Design and Fabrication of Closed Loop Systems (CLSs) for the Fast Flux Test Facility (FFTF)

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Abstract. Preservation of information related to FFTF CLSs is part of the U.S. Knowledge Management Program for Sodium Fast Reactors. The FFTF was designed to accommodate up to four Closed Loop Systems (CLS). Each CLS was an irradiation testing system capable of operating at 2.3 MWt with its own independently controlled coolant system. An irradiation test in a CLS would have been inserted into the core within a Closed Loop In-Reactor Assembly (CLIRA). An entire CLS consisted of a CLIRA, a primary and a secondary cooling loop, and a Dump Heat Exchanger (DHX) as the ultimate heat sink. Four CLSs were designed and two were fabricated. All connections needed to install a CLS were likewise fabricated including the branch arm piping within the reactor vessel. One CLS was installed but not connected and the other was not installed prior to startup of the FFTF due to resources being shifted to achieving full power as soon as possible. This paper will describe the design and fabrication of the FFTF CLSs as well as the lessons learned during design and fabrication.

Key Words: Fast Flux Test Facility, FFTF; Liquid Metal Fast Reactor; Closed Loops, Closed Loop Systems.

1. Introduction

Sodium-cooled Fast Reactors (SFRs) are one of the most promising Generation-IV reactor concepts for providing a safe, sustainable energy source. Worldwide, these reactors have demonstrated their capability with more than 400 accumulated reactor years of operating experience. For advancements in SFRs, test reactors provide the data and other test information needed for these advancements and test reactors have been part of the national programs in all SFR nations. Some examples are: EBR-II (60 MWt) and FFTF (400 MWt) in the United States, BOR-60 (60 MWt) in Russia, RAPSODIE (40 MWt) in France, CEFR (65 MWt) in China.

Test reactors support national programs by conducting tests on advanced materials or advanced fuels leading to more economical fuel systems. Such tests can be conducted either in Open Test Assemblies (OTAs) or in Closed Loop Systems (CLS). Closed Loops are advantageous because tests can be conducted under conditions different from those in the primary coolant system of the reactor. For example the FFTF CLSs were designed to conduct Loss of Flow Tests, Loss of Piping Integrity Tests, Transient Over-Power Tests, and Fuel Failure Propagation Tests.

The FFTF was originally designed to accommodate up to four Closed Loop Systems with each system capable of operating at 2.3 MWt, and with each system having its own independently operated and independently controlled coolant system. All four CLS were designed and components were procured for two systems which were completely fabricated.

Of these two systems, one was installed but not connected pending a later need and one was used for other purposes. The FFTF is now shut down with the bulk sodium drained and an argon cover gas blanket installed on the sodium systems. The reactor plant is now in a surveillance and maintenance mode.

Even though the FFTF is now shut down, preservation of design, operating, and testing knowledge associated with the FFTF is an essential part of the Knowledge Preservation program for SFRs in the United States. This has been a long-standing and important program funded by the Office of Nuclear Energy in the U.S. Department of Energy. References [1] through [7] attest to this goal. Preservation of the Closed Loop design information is included in this program.

2. Description of the Fast Flux Test Facility (FFTF)

The FFTF was the most recent Liquid Metal Reactor (LMR) to be designed and operated in the United States. It is located on the Department of Energy Hanford Site near Richland, Washington. Conceptual design of the FFTF began in 1965, followed by a period of construction and acceptance testing that ended in 1982. FFTF operations extended for a decade from 1982 until it was shut down in 1992. Relevant FFTF parameters are shown in Table I.

The primary mission of the FFTF was to test full-size nuclear fuels and components typical of those to be found in follow-on prototype, demonstration, and commercial liquid metal reactors. To accomplish this mission, the reactor plant was designed and operated to provide the information necessary to develop advanced materials, fuel assemblies, control rods, and other core components typical of those needed for SFRs to follow. The CLSs were designed to support this mission if required and needed.

The FFTF reactor plant with two CLS 2.3 MWt air Dump Heat Exchangers (DHXs) in the foreground and the reactor containment in the background is shown in FIG. 1. The FFTF reactor vessel with the Closed Loop In-Reactor Assembly (CLIRA) and Branch Arm Piping (BAP) is shown in FIG. 2. The BAP provides the inter-connection between the CLIRA, which is in the reactor core, and the remainder of the CLS.

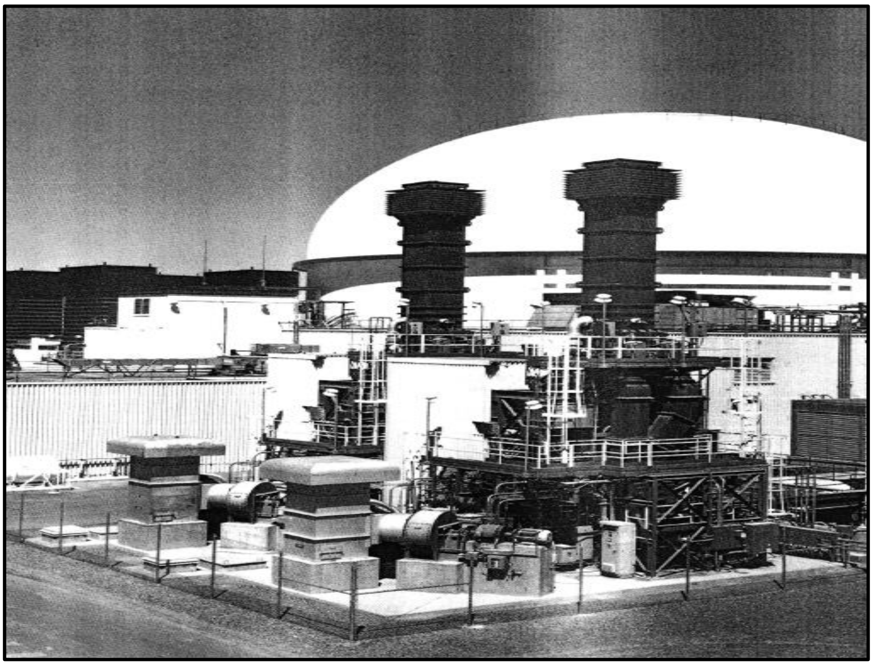

FIG. 1. FFTF Reactor Plant with Two 2.3 MWt DHXs for the CLSs in the Foreground

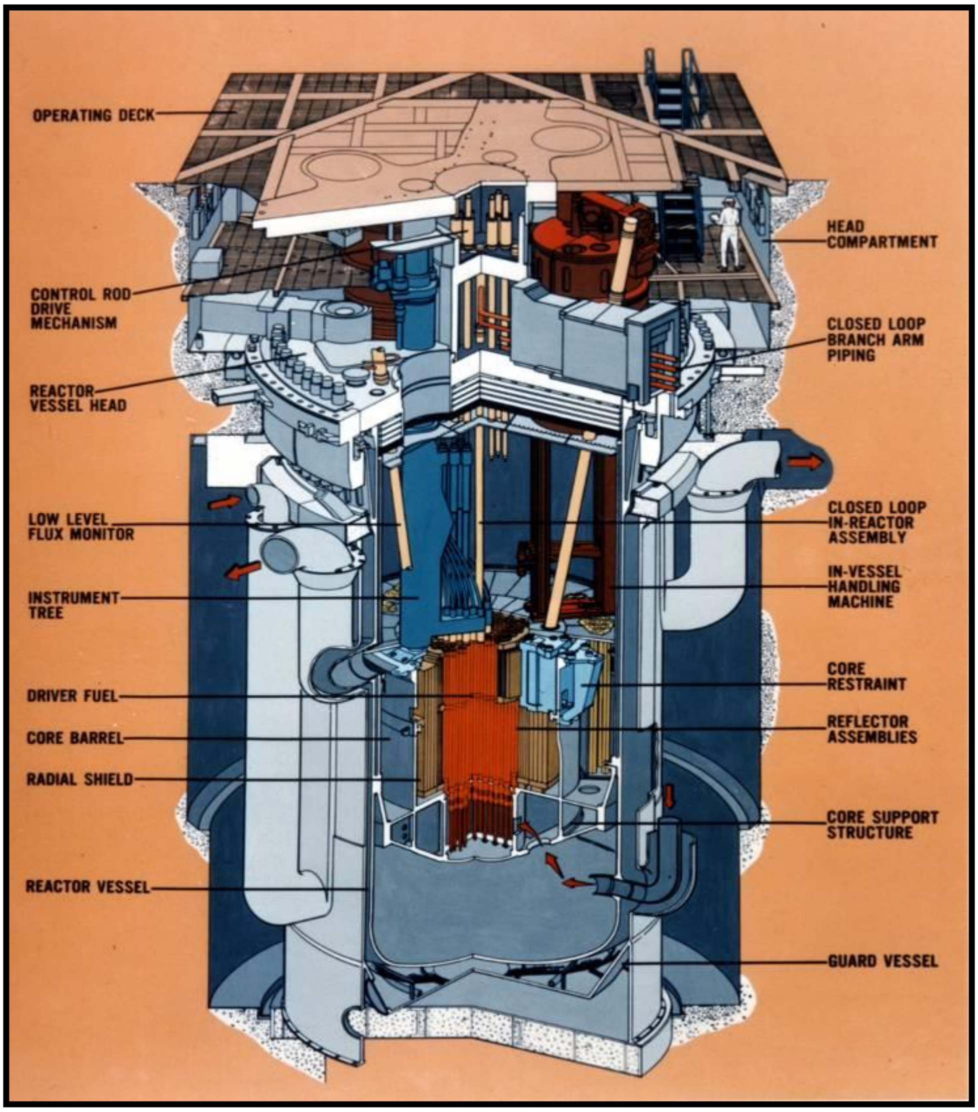

FIG. 2. FFTF Reactor Vessel Showing Closed Loop Branch Arm Piping Connections

TABLE I: FFTF PARAMETERS

Parameter	**Value**
Thermal Power	400 MW
Coolant	Sodium
Coolant Inlet/Outlet Temperatures	360/526 °C
Coolant Loops	3
Driver Fuel Material	$(Pu\text{-}U)O_2$
Enrichment Zones	2
Core Height	91.4 cm
Core Diameter	120 cm
Row 5 Control Rods (Nat. B_4C)	6
Row 3 Safety Rods (Nat. B4C)	3
In core Driver, Test Locations	82
Instrumented Through Head	8

3. Design Description of the FFTF Closed Loops

An FFTF CLS consists of three major subsystems: the Secondary Heat Rejection System (SHRS), the Primary Heat Removal Module (PHRM), and the Closed Loop In-Reactor Assembly (CLIRA). The general arrangement of a CLS is shown in FIG. 3 below.

The first major subsystem, the SHRS circulates sodium between an Intermediate Heat Exchanger (IHX) and an air-to-sodium Dump Heat Exchanger (DHX). The IHX is located in the Primary Heat Removal Module (PHRM). Sodium is circulated in the SHRS by an electromagnetic pump located in the cold leg. The major portion of the secondary loop is located outside containment with the IHX providing physical separation between the primary and secondary cooling systems. The secondary system is at a higher pressure than the primary system, so that in the event of a tube rupture in the IHX, the secondary system would not be contaminated with radioactive sodium from the primary system. The DHX is located above the IHX to facilitate circulation by natural convection in the event of a loss of pumping power.

The second major subsystem, the Primary Heat Removal Module (PHRM) is shown in FIG. 4. The PHRM support structure is designed so that it can be installed and removed as a unit from a closed loop cell using the reactor containment polar gantry crane. After entering the PHRM, sodium coolant passes through an electromagnetic flow meter and then flows upward through the PHRM IHX. The IHX is located as high as possible in the PHRM in order to facilitate circulation by natural convection between CLIRA and the IHX. A primary and an auxiliary electromagnetic pump are used to circulate the sodium, with each pump providing half the flow, thereby providing redundancy in the event of a pump failure. A fabricated CLS PHRM ready for installation in a Closed Loop Cell (CLC) in FFTF is shown in FIG. 5.

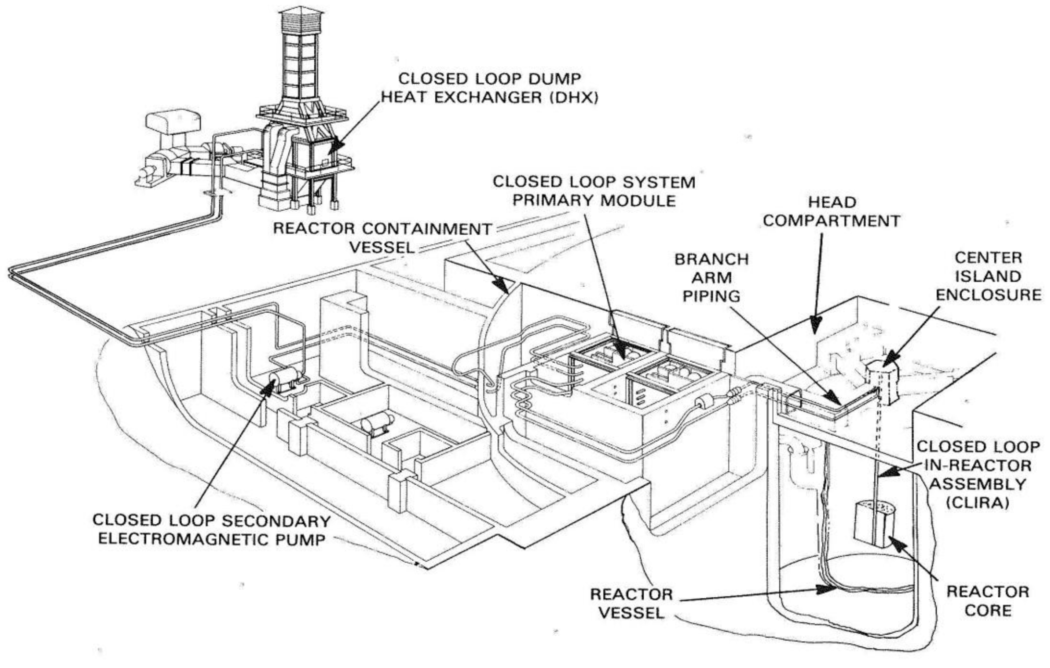

FIG. 3. General Arrangement of an FFTF Closed Loop System

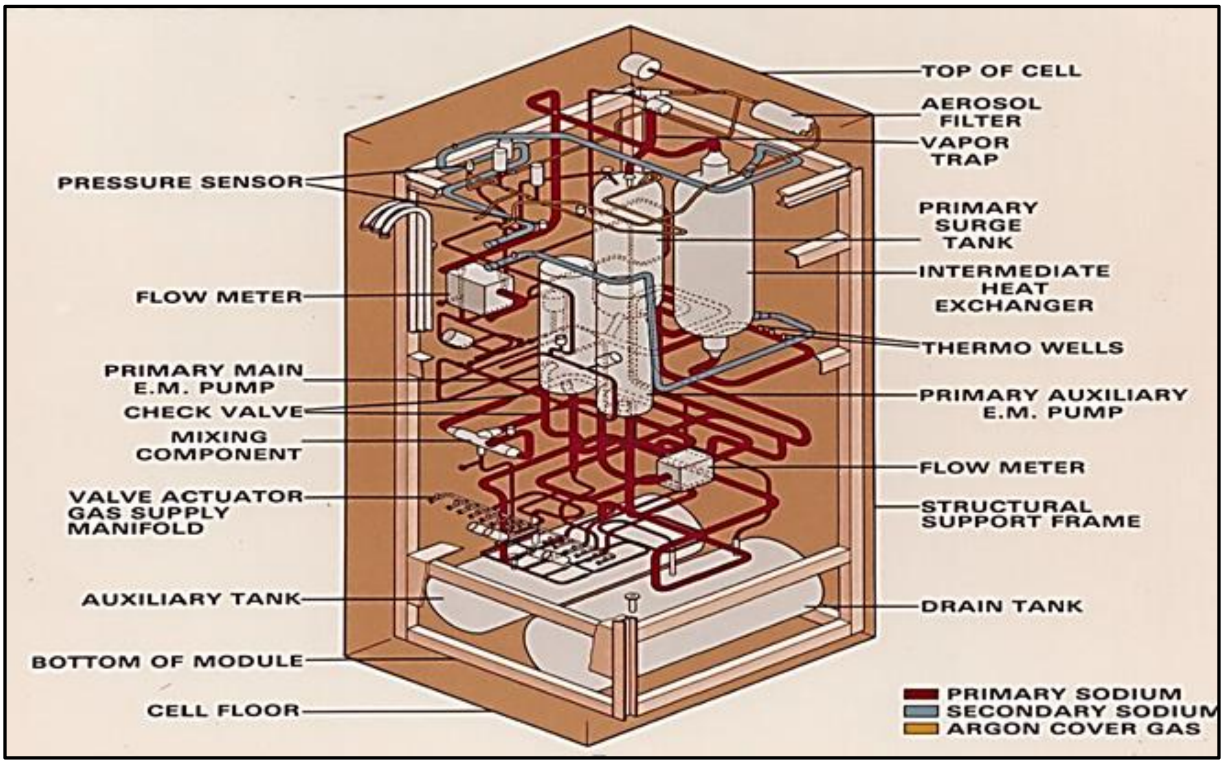

FIG. 4. FFTF Closed Loop System Primary Heat Removal Module (PHRM)

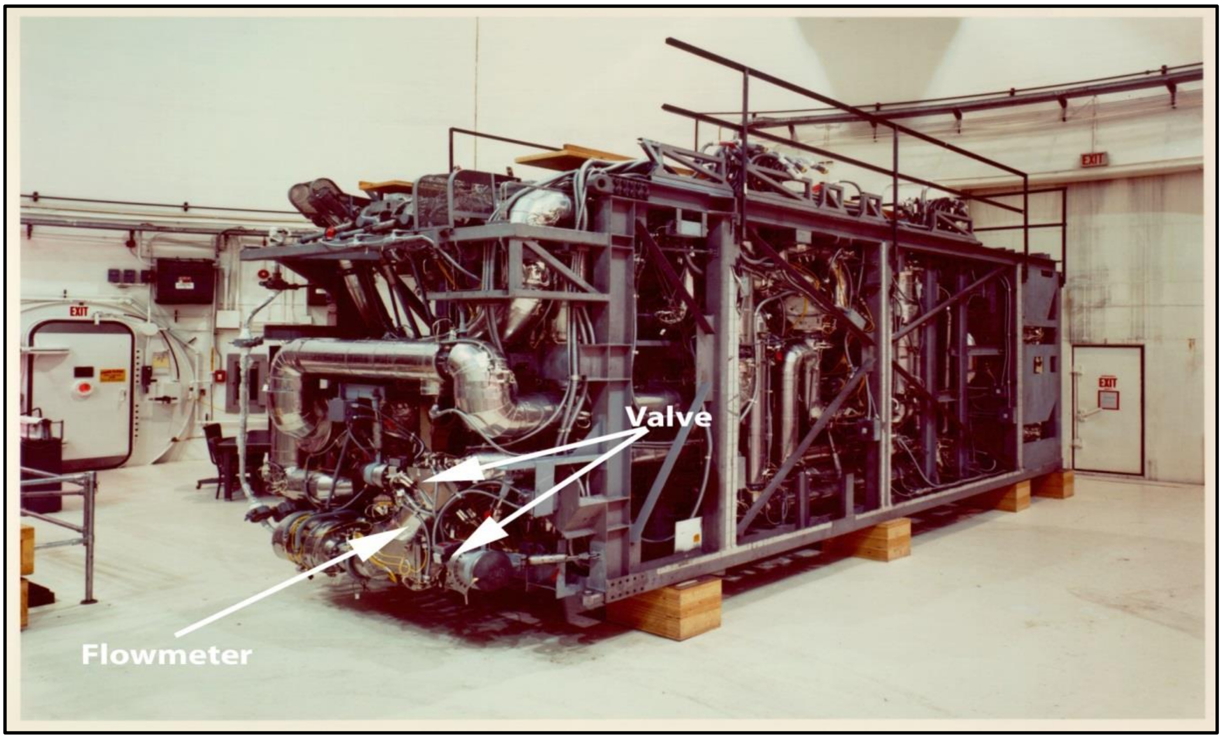

FIG. 5. Fabricated Closed Loop System Primary Heat Removal Module (PHRM) Ready for Installation in FFTF

The third major subsystem of an FFTF Closed Loop System was the Closed Loop In-Reactor Assembly (CLIRA). A CLIRA with its major components, along with its inlet and outlet ports, is shown in FIG. 6. The CLIRA penetrates the reactor vessel head and extends downward through the reactor core. The outside diameter of the test section can be as large as 7 centimeters, and twenty-six instrument channels are provided for monitoring variables in the test section such as pressure, temperature, flux, and strain. Sodium enters and exits the CLIRA through the Branch Arm Piping (BAP) in the Reactor Vessel, with the BAP shown in FIG. 2. From the inlet nozzle shown in FIG. 6 below, cold sodium flows down the pressure tube to the test inlet. Sodium then flows up through the test section and leaves the CLIRA through a 7.6 centimeter outlet leading to the BAP and then to the Primary Cooling System in the Primary Module. Other components of the CLIRA, shown in FIG 6, are listed with a brief description in TABLE II below.

TABLE II: DESCRIPTION OF OTHER MAIN COMPONENTS OF THE CLIRA

Pressure Tube	316 SST with Helium in the Annulus
Flow Tube	316 SST Single Walled
Spool Piece	To Connect to the Reactor Vessel Head
Instrument Tube	Forms Inner Diameter of the Return Flow Pathway
Connections to Branch Arm Piping	Provides Inlet and Exit Sodium Flow
Meltdown Cup Volume	1050 cm^3

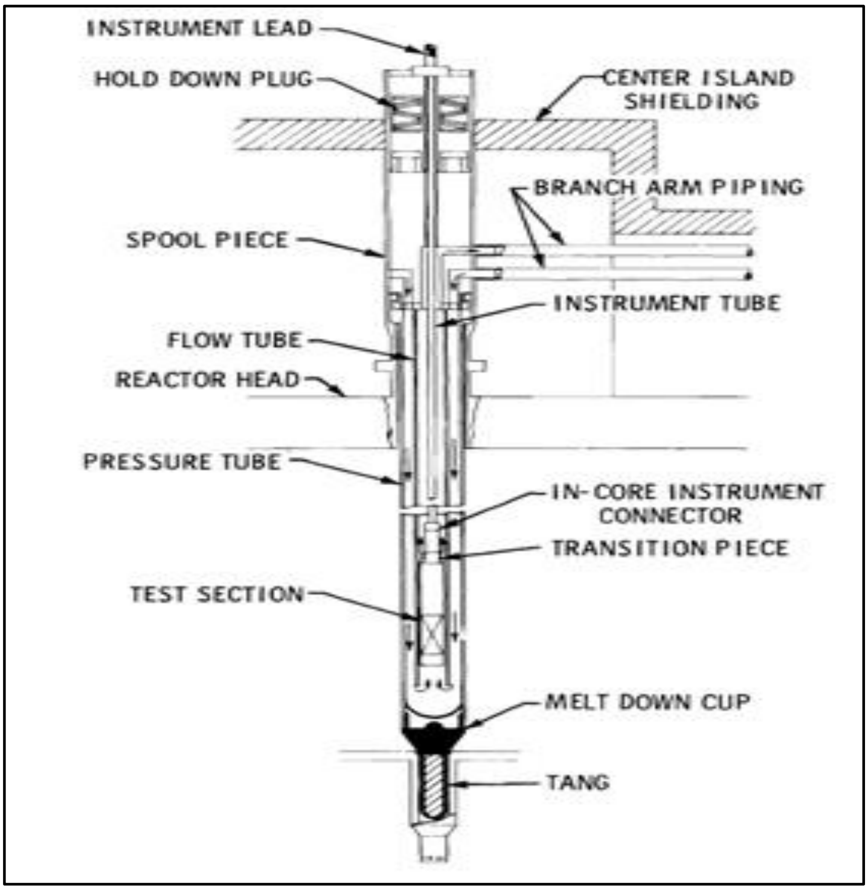

FIG. 6. Closed Loop In-Reactor Assembly General Arrangement

4. Closed Loop System Components

Many of the other components employed in the design of a FFTF Closed Loop System are shown but not explicitly identified in FIG. 3 to FIG. 6 nor discussed in the associated text. For completeness, a listing of those key components employed in the Primary and Secondary Cooling Loops is listed in TABLE III below.

TABLE III: KEY COMPONENTS EMPLOYED IN THE DESIGN OF THE FFTF CLOSED LOOP PRIMARY AND SECONDARY COOLING SYSTEMS

Primary Sodium Cooling Loop	Secondary Sodium Cooling Loop
CLIRA (Removable)	Main Pump (Electromagnetic)
Branch Arm Piping	Cold Trap
Main Pump (Electromagnetic)	Vent/Surge Tank
Auxiliary Pump	Dump Heat Exchanger
Surge Tank	Electromagnetic Sampling Pump
Vapour Trap	Aerosol Filter
Drain Tank	Magnetic Flow Meter
Auxiliary Tank	Mixing Component
Intermediate Heat Exchanger	
Cold Trap	
Sample Pump	

5. Closed Loop System Testing Capability

The FFTF Closed Loops were designed for a variety of tests spanning a range of accidents. To achieve this, they included the ability to physically simulate the transient conditions associated with accidents such as Loss of Coolant Flow, Loss of Piping Integrity, Transient Over-Power, and Potential Fuel Failure Propagation.

For Loss of Flow and Loss of Piping Integrity tests, the flow could be reduced to simulate accident conditions by controlling the electromagnetic pumps. With a large test volume, both radial and axial, an FFTF CLS was designed to provide real time accident simulation for either 19 or 37 pin geometries. With a large meltdown cup, an FFTF CLS would be able to accommodate gross radial or axial motion of molten fuel. For Loss of Piping Integrity tests, rapid reduction in the flow through the electromagnetic pumps could be used to investigate the consequences of coolant voiding and associated fuel melting.

For Transient Over-Power tests, a test assembly in an FFTF CLS could be first irradiated to a high burnup, thus preconditioning the fuel prior to the transient. To simulate a rapid transient, an FFTF CLS was designed with volume sufficient to include an absorber sleeve surrounding the fuel pins. This sleeve could then be removed at a designed rate, thereby simulating a rapid transient by providing a rapid increase in the linear heat rate and fuel temperature.

For Run Beyond Cladding Breach or Run to Potential Fuel Propagation Tests, the FFTF CLS was designed to accommodate either a 19 or 37 pin test assembly. Such testing was intended to provide experimental data and objective evidence regarding any fuel failure propagation concerns.

6. Summary and Conclusions

Closed Loops form a valuable part of the testing capability of any fast test reactor. CLS are important when testing fuels under accident conditions and are essential when other coolants are to be tested. The FFTF was designed to accommodate four CLS and two such systems were completely fabricated. But another and competing goal for the FFTF was to achieve initial criticality in 1980 with a full power demonstration the same year. The first was achieved on 9 February 1980 and the second was achieved on 21 December 1980. Achieving these milestones required all the resources available. Connection, and preparation for operation of these two CLS, even though completely fabricated, would have required manpower, time, and schedule that were just not available at that time if the two overarching December 1980 milestones mentioned above were to be met. Nonetheless, with the design and fabrication of the CLS described in this paper, there was no lack of confidence that they would have functioned as designed.

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