floor drains, sumps, drums and a small collection tank (200 gallon tank T-132), and routed to the 5000 gallon liquid waste storage tank T-103. Liquid wastes are temporarily stored and sampled, and the low/intermediate-level waste pH is adjusted prior to discharge to a tank car for shipment to the disposal area.

No sources of high-level liquid radioactive waste have been identified. However, all necessary receiving, sampling and transfer equipment has been provided.

14.5.2 Radioactive Solid Waste System

The Radioactive Solid Waste System handles both low-level and high-level solid wastes. Low-level solid wastes are collected and temporarily stored or scheduled for immediate transfer to the Hanford 200 Area. (Low-level solid wastes are wastes that do not require shielding to maintain a dose rate of less than 100 mrem/hr at the surface of the package.)

High-level solid wastes are packaged in a shielded container and transferred to the Hanford 200 Area. (High-level solid wastes are wastes that require shielding or the use of special handling procedures to maintain a dose rate of less than 100 mrem/hr at the surface of the package.)

14.6 RADIOACTIVE WASTE INSTRUMENTATION (SYSTEM 93-5)

The Radioactive Waste Instrumentation System provides instrumentation for the Radioactive Waste System (System 24) to monitor and control liquid waste storage, transfer from storage vessels to transportation equipment, and to provide signals to the Plant Annunciator System if limits are exceeded. No portion of the Radioactive Waste Instrumentation System is required for operation of the PPS.

The Radioactive Waste Instrumentation System is powered from the normal a-c power system. Functions include the monitoring of flow, temperature and liquid level; and the control of pumps and valves operation.

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CHAPTER 15.

RADIATION MONITORING AND FIRE PROTECTION (SYSTEMS 26, 93-7 AND 96)

	Page
15.1 RADIATION MONITORING (SYSTEM 96)	15-3
15.1.1 Area Monitoring	15-3
15.1.2 Containment Isolation Radiation Monitoring	15-4
15.1.3 Effluent Air Monitoring	15-4
15.1.4 Process Monitoring	15-5
RAPS Monitors	15-5
CAPS Monitors	15-5
Other Typical Monitors	15-5
15.2 PLANT FIRE PROTECTION (SYSTEM 26)	15-6
15.2.1 Nitrogen Flooding of Secondary Ex-Containment Sodium Areas	15-7
15.2.2 Automatic Gas Blanketing System for Computer Areas	15-7
15.2.3 Aqueous Film-Forming Foam System	15-7
15.2.4 Automatic Water Sprinkler Systems	15-8
15.2.5 Fire Hoses and Fire Hydrants	15-8
15.2.6 Portable Fire Fighting Equipment	15-8
Portable Fire Extinguishers	15-8
Miscellaneous Portable Equipment	15-8
15.2.7 Municipal Fire Alarm System	15-8
15.3 PLANT FIRE PROTECTION INSTRUMENTATION (SYSTEM 93-7)	15-9
15.3.1 Fire Detection and Alarm Instrumentation	15-9
15.3.2 Fire Water Supply System Controllers	15-9

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FIGURE 15-1. Fixed Radiation Monitor.

FIGURE 15-2. Functional Diagram of Fixed Radiation Monitor.

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CHAPTER 15.

RADIATION MONITORING AND FIRE PROTECTION (SYSTEMS 26, 93-7 AND 96)

15.1 RADIATION MONITORING (SYSTEM 96)

The policy for the FFTF is that exposure of employees, visitors and the public to ionizing radiations shall be as low as practicable, using direction of ERDA Manual Chapter 0524. Radiation exposure is minimized by identifying potential radiation hazards, using shielding, confining radiation sources, monitoring radiation levels, planning operations to minimize individual exposure, training personnel in radiation protection, and measuring and limiting exposure. Particular attention is given to limiting individuals to low radiation dose levels.

The Radiation Monitoring System (System 96) provides indications of radiation levels, warnings of any radiation conditions above limits, signals to various control functions, and inputs into the computer for recording and analysis. To ensure reliable service, all radiation monitors are powered from emergency power sources.

15.1.1 Area Monitoring

Area monitoring equipment consists of fixed and portable radiation monitoring sensors, readouts, alarms and air samplers whose primary purpose is to protect personnel by monitoring plant work areas and ventilating systems.

Fixed monitors (Figures 15-1 and 15-2) are provided throughout plant work areas to monitor continuously the radiation status of the plant and to provide indication and alarms in monitored areas and the control room if limits are exceeded. The monitors provide continuous measurement of gamma radiation levels from 0.1 mrem/hr to 10^4 mrem/hr.

Three gamma monitors in containment and three in the Reactor Service Building (RSB) are each connected in two-out-of-three logic; this arrangement automatically initiates an evacuation alarm if limits are exceeded.

Continuous Air Monitors (CAMs) sample the work area atmospheres. Most of the CAMs monitor beta and gamma activity in particulate matter and in gaseous form.

Other equipment includes portable samplers to collect airborne activity on filters, counting room equipment to measure the activity from filters and samples, general-purpose portable radiation monitors, and hand and shoe counters.

The portable health physics equipment includes state-of-the-art devices for maintaining an excellent radiation protection program. Provision is made for measuring all forms and energies of ionizing radiation anticipated in operation of the plant.

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88a
2/2/12

This includes the capability of discriminating one from another to the extent required for good control of the more hazardous isotopes. Portable air sampling and continuous monitoring capability is provided for collecting particles, halogens and other gases. Samples are taken from Heating and Ventilating (H&V) ducts as well as from spaces occupied by workers.

15.1.2 Containment Isolation Radiation Monitoring

The main H&V duct, which vents all of containment, and the H&V duct, which vents the head compartment to the main H&V duct, are each monitored with a set of three redundant gamma detectors to issue signals to the PPS to initiate closure of the Containment Building H&V valves if a preset limit is exceeded, and to initiate complete containment (see Table 6-3 in Chapter 6) when a higher preset limit is exceeded. These six monitoring channels are part of the PPS and meet PPS system requirements. They are powered from the Safety Power System.

The two sets of gamma detectors are of the same design. One set is adjacent to the main H&V exhaust duct, with about six seconds of transit time (at normal flow rate) before the exhaust air leaves containment, and the other set is adjacent to the head compartment duct upstream from its junction with the main containment exhaust duct. The sensors will respond to radioactivity caused by radioactive gases or particulates.

In either case, the radioactive gas or entrained particulates are detected with sufficient lead time that the H&V valves can be closed before the active material can leave containment.

A mobile continuous monitor is to be employed for monitoring airborne radioactivity of the atmosphere inside the containment vessel during any containment isolation.

15.1.3 Effluent Air Monitoring

Effluent air monitors are provided by System 96 on building exhausts that could potentially contain radioactive materials as the result of process system malfunctions or accident conditions. The design objectives of the Plant and of the Radiation Monitoring System are responsive to the direction of ERDA Manual Chapter 0524 to limit the release of radioactivity to as low as practicable.

The air in the Control Building is monitored for gaseous and beta particulate activity to determine whether the building air is contaminated to the extent that the life support system must be activated and to monitor the status of the air contamination when the life support system is in use. Air is sampled from the duct that transports air to the control room. The continuous monitors provide indication and annunciation in the control room and are recorded by the computer.

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2/2/12

15.1.4 Process Monitoring

The Process Monitoring equipment monitors gases at the Radioactive Argon Processing System (RAPS) inlet and outlet, CAPS inlet and outlet, selected inert gas cells and process equipment, and exhaust gases from unlined cells and pipeways of the Reactor Service Building.

RAPS Monitors — Radiation detection equipment monitors the inlet to the RAPS cryogenic section and provides a signal to System 82, which controls the inlet valve to maintain the rate of input of radioactivity below a specified value. Coupled to accessory equipment, one of these monitors performs the additional functions of diagnosis and calibration at the RAPS inlet to measure the concentration of selected radioisotopes.

A monitor, located on the RAPS outlet, controls a valve that allows re-use of the argon or diverts it to the CAPS inlet if the radioactivity level is above limits.

CAPS Monitors — A monitor on the CAPS cryogenic section inlet measures the inlet activity and provides a signal to System 82, which controls the inlet valve to restrict the rate of input of radioactivity at or below a specified value.

PPS monitors on the CAPS outlet permit release of the effluent to the H&V exhaust if the radioactivity is sufficiently low to conform to federal standards.

If not, the effluent is diverted back to the CAPS inlet for reprocessing. These monitors are powered by the Safety Power System.

Other Typical Monitors -- The nitrogen sampling and analysis equipment of System 82, which periodically samples the atmosphere from selected inerted cells, provides monitoring for cell atmosphere radioactivity.

The Reactor Service Building (RSB) exhaust from unlined cells and pipeways is monitored for gaseous radioactivity prior to dilution by the containment exhaust. A signal is provided for use by System 25 to divert this exhaust to the CAPS collection header when a predetermined level is exceeded.

The Interim Examination and Maintenance (IEM) cell monitors measure radiation levels within the IEM cell and IEM cell annex. They provide the capability to continuously monitor the radiation level inside the cell and allow monitoring of individual core components in the cell as required. One of the two detectors can be moved by remote handling equipment. The radiation in the cell consists primarily of beta and gamma radiation from irradiated reactor fuel and radioactive sodium that adheres to the core components. The monitors have a range of up to 10^6 R/hr. A remote display is provided in the IEM cell operating galleries.

Two monitors are provided to continuously monitor radiation levels at the CLEM. One is located on the main body of the

CLEM. This monitor indicates the presence of active fuel in the CLEM and utilizes an ionization chamber for detection. A display from this monitor is provided in the control cab on the CLEM transporter trolley. A second monitor is at the cold wall outlet of the CLEM. This monitor also provides display in the control cab and recording on magnetic tape.

A gamma-sensitive detector is mounted in a recess in the Bottom Loading Transfer Cask (BLTC) closure valve area. Radioactivity from the fuel assembly is monitored as it is withdrawn from a floor station. If the radiation level exceeds a predetermined limit, the grapple automatically reinserts the fuel assembly into the floor station.

A ^{235}U fission counter is provided to monitor neutron radiation levels in the Interim Decay Storage (IDS) cell, to confirm subcritical arrangement of the fuel stored and verify design calculations. Display is provided at the IDS control console on the operating floor level.

15.2 PLANT FIRE PROTECTION (SYSTEM 26)

The Plant Fire Protection System (System 26) and the associated Plant Fire Protection Instrumentation System (System 93-7) provide fire detection and alarms, as well as control of all types of fires that may occur in parts of the plant other than within inert atmosphere cells in the Reactor Containment Building.

System 26 provides two fire water pumps, each rated at 1736 gpm at 125 psig. Pump P-27 is driven by an electric motor. Pump

P-23 is driven by a diesel motor, which is started by an automatically rechargeable battery pack. Both P-27 and P-23 are identical split case double suction single-stage units. Each pump can be separately fed from either storage tank T-58 or T-87. The discharge of each pump is directly piped to the yard loop.

The yard loop is an 8-inch cast iron pipeline that supplies water at 125 psi static pressure for fire protection to all areas of the site. This loop also supplies the sanitary water needs for FFTF.

The Plant Fire Protection System employs nitrogen and portable sodium carbonate extinguishers to control secondary sodium fires, halogenated gas blanketing for computer fires, aqueous film-forming foam for Mobiltherm fires; portable CO_2 extinguishers for electrical equipment fires, and water for other fires. Also, fire alarm signals are relayed to the central fire station in the Hanford 300 Area.

All FFTF Fire Detection/Alarm/Protection equipment conforms to applicable requirements of the Underwriters' Laboratories, the Factory Mutual Laboratories, the National Fire Codes, and/or the National Fire Protection Association.

The effectiveness of the Plant Fire Protection System is augmented by many FFTF design features. Many fire doors are used and dampers are installed in ventilation ducts.

If a fire is detected in a cell, the dampers are automatically closed to stop air flow through the cell. The ex-containment fire doors are kept closed. One in-containment

stairwell is enclosed by a fire partition to allow egress from the lower levels in case of fire. Fire partitions are also used throughout the plant to divide corridors, cableways, buildings, etc. into physically separated fire zones.

Ex-containment secondary sodium areas (with a few minor exceptions) are provided with steel catch pans to prevent contact between the concrete and any leaking sodium.

A Factory Mutual Laboratories approved sprayable fire-retardant cable-coating material was applied to concentrated groups of combustible, insulated electrical cables (in lieu of the use of wet pipe sprinklers) in areas containing alkali metals and switchgear.

All penetrations (i.e., ducts, pipes, cables, cable trays, tubing and conduit) passing through fire partitions, fire floors, fire ceilings, nitrogen flooding boundaries or heating and ventilation boundaries are sealed; such fire penetrations have a two-hour fire rating.

15.2.1 Nitrogen Flooding of Secondary Ex-Containment Sodium Areas

The Fire Protection System uses manually activated nitrogen flooding in secondary ex-containment sodium areas for extinguishing sodium fires.

The nitrogen flooding system is designed to prevent inadvertent flooding of an occupied area. The connections between the nitrogen supply system and the N_2 lines for flooding the sodium areas are made by flexible hoses

with quick connect and disconnect couplings. Two separate actions (connecting a hose and manually opening a valve) are required to flood any area. The nitrogen is supplied by System 82.

15.2.2 Automatic Gas Blanketing System for Computer Areas

The computer room and equipment and the cable space below the computer room false floor are protected by independent self-contained automatic halogenated gas systems. The gas, stored in containers near each room, is used to avoid water and smoke damage to the computer equipment. A local manual trip is also provided in each room near the normal exit.

The system is designed so that gas concentration upon flooding is not hazardous to personnel; the concentration is maintained between 4 and 7%.

15.2.3 Aqueous Film-Forming Foam System

An aqueous film-forming foam system is installed to protect against Mobiltherm fires in the lower cooler areas of containment. During normal operation the distribution piping is filled with water. The sprinkler heads are designed to release at 395°F.

When extinguishing flow begins, a predetermined volume of liquid foam concentrate is mixed into the water stream to form a foam solution of 6% concentration in the sprinkler piping.

15.2.4 Automatic Water Sprinkler Systems

The automatic water sprinkler systems protect selected plant areas that do not contain sodium. For wet pipe sprinkler systems, the sprinkler heads are of the conventional "fusible link" type. When the heat from a fire reaches the melting temperature of the link, water flow begins.

Delayed action sprinkler systems are installed in the control room, in the cable spreading room in the control building, and in the cable spreading room in the Auxiliary Equipment Building - West. The distribution piping of these systems is kept dry and filled with air by a supervised system to prevent accidental discharge of water that would damage vital records or equipment. Water is admitted to the system only upon a signal from an ionization-type smoke detector. Thereafter, the system functions in the manner of a conventional automatic wet pipe sprinkler system.

15.2.5 Fire Hoses and Fire Hydrants

Eighteen fire hoses are provided throughout the plant along normal personnel traffic patterns for manual suppression of fires. The hoses are cross-zoned so that they can be used in conjunction with the sprinkler systems without reducing the quantity of water available to the sprinklers. Yard fire hydrants and pumper connections are provided on the fire and sanitary water loop.

15.2.6 Portable Fire Fighting Equipment

Portable Fire Extinguishers — Commercial manual fire extinguishers are distributed throughout FFTF for control of fires.

- ABC-type extinguishers are deployed where fires of Class A, B, or C may occur. (Class A fires are those in ordinary combustible materials, such as wood, cloth, paper and certain plastics. Class B fires are those in flammable liquids, gases and greases. Class C fires are those that involve energized electrical equipment.)
- CO₂ extinguishers are located near energized electrical equipment for Class C fires.
- Portable sodium carbonate extinguishers are located where sodium fires may occur.
- Halogenated gas extinguishers are located in areas with computer equipment.

The extinguishers are placed at accessible locations along the path of normal personnel traffic. A supply of extinguishers is also provided for special use during maintenance operations involving potential fire hazards.

Miscellaneous Portable Equipment —

Other fire-fighting equipment includes portable, hand-held and wheeled-type extinguishers, standard fire-fighting tools, and personnel protective devices such as gloves, fire-fighting coveralls, helmets and portable breathing apparatus.

15.2.7 Municipal Fire Alarm System

A Municipal Fire Alarm Loop is provided in conformance with NFPA 73. The loop includes municipal fire alarm boxes, master fire alarm boxes and trouble transmitters. This loop transmits coded signals (through System 15) by an underground cable from the site to the 300 Area Central Fire Station. A current of approximately 100 milliamperes is maintained in the Municipal Fire Alarm Loop from the 300 Area Central Fire Station power supply.

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15.3 PLANT FIRE PROTECTION INSTRUMENTATION (SYSTEM 93-7)

The Plant Fire Protection Instrumentation System (System 93-7) provides instrumentation to perform the following functions:

- Monitor and control the fire water supply system
- Detect and alarm fire conditions
- Monitor and control automatic extinguishing equipment
- Monitor and control charging of delayed action extinguishing systems

The system includes Area Local Control Panels (ALCPs) connected to master fire alarm boxes and trouble transmitters. The activation of a detection device initiates a coded signal to the 300 Area Fire Station, indicating a fire alarm or a trouble condition. The ALCPs control and monitor various types of signaling devices and systems, including:

- Manual pull boxes within the buildings (located near exits)
- Automatic fire detection devices
- Sprinkler system water flow alarms
- Supervisory circuits
- Tamper-indicating devices

Normal power to the ALCPs is provided at 120-V a-c by the Plant Power System. Rechargeable batteries, with all necessary recharging facilities and d-c/a-c inverting devices, are provided as an emergency power supply. The standby supply automatically continues operation if building power is lost.

15.3.1 Fire Detection and Alarm Instrumentation

Fire detectors and alarm equipment are provided by System 93-7 in the containment building, control building, auxiliary buildings, and DHX sump areas.

Three types of commercial detectors are used: rate-compensated/fixed-temperature thermal detectors, product-of-combustion ionization detectors, and infrared visible flame detectors. Selection of a sensor type for a particular area was based on the environmental and performance requirements of the area. Each detector provides input to local fire alarm panels.

Inputs are provided to the Fire Alarm System Annunciator for control room alarm in the event of malfunctions in the system or detection of fires.

15.3.2 Fire Water Supply System Controllers

Fire water supply controllers are designed to assure adequate water flow capability by automatically starting the two fire water pumps if water supply loop pressure falls below the nominal operating level. Either pump may be manually operated at local control stations.

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APPENDIX A

DETAILED MAP OF
FFTF CORE

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80a
2/2/12

ASSEMBLY FUNCTION

CL	CLOSED LOOPS-4
OT	OPEN TEST ASSEMBLIES-4
D	DRIVER { 29 INNER (ROWS 1 THRU 4)
	POSITIONS { 45 OUTER (ROWS 5 & 6)
SR	SAFETY RODS-3
CR	CONTROL RODS-6
PC	POTENTIAL FIXED SHIM OR MOVABLE PERIPHERAL CONTROL RODS-9
PFS	POTENTIAL FIXED SHIM LOCATIONS-6
R	REFLECTORS-93 TO 108 (ROWS 7-9)

REACTOR VESSEL HEAD PENETRATIONS (REF)

A1-A3	SAFETY RODS-3
A4-A9	CONTROL RODS-6
A10-A18	POTENTIAL FIXED SHIM OR MOVABLE PERIPHERAL CONTROL RODS-9
B-1	OT
B-2	PROXIMITY TEST PLUG
B-3	LOOP 2 CL
B-4	LOOP 4 CL
B-5	OT
B-6	LOOP 1 CL
B-7	LOOP 3 CL
B-8	OT
B-9	OT

FIGURE A-1. Legend for Detailed Map of FFTF Core.

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200
2/2/12

FIGURE A-2. Detailed Map of FFTF Core.

7

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APPENDIX B

GLOSSARY

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7

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GLOSSARY

a-c	Alternating current	CLS	Closed Loop System
AH	Ampere-hour	cm	Centimeters
ALCP	Area Local Control Panels	cm ²	Square centimeters
ASME	American Society of Mechanical Engineers	cm ³	Cubic centimeters
ASSY	Assembly	CO ₂	Carbon dioxide
ASTM	American Society for Testing and Materials	COND	Conditioning
B	Boron	CR	Core Restraint
B ₄ C	Boron carbide	CRDD	Control Rod Driveline Disconnect
BAP	Branch Arm Piping	CRDM	Control Rod Drive Mechanism
BAPS	Branch Arm Piping Shield	CRT	Cathode Ray Tube
BF ₃	Boron fluoride	CW	Cold-Worked
BLTC	Bottom Loading Transfer Cask	d-c or DC	direct current
BOC	Beginning of Cycle	DDH&DS	Digital Data Handling and Display System
BPA	Bonneville Power Administration	DG	Diesel Engine Generator
Btu	British thermal unit	DHX	Dump Heat Exchanger
C	Carbon or Celsius	diam	Diameter
CAM	Continuous Air Monitors	DN	Delayed neutron
CAPS	Cell Atmosphere Processing System	DOE	Department of Energy
CGE	Cover Gas Equalization Port	EM	Electromagnetic
CGF	Cover Gas Feed Port	EOC	End of Cycle
CGPS	Cover Gas Piping Shield	ERDA	Energy Research and Development Administration
CI	Curie	EVFM	Ex-Vessel Flux Monitor
CI	Center Island	F	Fahrenheit
CIC	Compensated Ion Chamber	FFTF	Fast Flux Test Facility
CIS	Containment Isolation System	FM	Flow meter
CL	Closed Loop position	FOTA	Fuels Open Test Assembly
CLEM	Closed Loop Ex-Vessel Machine	FSF	Fuel Storage Facility
CLIRA	Closed Loop In-Reactor Assembly	ft	Feet
		ft ³	Cubic feet

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882
2/2/12

GLOSSARY (Cont'd)

ft/s	Feet per second	IPCEA	Insulated Power Cable Engineers Association
FTP	Fuel Transfer Port	IT	Instrument Tree
FTP/FVA	Fuel Transfer Port Floor Valve Adapter	IVHM	In-Vessel Handling Machine
FTRIA	Flow-Temperature Removable Instrument Assembly	k	1000
gal	U.S. gallon	K	1024 (for computer)
gal/min or gpm	U.S. gallons per minute	K	Potassium
g/cm ³	Grams per cubic centimeter	keV	1000 electron volts
g/hr	Grams per hour	kg	Kilograms
gN ₂	Gaseous nitrogen	kV	1000 volts
G or GEN	Generator	kW	Kilowatts
Ge	Germanium	kW/ft	kilowatts per lineal foot
GT	Gas Turbine Generator	kWt	Kilowatts, thermal
H&V	Heating and Ventilating	lb/hr	pounds per hour
HB	Head Bolt Penetrations	lb/in ²	Pounds per square inch
HEPA	High Performance Particulate	LLFM	Low Level Flux Monitor
hp	Horsepower	LMFBR	Liquid Metal Fast Breeder Reactor
hr	Hour	LOG	Logarithmic
HTCS	Head Temperature Control System	LRIA	Level Removable Instrument Assembly
HTS	Heat Transport System	M	Motor
HX	Heat Exchanger	MG or M-G	Motor-Generator
Hz	Cycles per second	MC	Mixing Component
ID	Inside Diameter	MECH.	Mechanism
IDS	Interim Decay Storage	MFM	Magnetic Flow Meter
IEEE	Institute of Electrical and Electronics Engineers	MHTS	Main Heat Transport System (HTS)
IEM	Interim Examination and Maintenance	min	Minimum
IHX	Intermediate Heat Exchanger	MOTA	Materials Open Test Assembly
in.	Inches	MPS	Multipurpose Sampler
		MSV	Mean Square Voltage

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98A
2/2/12

GLOSSARY (Cont'd)

MVA	10 ⁶ volt-amperes	PRI	Primary
MW	Megawatts	psig	Pounds per square inch, gauge
MW/liter	Megawatts per liter	PTI	Plugging Temperature Indicator
MWd/kg	Megawatt days per kilogram	PTP	Proximity Test Plug
MWt	Megawatts thermal	Pu	Plutonium
Max	Maximum	PuO ₂	Plutonium dioxide
MeV	10 ⁶ electron volts	R	Roentgen, Unit of radiation
mil	0.001 inch	rad	Unit of radiation dose
Mil Std	Military Standard	RAPS	Radioactive Argon Processing System
ml	Milliliter	RCA	Reactor Cavity Access
mrem	0.001 rem	RE	Radiation Monitor
N ₂	Nitrogen	Reg.	Regulator
Na	Sodium	rem	Unit of radiation equivalent per individual
NaK	Sodium - Potassium Eutectic Alloy	REQ.	Required
n/cm ² -s	neutrons per square centimeter per second	r/min or rpm	Revolutions per minute
NC	Normally Closed	RRP	Reactor Refueling Plug
NFPA	National Fire Protection Association	RSB	Reactor Service Building
OD	Outside Diameter	RSS	Reactor Shutdown System
OT	Open Test position	RTD	Resistance Temperature Detector
OTA	Open Test Assembly	SCR	Secondary Control Rod position, or Silicon Controlled Rectifier
PC	Potential Control rod position	SCRAM	Rapid Reactor Shutdown
PCR	Primary Control Rod position	SEC	Secondary
PFS	Peripheral Fixed Shim absorber position	SISI	Surveillance and In-Service Inspection
pH	Negative logarithm of hydrogen ion concentration	SS or S.S.	Stainless Steel
PIOTA	Post-Irradiation Open Test Assembly	SSP	Secondary Sodium Package
ppm	Parts per million	std	Standard
PPS	Plant Protection System		

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882
2/2/12

GLOSSARY (Cont'd)

std ft ³ /min	Standard cubic feet per minute	TYP	Typical
SWGR	Switchgear	U	Uranium
T/C	Thermocouple	UO ₂	Uranium dioxide
temp	Temperature	V	Volt
T/LLM	Temperature/Liquid Level Monitor	VA	Volt-amperes
ton (thermal)	12,000 Btu/hr	volt.	Voltage
torr	unit of pressure (millimeters of mercury at 0°C)	W	Watt
TRIA	Temperature Removable Instrument Assembly	wt%	Weight percent
TTP	Test Transfer Port	Xe	Xenon
		yr	Year
		ZTO	Zero Time Outage

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88a
2/2/12

APPENDIX C

LIST OF FIGURES AND TABLES

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98a
2/2/12

7

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FIGURES

<u>Figure</u>		<u>HEDL No.</u>	<u>Photo No.</u>	<u>Page</u>
1-1	The Fast Flux Test Facility (FFTF) is located on the U.S. Government's Department of Energy Hanford Site near Richland, Washington.	8007-400.1-1	8005942-1	1-2
1-2	FFTF Location Map.	8007-400.1-2	8007959-1	1-2
1-3	Hanford Engineering Development Laboratory.	8007-400.1-3	91095-92	1-3
2-1	Fast Flux Test Facility.	8007-400.2-1a 8007-400.2-1b	P08974-1 91855-27	2-2
2-2	FFTF Plant Arrangement.	8007-400.2-2	P08974-2	2-3
2-3	Reactor Location Within Containment.	8007-400.2-3a 8007-400.2-3b	8009034-2 8007960-4	2-4
2-4	Reactor Containment Building Cutaway.	8007-400.2-4	P09208-1	2-5
2-5	Reactor Cutaway.	8007-400.2-5		2-7
2-6	Schematic of Heat Removal Facilities.	8007-400.2-6	8007960-7	2-9
2-7	Plan View of Heat Transport System.	8007-400.2-7	P08965-1	2-9
2-8	Elevation of One Circuit of the Heat Transport System.	8007-400.2-8	P08959-1	2-10
3-1	Components of System 3I.	8007-400.3-1		3-2
3-2	Instrument Tree Schematic.	8007-400.3-2	P09509-3	3-4
3-3	Nuclear Control System.	8007-400.3-3		3-5
3-4	Core Support Structure and Core Barrel.	8007-400.3-4		3-6
3-5	Arrangement of Core Restraint Mechanisms Around Core.	8007-400.3-5		3-7
3-6	In-Vessel Storage Module.	8007-400.3-6	8012586-4	3-8
3-7	Low Level Flux Monitor Assembly.	8007-400.3-7		3-8
3-8	Locations of In-Vessel Storage Modules.	8007-400.3-8		3-9
3-9	Core Map Showing Typical Arrangement.	8007-400.3-9		3-11
3-10	Construction View of the Top of the Core Loaded with Simulated Core Assemblies.	8007-400.3-10	764378-13cn	3-12
3-11	Driver Fuel Assembly.	8007-400.3-11	8012586-2	3-13
3-12	Driver Fuel Pin.	8007-400.3-12		3-14
3-13	Fuels Open Test Assembly (FOTA).	8007-400.3-13	P10047-1	3-15
3-14	Post Irradiation Open Test Assembly (PIOTA).	8007-400.3-14	8012586-1	3-16

~~OFFICIAL USE ONLY~~

JDA
2/2/12

FIGURES (Cont'd)

Figure		HEDL No.	Photo No.	Page
3-15	Materials Open Test Assembly (MOTA).	8007-400.3-15	P09498-6	3-17
3-16	Control Rod Absorber Assembly.	8007-400.3-16		3-18
3-17	Control Rod Absorber Pin.	8007-400.3-17	P09577-1	3-19
3-18	Radial Reflector Assembly.	8007-400.3-18	P09498-3	3-20
3-19	Instrument Tree.	8007-400.3-19	8010329-8	3-21
3-20	Instrument Tree Being Installed in Reactor.	8007-400.3-20	762777-92	3-23
3-21	Radial Total Flux Profile at Core Midplane at Full Power.	8007-400.3-21	8012617-2	3-24
3-22	Axial Total Flux Profile Through Core Centerline at Full Power.	8007-400.3-22	8012617-3	3-25
3-23	Neutron Flux Energy Spectrum at Center of Core.	8007-400.3-23		3-25
4-1	Components of System 32.	8007-400.4-1		4-2
4-2	Reactor Vessel.	8007-400.4-2	8012617-1	4-3
4-3	Reactor Vessel Support Arm.	8007-400.4-3	P08973-1	4-4
4-4	Main Support Structure Readied for Installation.	8007-400.4-4	8010329-5	4-4
4-5	Reactor Vessel Installation.	8007-400.4-5	8010329-7	4-4
4-6	Machining the Reactor Head.	8007-400.4-6	8010329-15	4-5
4-7	Reactor Head Support.	8007-400.4-7	P08969-1	4-6
4-8	Reactor Head Penetrations.	8007-400.4-8	P09130-1	4-7
4-9	Head Compartment Arrangement.	8007-400.4-9	P09577-5	4-8
4-10	Head Compartment Plan View.	8007-400.4-10	8008286-15	4-9
4-11	Center Island Shielding.	8007-400.4-11	8008286-1	4-10
4-12	Center Island Shielding Details.	8007-400.4-12	8008286-8	4-10
4-13	Temperature and Liquid Level Monitor Assembly.	8007-400.4-13	8008286-7	4-11
4-14	Proximity Test Plug.	8007-400.4-14	P09577-3	4-11
4-15	Fuel Transfer Port Assembly.	8007-400.4-15	8008286-5	4-12
4-16	Floor Valve Adapter (FTP/FVA).	8007-400.4-16	8010329-14	4-12
4-17	Test Transfer Port Assembly.	8007-400.4-17	8008286-4	4-12
4-18	Operating Deck Being Installed.	8007-400.4-18	PO1481-3	4-13

~~OFFICIAL USE ONLY~~

FIGURES (Cont'd)

Figure		HEDL No.	Photo No.	Page
4-19	Reactor Enclosure Preheat Systems.	8007-400.4-19		4-14
4-20	Reactor Cavity Shielding.	8007-400.4-20	8008286-2	4-15
5-1	Reactor Heat Transport System (HTS) Schematic.	8007-400.5-1	P08965-2	5-2
5-2	Reactor Heat Transport System Arrangement.	8007-400.5-2	P08959-3	5-2
5-3	One of the Three Cooling Circuits of the Heat Transport System.	8007-400.5-3	P08959-2	5-3
5-4	Sodium Flow Through FFTF Reactor Vessel.	8007-400.5-4	P09577-8	5-4
5-5	HTS Primary Loop Piping Schematic.	8007-400.5-5	P08976-1	5-5
5-6	HTS Primary Isolation Valve Installed.	8007-400.5-6	8010329-1	5-6
5-7	HTS Primary Cold Leg Check Valve.	8007-400.5-7	8008315-8	5-6
5-8	HTS Primary Pump with Guard Vessel.	8007-400.5-8	P09221-1	5-7
5-9	HTS Intermediate Heat Exchanger (IHX) and Guard Vessel.	8007-400.5-9	P09221-2	5-9
5-10	HTS Secondary Loop Schematic.	8007-400.5-10	8008315-9	5-10
5-11	HTS Secondary Pump.	8007-400.5-11	P09577-7	5-11
5-12	HTS Dump Heat Exchanger Module.	8007-400.5-12	8008315-11	5-12
5-13	HTS DHX Air Flow Diagram.	8007-400.5-13	8008315-12	5-13
5-14	HTS DHX Isolation Valve.	8007-400.5-14	8008315-13	5-13
5-15	Typical HTS Piping Trace Heating and Insulation.	8007-400.5-15	P09577-2	5-15
6-1	Typical View of FFTF Control Room.	8007-400.6-1	8005785-2cn	6-3
6-2	Reactor Plant Control System.	8007-400.6-2	8008447-20	6-5
6-3	FFTF Neutron Flux Control System.	8007-400.6-3	8008447-19	6-5
6-4	Block Diagram of CRDM Controller and Power Train.	8007-400.6-4	P09085-1	6-6
6-5	FFTF Sodium Flow Control System Subloop.	8007-400.6-5	8009427-2	6-7
6-6	FFTF DHX Control System Subloop.	8007-400.6-6	P08975-2	6-7
6-7	DHX Module.	8007-400.6-7	8008447-4	6-8
6-8	General Arrangement of Manned Portion of Control Room.	8007-400.6-8	P08975-2	6-9
6-9	Reactor Primary and Secondary Shutdown Systems.	8007-400.6-9		6-11

~~OFFICIAL USE ONLY~~

88A
2/2/12

FIGURES (Cont'd)

<u>Figure</u>		<u>HEDL No.</u>	<u>Photo No.</u>	<u>Page</u>
6-10	Neutron Flux Monitoring System Design Ranges.	8007-400.6-10	8008447-10	6-15
6-11	In-Vessel Nuclear Channel Block Diagram.	8007-400.6-11	8008447-16	6-16
6-12	Ex-Vessel Flux Monitoring System Thimble Locations.	8007-400.6-12	8012669-6	6-17
6-13	Ex-Vessel Primary "Wide-Range" Flux Monitoring System Block Diagram.	8007-400.6-13	8008447-9	6-18
6-14	Ex-Vessel Secondary Flux Monitoring System Block Diagram.	8007-400.6-14	8008447-8	6-19
6-15	Removable Assemblies for Measurement of Outlet Temperature and Flow of Core Components.	8007-400.6-15	8010329-13	6-21
6-16	Basic Configuration of Driver Fuel Instrumentation (FTRIA).	8007-400.6-16	8008447-14	6-21
6-17	Simplified Diagram of Eddy Current Flow Meter.	8007-400.6-17	P09498-1	6-21
6-18	Thermowell Assembly.	8007-400.6-18	8008447-12	6-24
6-19	Permanent Magnet Flow Meter Schematic.	8007-400.6-19	8008447-2	6-25
6-20	Pressure Sensor Installation.	8007-400.6-20	P09498-4	6-26
6-21	Digital Data Handling and Display System (DDH&DS) Schematic.	8007-400.6-21	P09509-6	6-27
6-22	Typical Control Channel Block Diagram for System 93-15.	8007-400.6-22	8008447-18	6-29
7-1	FFTF Secondary Sodium Storage Vessel.	8007-400.7-1a 8007-400.7-1b	8010329-12 P09218-1	7-2
7-2	FFTF Sodium Fill System.	8007-400.7-2	8012669-5	7-5
7-3	Reactor Primary Sodium Processing System.	8007-400.7-3	8012669-4	7-6
7-4	Electromagnetic Pump Schematic for System 81 Pumps.	8007-400.7-4	8008456-9	7-7
7-5	HTS Primary Sodium Cold Trap.	8007-400.7-5	8008456-6	7-7
7-6	Reactor Secondary Sodium Processing System Schematic Showing One of Three Cold Trap Circuits.	8007-400.7-6	8008456-3	7-8
7-7	Air-Cooled Cold Trap.	8007-400.7-7	8008456-2	7-8
7-8	IDS and Primary Sodium Storage Processing System.	8007-400.7-8	8008456-10	7-9
7-9	NaK IDS Cooling System.	8007-400.7-9	8008456-8	7-10

~~OFFICIAL USE ONLY~~

082
2/12/12

FIGURES (Cont'd)

Figure		HEDL No.	Photo No.	Page
7-10	NaK/Mobiltherm Heat Exchanger.	8007-400.7-10	P09498-5	7-11
7-11	NaK Diffusion Cold Trap.	8007-400.7-11	P09498-2	7-11
7-12	NaK Cold Trap Cooling System.	8007-400.7-12	8008456-7	7-11
7-13	Pneumatic Valve Operator Attached to Small Sodium Valve.	8007-400.7-13	7807729-3cn	7-12
7-14	Leak Detection for Reactor Vessel/Reactor Guard Vessel Annulus.	8007-400.7-14	8008456-4	7-14
8-1	Reactor and Primary HTS Argon Cover Gas System.	8007-400.8-1		8-2
8-2	Sodium Aerosol Filter.	8007-400.8-2	8008458-1	8-4
8-3	RAPS Flow Diagram.	8007-400.8-3	8008458-5	8-6
8-4	RAPS Cryogenic Processing System Flow Diagram.	8007-400.8-4	P08976-2	8-7
8-5	CAPS Flow Diagram.	8007-400.8-5	8008458-4	8-8
8-6	CAPS Dryers Installed.	8007-400.8-6	8010329-11	8-9
8-7	CAPS Cold Box Flow Diagram.	8007-400.8-7	8008458-2	8-9
9-1	The Two 2.3-MW Heat Dumps for the FFTF Closed Loops.	8007-400.9-1	8005945-3	9-2
9-2	Closed Loop System Schematic.	8007-400.9-2	8008471-4	9-3
9-3	CLS Primary Cooling System Schematic.	8007-400.9-3	8008471-9	9-4
9-4	Closed Loop In-Reactor Assembly (CLIRA).	8007-400.9-4	8007140-1	9-5
9-5	Closed Loop Primary Module Schematic.	8007-400.9-5	8008471-7	9-6
9-6	CLS Intermediate Heat Exchanger.	8007-400.9-6	8008471-2	9-7
9-7	CLS Primary Pump and Secondary Pump.	8007-400.9-7	P09577-4	9-7
9-8	CLS Primary Cold Trap Schematic.	8007-400.9-8	P09495-3	9-8
9-9	CLS Secondary Cooling System Schematic.	8007-400.9-9	P09495-1	9-9
9-10	Schematic of Closed Loop Dump Heat Exchanger.	8007-400.9-10	8008471-1	9-10
9-11	Principal Elements of CLS Control System.	8007-400.9-11	P08966-2	9-13
10-1	Laboratory Analysis of Sodium.	8007-400.10-1	8010329-4	10-2
10-2	Reactor Primary Sodium Sampling and Monitoring System.	8007-400.10-2	8008476-4	10-2
10-3	Secondary Sodium Sampling Package.	8007-400.10-3	8008476-7	10-4
10-4	Plugging Temperature Indicator.	8007-400.10-4	P09495-4	10-5

~~CONFIDENTIAL - EYES ONLY~~

FIGURES (Cont'd)

Figure		HEDL No.	Photo No.	Page
10-5	Multipurpose Sampler for Sodium.	8007-400.10-5	P09495-2	10-5
10-6	HTS Delayed Neutron Monitoring System.	8007-400.10-6	8008476-6	10-6
11-1	Aerial View of the FFTF.	8007-400.11-1	8010329-10	11-2
11-2	FFTF Containment Vessel.	8007-400.11-2	8008476-9	11-4
11-3	Placing Top on FFTF Containment Vessel.	8007-400.11-3	8010329-6	11-5
11-4	Typical Plan of Internal Structures Within the Containment Vessel.	8007-400.11-4	P09500-1	11-7
11-5	Typical Cross Section of Internal Structures Within the Containment Vessel.	8007-400.11-5	8008476-8	11-7
11-6	Typical Bellows-Type Piping Penetration of Inert Atmosphere Cell.	8007-400.11-6	8008476-2	11-8
12-1	General Arrangement of Reactor Refueling Facilities.	8007-400.12-1		12-2
12-2	Closed Loop Ex-Vessel Machine (CLEM).	8007-400.12-2	8010329-9	12-3
12-3	Driver Fuel Handling Sequence.	8007-400.12-3	8009653-1	12-5
12-4	Driver Fuel Handling Sequence Between Interim Decay Storage and Reactor Vessel.	8007-400.12-4	P09500-4	12-5
12-5	Removal of Fuels Open Test Assembly from the Reactor.	8007-400.12-5	P09577-6	12-6
12-6	Floor Valve.	8007-400.12-6	8008494-11	12-7
12-7	Schematic of Closed Loop Ex-Vessel Machine (CLEM) and Transporter.	8007-400.12-7		12-9
12-8	Bottom Loading Transfer Cask Schematic.	8007-400.12-8	8008494-2	12-10
12-9	Core Component Conditioning Stations.	8007-400.12-9	P09500-2	12-11
12-10	Interim Decay Storage.	8007-400.12-10	P09509-4	12-12
12-11	Fuel Storage Facility Under Construction.	8007-400.12-11	8005066-5	12-13
12-12	In-Vessel Handling Machine.	8007-400.12-12		12-15
12-13	Plan View Showing Locations of In-Vessel Handling Machines.	8007-400.12-13	P09509-2	12-16
12-14	Reactor Cutaway Showing In-Vessel Handling Machine.	8007-400.12-14	P09509-1	12-17
12-15	Plug Handling Fixture.	8007-400.12-15	764572-1	12-18
13-1	Simplified BPA Transmission Line Map for FFTF Interties.	8007-400.13-1		13-2

OFFICIAL USE ONLY

100R
2/2/12

FIGURES (Cont'd)

<u>Figure</u>		<u>HEDL No.</u>	<u>Photo No.</u>	<u>Page</u>
13-2	FFTF Building Electrical Power System Block Diagram.	8007-400.13-2	P09160-2	13-5
13-3	13.8-kV Transformers Ready for Installation.	8007-400.13-3	8010329-2	13-5
13-4	Simplified Single Line Diagram of FFTF Emergency Power System Incorporating Gas Turbine Generator.	8007-400.13-4	P09134-1	13-7
13-5	Diesel Engine Generator Set.	8007-400.13-5	8010329-3	13-7
13-6	One of the Two Safety Power Systems.	8007-400.13-6	8009251-2	13-8
13-7	Typical Electrical Penetration.	8007-400.13-7	8009251-7	13-11
14-1	Reactor Containment Building Air Conditioning Supply and Filtered Exhaust System.	8007-400.14-1		14-2
14-2	Control Area Life Support System.	8007-400.14-2	P09003-1	14-4
14-3	IDS Vessel N ₂ Backup Gas Cooling System and IDS Emergency Cooling System.	8007-400.14-3	8009251-9	14-6
14-4	Coolant Fluid System.	8007-400.14-4	8009251-4	14-8
14-5	Chilled Water Refrigerator Units for In-Containment Chilled Water System.	8007-400.14-5	779267-8	14-9
14-6	Cooling Water Towers.	8007-400.14-6	8008214-2	14-11
15-1	Fixed Radiation Monitor.	8007-400.15-1	8005066-1	15-2
15-2	Functional Diagram of Fixed Radiation Monitor.	8007-400.15-2	8009251-6	15-2
A-1	Legend for Detailed Map of FFTF Core	8007-400.A-1	P09019-1	A-2
A-2	Detailed Map of FFTF Core	8007-400.A-2	P09019-2	A-3

~~CONFIDENTIAL - EYES ONLY~~

gda
2/2/12

TABLES

<u>Table</u>	<u>Page</u>
1-1 FFTF Plant Systems Structure	1-5
2-1 Above-Core In-Vessel Components	2-8
2-2 FFTF Design Parameters	2-14
3-1 Typical Core Arrangement	3-10
3-2 Sodium Flow Distribution in Reactor	3-27
4-1 Reactor Head Major Penetrations	4-6
5-1 Reactor Heat Transport System Design Parameters	5-17
6-1 System 90 Control Functions	6-4
6-2 Trip Inputs for Reactor Shutdown Systems	6-13
6-3 Locations of Automatically Actuated Containment Isolation System Valves	6-14
6-4 Absorber Position Temperature Instrumentation	6-20
7-1 FFTF Liquid Metal Inventory	7-3
7-2 Major Equipment in System 81	7-4
8-1 Argon System Applications Within Containment	8-4
8-2 Argon System Applications Outside Containment	8-5
9-1 CLIRA Operating Conditions	9-8
9-2 CLS Sodium Impurity Control Caution Levels	9-11
9-3 CLS Argon Caution Levels	9-11
11-1 Principal FFTF Structures	11-3
11-2 Reactor Containment Vessel Design Parameters	11-5
13-1 Main Preferred Electrical Service Design Parameters	13-3
13-2 Alternate Preferred Electrical Service Design Parameters	13-4
13-3 Safety Power System Battery Loads for 7-Day Period Following Loss of All A-C Power	13-9

~~OFFICIAL USE ONLY~~

JBA
2/2/12

APPENDIX D

INDEX

~~OFFICIAL USE ONLY~~

gpa
2/2/12

7

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INDEX

	<u>Page</u>		<u>Page</u>
Acid Waste System	14-13	Cell Atmosphere Processing System (CAPS)	8-8
Aerosol Leak Detection	7-13	Cell Gas Cooling Systems	14-5
Alternate Preferred Electrical Service	13-4	Cell Oxygen Control	8-11
Aqueous Film-Forming Foam System	15-7	Cell Penetrations	11-8
Area Radiation Monitoring	15-3	Cell Purge Exhaust Systems	14-7
Argon Cover Gas Monitoring	10-1, 10-3 10-7	Center Island Enclosure	4-10
Argon Supply and Pressurization Instrumentation	8-10	CLIRA	9-4
Argon System	8-3	CLIRA Operating Conditions	9-8
Atmospheric Pressure Reference System	14-13	Closed Loop Ex-Vessel Machine	12-3, 12-8
Automatic Gas Blanketing System for Computer Areas	15-7	Closed Loop Instrumentation System	9-12
Automatic Water Sprinkler Systems	15-8	Closed Loop Process Instrumentation	6-22
Auxiliary Equipment Building - East	11-10	Closed Loop System Cells	11-6
Auxiliary Equipment Building - West	11-11	Closed Loop System Dump Heat Exchanger Structures	11-12
Auxiliary Liquid Metal Instrumentation System	7-12	Closed Loops System	9-3
Auxiliary Liquid Metal System	7-3	CLS Argon Cover Gas Purity Control	9-11
Auxiliary Systems	14-1	CLS Dump Heat Exchangers	9-10
Batteries	13-9	CLS Primary Cooling Systems	9-4
Bottom Loading Transfer Cask	12-10	CLS Primary Cover Gas System	9-8
Building Electrical Power System	13-4	CLS Primary Module	9-6
CAPS Radiation Monitors	15-5	CLS Primary Purification System	9-8
Cathodic Protection	13-12	CLS Secondary Cold Traps	9-9
Cell Access Closures	11-8	CLS Secondary Cooling Systems	9-8
Cell Atmosphere Processing System Instrumentation	8-11	CLS Sodium Leak Detection	9-11
		CLS Sodium Purity Control	9-11
		CLS Valves	9-11

~~OFFICIAL USE ONLY~~

802
2/2/12

INDEX (Cont'd)

	<u>Page</u>		<u>Page</u>
Communications System	6-29	Driver Fuel Instrumentation	6-19
Compressed Air System	14-12	Effluent Air Radiation Monitoring	15-4
Containment Isolation Radiation Monitoring	15-4	Electrical Contact Leak Detectors	7-14
Containment Isolation System	6-14	Electrical Penetrations	13-11
Containment Vessel Penetrations	11-5	Electrical Power Supply	13-1
Control Area Central Air Conditioning System	14-3	Emergency Lighting	13-10
Control Area Life Support System	14-4	Engineered Safety Features	6-13
Control Building	11-10	Equipment and Personnel Access	11-9
Control Rod Drive Mechanisms	3-4, 3-22	Ex-Containment Chilled Water System	14-10
Control Rod and Potential Fixed Shim Absorber Assembly Instrumentation	6-20	Ex-Vessel Flux Monitoring System	4-15, 6-17
Coolant Fluid System	14-8	Ex-Vessel Flux Monitors	2-8, 4-15
Cooling In-Vessel Storage Modules	3-27	FFTF Design Parameters	2-13
Cooling Water System	14-11	FFTF Emergency Power System	13-6
Core Barrel	3-6	FFTF Overall Description	2-1
Core Component Conditioning Stations	12-11	FFTF Plant Systems	1-4
Core Component Inventory Control	12-7	FFTF Program Summary	1-3
Core Cooling	3-27	Fire Detection and Alarm Instrumentation	15-9
Core Restraint	3-7	Fire Hoses and Fire Hydrants	15-8
Core Support Structure	3-6	Fire Water Supply System Controllers	15-9
CRDM Nozzle Shield Plugs and Closure Caps	3-22	Floor Valve Adapter (FTP/FVA)	4-12
Diesel Engine Generators	13-6	Floor Valves and Adapters	12-7
Diesel Generator Auxiliary Service Systems	14-13	Fuel Failure Location	10-8
Digital Data Handling and Display System	6-27	Fuel Failure Monitoring System	10-6, 10-8
Driver Fuel Assemblies	3-13	Fuel Oil Distribution System	14-12
		Fuel Storage Building	11-10
		Fuel Storage Facility	12-13

~~OFFICIAL USE ONLY~~

gda
2/2/12

INDEX (Cont'd)

	<u>Page</u>		<u>Page</u>
Fuel Transfer Port Assembly	4-12	HTS Primary Isolation Valves	5-6
Fuels Open Test Assemblies (FOTA)	3-14	HTS Primary Loops	5-4
Grounding System	13-11	HTS Primary Pumps	5-6
Handling of 12-Foot Assemblies	12-4	HTS Process Flow Measurements	6-25
Handling of CLIRA and MOTA	12-7	HTS Process Pressure Measurements	6-26
Handling of Fuels Open Test Assemblies	12-6	HTS Process Temperature Measurements	6-24
Handling of Post-Irradiation Open Test Assemblies	12-6	HTS Rotational Speed Measurements	6-26
Head Compartment	4-8	HTS Secondary Loop Expansion Tanks	5-14
Head Compartment Maintenance Floor	4-13	HTS Secondary Loops	5-10
Heat Transport System Cells	11-6	HTS Secondary Pumps	5-11
Heating and Ventilation Instrumentation System	14-7	HTS Service Building - South	11-11
Heating and Ventilation System	14-3	HTS Service Buildings - East and West	11-11
Horizontal Baffle	3-7	HTS Sodium Flow Control	6-6
HTS Decay Heat Removal Control	6-8	HTS Sodium Level Measurements	6-26
HTS Dump Heat Exchanger Structures	11-11	HTS System Control	5-16
HTS Dump Heat Exchanger Control	6-6	HTS Two-Circuit Operation	5-16
HTS Dump Heat Exchangers	5-12	IDS Special Cooling Systems	14-6
HTS Instrumentation and Control	6-1	IDS and Primary Sodium Storage Processing System	7-9
HTS Intermediate Heat Exchangers	5-8	Impurity Monitoring and Analysis System	10-3, 10-7
HTS Monitoring and Interlocking Instrumentation	6-27	Impurity Monitoring and Analysis Instrumentation System	10-8
HTS Natural Circulation Cooling	5-16	In-Containment Chilled Water System	14-9
HTS Normal Operation	5-15	In-Core Shim Assemblies	3-20
HTS Piping	5-14	In-Vessel Flux Monitoring System	6-16
HTS Position Measurements	6-26	In-Vessel Handling Machines	12-14
HTS Primary Check Valves	5-6		

INDEX (Cont'd)

	<u>Page</u>		<u>Page</u>
In-Vessel Storage Modules	3-8	Neutron Absorber Pins	3-19
Independently Cooled Irradiation Test Facilities	9-1	Neutron Flux Control	6-4
Inert Gas Receiving and Processing System	8-3	Neutron Flux Monitoring System	6-14
Inert Gas Receiving and Processing Instrumentation System	8-10	Nitrogen Flooding of Secondary Ex-Containment Sodium Areas	15-7
Instrument Trees	3-4, 3-21	Nitrogen Supply and Pressurization Instrumentation	8-10
Interim Decay Storage	12-12	Nitrogen System	8-5
Interim Examination and Maintenance Cell	11-8, 12-14	Open Test Assembly Instrumentation	6-22
Introduction	1-1	Operating Deck	4-13
Inverters	13-10	Piping and Component Heating for System 5I	5-15
Leak Detection Instrumentation System	7-13	Piping and Component Heating for System 8I	7-12
Liquid Metal Valves	7-12	Piping and Component Heating for System 6I	9-11
Local Air Conditioning and Supply Systems	14-5	Piping and Equipment Electrical Heating Control System	6-29
Low Level Flux Monitors	3-8	Plant Annunciator System	6-28
Main Heat Transport System Power System	13-4	Plant Fire Protection Instrumentation System	15-9
Main Preferred Electrical Service	13-3	Plant Fire Protection System	15-6
Materials Open Test Assemblies (MOTA)	3-16	Plant Power System	13-6
Miscellaneous Portable Fire Fighting Equipment	15-8	Plant Protection System	6-9
Mobiltherm System	14-11	Plug Handling Fixture	12-18
Multipurpose Sampler	10-5	Plugging Temperature Indicator	10-4
Municipal Fire Alarm System	15-8	Polar Gantry Crane	11-9
NaK Cold Trap Cooling System	7-10	Portable Fire Extinguishers	15-8
NaK IDS Cooling System	7-10	PPS Equipment Characteristics	6-10
NaK Systems	7-1	PPS Power Supply	6-10
Neutron Absorber Assemblies	3-18	Primary Electrical Power System	13-3
		Proximity Test Plug	4-11

~~CONFIDENTIAL - USE ONLY~~

82A
2/2/12

INDEX (Cont'd)

	<u>Page</u>		<u>Page</u>
Radial Reflectors	3-20	Reactor Core Map	3-11, A-3
Radial Shield	3-6	Reactor Enclosure System	4-1, 4-3
Radiation Monitoring System	15-3	Reactor Flow Patterns	3-26
Radioactive Argon Processing System (RAPS)	8-6	Reactor Guard Vessel	2-6, 4-5
Radioactive Argon Processing System Instrumentation	8-11	Reactor Head	2-6, 4-5
Radioactive Liquid Waste System	14-14	Reactor Head Temperature Instrumentation	6-23
Radioactive Solid Waste System	14-14	Reactor Heat Transport Instrumentation System	6-23
Radioactive Waste Instrumentation System	14-14	Reactor Heat Transport System	2-9, 5-1, 5-3
Radioactive Waste System	14-13	Reactor Heat Transport System Design Parameters	5-16
RAPS and CAPS Cell Cooling and Atmosphere Pressure Control Systems	14-5	Reactor Instrumentation and Control	6-1
RAPS Radiation Monitors	15-5	Reactor Internals	3-1
Reactor Cavity	11-6	Reactor Operations	3-24
Reactor Cavity Shielding	4-15	Reactor Plant Control System	6-4
Reactor Component Cooling Systems	14-6	Reactor Power and Flux	3-24
Reactor Containment	2-4, 2-5, 2-12, 11-4	Reactor Primary Sodium Processing System	7-6
Reactor Containment Building Air Conditioning Supply and Filtered Exhaust System	14-3	Reactor Reactivity Control	3-26
Reactor Containment Instrumentation System	11-12	Reactor Refueling System	12-1, 12-3
Reactor Containment Vessel	2-5, 11-5	Reactor Secondary Sodium Processing System	7-8
Reactor Control Room	6-8	Reactor Service Building	11-10
Reactor Coolant Level Instrumentation	6-22	Reactor Shutdown System	6-10
Reactor Coolant Outlet Temperature Instrumentation	6-23	Reactor Startup	3-26
Reactor Core	2-6, 3-3, 3-9, 3-10	Reactor Summary Description	2-6, 3-3
		Reactor Support Buildings System	11-9
		Reactor System	3-3
		Reactor Thermal Hydraulics	3-26

~~OFFICIAL USE ONLY~~

82a
2/2/12

INDEX (Cont'd)

	<u>Page</u>		<u>Page</u>
Reactor Vessel	2-6, 4-3	System 27	11-4
Reactor Vessel Temperature Instrumentation	6-23	System 31	3-3
Reactor and Vessel Instrumentation System	6-18	System 32	4-3
Reflector Instrumentation	6-22	System 41	12-3
Refueling Support Equipment	12-18	System 51	5-3
Safety Power Systems	13-8	System 61	9-3
Sanitary Water and Related Systems	14-7	System 81 Components	7-4
Service Piping Instrumentation System	14-13	System 81	7-3
Service Piping System	14-7	System 82	8-3
Sewer Systems	14-13	System 85	10-3, 10-7
Shield Plug Storage Station	12-18	System 90	6-4
Simulated Core Assemblies	3-20	System 91	6-27
Sodium Analysis	10-6	System 92	6-18
Sodium Monitoring	10-1, 10-3	System 93-1	11-12
Sodium Receiving and Unloading System	7-4	System 93-2	6-23
Sodium Systems	7-1	System 93-3	9-12
Standby Chilled Water System	14-10	System 93-4	14-13
Structures	11-1	System 93-5	14-14
Summary	2-1	System 93-6	14-7
System 11	13-3	System 93-7	15-9
System 12	13-4, 13-10	System 93-8	8-10
System 15	6-29	System 93-9	10-8
System 21	11-9	System 93-10 Control Functions	7-13
System 23	14-7	System 93-10 Monitoring Functions	7-12
System 24	14-13	System 93-10	7-12
System 25	14-3	System 93-13	7-13
System 26	15-6	System 93-14	6-28
		System 93-15	6-29
		System 94	10-6, 10-8

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182
2/2/12

INDEX (Cont'd)

	<u>Page</u>		<u>Page</u>
System 95	6-14	Test Specimen Handling	12-1
System 96	15-3	Test Transfer Port Assembly	4-12
System 99	6-9	Vacuum Relief Valves	11-5
Temperature Control Systems for System 32	4-13	Vacuum System	8-10
Temperature and Liquid Level Monitor Assemblies	4-11	Wire and Cable	13-10
Test Assembly Conditioning Station	12-11	ZTO Systems	13-9

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80a
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7

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ACKNOWLEDGMENTS

The compiler acknowledges with thanks the efforts of the Westinghouse Hanford Company management and technical staffs for reviewing drafts of this document and making many helpful comments and suggestions.

The document was produced by HEDL Technical Communications. Particular thanks are due the staff for editing, word processing, graphics, photography, duplicating and printing.

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80a
2/2/12