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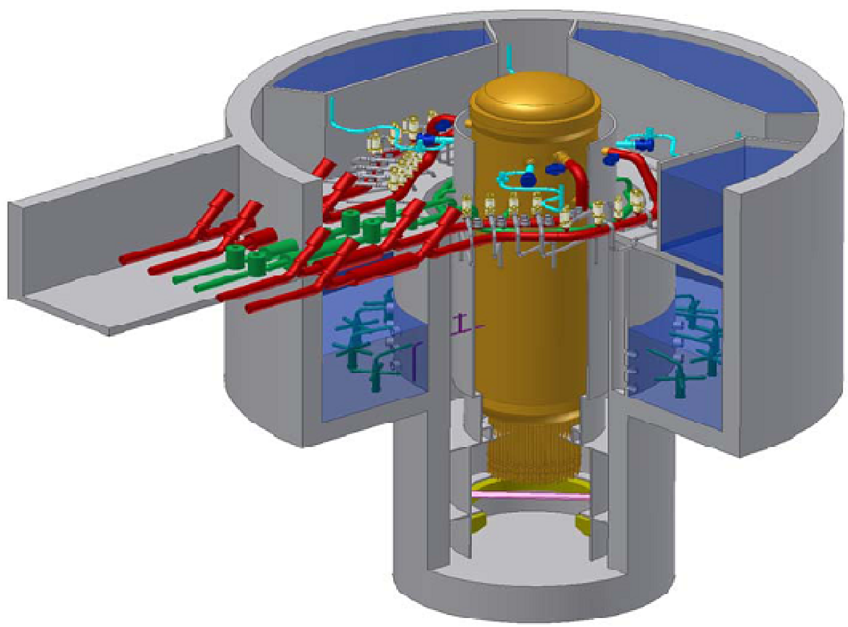

Part II
Introduction to Reactor Technology - BWR

Chapter 3.0, Reactor Vessel Instrumentation System

UNITED STATES

NUCLEAR REGULATORY COMMISSION

HUMAN RESOURCES TRAINING & DEVELOPMENT

Introduction to Reactor Technology

This manual is a text and reference document for the Introduction to Reactor Technology for the media briefing. It should be used by students as a study guide during attendance at this course. This manual was compiled by staff members from the Human Resources Training & Development in the Office of Human Resources.

The information in this manual was compiled for NRC personnel in support of internal training and qualification programs. No assumptions should be made as to its applicability for any other purpose. Information or statements contained in this manual should not be interpreted as setting official policy. The data provided are not necessarily specific to any particular nuclear power plant, but can be considered to be representative of the vendor design.
The Introduction to Reactor Technology – BWR briefing manual outlines the differences between the Boiling Water Reactors (BWR), Advanced Boiling Water Reactor (ABWR), and Economic Simplified Boiling Water Reactor (ESBWR). The course is broken down into discussions on design features, facility and plant layout, containment systems, nuclear steam supply systems, control and instrumentation, safety systems, balance of plant systems, normal, abnormal, and emergency operations.
The content of this course was based on the content provided in the following references:

- General Electric Systems Manual
- Introduction to ABWR Manual
- Introduction to ESBWR Course Manual
- Economic Simplified Boiling Water Reactor Plant General Description; June 2006, General Electric Company
- NUREG-1503, Final Safety Evaluation Report Related to the Certification of the Advanced Boiling Water Reactor Design and Appendices, U.S. Nuclear Regulatory Commission Office of Nuclear Reactor Regulation, July 1994
- ABWR, Advanced Boiling Water Reactor Plant General Description, “First of the Next Generation,” GE Nuclear Energy, June 2000
- Nuclear News, World List of Nuclear Power Plants, American Nuclear Society, March 2007
- J. Alan Beard & L.E. Fennern, General Electric presentation to DOE et.al, April 13th 2007, Germantown Md.

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The information contained in this chapter pertains to current operational reactor designs. Advanced reactor designs are provided in separate chapters.

3.0 REACTOR VESSEL INSTRUMENTATION SYSTEM

The purpose of the Reactor Vessel Instrumentation system is to provide sufficient information concerning reactor vessel water level, reactor vessel pressure, reactor vessel temperature, and core flow rate to allow safe plant operation.

The functional classification of the Reactor Vessel Instrumentation system is that of a safety related system, although some portions are strictly for power generation.

3.1 System Description

Reactor vessel instrumentation consists of several individual subsystems that monitor reactor parameters such as water level, pressure, flow and temperature. Reactor vessel water level is measured in the reactor vessel downcomer annulus. This parameter is monitored and displayed for operation on five different ranges.

Reactor vessel pressure is measured in the vessel steam space and displayed to aid the operator in safe plant operation. Both narrow and wide range pressure indications are provided for normal plant operation and for full range pressure coverage.

The plant power output capability should be proportional to the ability to remove the heat generated, therefore accurate core coolant flow measurements are required to evaluate core thermal behavior. Since the total flow that passes through the core must also pass through the jet pumps, the flow through each jet pump is measured and summed to yield total core flow.

Reactor vessel instrumentation supplies needed information to several systems such as the Reactor Protection System (RPS), Primary Containment Isolation System (PCIS), Feedwater Control System (FWCS) and the Emergency Core Cooling Systems (ECCS).

3.2 Component Description

The major components of the Reactor Vessel Instrumentation system are discussed in the paragraphs which follow.

3.2.1 Reactor Vessel Water Level Instrumentation

Reactor vessel water level is obtained through sensors which compare the weight of water in a reference column to the height (weight) of the water in the reactor downcomer annulus. Condensing chambers, external to the reactor vessel, are used to provide a constant reference column of water.

During normal reactor operation, reactor water level is maintained approximately 17 feet above the top of the active fuel. Maintaining an acceptable water level in the reactor vessel ensures that a sufficient quantity of reactor coolant is available to dissipate the heat generated by the core and the reactor is operating within the initial conditions assumed for the various analyzed events.

The level sensors, most of which –also indicate locally, are located throughout the reactor building at instrument racks. From the instrument racks, the level is transmitted to nine separate reactor vessel water level indicators in the control room and various trip circuits as shown on Figure 3.0-1 and Table 3.0-1.

Table 3.0-1, Reactor Vessel Level Setpoints and Functions

LEVEL	FUNCTIONS
+56.5"(L8)	High Level Trips Main Turbine and Reactor Feed Pump Turbines. Closes RCIC and HPCI Steam Supply Shutoff Valves
+40.5"(L7)	High Level Alarm
+37"(L5)	Normal Operating Level
+33.5"(L4)	Low Level Alarm, Recirc Runback
+12.5"(L3)	Reactor Scram, Primary Containment Isolation, Start Standby Gas Treatment system, ADS Permissive
-38"(L2)	Initiate HPCI, RCIC systems, Recirculation Pump Trip (ATWS-RPT)
-132.5"(L1)	Initiate Core Spray, Residual Heat Removal, ADS and Diesel Generators, and Main Steam Line Isolation

3.2.2 Reactor Vessel Pressure

Reactor Vessel Pressure is sensed in the steam dome area using the same instrument piping that exists for vessel level instrumentation. The reactor vessel pressure instruments contain numerous pressure transmitters (PT), pressure switches (PS) and pressure indicators (PI). A summary of reactor pressure trips is shown in Table 3.0-2.

Table 3.0-2, Reactor Vessel Pressure Setpoints and Functions

Pressure Setpoint	Functions
1120 psig	ATWS-RPT
1043 psig	Reactor Scram
1025 psig	High Pressure Alarm
465 psig & 338 psig	Core Spray, RHR Initiation & Valve Interlocks
310 psig	Recirculation Pump Discharge Valve Closure on LPCI Initiation Signal
125 psig	RHR Isolation (Shutdown Cooling Mode)

3.2.3 Core Flow Instrumentation

To evaluate reactor core power level and core thermal characteristics, accurate core flow measurements are required. Since all core flow, except control rod drive cooling water, must pass through the jet pumps, the flow through each jet pump is measured and summed to yield total core flow.

All 20 jet pumps have a pressure tap on the pump throat which is compared to core inlet plenum area pressure. The square root of this differential pressure provides a signal representing jet pump flow. As indicated on Figure 3.0-2, five jet pump flow signals are summed and then added to another five jet pump flow signals to yield loop flow. The two loop flow signals are then summed to yield total core flow.

During normal plant operation with both recirculation pumps operating, the loop flows are simply added together in a summation network. However, if one recirculation pump is off and the other is operating, the inactive loop will have reverse flow. The jet pump flow transmitters are not capable of distinguishing the direction of flow through the jet pumps. As a result, a relay logic system senses recirculation pump status to subtract the idle loop flow from the operating loop flow to yield an accurate total core flow output signal.

3.2.4 Reactor Vessel Temperature Instrumentation

The reactor vessel metal temperature is measured and monitored to provide temperature data representative of thick, thin, penetration and transitional sections of the vessel. The temperature monitoring system is designed to map temperature gradients during startup and shutdown conditions. The data is recorded by a multipoint recorder and a two pen recorder, providing the basis to establish the rate of heating or cooling performed on the vessel.

3.3 System Features

A short discussion of the system features is given in the paragraphs which follow.

3.3.1 Bases for Level Setpoints

Vessel level instrumentation used to initiate safety systems, cause operational trips and provide control system inputs, is listed in Table 3.1-1. The reactor vessel water level trip setpoints are referred to as numbered levels. These levels and their elevation referenced to instrument zero are: Level 1 (-132.5"), Level 2 (-38"), Level 3 (+12.5"), Level 4 (+33.5"), Level 5 (+37"), Level 7 (+40.5") and Level 8 (+56.5"). The bases for the various level setpoints are discussed in the paragraphs which follow.

3.3.1.1 Level 8 (+56.5")

The trip of the main turbine is to protect it against the occurrence of gross carryover of moisture and subsequent damage to the turbine bladeing. The reactor feed pump turbines are tripped to prevent overfilling the reactor vessel. The reactor core isolation cooling and the high pressure coolant injection turbines are tripped, in the event these systems have activated, to prevent flooding of steam lines.

3.3.1.2 Level 7 Alarm (+40.5")

While operating at full power, the high level alarm annunciates indicating that as level continues to rise, moisture carryover in the steam is expected to increase at a significant rate. The alarm warns the operator of the need to take action to prevent this undesirable condition.

3.3.1.3 Normal Operating Level (+37")

Reactor vessel water level can be controlled at any point between the high and low level alarms. However, the Feedwater Control System is usually set to maintain vessel level at +37 inches.

3.3.1.4 Level 4 Alarm Trip (+33.5")

The low water level alarm annunciates indicating that as level continues to drop, steam carryunder in the water will begin affecting the reactor recirculation flow rate significantly at full power because of recirculation pump cavitation. A water decrease to this point, coincident with a reactor feed pump trip, causes the recirculation pumps to runback to a predetermined speed to reduce thermal power output within the capacity of the remaining reactor feed pump.

3.3.1.5 Level 3 Trip (+12.5")

The low level scram function is for protection against high moisture carryover because of steam bypassing the dryer under the seal skirt. The scram occurs while the water level is above the bottom of the dryer seal skirt. The level selection also results in a quantity of reserve coolant between this level and the top of the active fuel to account for evaporation (decay heat boil off) losses, steam void collapse and other coolant losses from the reactor vessel following a loss of feedwater flow. Adequate water supply is provided to avoid vessel level decreasing to -132.5", which would initiate the Emergency Core Cooling Systems (ECCS). A decrease of reactor vessel inventory to this level also causes actuation of the Primary Containment Isolation System.

3.3.1.6 Level 2 Trip (-38")

This setpoint is selected to be low enough so that the RCIC and High Pressure Coolant Injection (HPCI) Systems will not be initiated on low level after a reactor scram unless feedwater flow has been terminated. The setpoint accounts for the expected level decrease caused by steam void collapse which occurs following any scram. The setpoint is selected high enough so that the RCIC system design flow is sufficient, taking into account system startup time following a loss of feedwater flow, to recover reactor vessel water level and prevent a level decrease to -132.5" with the subsequent initiation of emergency systems. The various system isolations are to prevent or limit the loss of reactor coolant and the release of radioactive products to the atmosphere assuming that the vessel water level decrease was due to a leak from one or more of the effected systems.

The recirculation pumps are tripped to insert negative reactivity using subsequent void formation, in the unlikely event that the reactor did not scram on a reactor vessel low water level signal. This event is referred to as an Anticipated Transient without Scram - Recirculation Pump Trip (ATWS-RPT).

3.3.1.7 Level 1 Trip (-132.5")

This level setpoint is selected to be high enough above the top of active fuel to initiate the remaining ECCSs. Thus, providing adequate time for the ECCS to function in the event of a Loss of Coolant Accident (LOCA) providing adequate core cooling and minimizing fuel damage.

3.3.2 Bases for Reactor Pressure Setpoints

A summary of reactor pressure trips is given in Table 3.0-2 and discussed in the paragraphs which follow.

A reactor pressure of 1120 psig trips the recirculation pumps to insert negative reactivity by means of void formation, assuming the reactor failed to scram on high pressure. This event is another (ATWS-RPT).

3.3.2.1 Scram Setpoint

The reactor scram setpoint (1043 psig) prevents reactor vessel over pressurization and, in conjunction with safety/relief valve operation, provides sufficient margin to the maximum allowable reactor coolant boundary pressure.

3.3.2.2 High Pressure Alarm

The high pressure alarm (1025 psig) alerts the operator to abnormal system pressure.

3.3.2.3 Low Pressure Injection Setpoints

Water injection by the Core Spray (CS) and Residual Heat Removal (RHR) systems is delayed until reactor vessel pressure is reduced to 465 and 338 psig to prevent reverse flow and over pressurization of these emergency core cooling systems.

3.3.2.4 Recirculation Pump Discharge Valve Closure

As a part of the RHR initiation logic, the recirculation pump discharge valves close when pressure decreases to 310 psig to ensure RHR water enters the reactor vessel on a recirculation suction line LOCA. Delaying valve closure to this pressure will ensure the valve will be able to close since it is designed to close with a maximum differential pressure of <200 psi.

3.3.2.5 RHR Isolation

Pressure above 125 psig isolates the RHR system while in the shutdown cooling mode to protect low pressure piping.

3.4 System Interfaces

The interfaces are listed in Tables 3.0-1 and 3.0-2.

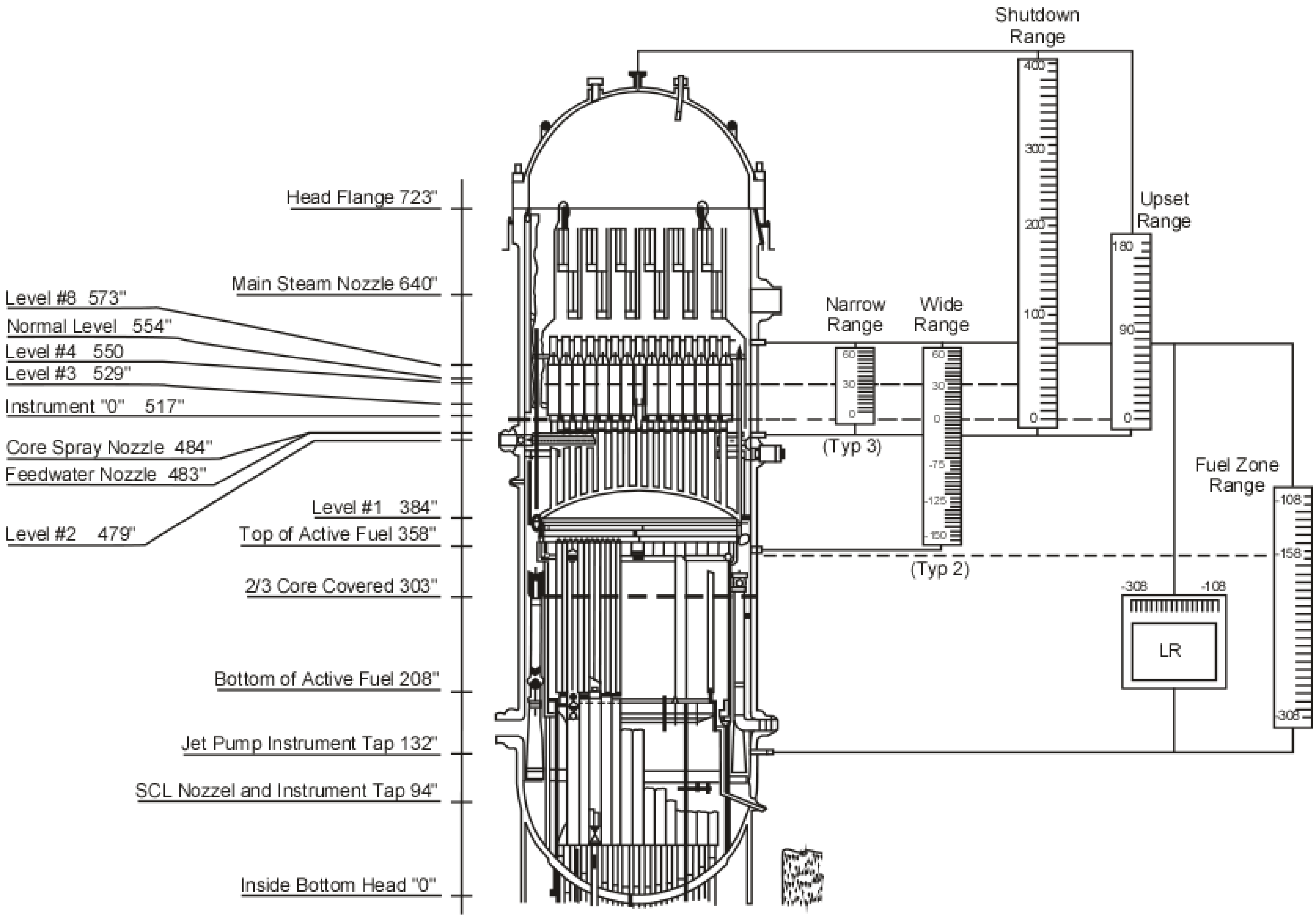

Figure 3.0-1, Reactor Vessel Level Instrumentation Ranges

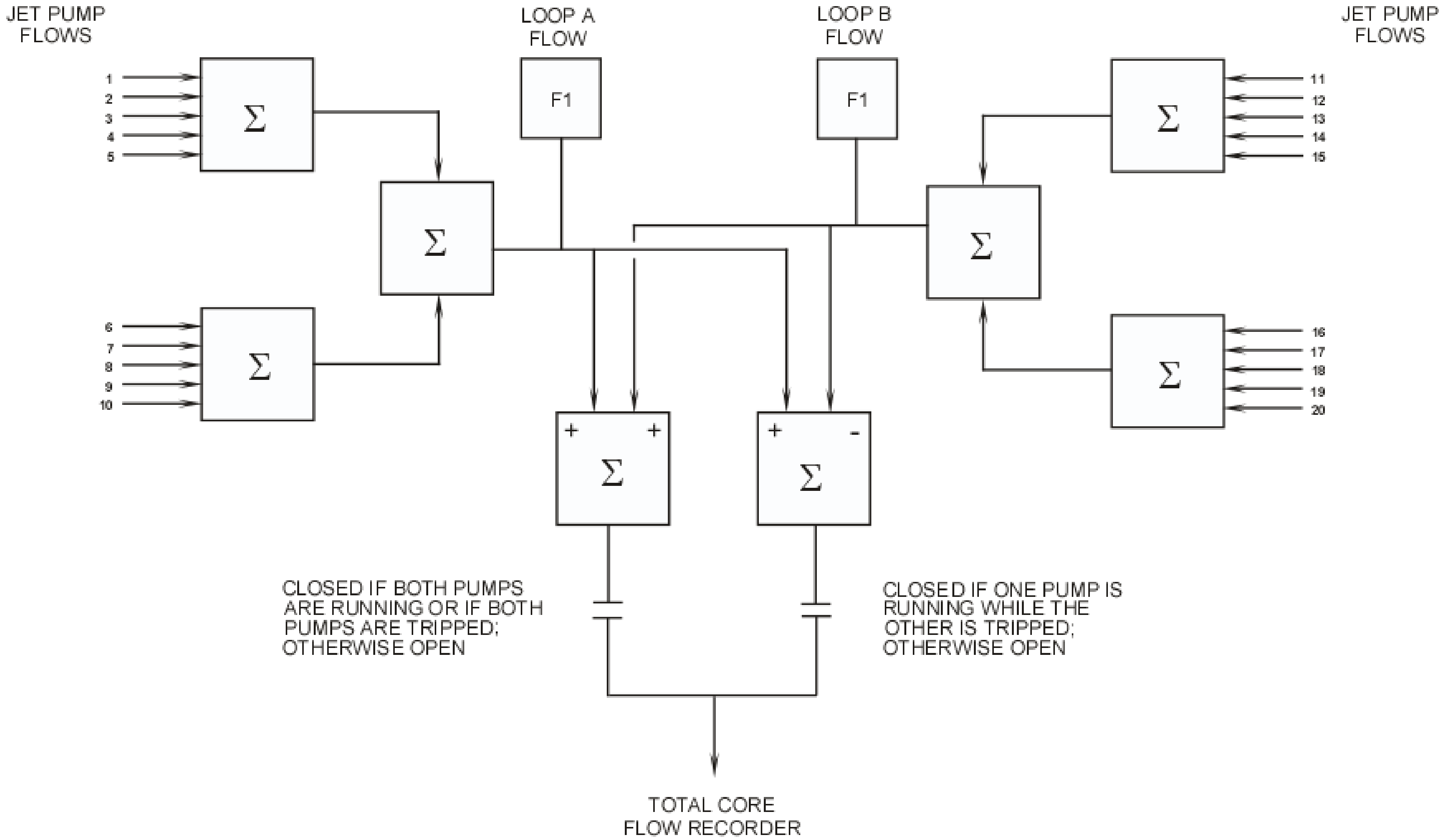

Figure 3.0-2, Core Flow Summing Network