Westinghouse Technology Systems Manual

Chapter 12

REACTOR PROTECTION SYSTEM

Section

Westinghouse Technology Systems Manual

Section 12.1

Reactor Protection Systems

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12.1 REACTOR PROTECTION SYSTEM

Learning Objectives:

1. State the purposes of the Reactor Protection System (RPS)
2. Explain how the following design features are incorporated into the RPS:
   a. Single failure criterion
   b. Testability
   c. Equipment qualification
   d. Independence
   e. Diversity
   f. Control and protection system interaction
3. Describe the sequence of events (flowpath) beginning at the sensor up to and including the starting of an Engineered Safety Feature (ESF) component and/or the opening of a reactor trip breaker.
4. Explain how failures in the rod control system are prevented from affecting reactor trip capability.

12.1.1 Introduction

The purposes of the reactor protection system are as follows:

1. Initiate a reactor trip if safe operating limits are exceeded.
2. Initiate engineered safety features actuation if an accident occurs.

The overall purpose of the reactor protection system is to prevent the release of radioactivity to the environment. To meet this objective, the RPS acts to prevent the unsafe operation of the reactor, which could lead to an accident condition. The initiation of a reactor trip by the RPS prevents the core from operating in a condition that could cause damage to the core. However, if an accident occurs, the RPS trips the reactor and actuates the engineered safety features. These safety features mitigate the consequences of an accident.

The reactor plant operating limits are determined and set by the utility's Final Safety Analysis Report (FSAR). The plant incorporates these limits into their technical specifications, and the NRC appends the technical specifications to the plants' operating license. Local sensors monitor various processes, and these sensors are capable of detecting a condition that would require a reactor trip or an engineered safety features actuation.

Analog circuitry (located within the analog cabinets) compares an analog input signal, supplied by a process sensor, to a preselected trip setpoint. If the process signal is equal to or exceeds the setpoint, this circuitry converts the analog signal into a digital output monitored by the trip logic matrix. Based upon the input signals, the logic matrix (located within the logic cabinet) determines whether the RPS should actuate a reactor trip or an engineered safety feature.

12.1.2 System Description

12.1.2.1Reactor Protection System Design

To guarantee the integrity of the reactor systems and to avoid an undue risk to the public health and safety, the plant design incorporates a reactor protection system. This system is capable of supplying reactor and component trip signals and initiates the engineered safety features, which provides protection for normal operating, transient, and accident conditions.

The reactor protection system contains two complete and independent trains of analog and logic circuits. If an analog circuit senses an unsafe condition, a signal is sent to the protection system logic cabinets, where the appropriate logic contact opens. The logic matrix (circuit) determines if the coincidence for a protective feature is satisfied. If so, the protection system opens the reactor trip breakers. Opening these breakers removes power from the rod drive mechanisms, allowing the rods to fall into the reactor core. If an accident occurs and an engineered safety features actuation is required, the protection system actuates the appropriate safety equipment. In addition, the logic trains generate permissive signals, which automatically initiate or remove protection grade bypasses or interlocks.

12.1.2.2 Compliance With General Design Criteria (GDC)

The reactor protection system designed by Westinghouse meets the General Design Criteria of 10 CFR part 50. In addition, the protection system complies with various Regulatory Guides and several different IEEE Standards. Some of the documents that the protection system complies with are:

1. "General Design Criteria for Nuclear Power Plants" Appendix A to Title 10 CFR 50
2. United States Nuclear Regulatory Commission Regulatory Guides
3. "Criteria for Protection Systems for Nuclear Power Generating Stations" IEEE 279-1971
4. "Criteria for Class 1E Electrical Systems for Nuclear Power Generating Stations" IEEE 308-1971
5. "Trial-Use Criteria for Periodic Testing of Nuclear Power Generating Station Protection Systems" IEEE 338-1971

12.1.2.3 Single Failure Criterion

The reactor protection system contains redundant instrumentation channels (two to four instruments) for each protective function. These process instruments provide signals to a one-out-of-two logic train scheme and are electrically isolated and physically separate from each other. Either logic train sensing the required coincidence can provide the required protective actions (either a reactor trip or an engineered safety features actuation). Any single failure within a channel or train will not prevent a protective action when required, and this system shall be testable, with an operating reactor, without reducing its reliability of operation. This meets the requirements of General Design Criterion (GDC) 21 and 22 and Regulatory Guide 1.53. A loss of input power (the most likely mode of failure) to the protection system results in the system failing to a safe state or into a state demonstrated to be acceptable. This meets the requirements of GDC 23.

12.1.2.4 Testability

The RPS is testable during all plant conditions. The RPS is tested in a segmented fashion, where each test section overlaps an adjacent test section. This insures both availability and accuracy of the system from the sensors to the final devices (trip breakers, ESF equipment, etc.).

12.1.2.5 Equipment Qualification

Following an accident, specifically a loss of coolant accident (LOCA), the environmental conditions inside the containment (i.e., temperature, pressure and radiation) increase. All safety systems, components and instruments important to safety must remain functional in order to provide their intended safety functions. Therefore, a wide range of environmental qualification tests, and functional performance tests, are employed to insure equipment survivability. These test results demonstrate that the safety equipment meets the requirements of GDC 22.

12.1.2.6 Independence

Each process instrument is assigned to one of the four protection channels, e.g., Channel I, II, III, or IV. Channel independence is maintained throughout the system. This independence extends from the sensor to the devices actuating the protective function. Physical separation is used to achieve separation of redundant transmitters. Separation of wiring is achieved using separate wireways, cable trays, conduit runs and containment penetrations for each redundant channel. Redundant analog equipment is separated by locating modules in different protection rack sets. Finally, each redundant channel is powered from a separate vital ac power source. This meets the requirements of GDC 22.

There are two reactor trip breakers, of which each breaker is automatically opened (tripped) by its own dedicated logic matrix. The series connected reactor trip breakers' supply power to the rod drive mechanisms. Opening either breaker interrupts power to all rod drive mechanisms, allowing the rods to free fall into the core.

12.1.2.7 Diversity

To ensure the safe operation of the reactor core and protect the reactor coolant system pressure boundary, the RPS continuously monitors numerous diverse process system variables. The extent of this diversity has been evaluated for a great number of postulated accidents. Generally, one or more diverse protection functions would terminate an accident before intolerable consequences could occur. This meets the requirements of GDC 21 and GDC 22.

12.1.2.8 Control and Protection System Interaction

The reactor protection system is designed to be independent of all process control systems. However, in certain applications, some control signals and other non-protective functions are derived from individual protective channels through isolation amplifiers. The isolation amplifiers are classified as part of the protection system and are most often located within the reactor protection analog racks.

Non-protective signals are used for system or component control, indication, and computer monitoring. Isolation amplifiers are designed and installed so that, a short circuit, an open circuit, or if a voltage (ac or dc) is applied to the isolated output portion of the amplifier (i.e., the control side of the circuit) the input (protective) side of the circuit remains unaffected. Any signal passed through an isolation amplifier is never returned to the protection racks. This meets the requirements of GCD 24.

If the failure of a protection system process instrument or component causes a plant transient which requires a protective action (i.e., a reactor trip), the protection system is designed to withstand another, independent failure without loss of the protective function. This meets the requirements of GCD 25.

12.1.3 Component Description

The Westinghouse protection system may be of several different designs. The common designs are the relay protection system and the solid state protection system. Either of these systems performs the same functions as stated in the system description, with the solid state protection system being a later design. A description of both systems is included with specific differences explained. This section also provides a description of the reactor trip breakers and their protection system interfaces.

Some facilities have upgraded portions of the solid state protection system to the Eagle-21 protection system sold by Westinghouse. This chapter will not discuss the Eagle-21 system; however, a few comments of this system follow. The Eagle-21 protection system incorporates a number of different cabinets, of which each cabinet performs a specific task. The innovative feature of the entire system is the fact that it is an on-line, self-testing protection system. Using solid state devices, this system checks the entire protection system regardless of the operational condition of the reactor, and it performs these functional tests continuously.

12.1.3.1 Relay Protection System

The relay protection system is explained by describing the features shown on Figure 12.1-1.

1. Red, White, Blue, Yellow - Redundant analog protection channels originate at the process sensors. Each channel is powered from an independent vital power supply.

2. Isolation Amplifier - The control systems are separate and distinct from the protection system. The control systems are, however, dependent upon signals derived from the protection system through these isolation amplifiers.

3. External Signal Input - The signal conditioning equipment of each protection channel in service during normal operations is capable of being calibrated and tested independently. This is accomplished by inserting analog signals to verify proper operation without tripping the reactor. This allows testing through the channel to the protection bistable output.

4. Channel Test Switch - Provides a path for an "external signal input" to the protection bistable, and it also provides a path to an "alarm" which alerts the operator to a protection channel test condition.

5. Protection Bistable - Is an electronic switch with an adjustable on-off set point. It is designed to interrupt control power to both the train A and train B logic cabinet input relays. Within the bistable, a signal from the process sensor is compared to a pre-set, adjustable set point. When the process signal equals or exceeds the set point value, the bistables' output is turned off (de-energized); and its output voltage goes to zero (bistable is tripped). This electronic device or switch converts the analog (variable) input signal into a digital (on-off) output signal. The input relays (item 7) of the logic cabinets receive this digital signal.

6. Bistable Output Trip Switch - Permits bistable testing and verification of the bistable's operability by providing continuity through the "Proving Lamp". When this switch is placed in the trip position, the bistable provides a trip input to the logic matrix. The technician varies a test input signal via a signal generator as described in items '3' and '4' above. When the test signal equals the trip set point, the "Proving Lamp" de-energizes. This provides verification of the bistable's set point.

   In addition, an alarm sequence violation circuit is provided to ensure that the technician trips the bistable prior to performing any testing on the analog section of the protection system. If this alarm actuates, it alerts the control room operator that the technician performing the surveillance is not following the proper procedural steps for testing. When this switch is in the normal position (not tripped), power is supplied through the bistable to both train A and train B logic cabinets.

7. Input Relays - The input relays are operated by the output of the bistables described in item '5' above. When energized (bistable not tripped), the relays hold closed a contact in the logic matrix providing circuit continuity to the reactor trip breaker under-voltage coils. When the protection bistable trips, its input relay de-energizes, opening its corresponding contacts in the logic matrix. In Figure 12.1-1, the red

channel is shown from the sensor of some parameter to the output in the logic section.

For this discussion assume the red channel , in this figure, is an output from pressurizer pressure. If this channel senses a pressure in excess of 2385 psig, its associated bistable trips; causing the bistable output voltage to go to zero.

With the bistable output at zero volts, the red input relays de-energize in both the train A and train B logic cabinets. When the input relays de-energize, they open the contacts labeled (1) in the logic matrix of train A and the (A) contacts in the train B logic matrix. The logic coincidence for this particular trip function is a two-out-of-four (2/4). Therefore, two channels must de-energize to produce a reactor trip. Note; even with all of the number 1 contacts or and all the "A" contacts open, power is still delivered from the 125 Vdc battery bus to the under-voltage (UV) coils on the reactor trip and reactor trip bypass breakers.

A reactor trip will not occur until one of the other three channels also senses a high pressure condition and trips its associated bistable and input relay. With any two sets of logic matrix contacts open, power is interrupted to the under-voltage coils of the reactor trip breakers, causing them to open.

8. Logic Cabinets - Receive the signal inputs from the protection bistables (either on or off). The bistable output signals provide the protection system inputs for all reactor trips. Energized input relays 1, 2, 3, and 4, (for train A) or A, B, C, and D, (for train B) hold their associated contacts closed, which maintains continuity of the power supply circuitry to the under-voltage coils of the reactor trip breakers. If these under-voltage coils de-energize as result of bistable action, incorrect testing, or any other manner, the series-connected, reactor trip breakers open - allowing all shutdown and control rods to fall into the core.

9. Pushbuttons 1, 2, 3, and 4 - Allow complete logic testing to insure reactor trip breaker operation when the correct channel coincidence is established. For example, when an electronic technician depresses one of these pushbuttons, its associated test relay energizes, opening its associated test contact (shown beneath the input relays in Figure 12.1-1). When the test contact opens, the input relay de-energizes, allowing its associated logic contact in the logic matrix to open. This action interrupts power to the reactor trip breaker under-voltage coils if the correct logic coincidence is satisfied. During this test, the reactor trip bypass breaker must be closed to prevent a reactor trip. The reactor trip breakers and their associated bypass breakers are described in Section 12.1.7.

12.1.3.2 Solid State Protection System

Applying solid state techniques to the design of the reactor protection system provided significant improvements over previous designs utilizing relays and contacts. Approximately 750 relays with 4000 contacts connected in various matrices are contained in a relay protection system for a Westinghouse designed four-loop plant. This vast quantity of relays and contacts requires fourteen - 30 inch wide by 30 inch deep cabinets, contrasted with six cabinets of the same size supplied with the solid state system.

The addition of a semi-automatic fast pulse test circuit reduces the test time for the logic section of the protection system from four hours per train on the relay system to approximately one hour per train on the solid state system. Fast pulse testing also eliminates the need to bypass the reactor trip breakers each time the logic section is tested. The duration of the logic test pulse is so short that the under-voltage driver card output is not interrupted.

Therefore, the reactor trip breaker for the train undergoing this surveillance test is unaffected.

Figure 12.1-2 shows a single line block diagram of the solid state reactor protection system. This system, like the analog reactor protection system, is comprised of two redundant, identical trains (A and B) that are physically and electrically independent. Inputs into this system are derived from various nuclear and non-nuclear sensors located both inside and outside of the containment building. Most of these signals are processed in the analog cabinets and result in bistable outputs (128 volts ac normal or zero volts when tripped) to the solid state protection system. Other protection signals are derived directly from the process sensor by way of contacts at the sensor (examples of such are - oil pressure switches on the turbine, auxiliary contacts on circuit breakers, and limit switches on valves).

The physical arrangement of the input relay contacts within the logic portion of this system determine the coincidence logic (i.e., 2/3, or 2/4). Additional inputs, which carry the train designation, enter the logic directly from control board switches and pushbuttons.

Information concerning the status of this system is transmitted to the control board status lamps and annunciators via a control board demultiplexing circuit and to the computer via a computer demultiplexing circuit. The purpose of these multiplexing systems is to transmit a large amount of status information over a small number of conductors, thereby simplifying and reducing field wiring requirements. About 200 status lamps and 100 annunciators are operated by the control board demultiplexer and about 200 signals are recorded by the plant computer by its demultiplexer.

Status information taken from the solid state logic is transmitted to the demultiplexers through isolation devices in the trains (light transmission is used to achieve this isolation). The purpose of the isolation is to separate the monitoring circuit (which is considered to be a non-protective function) from the protection circuitry. By design there is no possibility of short circuits, open circuits, or high voltage connections on the multiplexing line affecting operation of the protection circuits. Multiplexed outputs of the two trains are designed so that a status lamp or annunciator is actuated by either train A or train B. Normally both trains actuate the devices simultaneously. A flashing lamp or annunciator indicates status disagreement between train A and train B.

The solid state logic circuitry can be tested with the plant either shutdown or at power. Each train contains an identical semi-automatic test panel with the necessary controls for testing. During the logic matrix surveillance, all reactor trips and engineered safety features actuations for the train under test are inhibited (prevented from actuating). In addition, all information transmitted to the control board status lamps and annunciators, and to the plant computer from that same train, are inhibited. To perform this surveillance, the operator needs only to select the process to be tested using a rotary selector switch, press a "start test" pushbutton and wait for either a green "good" lamp or a red "bad" lamp to illuminate. During the test sequence all possible combinations of non-trip and trip conditions for that process logic are checked.

The semi-automatic tester checks the solid state logic including continuity to the under-voltage coil of the reactor trip breaker or to the master relay coils, excluding the input relays and contacts. The input relays and contacts are checked during testing of the analog portion of the protection system by tripping a bistable while monitoring the control board status lamp for the specific trip function. Since the lamp is operated through the multiplexing system, it cannot light until the input relay is actuated.

12.1.3.3 Reactor Trip Breakers

Two series-connected reactor trip breakers, Figure 12.1-2, deliver power from the rod control motor-generator sets to the rod control power cabinets. A loss of power to these cabinets causes all rods to drop into the core.

Under-voltage coils keep the reactor trip breakers closed. The reactor protection system logic matrix provides a current flow path for these coils. If a reactor trip coincidence is satisfied contacts within the logic matrix open, breaking the continuity of this circuit, and the under-voltage coils de-energize. Removing power to these coils opens the reactor trip breakers.

Installed in parallel with each reactor trip breaker is a reactor trip bypass breaker. This breakers function allows on-line testing of the reactor trip breakers, without interrupting power to the rod drive mechanisms. The train A protection system de-energizes the under-voltage coil for the train A reactor trip breaker and the train B bypass breaker. While the train B portion of the reactor protection system de-energizes the under-voltage coil for the train B reactor trip breaker and the train A reactor trip bypass breaker. Whenever a reactor trip breaker is bypassed, the protection train associated with that breaker is considered to be inoperable.

The bypass breakers are interlocked so that if an attempt is made to close a bypass breaker with one reactor trip bypass breaker already closed, both bypass breakers trip open. This interlock prevents bypassing both protection trains simultaneously.

12.1.3.4 Output Cabinet

The mechanism for initiating engineered safety feature functions is the protection system output cabinet (one for each protection train). The output cabinet contains approximately 20 master relays and 40 slave relays. Actuation of the master relays occurs when the logic section initiates an engineered safety features signal. The master relays, in turn, actuate from one to four slave relays (See Figure 12.1-3). The slave relays close contacts in pump starting circuits, close contacts to open or close valves, or actuate solenoids for air-operated equipment.

Test cabinets for both the slave and master relays allow periodic testing. Testing of this circuitry consists of introducing a low voltage electrical signal to each coil. This low voltage is not strong enough to actuate the relay, but is sufficient to demonstrate continuity through the coil.

Integrated full scale operability testing requires the actuation of the engineered safety features equipment (final device testing). Testing of this nature can only be accomplished during plant shutdown, and requires extensive preparation and system realignments. Generally, one entire train (either train A or train B) will be alternately tested during each refueling outage (every 14 to 24 months).

12.1.4 System Interrelationships

12.1.4.1 Protection System Testing

While only portions of this system are tested at a time, the testing sequence provides an overlap to assure complete system operability. Testing the analog portion of the protection system at power is accomplished without initiating a protective action unless a trip condition actually exists. A trip does not occur because of the two-out-of-three or the two-out-of-four coincidence logic required for a reactor trip. The source and intermediate range nuclear instruments have a one-out-of-two logic scheme. Therefore, placing one of these channels in test would generate a reactor trip. To prevent this action, these instruments have a local bypass switch. However, placing one channel in bypass reduces the system coincidence to a one-out-of-one coincidence.

The proper operation of process sensors, a channel check, is verified by comparing redundant channels monitoring the same process variable or those with a fixed known relationship to the parameter being checked. Calibration of the sensors is normally accomplished during plant shutdown. The voltage and current of a channel from the sensor to the bistable is variable in magnitude and is referred to as the analog signal. From the bistable to the input relays, only ON-OFF signals are found. This portion of the channel is referred to as digital. Analog testing is performed at the analog instrumentation rack by individually introducing test signals into the instrumentation channels and observing that the appropriate output bistable action.

The power range channels of the nuclear instrumentation system are tested by superimposing a test signal on the actual detector signal at the time of testing. The output of the bistable is not placed in a tripped condition prior to testing. Also, since the power range channel logic is a two-out-of-four, bypassing this reactor trip function is not required.

The logic trains of the reactor protection system are designed to be capable of complete testing at power, except for those trips listed below. Annunciation is provided in the control room to indicate when: a train is in test, a reactor trip is bypassed, or if a reactor trip bypass breaker is racked in and closed.

The reactor coolant pump breakers cannot be tripped at power without causing a reactor trip. However, the reactor coolant pump breaker open trip logic and continuity through the shunt trip coil can be tested at power. The manual reactor trip switches cannot be tested at power without causing a reactor trip since operation of either manual trip switch actuates both trains of the protection system. Initiating a safety injection or opening the turbine-generator output breakers cannot be performed at power without upsetting normal plant operations. However, the logic for these trips is testable at power.

12.1.4.2 Testing Input Relays

Testing the logic trains of the reactor protection system includes a check of the input relays and a logic matrix check. During a process instrumentation system test, the technician trips each bistable. Each bistable under test, and tripped, de-energizes one input relay in train A and one input relay in train B. A contact from each relay is connected to a universal logic printed circuit card. This printed circuit card performs both trip and monitoring functions. The contact that creates the reactor trip signal also actuates a status lamp and an annunciator on the control board. Operation of the input relay from either train lights the status lamp and the annunciator.

Each train contains a multiplexing test switch. At the start of a process or nuclear instrumentation system test, this switch (in either train) is placed in the A+B position. The A+B position alternately transmits information from the two trains to the control board. A steady status lamp and annunciator indicates that the input relays in both trains have been de-energized. A flashing lamp means that the input relays in the two trains have not both de-energized. Contact inputs to the protection system logic, such as reactor coolant pump bus under-frequency relays, operate input relays which are tested by operating the remote contacts and using the same type of indications as those provided for bistable input relays.

Actuation of the input relays provides the overlap between testing the logic portion of the protection system and testing of those systems supplying the inputs to the logic section. Inputs to the logic section are checked one channel at a time, leaving the other channels in service. For example, a function that trips the reactor when two out of four channels trip becomes a one out of three trip when the channel in test is placed in the trip mode. Both trains of the logic section remain in service during this portion of the test.

12.1.4.3 Testing Logic Matrices

Logic matrices are checked one train at a time. Input relays are not operated during this portion of the test. Reactor trips from the train under test are inhibited by the input error inhibit switch on the semi-automatic test panel in the train. At the completion of the logic matrix tests, one bistable in each channel of process instrumentation or nuclear instrumentation is tripped to check closure of the input error inhibit switch.

The logic test scheme uses short duration pulse techniques to check the coincidence logic. All possible trip and non-trip combinations are checked. Pulses from the tester are applied to the inputs of the universal logic card at the same terminals that connect the input relay contacts. Thus, there is an overlap between the input relay check and the logic matrix check. Pulses are fed back from the reactor trip breaker under-voltage coil to the tester. These pulses are of such short duration that the reactor trip breaker under-voltage coil armature cannot respond mechanically.

12.1.4.4 Testing of Reactor Trip Breakers

Normally, reactor trip breakers A and B are in service, and their associated reactor trip bypass breakers A and B are open and racked out (out of service). The following procedure briefly describes the method used for testing the reactor trip breakers:

1. With reactor trip bypass breaker A racked out, manually close and trip this breaker to verify its operability.
2. Rack in and close reactor trip bypass breaker A. Trip reactor trip breaker A using the protection system logic matrix.
3. Re-close reactor trip breaker A.
4. Trip (open) and rack out reactor trip bypass breaker A.
5. Repeat the above steps to test reactor trip breaker B using reactor trip bypass breaker B.

Auxiliary contacts of the reactor trip bypass breakers are connected to an alarm system of their respective trains. If either train is placed in test while the reactor trip bypass breaker of the other train is closed, both reactor trip breakers and both reactor trip bypass breakers automatically trip.

The RPS is normally required to be in service. However, to permit on-line testing of the various protection channels or to permit continued operation in the event of a subsystem instrumentation channel failure, a technical specification limiting condition for operation defining the minimum number of operable channels and the minimum degree of channel redundancy has been formulated. The technical specifications also define the required restrictions to operation in the event that the channel operability and degree of redundancy requirements cannot be met.

The RPS is designed so that response time tests can only be performed during shutdown. However, the safety analysis utilizes conservative numbers for trip channel response time. The measured channel response times are compared with those used in the safety evaluations. On the basis of startup tests conducted on several plants, the actual response times measured are less than the times used in the safety analyses.

12.1.4.5 Testing of Bypasses

Where operating requirements necessitate automatic or manual bypass of a protective function, the system is designed so that any actuated bypass is automatically removed whenever permissive conditions are not met. Devices used to achieve automatic removal of the bypass of a protective function are considered part of the protective system and are designed in accordance with the criteria of this section (IEEE Standard 279). Indication is provided in the control room if some part of the system has been administratively bypassed or taken out of service.

12.1.5 PRA Insights

The purpose of the reactor protection system is to initiate reactor trips to prevent the plant from exceeding a safety limit and to initiate engineered safety features to mitigate the consequences of an accident. A failure of the reactor protection system would allow the heat production to continue and prevent the initiation of the heat removal systems. Therefore, the failure of the RPS could lead to significant core damage.

The failure of the reactor protection system is not a significant contributor to sequences which lead to core damage (6.3% at Surry, 1.3% at Sequoyah). However, the failure of the reactor protection system to perform its function is a major factor in the importance measures. Specifically, the core damage frequency at Surry would be a factor of 1300 greater if the probability of a failure of the RPS was one. At Sequoyah, the factor would be 450.

12.1.6 Summary

Due to its importance to safety, the RPS is designed, constructed, and tested to the highest standards. This includes the requirements to be able to meet single failures and still provide full protection, independence of the separate trains, and testability to insure continued reliability.

The RPS contains process sensors (multiple sensors for each parameter) which produce a variable output to a comparator (bistable). The variable signal from the sensor is compared to a pre-set bistable trip set point. If the process variable exceeds the preselected set point value, the bistable changes state and de-energizes (its output goes to zero). The bistables's output is sensed by both trains A and B logic cabinets.

The logic cabinets continuously monitor the status of the bistables and produce protective actions (reactor trip or ESF) when the coincidence of tripped bistables indicate the need for protective actions. Either logic train, by itself, is sufficient to provide full protective actions independent of the other logic train. Testing the RPS at power is necessary to insure continued reliability and integrity of the RPS. Testing is performed by "overlapping" individual tests to insure no blind spots exist. Sensor calibration and final device testing is normally performed when the plant is shutdown.

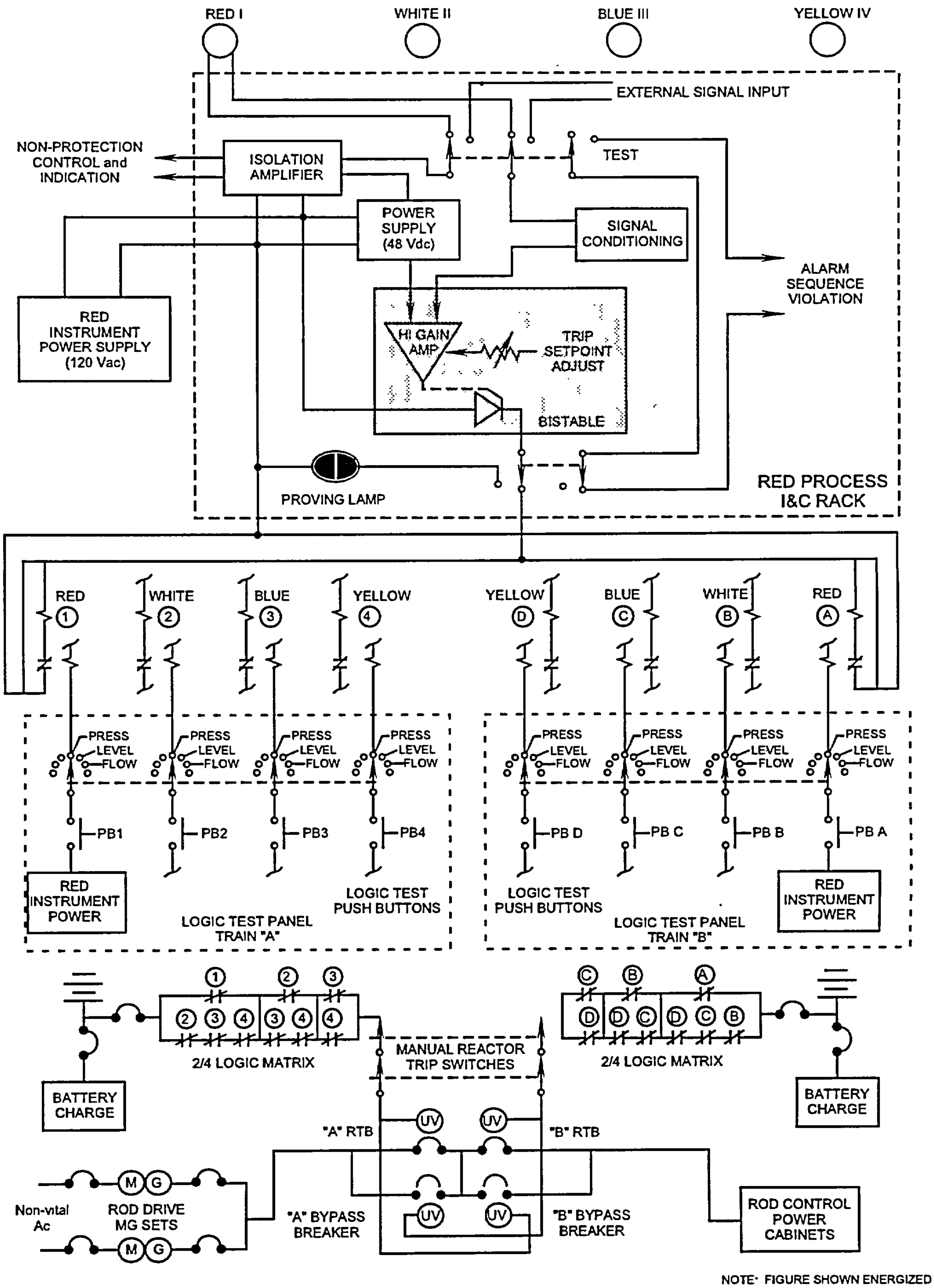

Figure 12.1-1 Relay Protection System

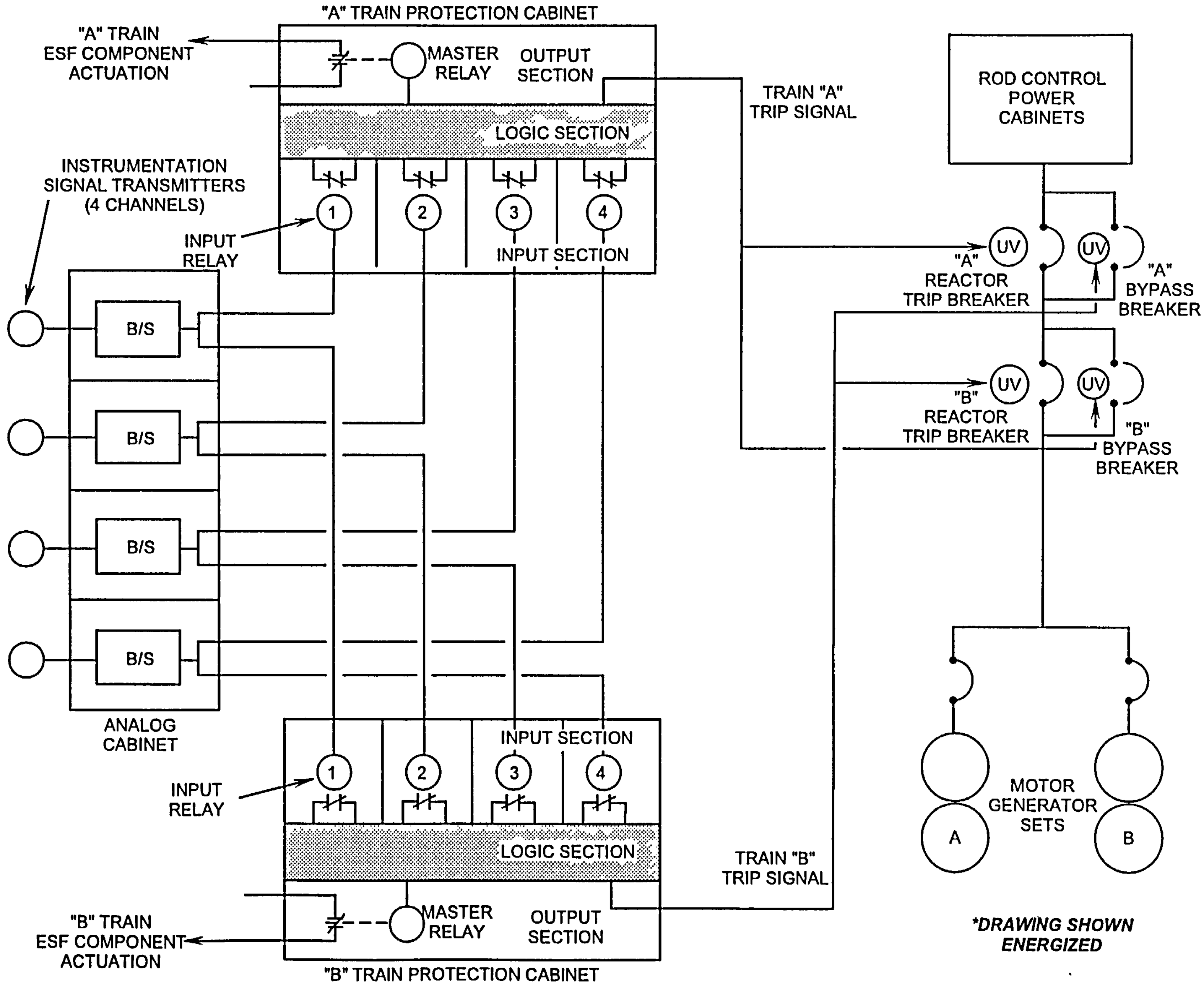

Figure 12.1-2 Solid State Protection System

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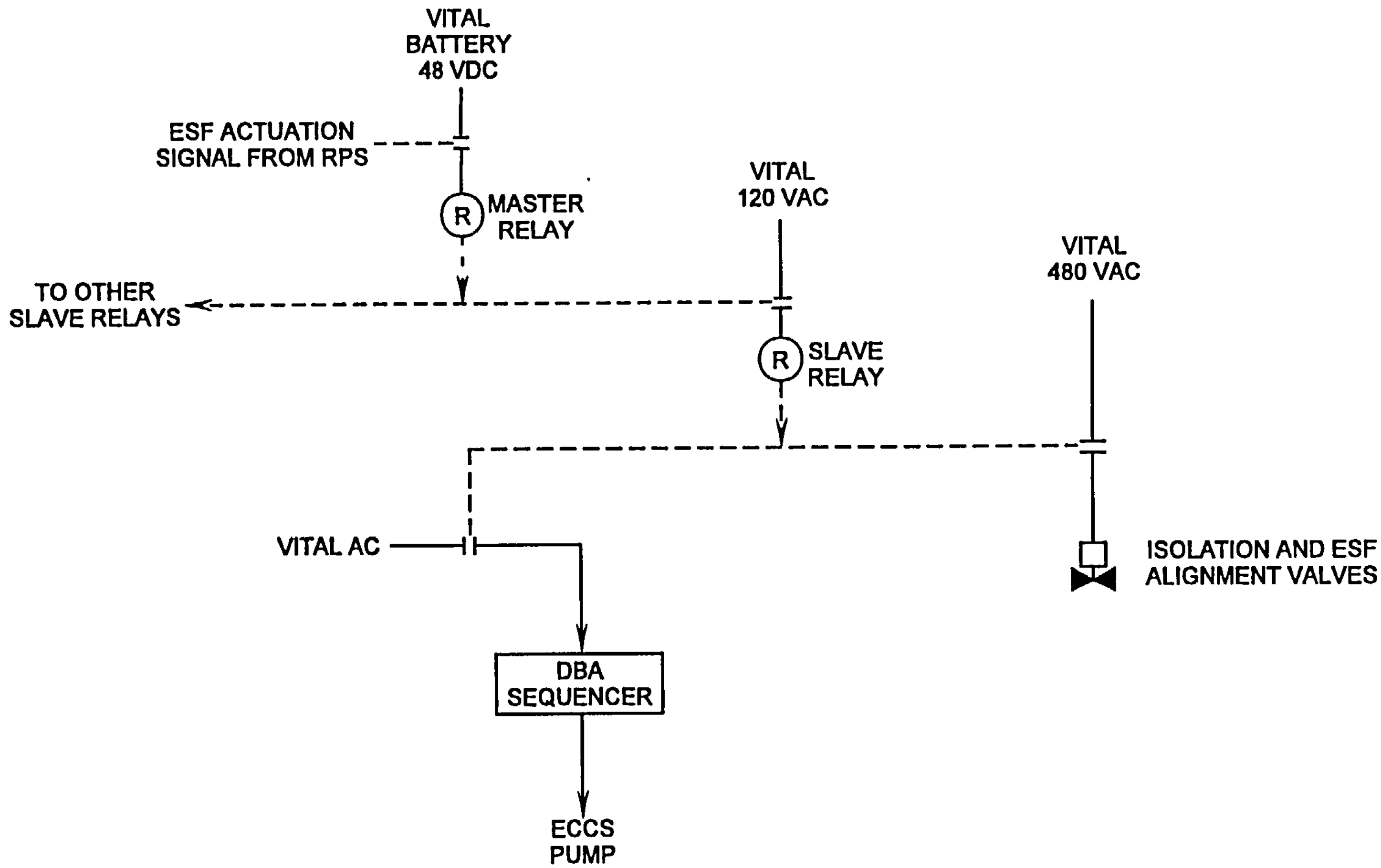

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Section 12.2

Reactor Protection System - Reactor Trip Signals

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12.2 REACTOR PROTECTION SYSTEM REACTOR TRIP SIGNALS

Learning Objectives:

1. Given a list of reactor trips, explain the purpose (basis) of each.

2. Given a list of Reactor Protection System (RPS) interlocks, explain the purpose of each.

3. Given a list of control grade interlocks, explain the purpose of each.

12.2.1 Introduction

The purposes of the reactor trip signals are to initiate a reactor trip if safe operating limits are exceeded. The safe operating limits bounded by these trips are monitored by sensors and are compared to preselected bistable setpoints. If the processed parameter exceeds its associated setpoint a reactor trip occurs. The specific function of each reactor trip is discussed in the following sections.

12.2.2 Reactor Trip Functions

The philosophy of the reactor protection system is to define an area of permissible operation in terms of power, flow, axial power distribution, and primary coolant temperature and pressure so that the reactor is tripped when the limits of a selected area or concern are approached. When the protection system receives signals indicative of an approach to unsafe operating condition, the system actuates alarms, prevents control rod withdrawal (if applicable), initiates a turbine runback (if applicable), and/or opens the reactor trip breakers. The overpower ΔT (OPΔT) and overtemperature ΔT (OTΔT) reactor trips provide core protection for situations where:

- The transient is slow with respect to coolant piping delays from the core to the temperature sensors: and
- pressure is within the range between the high and low pressure reactor trips.

Other reactor trips as shown in Figure 12.2-1, such as low coolant flow and high nuclear flux provide core protection for accidents in which the loop ΔT signal does not respond quickly enough. Additional reactor trips such as high pressurizer water level and low feedwater flow are provided primarily for equipment protection. Finally, some reactor trips, such as those produced by a turbine trip or reactor coolant pump circuit breaker position, are provided to anticipate probable plant transients and minimize the resulting thermal transient on the reactor coolant system (RCS). A description of the reactor trips is provided in Section 12.2.3 and in Table 12.2-1.

Reference to permissive circuits (designated as P-n) is made frequently in this discussion. A permissive circuit is used to block certain activities as well as to permit others. A description and a list of these circuits is provided in sections 12.2.3, 12.2.4 and in Tables 12.2-2, 12.2.3. Rod stops are also provided to prevent abnormal conditions which could result from excessive control rod withdrawal initiated by either a control system malfunction, or violation of administrative procedures by the operator.

A reactor trip is actuated by interrupting power to the Rod Cluster Control Assemblies (RCCA's). Power is delivered to the RCCA's from the rod drive motor generator sets through two series-connected trip breakers. Opening either trip breaker removes power to the rods. The breakers are arranged to trip open by spring action when a small undervoltage coil in the breaker assembly is de-energized. When this coil is de-energized, it allows a mechanical latch to move, allowing the spring to open the trip breaker. The undervoltage coil to reactor trip breaker (RTB) A is powered by protection train "A," and RTB B is supplied by protection train "B." Therefore, either protection train is capable of initiating a reactor trip regardless of the action by the opposite train.

12.2.3 Trip Signal Functions

Reactor trip signals are provided by the RPS to protect the plant during various analyzed transients or accidents. The reliability of the RPS is assured by providing more than one trip function to protect the plant against the same event. The following provides a brief description of each of the various reactor trip signals.

12.2.3.1 Manual Trip

The manual actuating devices (reactor trip switches) are independent of the automatic trip circuitry, and are not subject to the same failures which may render a portion of the automatic circuitry inoperable. Actuating either of the two manual reactor trip switches located in the control room initiates a reactor trip and a turbine trip.

12.2.3.2 High Neutron Flux Trip Source Range

This circuit, Figure 12.2-2, trips the reactor when one of the two source range channels indicates greater than 10^5 cps. The source range trip, provides protection against reactivity excursions and startup accidents. This trip may be manually blocked when one of the two intermediate range channels exceeds the P-6 setpoint value of 10^{-10} amps and the trip function is automatically reinstated when both intermediate range channels decrease below the P-6 setpoint.

When this trip is manually blocked, power is removed from the source range neutron detectors, de-energizing both channels. The operator can manually restore power to the source range detectors by momentarily placing the BLOCK-RESET switches to reset. When P-10 (10% power on the power range instruments) activates, the logic is aligned which prevents an operator form inadvertently energizing the source range detectors (placing the block reset switch to the reset position). Applying a high voltage to these detectors in the presence of a high neutron flux could damage the detectors.

12.2.3.3 High Neutron Flux Trip Intermediate Range

This circuit, Figure 12.2-3, trips the reactor when one out of the two intermediate range channels indicates greater than the current equal to 25% power. The intermediate range trip, which provides protection against reactivity excursions and startup accidents, can be manually blocked if two out of four power range channels are above 10 percent of full power (P-10). If three of four (3/4) power range channels fall below the P-10 setpoint value, the trip function is automatically reinstated.

12.2.3.4 High Neutron Flux Trip Power Range

This circuit, Figure 12.2-4, trips the reactor when two of four (2/4) power range channels indicate greater than the trip setpoint. Two independent trips are provided, a high setting at 109% and a low setting at 25%. The high trip setting provides protection against overpower during normal power operations. The low setting, which provides protection against reactivity excursions and startup accidents, can be manually blocked when two of four (2/4) power range channels indicate greater than 10 percent of full power (P10).

If three of four (3/4) power range channels drop below 10 percent power, the low power trip function is automatically reinstated. The high trip setting is always active (cannot be blocked). Prior to reaching the 109% trip setpoint a signal is generated to block automatic and manual rod withdrawal. This action occurs if any one of the four power range channels exceeds 103% power.

12.2.3.5 Positive Neutron Flux Rate Trip Power Range

This circuit, Figure 12.2-5, trips the reactor when an abnormal rate of increase in nuclear power (+5% with a 2 second time constant) occurs in two of four (2/4) power range channels. This trip provides protection for rod ejection accidents and cannot be bypassed or blocked.

12.2.3.6 Negative Neutron Flux Rate Trip Power Range

This circuit, Figure 12.2-5, trips the reactor when an abnormal rate of decrease in nuclear power (-5% with a 2 second time constant) occurs in two of four (2/4) power range channels. This trip provides protection against dropped rod accidents and cannot be bypassed or blocked.

12.2.3.7 Overtemperature ΔT Reactor Trip

The OTΔT trip, Figure 12.2-6, is designed to protect against departure from nucleate boiling (DNB) which causes a large decrease in the heat transfer coefficient between the fuel rods and the reactor coolant, resulting in high fuel clad temperatures. The indicated loop ΔT is used as a measure of reactor power and is compared with a continuously calculated trip setpoint. This setpoint is a function of Tavg, pressurizer pressure and axial flux difference. If the indicated ΔT equals the calculated trip setpoint, the affected channel is tripped.

If two or more channels are simultaneously tripped, the reactor is automatically shutdown. A turbine runback occurs and both automatic and manual rod withdrawal are inhibited at a ΔT value 3% below the trip setpoint. The equation for the calculation of the OTΔT setpoint is:

OTΔT setpoint =

$$\Delta T_0\left[K_1 - K_2\left(\frac{1+t_1S}{1+t_2S}\right)(T-T') + K_3(P-P') - f_1(\Delta I)\right]$$

where:

$\Delta T_0 = \left(\text{Indicated } \Delta T \text{ at RATED THERMAL POWER}\right)$

$T = \left(\text{Average temperature, } ^{\circ}F\right)$

$T' = \left(\text{Indicated } T_{avg} \text{ at RATED THERMAL POWER}\right)$

$P = \left(\text{Pressurizer pressure, psig}\right)$

$P' = \left(\text{2235 psig, RCS nominal operating pressure}\right)$

$K_1 = \left(\text{a manually adjusted preset bias that sets the steady state trip point when the other parameters are at their rated values}\right)$

$K_2 \;\&\; K_3 = \left(\text{manually adjusted preset gains}\right)$

$\left(\frac{1=t_1S}{1=t_2S}\right) = \left(\text{The lead - lag function generated by the controller for the dynamic response of } T_{avg}\right)$

$t_1 \;\&\; t_2 = \left(\text{The time constants utilized in the lead - lag controller}\right)$

$S = \left(\text{Laplace transform operator}\right)$

$f_1(\Delta I) = \left(\text{A function of the indicated difference between the top and bottom detectors of the nuclear power range instru - ments}\right)$

The Tavg term in the equation acts to lower the trip point when above normal full power Tavg. This is necessary because the increased average temperature reduces the margin to DNB. The pressure signal reduces the ΔT setpoint when pressure is lower than rated since this condition reduces the margin to DNB. The f(ΔI) term reduces the value of the trip point to reflect an increase in the hot channel factors which could result in localized DNB. The best axial flux distribution is a cosine function and results in equal power production in the upper and lower portions of the core. Any deviation from this shape is sensed by a difference between the upper and lower power range detector channels. This difference is referred to as axial flux difference or ΔI and is used to generate an output which reduces the trip setpoint. This insures DNB limits are not exceeded even for highly skewed power distributions. The OTΔT trip ensures that the DNBR not less than 1.30 at the time of the reactor trip if:

- The transient is slow with respect to piping transient delays from the core to the temperature detectors and
- The reactor coolant pressure is within the bounds set by the high and low pressure trips.

Prior to the actual ΔT reaching the OTΔT trip setpoint, both automatic and manual control rod withdrawal is inhibited and a cyclic turbine runback is initiated as long as the overtemperature condition exists. This action occurs if two of the four channels are within 3% of design full power ΔT of the trip setpoint.

12.2.3.8 Overpower ΔT Reactor Trip

The OPΔT trip, Figure 12.2-7, is designed to protect against a high fuel rod power density (excessive kw/ft) and subsequent fuel rod cladding failure and fuel melt. This is avoided by limiting fuel centerline temperature to less than 4700°F, which is significantly below the actual UO_2 melting temperature. The indicated ΔT is used as a measure of reactor power and is compared with a setpoint that is automatically calculated as a function of Tavg and axial flux difference. If the ΔT signal exceeds the calculated setpoint, the affected channel is tripped. If two or more channels are tripped simultaneously, the reactor is tripped. A turbine runback occurs and both automatic and manual rod withdrawal is inhibited at a ΔT value 3% below the OPΔT trip point. Since core thermal power is not precisely proportional to ΔT due to the effects of changes in coolant density and heat capacity, a compensating term which is a function of average temperature is used. Similarly, since the prescribed overpower limit may not be adequate for highly skewed axial power distributions, a compensating term related to ΔI is used. The setpoint equation is:

OPΔT setpoint =

$$\Delta T_0\left[K_4 - K_5\left(\frac{t_3 S}{1+t_3 S}\right) + (T-K_6) + (T-T') - f_2(\Delta I)\right]$$

where:

$$\Delta T_0 = \begin{pmatrix}\text{Indicated } \Delta T \text{ at RATED}\\ \text{THERMAL POWER}\end{pmatrix}$$

$$T = \left(\text{Average temperature, } ^{\circ}\text{F}\right)$$

$$T' = \begin{pmatrix}\text{Indicated Tavg at RATED THERMAL}\\ \text{POWER} \le 584.7\ ^{\circ}\text{F}\end{pmatrix}$$

$$\frac{t_3 S}{1+t_3} = \begin{pmatrix}\text{The function generated by the rate}\\ \text{lag controller for Tavg dynamic}\\ \text{compensation}\end{pmatrix}$$

$$t_3 = \begin{pmatrix}\text{The time constant utilized th the} \\ \text{rate lag controller for Tavg}\end{pmatrix}$$

$$S = (\text{Laplace transform operator})$$

$$f_2(\Delta I) = \begin{pmatrix}\text{A function of the indicated} \\ \text{difference between the top and} \\ \text{bottom detectors of the power} \\ \text{range ion chambers}\end{pmatrix}$$

$$K_4 = \begin{pmatrix}\text{A manually adjusted preset bias that} \\ \text{sets the steady state trip point when} \\ \text{the other parameters are at their rated} \\ \text{values}\end{pmatrix}$$

$$K_5 \;\&\; K_6 = (\text{Manually adjustable preset gain})$$

The T - T' term represents an upper limit of the equation which is based upon full power. Since it is possible for the average temperature to exceed the programmed full power average temperature, the setpoint must be reduced to take into account the increase in the heat capacity of the reactor coolant at higher temperatures. This term can only decrease the ΔT setpoint from its normal full power value. Prior to the actual ΔT reaching the OPΔT trip point, both automatic and manual control rod withdrawal is inhibited and a cyclic turbine runback will be initiated as long as the overtemperature condition is present. This action occurs if two of the four channels are within 3% of the setpoint.

12.2.3.9 Pressurizer Low Pressure Trip

The pressurizer low pressure trip, Figure 12.2-8, protects against excessive core steam voids and limits the range of required protection afforded by the OTΔT trip. The reactor trips when two of four (2/4) pressurizer pressure signals fall below 1865 psig. This trip is automatically blocked when turbine first stage pressure or reactor power are less than approximately 10 percent power (P-7).

12.2.3.10 Pressurizer High Pressure Trip

The high pressurizer pressure trip protects against reactor coolant system over pressure, thereby protecting the RCS pressure boundary. As shown in Figure 12.2-9, the reactor trips when two of four (2/4) high pressurizer pressure signals exceed 2385 psig. This trip is always in service and cannot be bypassed or blocked.

12.2.3.11 Pressurizer High Water Level Trip

The pressurizer high water level trip, shown in Figure 12.2-10, is provided to prevent rapid thermal expansions of reactor coolant fluid from filling the pressurizer and causing an over pressurization of the reactor coolant system. In addition a change from relieving steam to water could be damaging to the relief and safety valves. The reactor is tripped when two of three (2/3) high pressurizer water level signals exceed 92% level. This trip is automatically blocked below 10 percent power (P-7).

12.2.3.12 Low Reactor Coolant Flow Trip

The low flow reactor trips protect the core from DNB following a loss of coolant flow. The methods of sensing a loss of reactor coolant flow are shown in Figure 12.2-11 and described below:

a. Low primary coolant flow trip: A low loop flow signal is generated by two-out-of-three low flow signals per loop. Above the P-7 setpoint (approximately 10% of full power), a low flow in two or more loops results in a reactor trip. Above the P-8 setpoint (approximately 39% of full power) low flow in any single loop results in a direct reactor trip.
b. Reactor coolant pump breaker position trip: Each reactor coolant pump breaker supplies a

signal to the logic section of the reactor protection system. Above the P-8 setpoint, the reactor trips if any single reactor coolant pump breaker opens.

c. Reactor coolant pump under-voltage trip: The RCP under-voltage trip anticipates and improves the response of the RPS to a complete loss of reactor coolant flow. Each of the two RCP busses is equipped with two under-voltage sensors. An under-voltage condition, as sensed by one of two (1/2) devices on the bus, must exist on two of two (2/2) RCP busses to produce a reactor trip.

d. Under-frequency trips: An under-frequency condition on the RCP busses reduces the speed of the pumps (with a subsequent reduction in flow). This is undesirable because it reduces the coast down of the pumps if power is lost to the busses. Each of the two RCP busses is equipped with two under-frequency sensors. An under-frequency condition as sensed by one of two (1/2) devices on the bus, must exist on two of two (2/2) RCP busses to produce a reactor trip. In addition to tripping the reactor; if an under-frequency condition exists, a signal is sent to trip the RCP breakers

Note: All the reactor coolant low flow trips are automatically blocked below the P-7 setpoint (10% power).

12.2.3.13 Low Feedwater Flow Trip

The low feedwater flow trip, Figure 12.2-12, protects the reactor from a loss of primary heat sink. The trip is actuated by the logic of a steam flow greater than feed flow mismatch signal coincident with a steam generator low level.

12.2.3.14 Low-Low Steam Generator Water Level Trip

This trip (Figure 12.2-13) protects the reactor against a loss of heat sink. The setpoint of this trip is 11.5% as indicated on the narrow range indicators and is actuated on two of three (2/3) low-low water level signals in any single steam generator.

12.2.3.15 Engineered Safety Features Actuation Trip

If a reactor trip has not already been generated by any other reactor protective instrumentation, the engineered safety features automatic actuation signals initiate a reactor trip upon sensing any condition which initiates a safety injection. These trips are provided to protect the core in the event of a loss of coolant accident or a steam line break accident.

The means of actuating the engineered safety features trips are discussed in the engineered safety features actuation Chapter 12.3.

12.2.3.16 Turbine Trip

A turbine trip - reactor trip signal, Figure 12.2-14, is provided to protect the reactor coolant system from a thermal transient (over pressure or overtemperature). This trip occurs at a power of greater than 10% (P-7), or in plants with P-9 installed, at 50 percent. The signals used to sense that the turbine has tripped are:

1. four of four (4/4) turbine throttle valves fully closed or
2. two of three (2/3) low EHC trip header fluid pressure (800 psig - General Electric turbine) two of three (2/3) low auto-stop oil pressure (45 psig - Westinghouse turbine)

12.2.4 Interlock Circuits

Various signals are generated throughout the plant for the purpose of:

1. Automatically prohibiting and/or allowing the actuation of certain protective circuits and the operation of certain control systems; and
2. Allowing the operator to manually prohibit certain protective actions.

The interlocks can be divided into two broad categories designated as Protective (P) interlocks and Control (C) interlocks. Protective interlocks are those which are developed within the solid state protection system. Control interlocks are those which are developed within the process instrumentation racks (with the exception of C-8). Although not part of the protection system, the control interlocks will be mentioned here for the sake of completeness.

12.2.4.1 Control Grade Interlocks

An interlock is a signal or device that prevents or allows an action or a function to be performed if a certain set of conditions exist. Listed below are various interlocks (designated by a C) employed in most Westinghouse PWRs. They are designated as Control Grade (C) to differentiate from Protection Grade (P) as previously discussed.

- **C-1 -Hi Neutron Flux Rod Stop Interlock**

When one of two IR detectors is above a current equivalent of 20% power, a rod stop occurs in both automatic and manual rod control. The rod stop may be blocked when at or above the P-10 (2/4 coincidence) setpoint, but is automatically reinstated below P-10 (3/4 coincidence).

- **C-2 -Over Power Rod Stop Interlock**

If one of the four (1/4) excore power range flux detectors indicates a power output of greater than 103 percent reactor power; a rod stop signal is actuated. This interlock may be bypassed by the control operator to allow for continued operation with one inoperable power range channel.

- **C-3 -OTΔT Rod Stop and Turbine Runback Interlock**

When two of four (2/4) OTΔT channels indicate 3% below the reactor trip, automatic and manual rod withdrawal are blocked and a turbine runback is initiated.

- **C-4 -OPΔT Rod Stop and Turbine Runback Interlock**

When two of four (2/4) OPΔT channels indicate 3% below the reactor trip, automatic and manual rod withdrawal are blocked and a turbine runback is initiated.

- **C-5 -Low Power Interlock**

This interlock setpoint is power equivalent to 15% as sensed by turbine impulse pressure. If power drops below 15%, automatic rod withdrawal is inhibited. C-5 is supplied from only one turbine impulse pressure sensor.

- **C-7 -Loss of Load Interlock**

This interlock senses a loss of turbine load and arms the steam dump system (makes the steam dumps available for operation). C-7 senses only load decreases and must be manually reset. It is normally set for a 10% step or a 5%/min load decrease.

- **C-8 -Turbine Tripped Interlock**

When the C-8 interlock is actuated, the steam dump system (if in the Tavg mode of control) shifts from the load rejection controller to the turbine trip controller. Permissive C-8 requires:

1. four of four (4/4) turbine throttle valves fully closed or
2. two of three (2/3) low auto-stop oil pressure (45 psig - Westinghouse turbine) or two of three (2/3) low EHC oil header pressure (800 psig - General Electric turbine)

In addition, C-8 arms the steam dumps. The C-8 interlock is not installed in Westinghouse designed units that utilize the P-9 permissive.

- **C-9 -Condenser Available Interlock**

The condenser must be available in order to allow steam dump operation. To activate C-9, one of two (1/2) circulating water pump breakers must be shut AND two of two (2/2) condenser vacuum switches must be shut (<5" Hg backpressure). If backpressure in the condenser increases to 7.6" Hg, then C-9 is defeated.

- **C-11 -Control Bank D Rod Withdrawal Limit Interlock**

This signal prevents misalignment of rod position counters by blocking automatic withdrawal of control bank D when control bank D position is at 223 steps.

12.2.4.2 Protection Grade Interlocks

During controlled plant evolutions, certain protection signals are not required for plant safety and may be blocked to prevent inadvertent reactor trips or engineered safety feature (ESF) actuations. The RPS or the operator may disable certain signals when they are not required. The mechanism that provides for blocking of these trips are the protection grade permissives. The protection system is designed so that any signal which is blocked, will be automatically unblocked whenever the conditions for that permissive are not met (Required by IEEE Std. 279-1971). The following provides a brief description of the various permissives.

- **P-4 -Reactor Trip Permissive**

This permissive is derived from a "b" contact on the reactor trip breakers (RTB), (closed when the RTB is open and open when the RTB is closed). The permissive is in effect whenever an RTB is open, (the contact is closed) and performs the following functions:

1. Actuates a turbine trip.
2. Initiates feedwater isolation below 564°F Tavg,
3. Inputs to the ESF block-reset logic, and
4. Prevents opening of the main feedwater isolation valves which were closed by an ESF actuation signal or high-high steam generator level (P-14).

Permissive P-4 (and P-14 as discussed later) is not a permissive signal in the classic sense, in that it does not enable or reinstate some switch or function. It does not have an individual light on the permissive /bistable status panel that is located in the control room.

- **P-6 -Source Range Block Permissive**

Permissive P-6 enables the source range BLOCK-RESET switches on the main control board. The operator can then use the BLOCK-RESET switches to remove power from the source range detectors, blocking the source range high flux trip. On a power increase when one of two (1/2) intermediate range channels is greater than 10^{-10} amps, permissive P-6 is in effect. On a power decrease when BOTH intermediate range channel outputs drop below 10^{-10} amps, permissive P-6 is removed.

- **P-7 -At Power Permissive**

The at-power permissive P-7 is in effect below 10% power and automatically blocks the at-power trips listed below:

1. Two loop low flow,
2. RCP bus under-voltage,
3. RCP bus under-frequency,
4. Pressurizer low pressure,
5. Pressurizer high level, and
6. Turbine trip (except at plants with P-9).

On a power increase, when either the turbine (P-13) or the reactor (P-10) is greater than 10% power, permissive P-7 is removed and the at-power trips are automatically enabled. On a power decrease, both the turbine (2/2) and the reactor (3/4) must be below 10% to enable permissive P-7 and disable the at-power trips.

- **P-8 -Three Loop Flow Permissive**

Permissive P-8 is in effect below 39% reactor power. The permissive allows the loss of flow in one reactor coolant loop without generating a direct reactor trip signal. When two of four (2/4) power range channels indicate greater than 39%, a loss-of-flow signal in any single loop initiates a reactor trip signal.

- **P-9 -Turbine Trip/Reactor Trip Permissive**

Permissive P-9 is in effect below 50% power (Note: not all Westinghouse units use this permissive). This permissive allows the reactor to remain in operation if the turbine trips. Facilities with this permissive have demonstrated that sufficient steam dump capacity is available with the steam dump system to remove the excess heat in the reactor coolant system until reactor power is reduced to the no-load condition.

- **P-10 -Nuclear AT Power Permissive**

Inputs to the P-10 permissive circuit are from each of the four power range channels. The P-10 setpoint is 10%. When two of four (2/4) channels are greater than or equal to this setpoint, the operator may block the intermediate and power range low setpoint reactor trips along with the C-1 (High Neutron Flux Rod Stop). When 3/4 power range channels drop below the P-10 setpoint, the functions previously mentioned are automatically reinstated. The following is a list of functions provided by P-10:

1. Allows the operator to manually block the intermediate range high flux trip and C-1 rod stop,
2. Allows the operator to manually block the low setpoint power range trip,
3. Automatically restores intermediate range trip and C-1 rod stop when power falls below the P-10 setpoint,
4. Automatically restores the low setpoint power range trip when power falls below the P-10 setpoint,
5. Provides an input to the P-7 circuit, and
6. Serves as a backup to P-6 by preventing the operator from inadvertently re-energizing the source range high voltage.

- **P-11 -Pressurizer SI Block Permissive**

Permissive P-11 is in effect below 1915 psig. When two of three (2/3) pressure channels indicate less than 1915 psig, the block switches for the low pressure engineered safety features actuation signal are enabled and the operator may block the actuation signal before the low pressure SI setpoint of 1807 psig is reached. On an increasing pressure, when two of three (2/3) channels indicate greater than 1915 psig the block is automatically removed and the ESF pressurizer low pressure actuation signal is reinstated.

- **P-12 -Hi Steam Flow SI Block Permissive**

Permissive P-12 is in effect below 553°F. If two of four (2/4) loop Tavg signals are below the low-low Tavg value of 553°F, the block switches for the high steamline flow engineered safety features actuation is enabled, and the operator can block this signal. This signal is blocked during a controlled plant cooldown to prevent an automatic initiation of the ESF equipment. Permissive P-12 also automatically blocks steam dump operation to prevent an uncontrolled cooldown caused by an instrumentation malfunction. This permissive is automatically removed when three of four (3/4) Tavg channels indicate greater than 553°F. This automatically reinstates the remaining nine steam dump valves to operation and removes the block of the high steamline flow ESF signal.

- **P-13 -Turbine At-Power Permissive**

Permissive P-13 senses turbine impulse chamber pressure. When one of two (1/2) detectors senses the impulse pressure greater than or equal to 10% power, all the reactor trips associated with P-7 are automatically unblocked. P-13 is one of two inputs to the at-power permissive P-7.

- **P-14 -Steam Generator Hi Level Override**

The P-14 setpoint is 69.0% steam generator narrow range level and is enabled with a coincidence of two of three (2/3) level indicators per steam generator, with one of four (1/4) generators enabling the permissive. When this permissive is activated the following actions occur:

1. Main turbine trip,
2. Main feedwater pumps trip,
3. All feed regulating and bypass valves shut, and
4. All main feedwater isolation valves shut.

Permissive P-14, like Permissive P-4, is not a permissive in the classic sense in that it does not enable or reinstate some switch or function. Individual bistable lights for the hi-hi level trip function are on the permissive/bistable status panel.

12.2.5 Summary

The reactor protection system encompasses the components which sense and protect against unsafe plant conditions. Reliability of the system is greatly improved by utilizing redundant instrument channels and protection trains. By maintaining independence between these trains and channels, true redundancy is achieved.

Table 12.2-1
SUMMARY OF REACTOR TRIPS

Trip	Co.	Setpoint	Interlocks	Purpose	Accident
1. Source Range Hi Neutron Flux	½	10^5 cps	Manual block permitted by P-6, power to source range detectors is removed when manual block is initiated. Power to detectors cannot be turned on when power is above P-10	Prevents an inadvertent power rise (excursion). A trip will occur unless the operator deliberately blocks the trip.	Reactivity addition accidents such as: a. Uncontrolled rod withdrawal from subcritical or low power condition. b. Inadvertent boron dilution. c. Excessive heat removal caused by steamline break or feedwater addition accidents.
2. Intermediate Range Hi Neutron Flux	½	Current equivalent to 25% power level	Manual block permitted by P-10	Prevents an inadvertent power rise (excursion). A trip will occur unless the operator deliberately blocks the trip.	Reactivity addition accidents such as: a. Uncontrolled rod withdrawal from subcritical or low power condition. b. Inadvertent boron dilution. c. Excessive heat removal caused by steamline break or feedwater addition accidents.
3. Power Range High Neutron Flux - low setpoint	2/4	25%	Manual block permitted by P-10	Prevents an inadvertent power rise (excursion). A trip will occur unless the operator deliberately blocks the trip.	Reactivity addition accidents such as: a. Uncontrolled rod withdrawal from subcritical or low power condition. b. Inadvertent boron dilution. c. Excessive heat removal caused by steamline break or feedwater addition accidents.
4 Power Range High Flux - high setpoint	2/4	109%	No Interlocks	Limit maximum power level to prevent damage to fuel clad and protect against centerline melting	Inadvertent power excursions such as: a. Excessive load increase b. Excessive heat removal c. Boron dilution accidents d. Inadvertent rod withdrawal e. Rod ejection accident
5. High Positive Rate Neutron Flux	2/4	+5% change with a 2 sec. time constant	No Interlocks	Limit power excursions. Prevent unacceptable power distribution	Rod Ejection Accident

Table 12.2-1
SUMMARY OF REACTOR TRIPS

Trip	Co.	Setpoint	Interlocks	Purpose	Accident
6. High Negative Rate Neutron Flux	2/4	-5% change with a 2 sec time constant	No Interlocks	Prevent unacceptable power dist. Limit power overshoot from the rod control system which would withdraw rods to compensate for a dropped rod	Dropped Rod Accident
7. OTΔT	2/4	Variable cont. calc	No Interlocks	Prevent operation with DNBR <1.30	Relatively slow transients such as: a. Uncontrolled rod withdrawal at power b Uncontrolled boron dilution c. Excessive load increase d. Depressurization of the RCS
8. OPΔT	2/4	Variable cont. calc	No Interlocks	Prevent excessive power density (KW/ft)	Relatively slow transients such as: a. Uncontrolled rod withdrawal at power b. Uncontrolled boron dilution c. Excessive load increase d. Steamline breaks
9. Pressurizer Low Pressure	2/4	1865 psig. (Rate compensated)	Disabled below P-7 (10%)	Prevent DNBR <1.30. Limit required range of OTΔT	Depressurization of RCS due to: a. LOCA b. Steamline break c. SG Tube Rupture
10. Pressurizer High Pressure	2/4	2385 psig.	No Interlocks	Protect integrity of RCS pressure boundary	Uncontrolled rod withdrawal at power, loss of electrical load, or turbine trip
11. Pressurizer High Water Level	2/3	92%	Disabled below P-7 (10%)	Prevent "solid water" operations, prevent discharge of high energy water through relief and safety valves.	Uncontrolled rod withdrawal at power, loss of electrical load, or turbine trip

Table 12.2-1
SUMMARY OF REACTOR TRIPS

Trip	Co.	Setpoint	Interlocks	Purpose	Accident
12. Low Reactor Coolant Flow	2/3	<90% Flow	P-8 (<39%) Loss of flow in one loop, no direct trip signal. P-7 (<10%) Loss of flow in two or more loops, no direct trip.	Ensure adequate loop flow to remove core heat DNBR considerations.	Partial loss of RCS flow. Complete loss of forced RCS flow. Loss of off-site power to station auxiliaries.
13. Reactor Coolant Pump Undervoltage	1/2 on 2/2 buses	68.6% nominal bus voltage	Disabled below P-7 (10%)	Redundant to low flow trip	Redundant to low flow trip
14. Reactor Coolant Pump Under-frequency	1/2 on 2/2 buses	57.7 Hz.	Disabled below P-7 (10%), trips open the pump motor breakers when actuated to preserve pump coastdown time	Redundant to low flow trip	Redundant to low flow trip
15. Reactor Coolant Pump Breaker	1/1 per Brk.	Brk Position or Under-freq	Disabled below P-8 (39%)	Redundant to low flow trip	Redundant to low flow trip
15. Steam Generator Low-Low Level	2/3 on 1/4	11.5%	No Interlocks	Prevent Loss of heat sink	Loss of normal feedwater
16. Low Feedwater Flow	1/2 on 1/4	25.5% SG level AND $1.5x10^6$ LBm/hr mismatch $W_s>W_f$	No Interlocks	Anticipate loss of heat sink	Partial loss of normal feedwater

Table 12.2-1
SUMMARY OF REACTOR TRIPS

Trip	Co.	Setpoint	Interlocks	Purpose	Accident
17. Turbine Trip	2/3 low auto oil, 4/4 T. vlvs cls.	45psig low oil press on West. 800 psig low trip hdr fluid press on G.E.	Disabled below P-7 (10%)	Remove heat source if steam load is lost to SGs	Turbine trip, loss of load
18. ESF Actuation	1/2 trns		No Interlocks		Any accident requiring an Engineered Safety Features Actuation Signal
19. Manual	1/2		No Interlocks	Operator initiated backup to all trips	Any condition requiring a reactor trip
20. SSPS General Warning	2/2	General Warning		The SSPS has a self-check feature that will trip the reactor if both protection trains develop trouble.	

Table 12.2-2
SUMMARY OF PROTECTION GRADE INTERLOCKS

Number	Name	Setpoint	Coincidence	Functions
P-4	Reactor Trip Breaker Contact	Open if trip breaker is closed Closed if trip breaker is open.	Trip breaker and its bypass breaker both open	1. Trips main turbine. 2. Trips main feed reg valves with Tavg <564 °F on 2/4 channels 3. Input to ESF block and reset logic. 4 If main feed regulating and bypass valves are tripped by SI or S/G high level, P-4 seals in the trip.
P-6	Source Range Block Permissive	Intermediate Range $>10^{-10}$ amps.	1/2 Channels.	Enables the BLOCK/RESET switches to allow the operator to block SR high flux trip.
P-7	At-Power Permissive	Power < 10%.	Nuclear Power <10% (P-10) and, Turbine Power <10% (P-13).	Automatically blocks the "at-power" trips: 1. Pressurizer low pressure. 2. Pressurizer high level. 3. Reactor coolant system low flow. 4. Turbine tripped.
P-8	3-Loop Flow Permissive	Power Range > 39%.	2/4 Channels.	Automatically unblocks the single loop low flow reactor trip.
P-9 (Not on all plants)	Turbine Trip/Reactor Trip Permissive	Power Range > 50%.	2/4 Channels	Unlocks reactor trip on turbine trip above 50%.
P-10	Nuclear At-Power Block Permissive	Power Range > 10%.	2/4 Channels.	1. Opens contacts to SR high voltage power supply. 2. Enables BLOCK switches to allow the operator to block IR high flux and rod stop. 3. Permits operator to block PR low setpoint 4. Input to P-7.
P-11	Pressurizer SI Block Permissive	Pressurizer Pressure < 1915 psig	2/3 Channels.	Enables BLOCK switches to allow the operator to block low pressurizer pressure SI signal.

Table 12.2-2
SUMMARY OF PROTECTION GRADE INTERLOCKS

Number	Name	Setpoint	Coincidence	Functions
P-12	High Steam Flow SI Permissive	Tavg < 553 °F.	2/4 Channels.	1. Enables BLOCK switches to allow the operator to block high steam flow SI signal. 2. Input to high steam flow SI logic. 3. Blocks steam dump valves at 553 °F. Operator may bypass the interlock on three of the cooldown valves.
P-13	Turbine At-Power Permissive	Turbine Power < 10%.	1/2 Channels.	Input to P-7.
P-14	SG High Level Override	Steam Generator Narrow Range Level > 69%.	2/3 per S/G on 1/4 S/G's.	1. Closes main feedwater regulating and bypass valves. 2. Trips all main feed pumps. 3. Trips main turbine. 4. Closes all main feedwater isolation valves.

Table 12.2-3
SUMMARY OF CONTROL GRADE INTERLOCKS

Number	Name	Setpoint	Coincidence	Interlocks	Function
C-1	Intermediate Range Hi Flux Rod Stop	Amps = 20% Power.	½ channels.	Blocked when IR trip is blocked. Bypassed when IR trip is bypassed.	Stops control rod outward motion.
C-2	Power Range Hi Flux Rod Stop	103% Power.	1/4 channels.	Individual channel can be bypassed at local cabinet.	Stops control rod outward motion.
C-3	OTΔT Rod Stop & Runback	3% below OTΔT Reactor trip setpoint.	2/4 channels.	None.	Stops control rod outward motion and initiates a turbine runback.
C-4	OPΔT Rod Stop & Runback	3% below OPΔT Reactor trip setpoint.	2/4 channels.	None	Stops control rod outward motion and initiates a turbine runback.
C-5	Low Power Interlock	15% turbine power (impulse pressure)	One channel assigned	None.	Stops control rod outward motion in Automatic only.
C-7	Loss of Load	-10% turbine power rate (impulse pressure)	One channel assigned	Seals in. Must be reset.	Arms steam dumps in load rejection mode if C-9 is present.
C-8 (Not in plant if P-9)	Turbine Tripped	Stop valves closed. Auto stop oil pressure (<45 psig West.) and (800psig low trip fluid press. G.E.)	4/4 valves. 2/3 Press sensors	Disabled below P-7 (10%)	Shifts steam dump Tavg control from load rejection mode to reactor trip mode. Arms steam dumps if C-9 is present.
C-9	Condenser Interlock	Condenser vacuum >63.5 cm. H_2O.	1/3 channel.	None	Ensures condenser is ready for steam dump operation.
C-11	Control Bank D Withdrawal Interlock	Control bank D >223 steps.	One channel assigned.	None.	Stops outward rod motion in Automatic only.

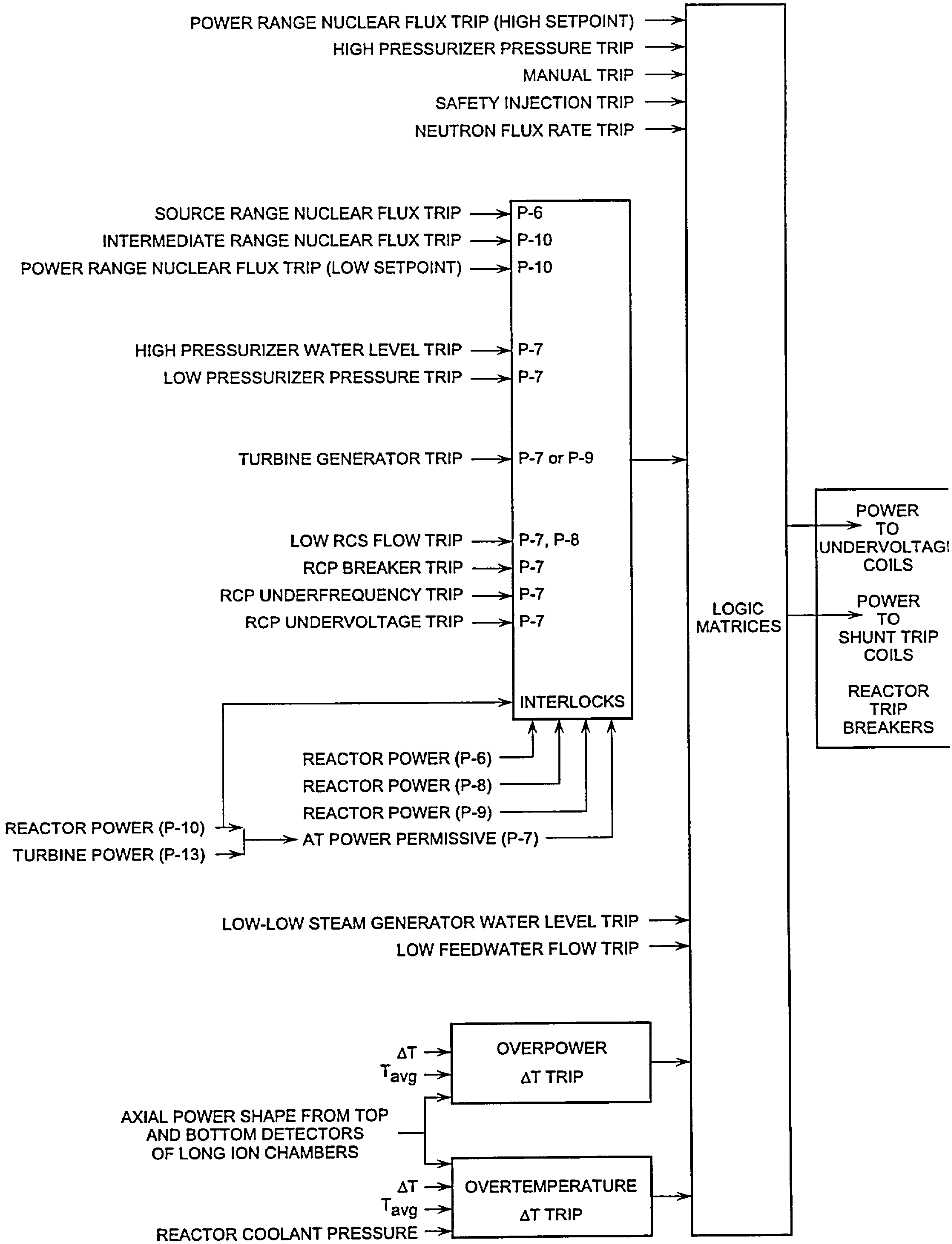

Figure 12.2-1 Reactor Protection System, Block Diagram

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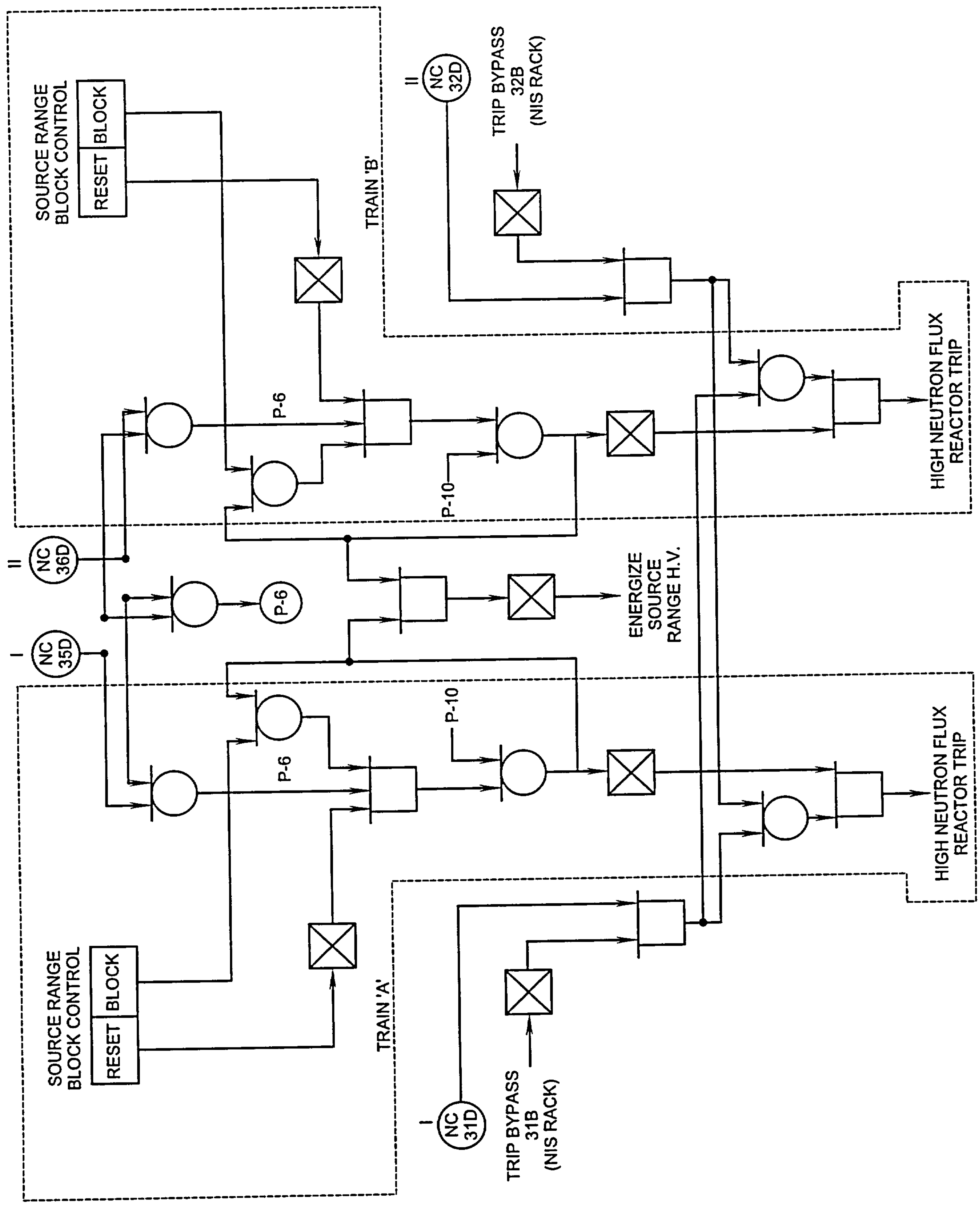

Figure 12.2-2 Source Range Reactor Trip Logic

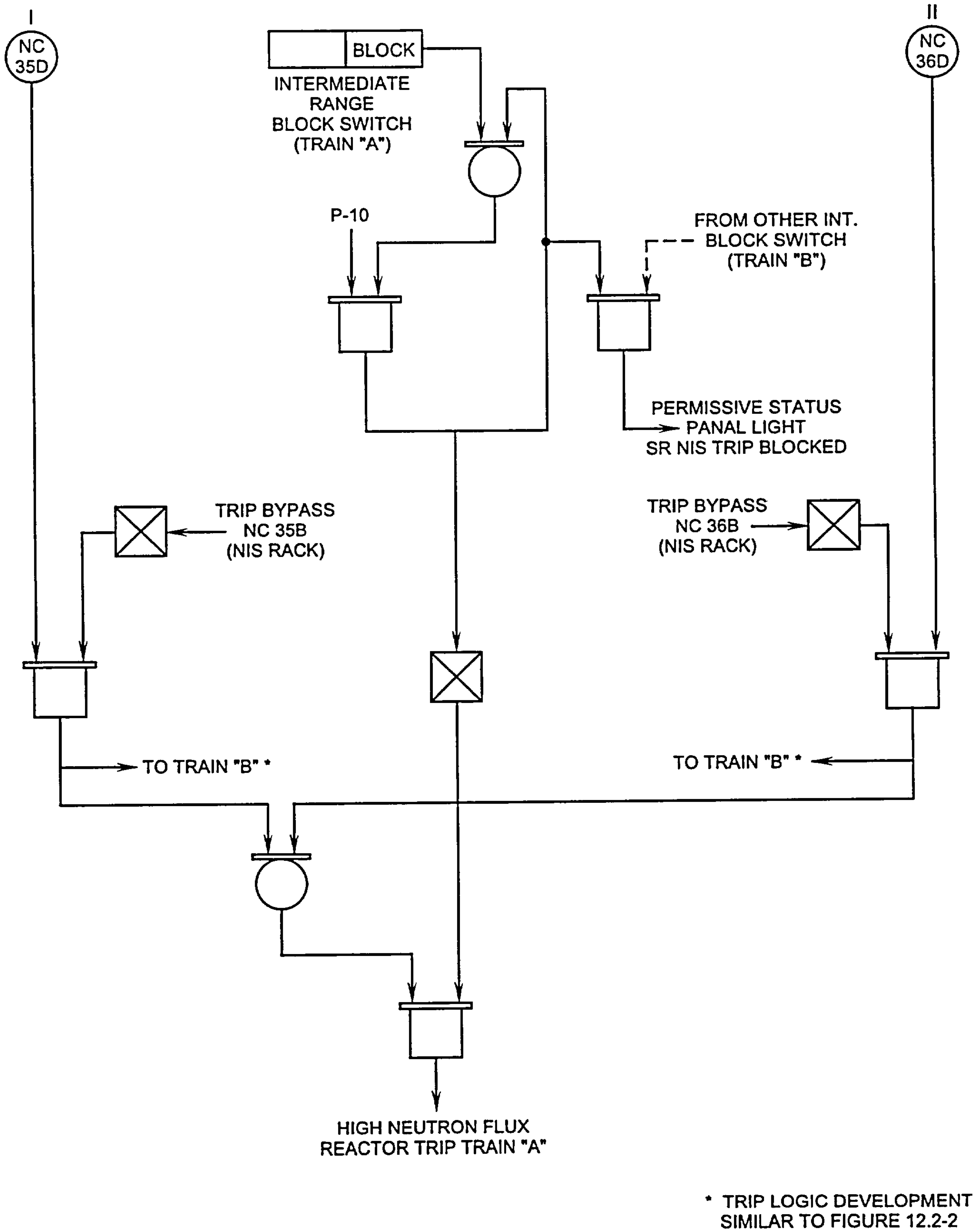

Figure 12.2-3 Intermediate Range Reactor Trip Logic

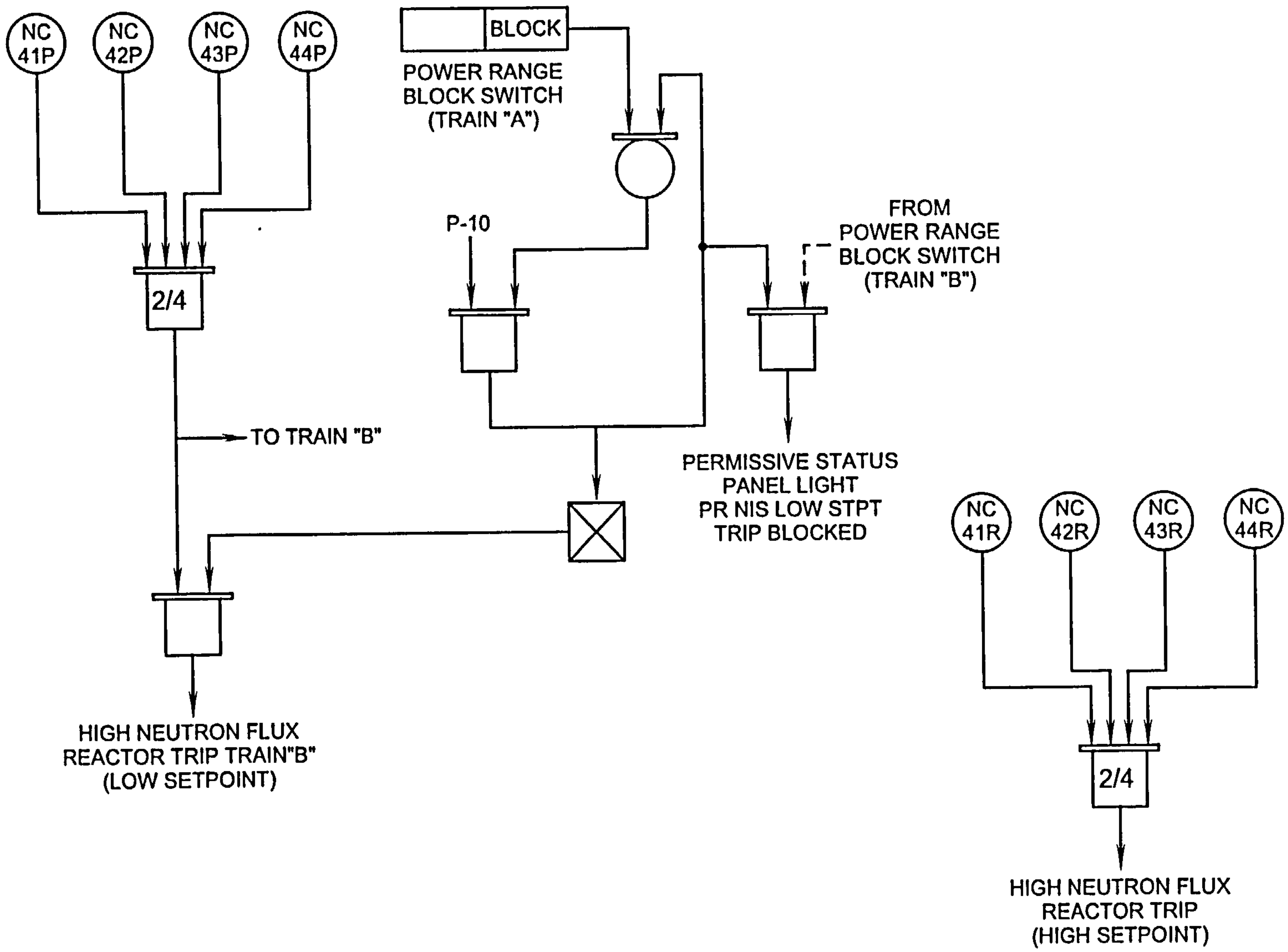

Figure 12.2-4 Power Range Reactor Trip Logic

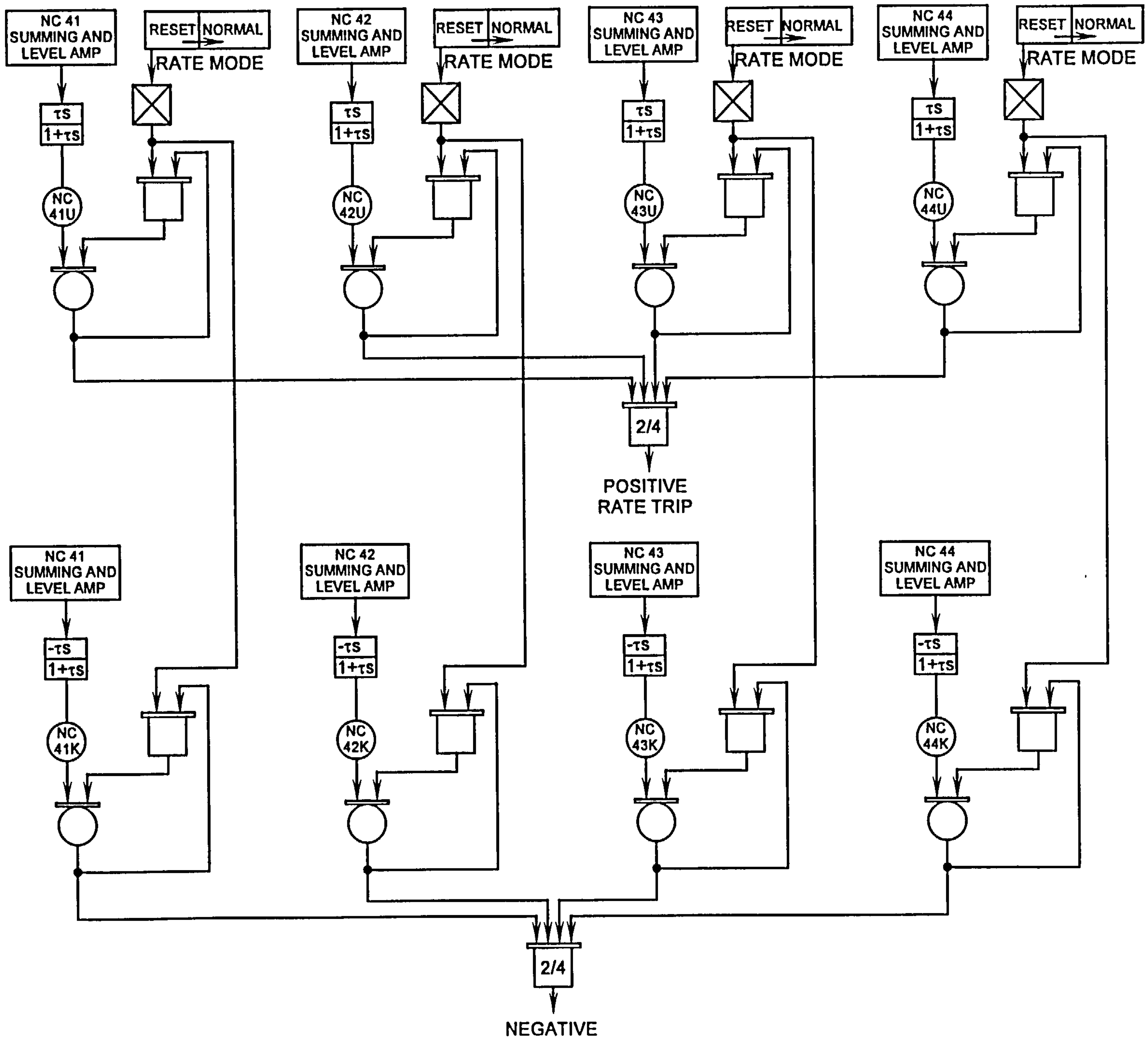

Figure 12.2-5 Power Range Flux Rate Trips

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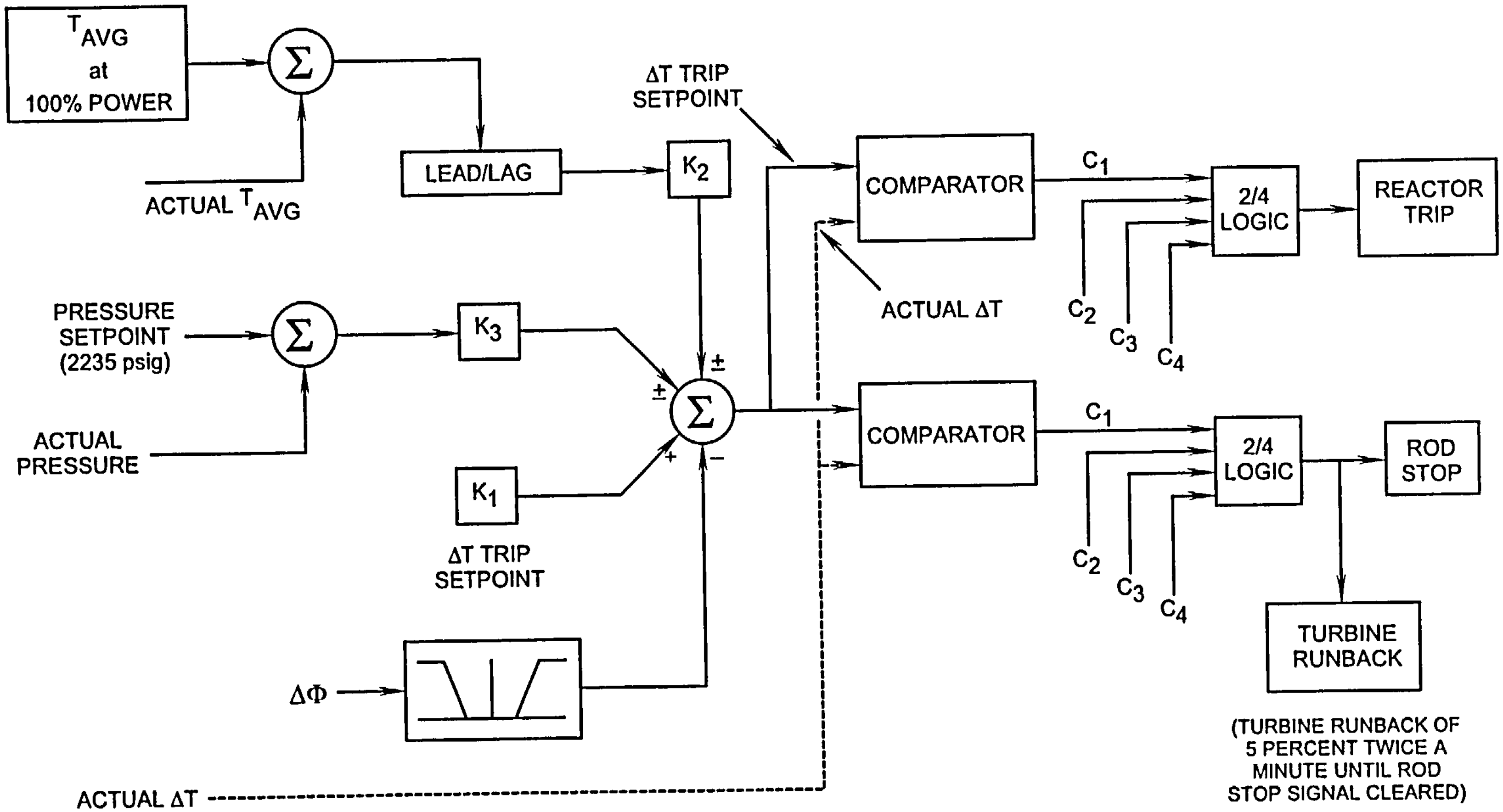

Figure 12.2-6 Overtemperature ΔT Channel Block Diagram

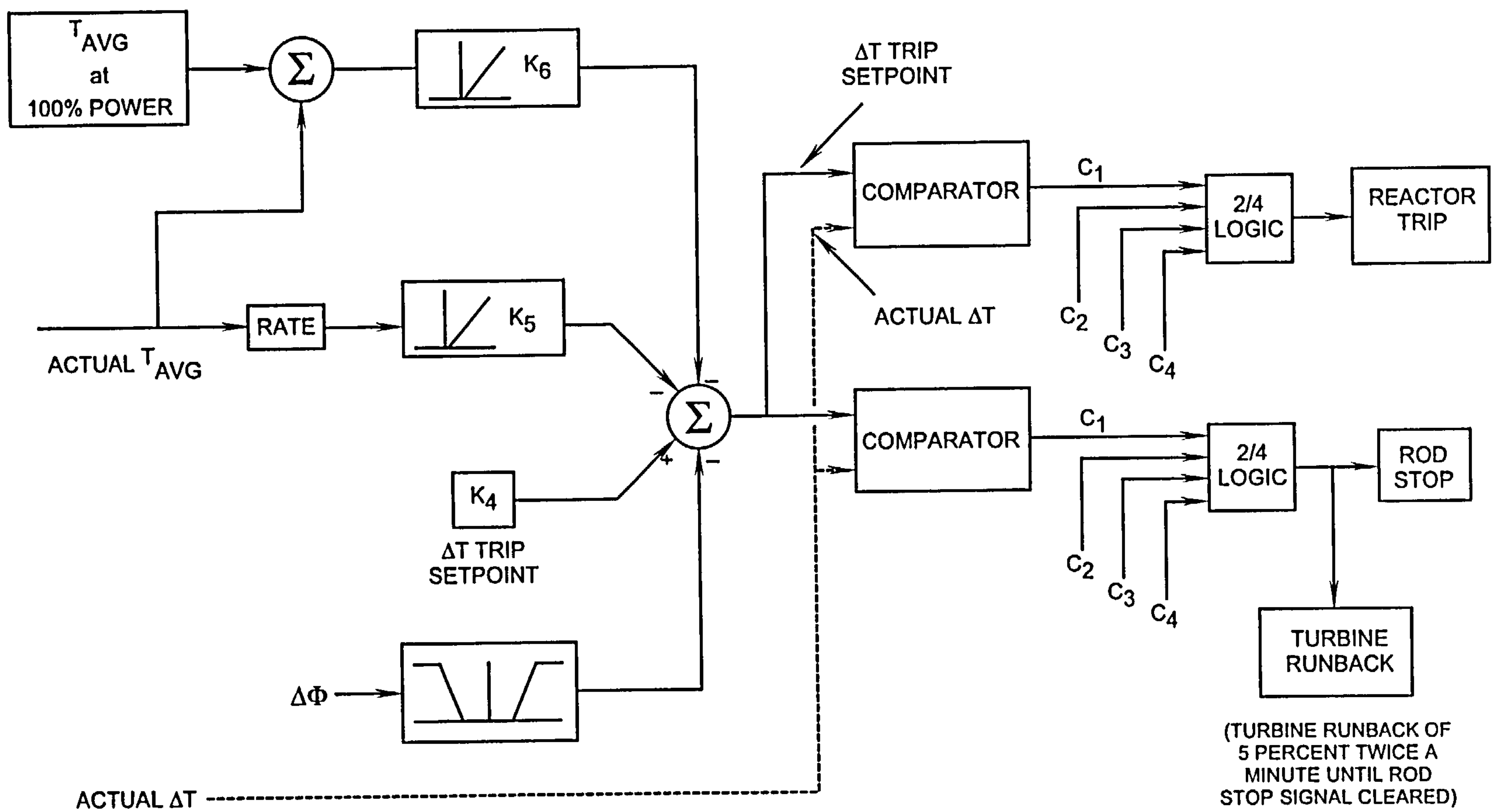

Figure 12.2-7 Overpower ΔT Channel Block Diagram

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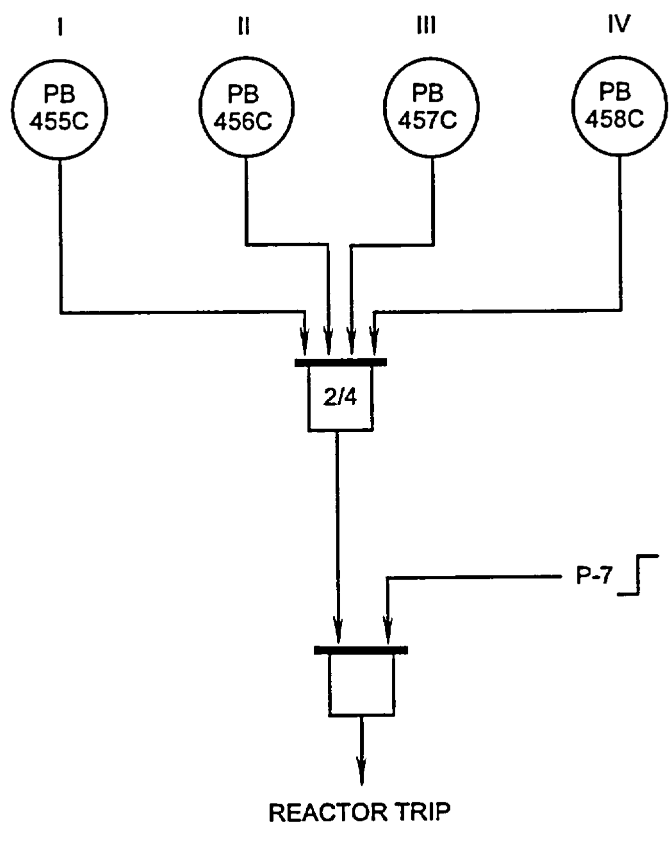

Figure 12.2-8 Pressurizer Low Pressure Reactor Trip

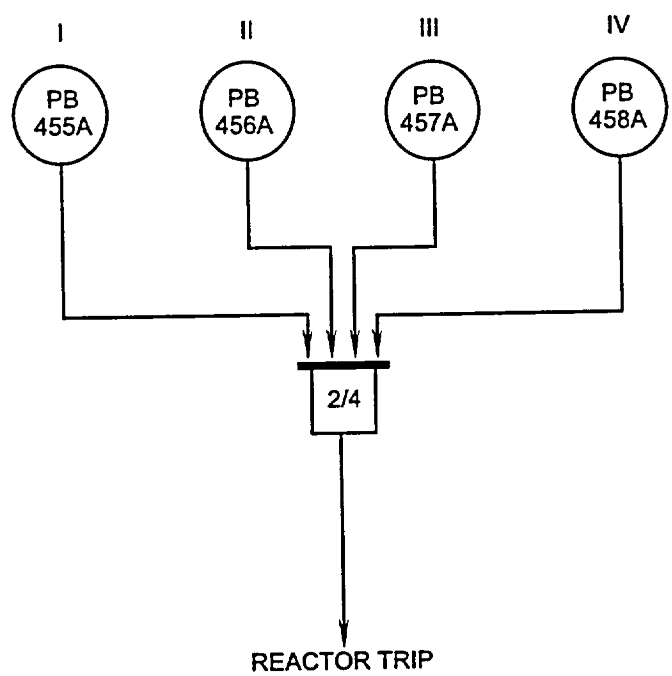

Figure 12.2-9 Pressurizer High Pressure Reactor Trip

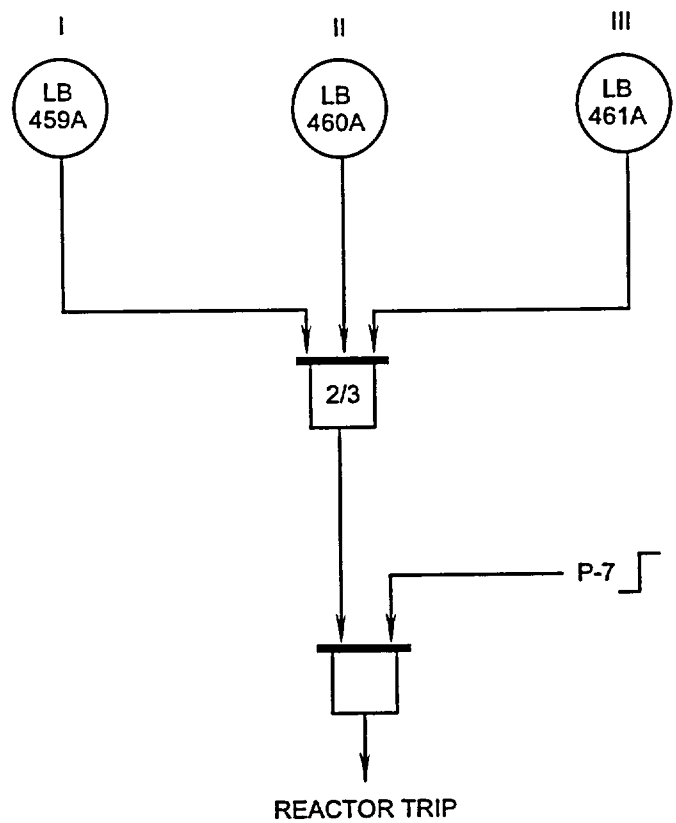

Figure 12.2-10 Pressurizer High Water Level Reactor Trip

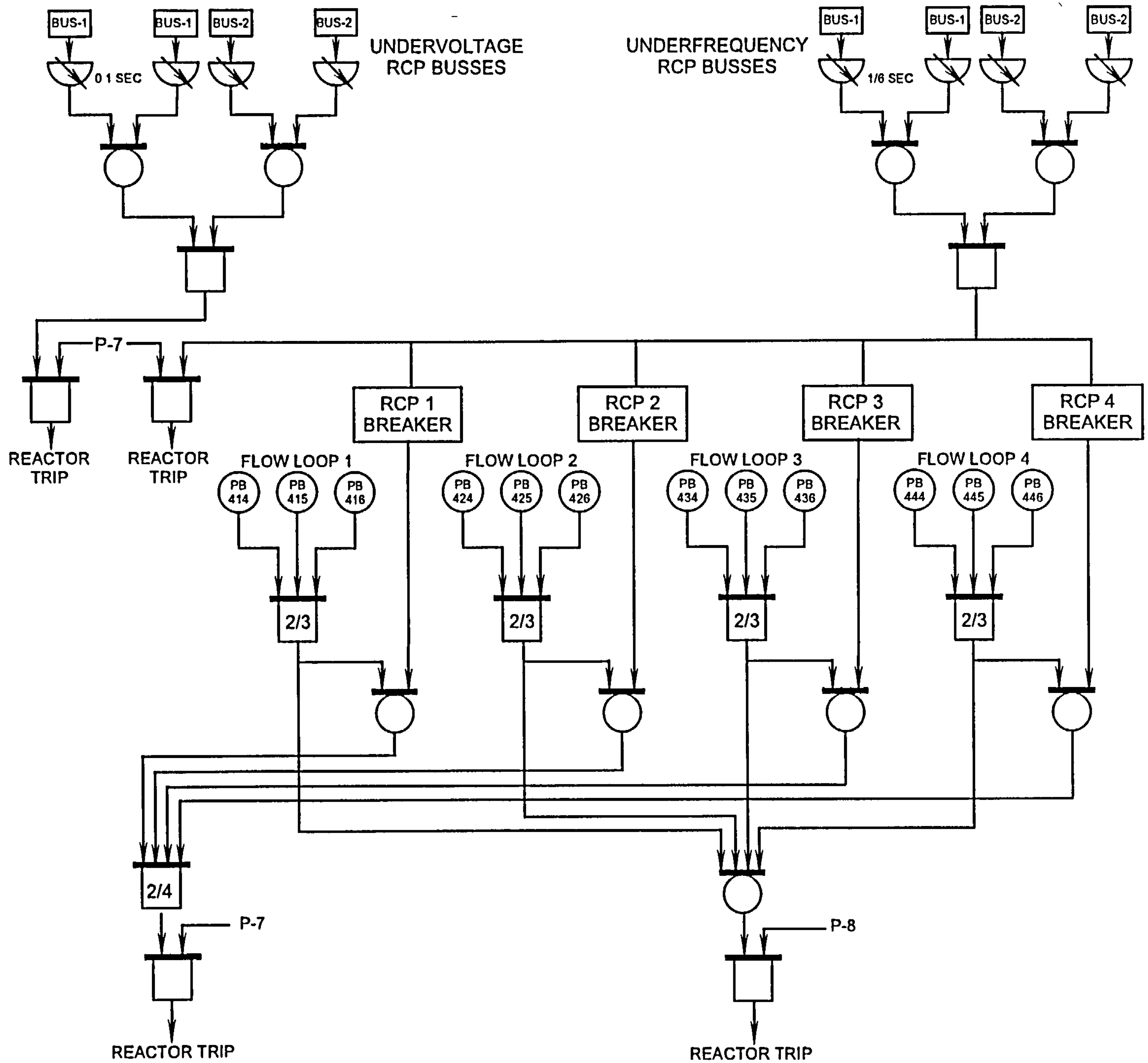

Figure 12.2-11 Low Flow Trips

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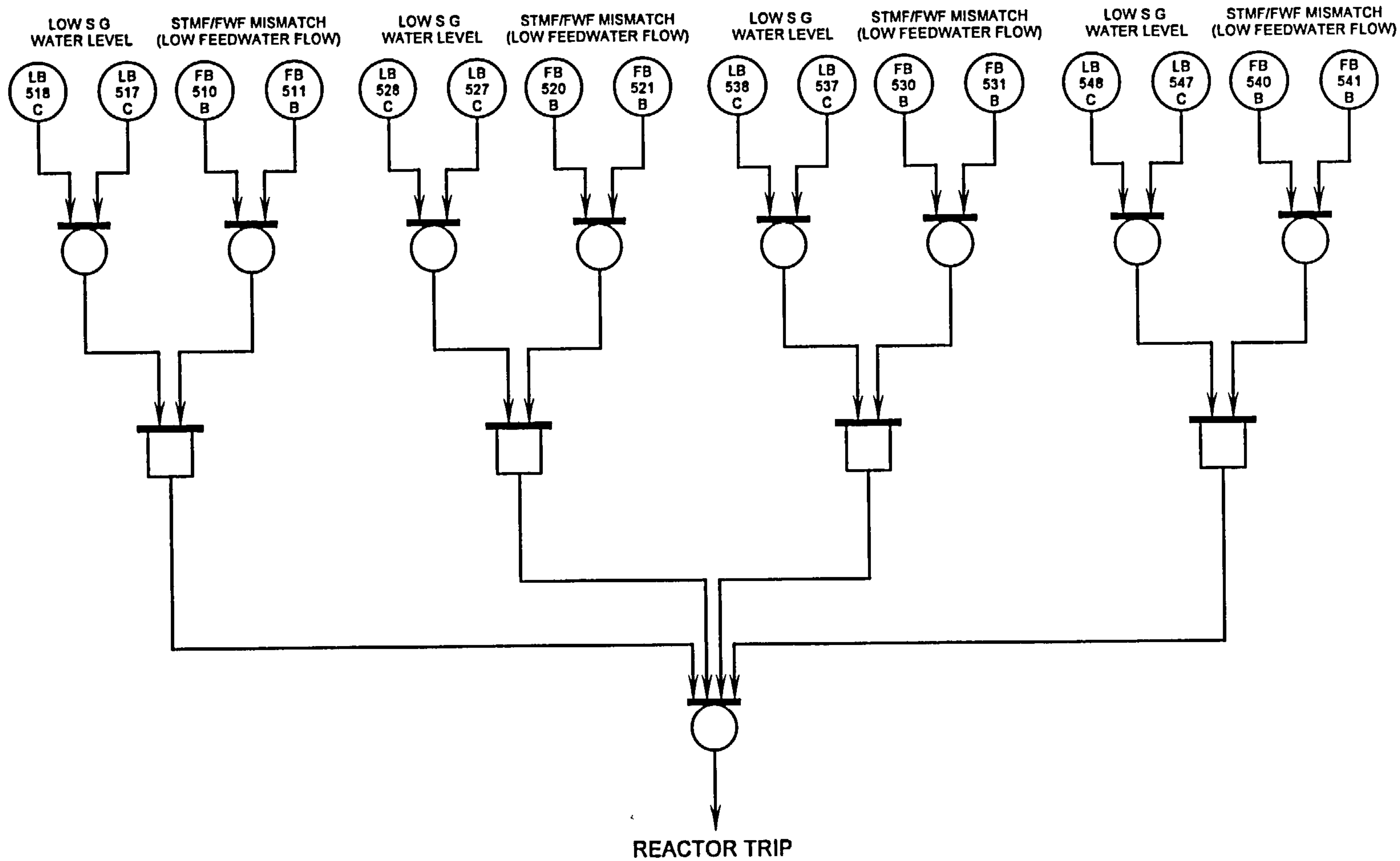

Figure 12.2-12 Low Feedwater Flow Reactor Trip

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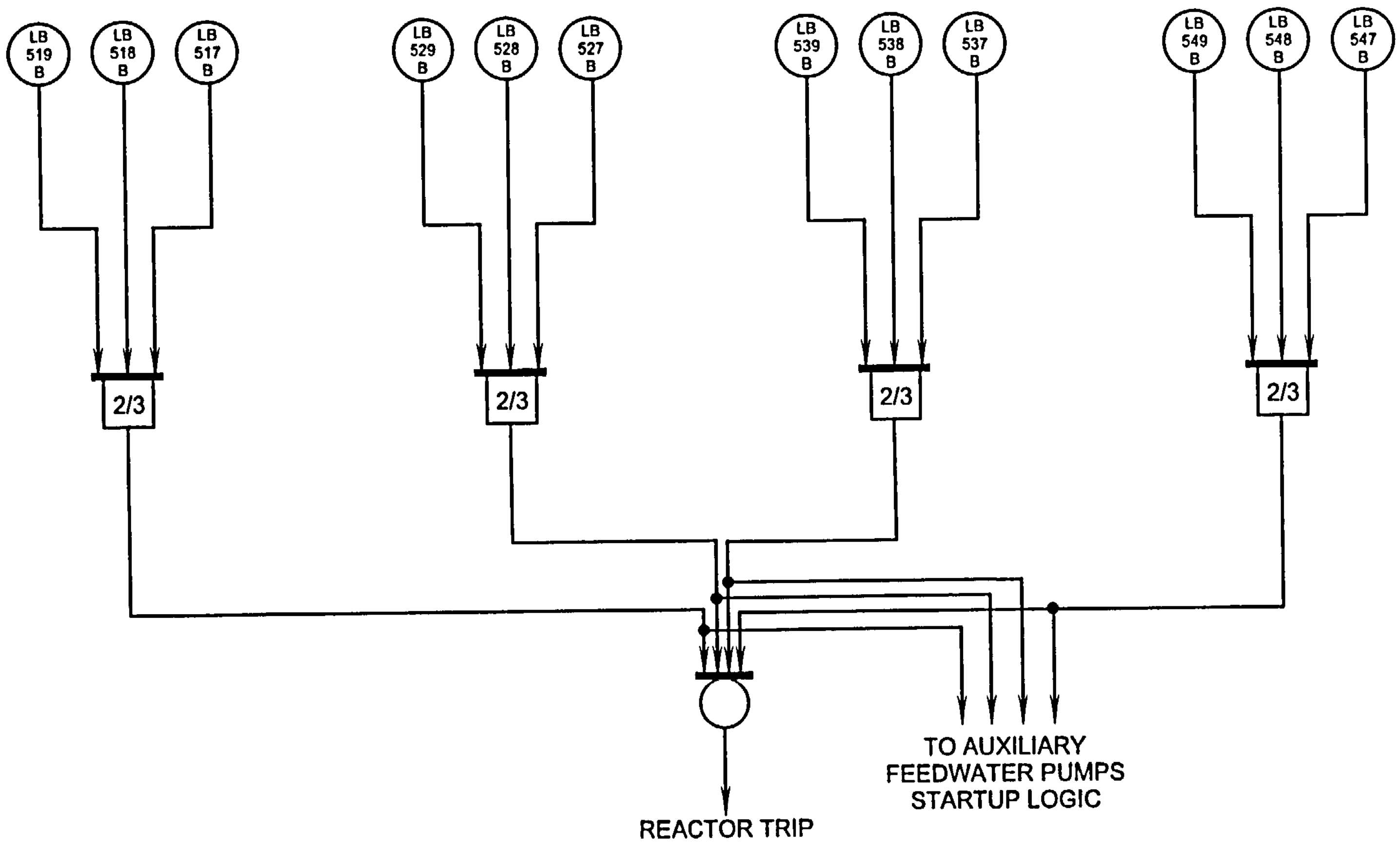

Figure 12.2-13 Steam Generator Low-Low Water Level Reactor Trip

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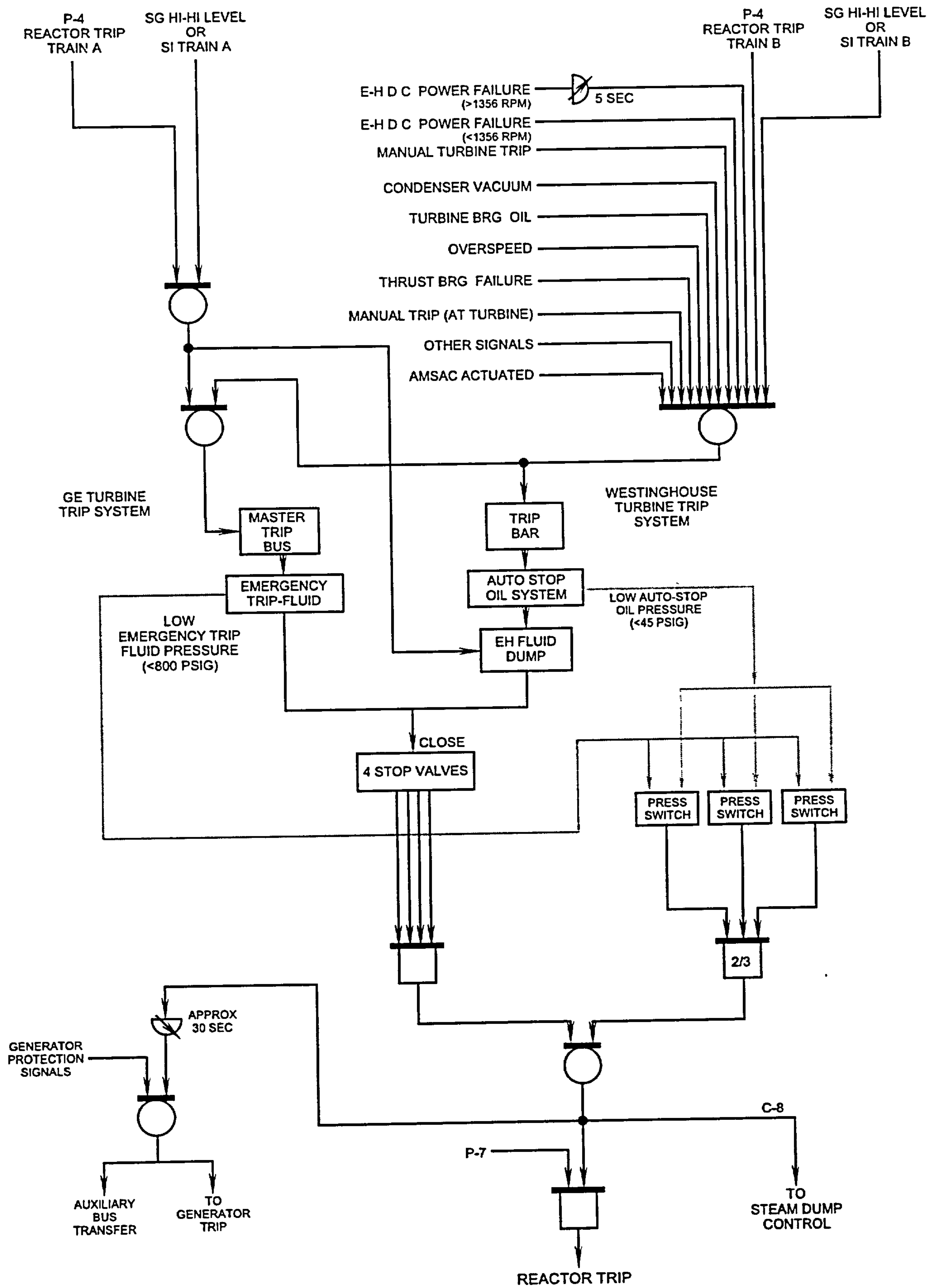

Figure 12.2-14 Turbine Trip - Reactor Trip

Westinghouse Technology Systems Manual

Section 12.3

Reactor Protection System - Engineered Safety Features Actuation Signals

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12.3 REACTOR PROTECTION SYSTEM ENGINEERED SAFETY FEATURES ACTUATION SIGNALS

Learning Objectives:

1. List the Engineered Safety Features (ESF) actuation signals and the accident(s) which will initiate each.

2. List the systems or components that are actuated by an engineered safety features actuation signal.

3. Describe the effects of "resetting" an engineered safety features actuation signal and how the "reset" signal is automatically removed.

12.3.1 Introduction

If an accident occurs, the purposes of the engineered safety features signals are to start, or actuate, safety systems, equipment, and/or components and to isolate non-safety systems. The reactor protection system (RPS) monitors various processes with selected pressure, temperature, and flow instruments to determine if an accident has occurred. These process analog signals are compared to bistable setpoints and based upon the number of signals that have exceeded their respective setpoints will generate the protective actions.

12.3.2 Engineered Safety Features Actuation

The reactor protection system automatically initiates the engineered safety features to limit the consequences of infrequent faults (Condition III events) and to mitigate limiting faults (Condition IV events) to reduce the potential for a significant release of radioactive material to the environment.

The ESF signals function to shutdown the reactor if it is still operating, maintain the reactor in a shutdown condition, provide sufficient core cooling to limit cladding and possible fuel damage, and finally ensure the integrity of the containment. Figure 12.3-1 illustrates the engineering safety features actuation signals and the components or systems affected by actuating the ESF. The accident signals and the accidents for which that specific signal is designed to sense is discussed in section 12.3.3 of this chapter.

If the reactor protection system logic senses a condition requiring an engineered safety features actuation, it activates the appropriate master relays as shown in Figure 12.3-2. Each master relay actuates up to four slave relays. The slave relays supply operating current to a maximum of four engineered safety feature devices.

If the reactor protection system senses either a loss of coolant accident (LOCA) or a secondary system (steam line or feed line) break, it initiates the engineered safety features. Either of these accidents requires the operation of various safety features to insure the safety of the public and the safety of the reactor core. Regardless of the accident, the functions of the engineered safety features are to:

1. Place the plant in a safe shutdown configuration. This includes tripping the reactor and injecting boric acid into the reactor coolant system.

2. Provide cool, borated water at a rate sufficient to prevent excessive core damage following a LOCA.

3. Isolate the containment from the outside environment to limit the amount of radioactive effluent releases.

4. Provide a heat sink to remove the residual heat of the reactor core during the injection phase

of the accident and to remove decay heat for the long term.

5. Provide a reliable source of emergency power (diesel generators) if the preferred source of power is lost.

12.3.3 ESF Actuation Signals

The engineered safety feature actuation signals are listed below.

12.3.3.1 Low Pressurizer Pressure

The logic circuitry for pressurizer low pressure is shown in figure 12.3-4. The actuation setpoint is 1807 psig with a coincidence of two-out-of-three channels. Actuation of this circuit is indicative of a LOCA. If the plant operating staff wishes to perform a cooldown and a normal depressurization of the plant, this signal can be manually blocked when pressurizer pressure drops below 1915 psig (P-11 setpoint).

12.3.3.2 High Containment Pressure

The Hi containment pressure signal is designed to serve as a backup protection signal for a LOCA, or a high energy secondary break inside the containment. The high containment pressure circuit, shown in figure 12.3-5, could also occur if the size of the break is large enough to cause an increase in containment pressure, but not large enough to trigger the actuation of the signal associated with that accident. The setpoint for this protection signal is usually 10% of the design pressure of the containment.

An additional signal, Hi-Hi containment pressure, is generated from these same pressure sensors. The setpoint for the Hi-Hi containment pressure is generally set to actuate at 50% of the design pressure of the containment. When this signal actuates the following occurs:

1. Phase "B" isolation - phase "B" isolates the systems not isolated on phase "A" isolation.

2. Containment spray actuation - the containment spray pumps are started and the spray header isolation valves receive a check open signal.

3. Main steam isolation - the main steam line isolation valves receive a close signal.

12.3.3.3 High Steam Line Flow Coincident with either Low Steam Line Pressure or Low-Low T_{avg}

This set of circumstances (high steam line flow in conjunction with either a low steam pressure or a lo-lo T_{avg}) happens if a steam line break occurs downstream of the main steam line isolation and check valves. A steam line break accident, at this location, is common to all S/Gs. It causes a steam flow increase and a steam pressure decrease in all main steam lines. The increased steam flow i.e., a heat removal increase, reduces reactor coolant system temperature (T_{avg}). If this signal actuates, not only does it start the ESF loads, but it also shuts all four steam line isolation valves.

The control room operator may manually block this actuation signal, shown in figure 12.3-6. Permissive P-12 (T_{avg}<553°F) provides an input into the logic that allows the control room operator to block this signal. Bypassing this ESF signal allows the operating staff to shutdown, cooldown, and depressurize the plant without inadvertently actuating an ESF on high steam flow.

12.3.3.4 Steam Line High Differential Pressure

This signal is indicative of a steam line break upstream of the main steam line isolation and check valves. A break in this area results in the affected steam line pressure dropping to a pressure significantly lower than the other steam lines due to its associated check valve seating. If the pressure in the affected steam generator is 100 psi lower than two of the remaining three steam generators, as shown in figure 12.3-7, this signal is actuated. In addition, like the hi containment pressure, this ESF signal cannot be blocked by the operator.

12.3.3.5 Manual

This function allows the operator to initiate an ESF (from either of two main control board locations) at any time.

12.3.4 Engineered Safety Features Functions

When an engineered safety features actuation is initiated, as shown in Figure 12.3-1, by any of the previously described signals, various actions are completed to place the plant in a safe shutdown configuration. The specific actions that occur are as follows:

1. Reactor trip - Shuts down the reactor if a reactor trip has not already occurred.

2. ECCS components - Aligns the high head injection portion of the chemical and volume control system (CVCS) diverting flow from the normal charging path to force flow through the boron injection tank (BIT). From the BIT (if installed), borated water is directed into the reactor coolant system (RCS) cold legs. In addition, the second charging pump starts along with the safety injection (SI) pumps and the residual heat removal (RHR) pumps. The RHR and SI systems are normally aligned for the injection phase, as required by Technical Specifications, to inject borated water from the refueling water storage tank (RWST) into the reactor coolant system cold legs. Refer to chapter 5.2 for a detailed description of these systems.

3. Initiates phase "A" containment isolation - Shuts dual isolation valves in all non-essential containment penetration lines. The only exceptions to the isolation of non-essential process piping is the component cooling water supply and return lines for the reactor coolant pumps (RCPs) and the main steam line isolation valves (MSIVs).

   The RCPs, although not essential, are used to circulate reactor coolant through the core. The component cooling water isolation valves, that allow cooling water to the reactor coolant pumps, receive a closed signal if the pressure inside the containment exceeds the hi-hi containment pressure signal (i.e. phase "B" containment isolation).

   The MSIVs are kept open because they are part of the high pressure steam system and if they are kept open, the steam dump system may be used to remove core decay heat. The MSIVs automatically close if the ESF initiating signal is due to a high steam line flow signal or due to a phase "B" containment isolation. This isolation prevents all four steam generators from blowing down from a (assumed) downstream steam line break.

4. Initiates auxiliary feed - The auxiliary feedwater system (AFW) provides a reliable, safety grade source of water to the steam generators to ensure a reactor heat sink is available.

5. Main feed water isolation - Main feed is isolated to prevent an inadvertent cooldown which occurs when the steam generator level control (SGWLC) system tries to return S/G level to program and overfeeds the S/Gs. Following a reactor trip from power, a large prolonged "shrink" causes the water level

control system to feed at a high rate in order to return S/G level to program.

6. Emergency diesel generator startup - The diesel generators are the emergency power source for the engineered safety systems. They are started whenever an ESF actuation takes place, regardless of the status of off-site power. The diesels run in standby but will not supply the vital loads until required by a loss of off-site power. If the preferred power source (off-site power) is lost; the diesel generators automatically tie onto the dead class IE power buses.

7. Auxiliary cooling system alignment - The service water system (SWS) and the component cooling water system (CCW) automatically align to the ESF configuration. In addition, a start signal is sent to the correct number of pumps in each system.

8. Control room ventilation isolation - The ventilation supply to the control room realigns to a self-contained habitability system to prevent smoke or radiation levels in the auxiliary building from causing a control room evacuation.

9. Containment ventilation isolation - The containment purge and exhaust system is periodically used to ventilate the containment atmosphere prior to personnel entry. These systems are isolated if they are running when an accident occurs.

12.3.5 ESF Actuation Reset

As shown in figure 12.3-3 after an ESF actuation, a retentive memory device is placed in the "ON" position. This means that the ESF functions described above, continue to receive an actuation signal even if the original ESF signal is removed or cleared. The control room operator cannot interrupt any of the ESF functions until the reset logic is activated. This "locking out" of the operator is very important to prevent the interruption of a valid ESF actuation. Additionally, some of the ESF functions take several seconds to complete their alignments and interrupting the start sequence could leave some systems incorrectly aligned.

To prevent an interruption of any ESF starting sequence; the reset logic must be made-up before the reactor operator can manually reset (turn off) the ESF actuation signal. When the retentive memory is turned on (Relay K1 energizes), the K1 contact in the Reset logic closes -- starting the time delay relay (Relay TD).

The time delay relay produces an output (energizes) some time after it is started (usually 60 sec). After the time delay relay times out, it energizes and it closes the TD contact in the Reset circuit. This action, along with the P-4 contact closed (P-4 input described in Chapter 12.2), allows the control room operator to reset (turn off) the ESF actuation signal.

Resetting the ESF, places the retentive memory device in the "OFF" position. Removing the "ON" signal from the ESF actuation circuitry does not turn off any ESF equipment, realign any valves, or change any other functions of the ESF. All that happens when the operator depresses the reset push-button is the removal of the start signal. However, after turning off the actuation circuitry the control room operator/s can change system alignment start or stop equipment as needed and control the plant as required by the plant's emergency operating procedures to recover from the accident.

To insure that all systems and component realignments are complete prior to resetting the ESF, a one-minute timer must time out. A significant feature of this reset is that after the

ESF signal is reset any further automatic actions associated with this circuit are blocked. As shown in figure 12.3-3, after the TD contact closes and, after the reset push-button is depressed, the R1 relay energizes closing an "a" contact (labeled R1). This contact is located in the reset portion of the logic circuit and it is in parallel with the reset push-button. After this contact closes, the control room operator can release the reset push-button and current flows through the closed R1 contact keeping the R1 relay energized.

The R1 relay also controls two "b" contacts. One of these "b" contacts is located in the time delay circuitry. This contact (labeled R1) opens when the R1 relay is energized. This action de-energizes the TD relay. Simultaneously, the other "b" contact opens. This contact (also labeled R1) is located in the retentive memory portion of the circuit. After this contact opens the K1 relay de-energizes which removes power to the output relays. As long as the R1 relay remains energized, all automatic ESF signals are blocked.

As previously stated, after the control room operator resets the ESF actuation signal, all automatic actuation's of the engineered safety features are blocked. However, a manual actuation of the engineered safety features is still available. If the control room operator depresses either of the two manual ESF pushbuttons located in the main control room, relay K2 energizes. When this relay energizes it closes an "a" contact (labeled K2). This contact is located in the "ON" side of the retentive memory. When the K2 contact closes in the "ON" side of the retentive memory it energizes the K1 relay. This action provides 48 Vdc to the output relays (actuates the ESF loads). Meanwhile a "b" contact (labeled K2) opens in the "OFF" side of the retentive memory. When it opens, it de-energizes relay R1 which closes the "b" contact (labeled R1) in the "ON" side of the retentive memory. With this contact closed the operator can release the manual ESF push-button and relay K1 remains energized.

De-energizing the R1 relay also opens an R1 contact (in parallel with the reset push-button) and simultaneously closes the R1 contact in the time delay relay circuit. The operator is again locked out of the system until the time delay relay times out and makes-up the circuitry allowing the control room operator permission to block the actuation signal.

After the control room operator resets the ESF actuation, all automatic ESF actuation signals are disabled until the control room operator manually initiates an ESF or until the reactor trip signal (P-4) is cleared by closing the reactor trip breakers. Before closing the reactor trip breakers, the operator should ensure that all ESF signals are clear. Otherwise, when the control room operator closes the reactor trip breakers, which removes the reset signal, and if an ESF signal is present the actuation sequence restarts.

Another important feature of the ESF actuation circuitry is the maintenance of the principles of independence and redundancy. These features are accomplished by having each, separate, protection train actuate only those systems and components associated with their respective train.

For example, protection train "A" starts the "A" train equipment such as the "A" diesel, "A" RHR pump, "A" SI pump, and the "A" isolation and/or flow control valves. The "B" protection train operates all the train "B" equipment. Since all the safety equipment is fully redundant, only one train is required to operate to mitigate the consequences of an accident, and to provide protection for the public health and safety. Either protection train may operate additional equipment when it does not fit the specific category of either train "A" or "B."

12.3.6 Summary

The reactor protection system actuates to limit the severity and consequences of postulated accidents by the actuation of the engineered safety features. These systems and components are actuated to place the plant in the most stable, safe shutdown condition possible following an accident. The ESF reset interlock prevents interruption of the safety features by the operators until completion of the sequence. After a brief time period, the operator can take manual control of the ESF equipment by manually resetting the ESF actuation signal.

TABLE 12.3-1
SUMMARY OF ENGINEERED SAFETY FEATURES ACTUATION SIGNALS

Signal	Coincidence	Setpoint	Interlocks	Accident
Low Pressurizer Pressure	two-out-of-three	1807 psig	Manual block. Block switches enabled by P-11 (1915) psig)	Loss of Coolant Accident
High Differential Pressure between Steam lines	Any steam line 100 psi lower than any two of the remaining three steam lines	100 psi ΔP	No Interlocks	Steam line break upstream of the main steam line isolation valves
High steam line flow COINCIDENT WITH Low Steam line Pressure OR Low-Low T_{avg}	one-out-of-two flow transmitters on two or more steam lines 2/4 steam lines 2/4 RCS loops	Setpoint varies with turbine power 600 psig 553 °F	Manual block - the BLOCK switches are enabled by P-12 (T_{avg} <553 °F) used for a controlled plant shutdown and cooldown	Steam line break downstream of the isolation valves (common to all steam generators). This signal also closes the main steam line isolation valves
High Containment Pressure	two-out-of-three	3.5 psig	No Interlocks	High energy break inside containment for a LOCA, or a Secondary pipe break
Manual	one-out-of-two Actuation switches on Main Control Board		No Interlocks	Operator backup to any accident

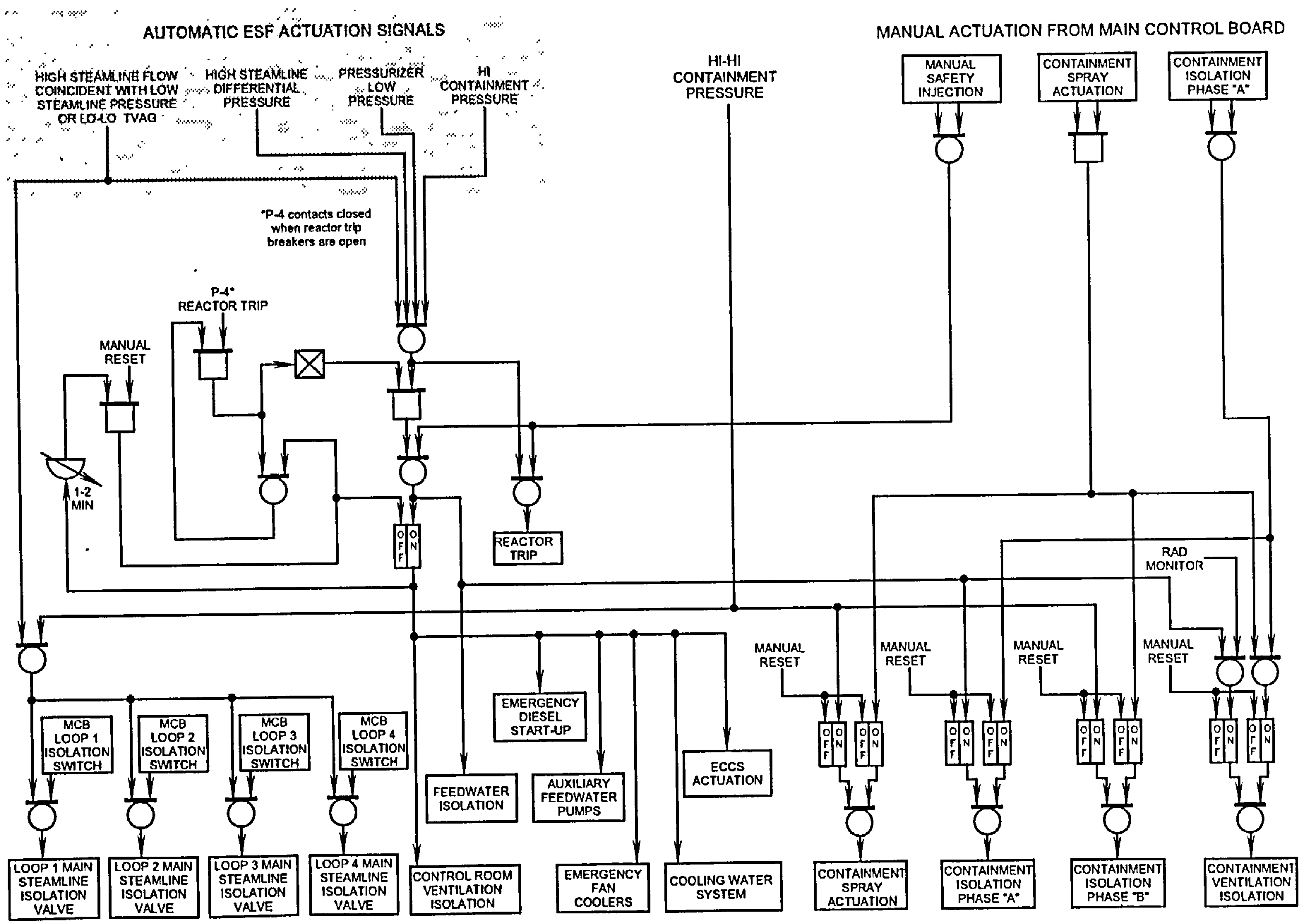

Figure 12.3-1 Engineered Safety Features Logic

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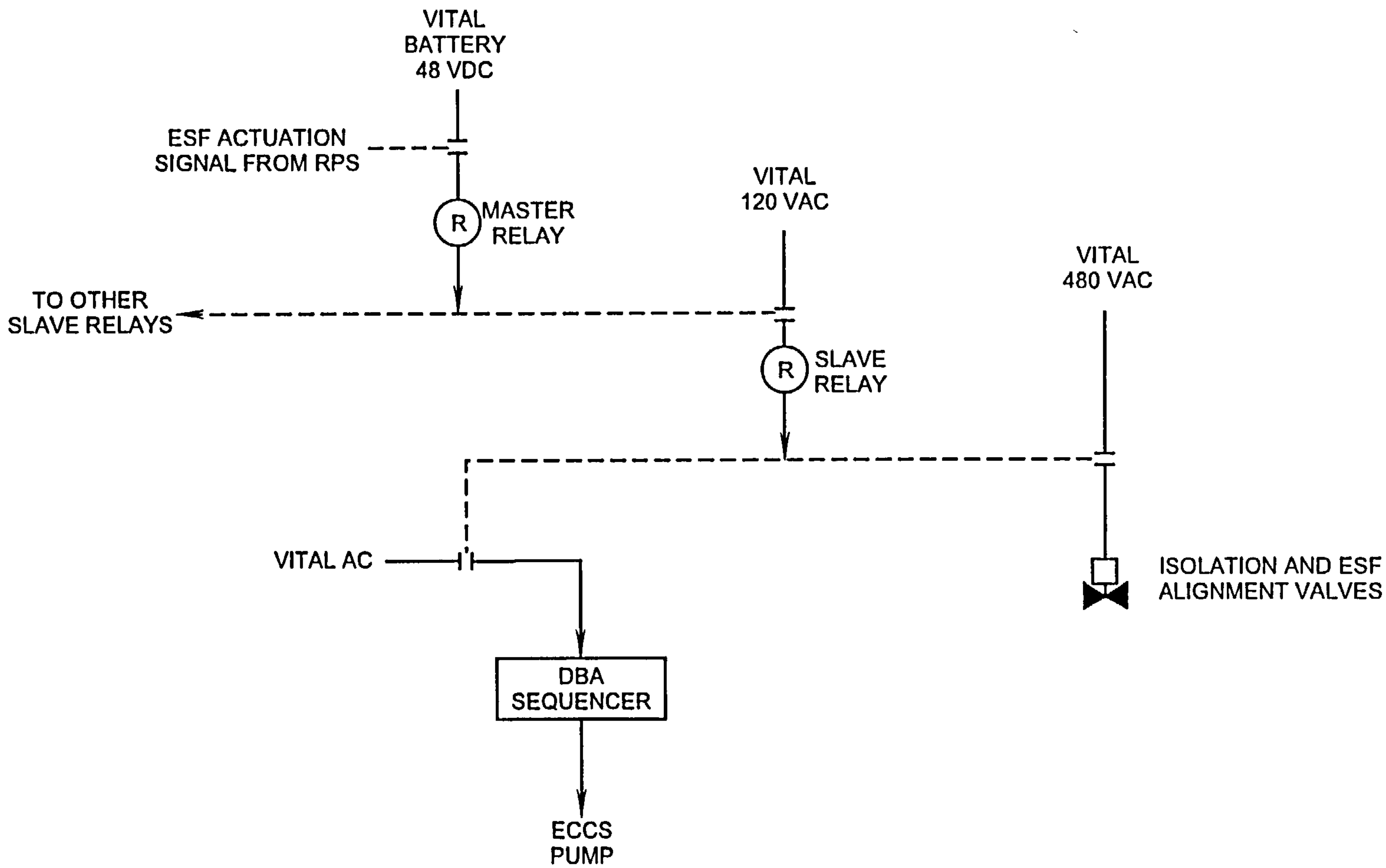

Figure 12.3-2 ESF Output Relay Operation

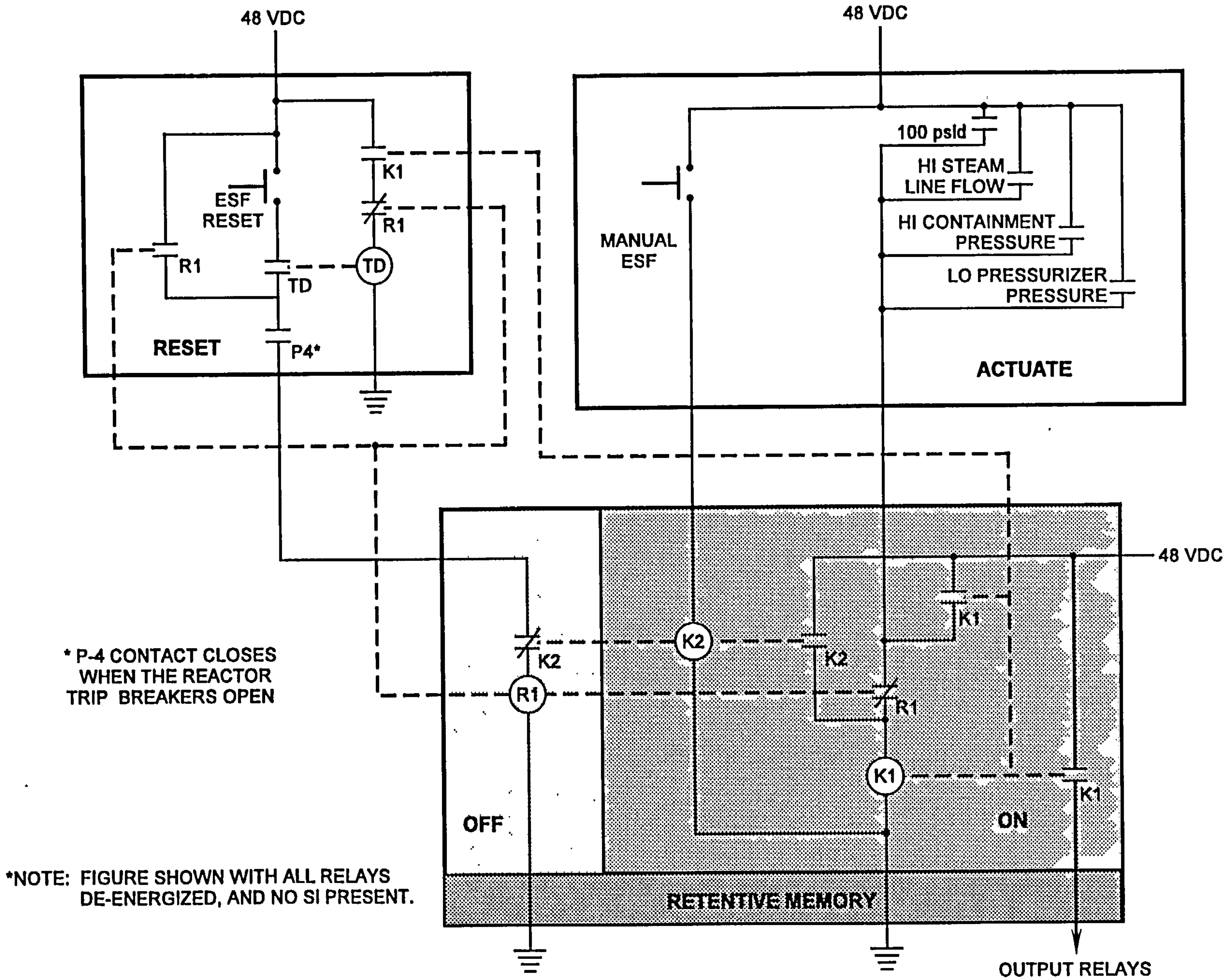

Figure 12.3-3 ESF Retentive Memory and Reset Circuit

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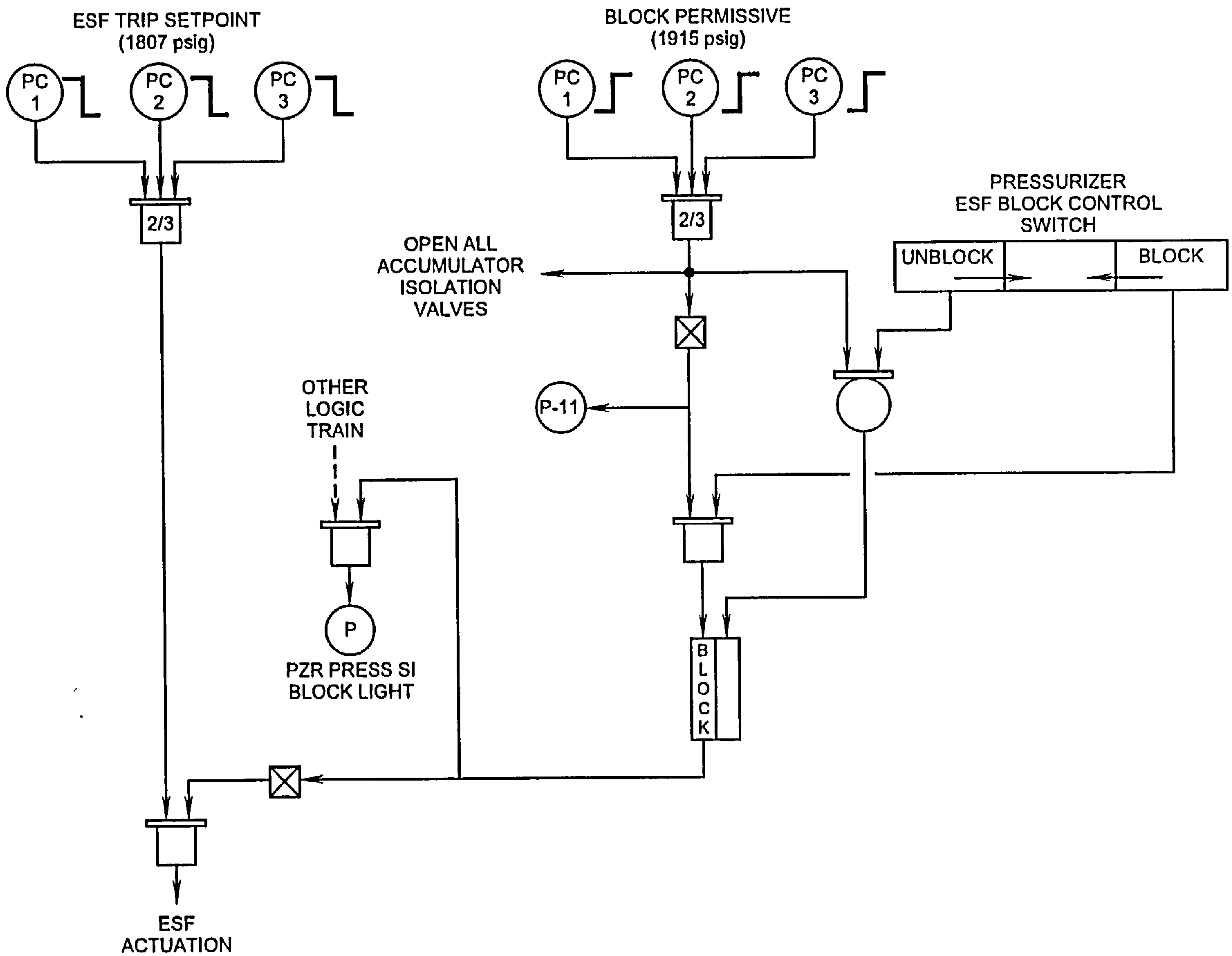

Figure 12.3-4 Low Pressurizer Pressure ESF Logic

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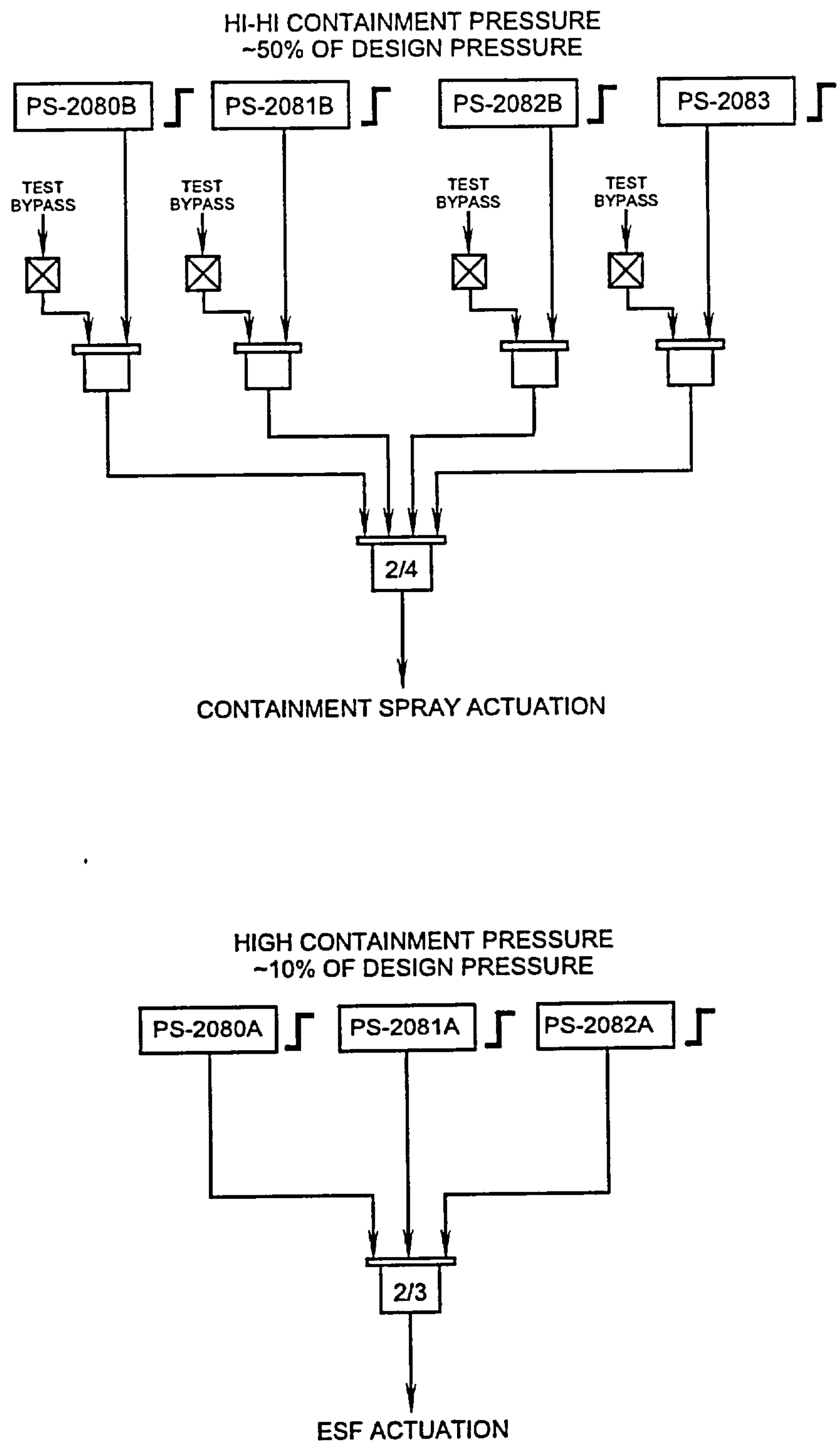

Figure 12.3-5 High Containment Pressure ESF Logic

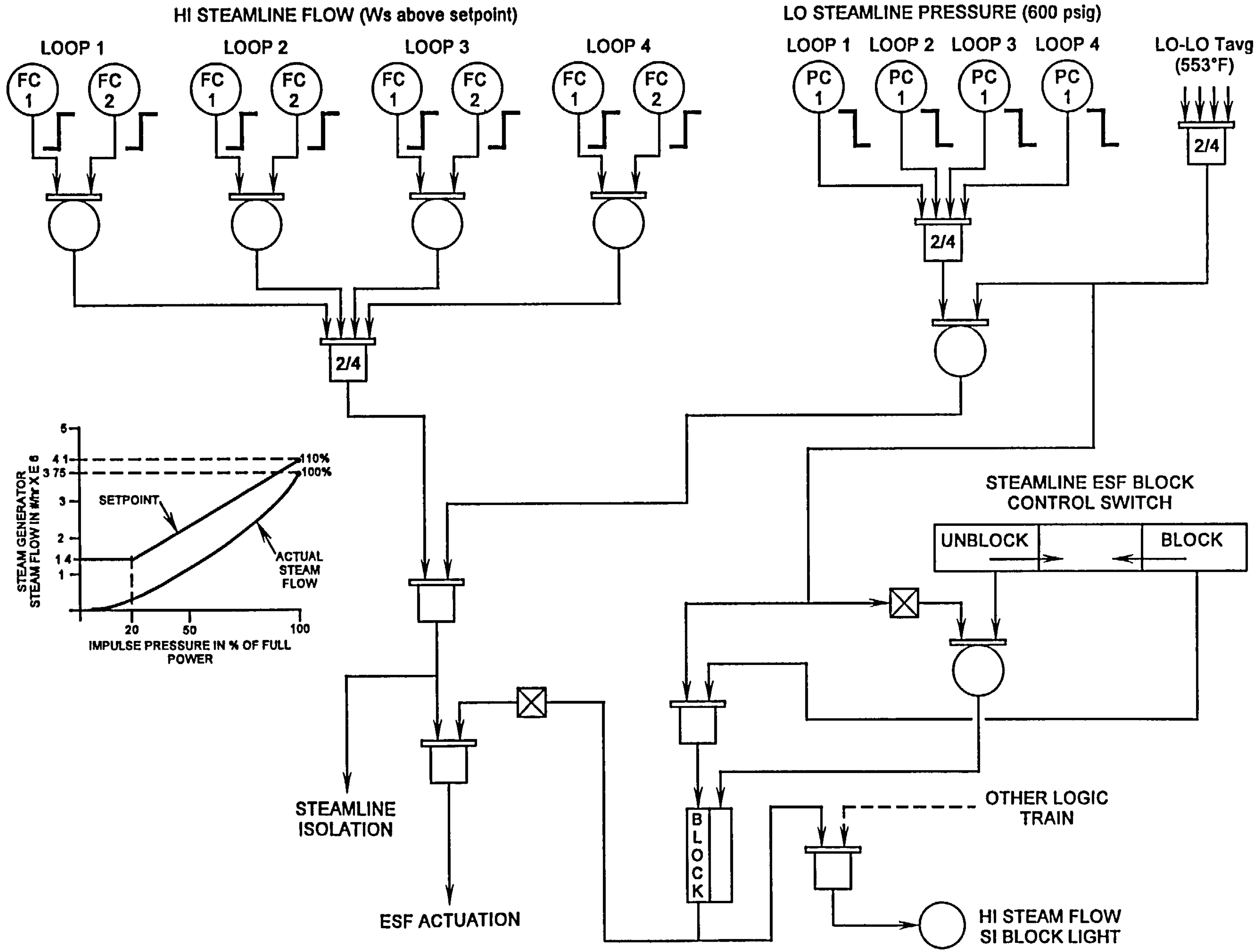

Figure 12.3-6 High Steamline Flow ESF Logic

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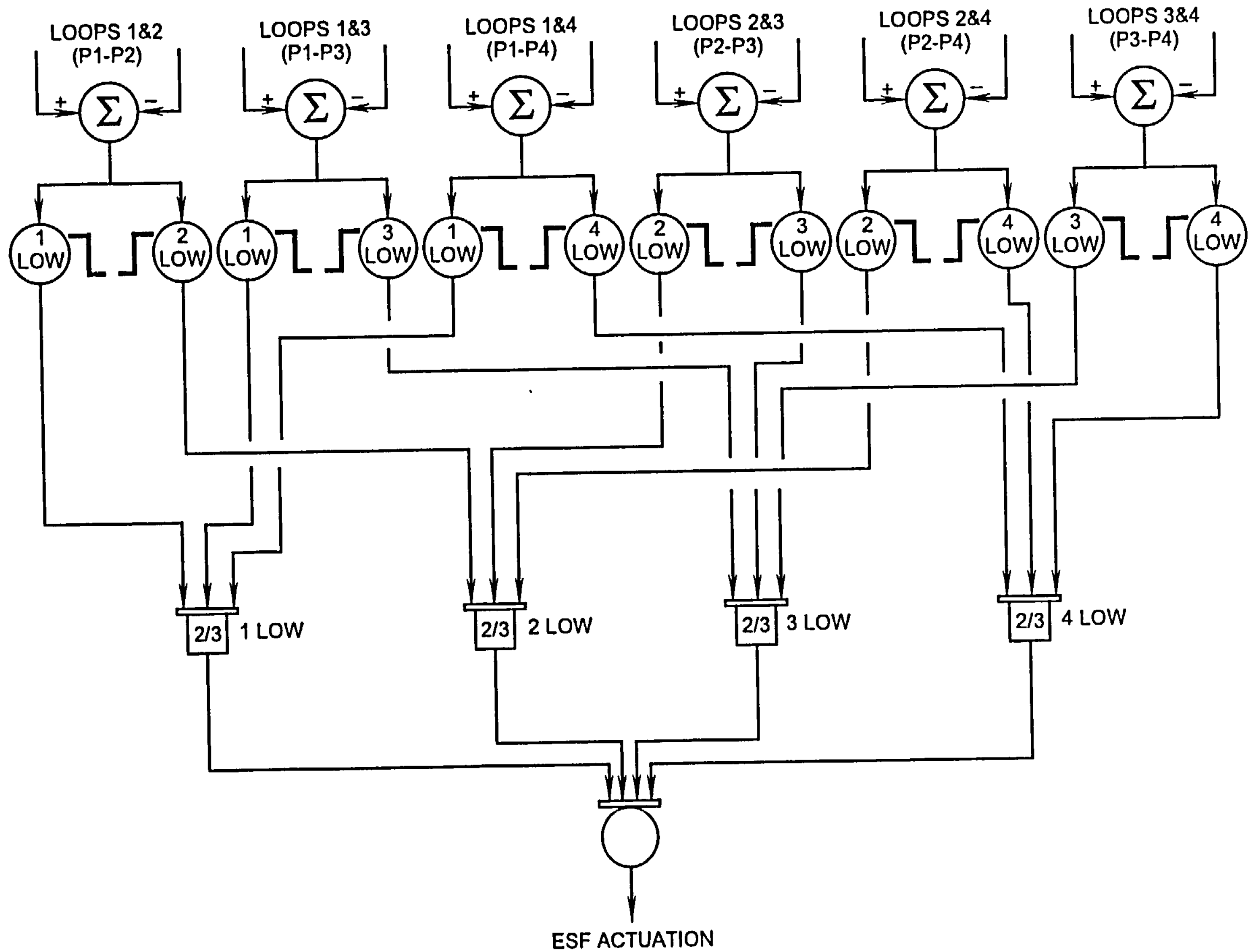

Figure 12.3-7 Steamline High Differential Pressure ESF Logic

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Westinghouse Technology Systems Manual

Chapter 13

PLANT AIR SYSTEMS

Section

Westinghouse Technology Systems Manual

Section 13.0

Plant Air Systems

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13.0 INSTRUMENT AND SERVICE AIR SYSTEMS

Learning Objectives:

1. Explain the purpose of the instrument and service air system.

2. Describe the basic components of the instrument and service air system.

3. Explain the interconnections between the instrument and service air system and support systems.

13.1 Introduction

The instrument and service air system supplies compressed air for valves, pneumatic instruments, and service air outlets throughout the plant. Because of the severe transients which could be placed on the plant during a loss of air event, the system is designed with a high degree of reliability. This system is required for startup and normal operation of the plant, however, all pneumatically operated devices in the plant that are essential for safe shutdown of the reactor are designed to "fail safe" upon loss of air pressure. Pneumatic components which are required to operate following a loss of air are supplied with accumulators. The instrument and service air system supplied components are designed to fail to a position which allows the plant to achieve and maintain the following performance goals (safe shutdown):

1. Subcritical reactor in a stable configuration,
2. Reactor coolant system in a controlled condition with pressure, temperature, reactor coolant inventory, and cooldown rate within acceptable limits, and
3. Reactor decay and sensible heat are being removed at a controlled rate.

For discussion purposes, the instrument and service air system will be divided into three sections. The first section is the air supply portion of the system. In this portion, the air compressors take air and compress it, then pass the compressed air through after-coolers and into air receivers where the air is stored before passing through a pair of filters as shown in Figure 13-1. The second section, instrument air, takes the compressed air, filters and dries it before making it available to the instrument air header, where the dried air is supplied to the various loads throughout the plant. As illustrated in Figure 13-1, there are two trains for drying the compressed air. Each train is capable of handling the normal maximum air demand of the instrument air loads. The dual train capability enables continual drying of air by one train along with the regeneration of the other train's air dryer. In the third section, service air, the compressed air from the supply section is supplied to the service air header where it is distributed to the service air loads throughout the plant.

13.2 System Description

The instrument and service air system receives air at atmospheric pressure and compresses it to 125 psig. The air is filtered and then supplied to the instrument and service air headers where it is directed to the plant loads. The system is divided into three sections: air supply, instrument air, and service air. Figure 13-1 illustrates these divisions and component makeup. The air supply section consists of four air compressors, associated components and a pair of outlet filters. Each air compressor takes a suction on the turbine building atmosphere through its intake filter and compresses the air to 125 psig. The high pressure air passes through an after-cooler, where the air is cooled to reduce the air temperature and condense any moisture contained in the air before flowing into the air receiver. The air receiver acts as a storage tank for the air. As air is required by the loads, the air flows through two filters. These filters remove particulate and aerosols entrained in the air. The high pressure air is now available for use by the instrument air and service air sections.

The instrument air section takes the supplied air and further filters and dries it before supplying it to the instrument air loads. Due to the delicate nature of the instrument air devices, the air must be of a higher quality than that supplied to the service air loads. This is accomplished by a dual train of pre-filters, air dryers, and after-filters as illustrated in Figure 13-1. Each train is capable of handling maximum air demand through one pre-filter, air dryer, and after-filter.

The loads on the service air section (such as breathing air) are not as delicate as those on the instrument air header and therefore do not require additional filtering and drying. The high pressure air is supplied to the service air header through an inlet control valve (CV-4467), and upon a decrease in instrument air header pressure to 80 psig, this valve closes to maintain instrument air header pressure. This is desirable because instrument air loads are of greater importance to plant operation than service air loads.

13.3 Component Description

13.3.1 Air Compressors

There are four air compressors associated with the air supply system, all located in the turbine building. All of the compressors are cooled by bearing cooling water. The normal compressor used to maintain system pressure (C-116) is a rotary type compressor. It is rated at 650 cfm (full capacity). It will normally maintain air pressure between 110 and 125 psig. This single stage, positive displacement compressor is driven by a 150 hp motor powered from 480v non-vital power. Running indication is provided on the local control panel and on the main control board.

There are three half-capacity (315 cfm at 125 psig) compressors which will automatically operate as needed to help maintain pressure. These compressors are vertically-mounted, single-stage, double-acting, water-cooled, positive displacement, reciprocating compressors. The compressors are driven by 100 hp motors powered from 480v non-vital for compressors C-102A and C-102C, and 480v vital for compressor C-102B. Compressor C-102B is the only compressor of the four that is powered from an ESF source, thus providing the flexibility necessary during an emergency condition that may de-energize the non-vital load centers.

13.3.2 After-cooler

Associated with each compressor is an after-cooler. The after-coolers are cooled by bearing cooling water, with the air flowing on the shell side. The cooling of the air helps to condense any moisture that could cause equipment damage and aids in the removal of entrained oil by cooling and coalescing it.

On the outlet of each after-cooler is a moisture separator. The condensed moisture/oil mixture is removed from the air by the use of baffles, and then removed from the separator by the use of an automatic condensate trap.

13.3.3 Air Receiver

Compressed air from the outlet of each after-cooler flows into its associated air receiver. The air receivers reduce pressure pulsations from the discharge lines and serve as a storage volume. They will supply a limited amount of compressed air following a compressor failure. Receiver T-160 has a capacity of 96 cubic feet, and the other three receivers have a capacity of 57 cubic feet.

13.3.4 Service and Instrument Air Filters

After leaving the air receivers, the air passes through the service and instrument air filters. The first filter, F-135, will remove particles 0.3 microns and larger. This filter also handles water carryover if the after-cooler drain trap fails. Filter F-136 will remove particulates and aerosols larger than 0.01 microns. This second step of filtration is necessary because service air receives no further drying or filtration.

13.3.5 Dryer/Filter Train

To reduce the possibility of damage to the instrument air components caused by moisture in the air, the system uses a dual train arrangement to dry the air. The arrangement consists of pre-filters, air dryers, and after-filters. Redundant components allow one side of the arrangement to be on line while the other side is undergoing maintenance such as filter media replacement and air dryer regeneration.

The pre-filters remove the bulk of any moisture present by passing it through a bed of absorbent material. The air handling capacity of the pre-filters is 600 cfm. Each pre-filter is also equipped with an automatic drain trap to remove any liquid that accumulates in the bottom of the unit. To change the line-up, the pre-filters (and after-filters) must be valved in and out manually (normally when the differential pressure across each filter reaches 6 psid). An alarm actuates at 10 psid on the local control panel to indicate a need to shift a filter.

From the pre-filters, the air is then passed through an air dryer where any excess moisture is absorbed by desiccant. A motor driven timer automatically switches the dryer in service every four hours. The dryer coming out of service then enters into a regeneration mode in which an electrical heater is energized and a small amount of dry air is passed through the dryer in order to dry the desiccant. This ensures a continuous supply of dry air is available for the instrument air loads.

The dried air then passes through the 0.3 micron after-filters, where a final filtration removes entrained desiccant. The air exiting this arrangement is very pure and dry, with a dew point temperature of -40°F at 125 psig. The moisture content is monitored with a hygrometer. A lineup change for the after-filters is accomplished as described above for the pre-filters.

13.3.6 Accumulators

Several air operated valves in the plant are vital to plant safety. To ensure extended operation of these valves upon a loss of power, accumulators are provided to supply air to the components. The pressurizer power operated relief valves have two accumulators each which are designed to provide enough air for 32 cycles of the PORVs during the 10 minute period following a loss of instrument air. The steam supply valves to the turbine driven auxiliary feedwater pump each have an accumulator designed to allow three movements of the valves (open-closed-open). The main steam isolation valves each have an accumulator designed to maintain the valve open for 10 to 15 minutes following a loss of instrument air.

In addition to these valves, several fire protection system water spray system valves have accumulators designed to provide sufficient air pressure for operation for a minimum of one hour following a loss of instrument air. Examples of some of these spray systems are the unit substation transformers, the main transformers, the main generator lube oil reservoir, and the steam generator feedwater pump lube oil reservoir.

13.3.7 Instrumentation and Control

The air compressors and associated equipment are provided with local control panels. Each control panel consists of temperature and pressure switches, indicators, and automatic protection devices. Equipment status is indicated in the control room by a series of indicating lights and annunciators. Indications and alarms are also provided for air system header pressure.

13.4 System Interrelationships

13.4.1 System Interfaces

Service air is supplied throughout the plant for service and maintenance operation. Instrument air is provided throughout the plant to operate diaphragm valves and control devices. The instrument air system is physically connected to every major system in the plant. The following systems are needed to support the Service and Instrument Air Systems:

1. Bearing Cooling Water - used to cool the air compressors and after-coolers during normal operation.
2. Fire main - provides backup cooling water to the compressor powered from the vital electrical system.
3. AC electrical power systems - provide power to the compressors and control.

Since instrument air and service air penetrate the containment, automatic isolation of the lines is provided (Figure 13-2). The instrument air header isolation valve (CV-4471) is normally open (solenoid energized) and will automatically shut when a signal is received from the containment isolation system channel B. The service air containment isolation valve (CV-4470) is normally shut (solenoid de-energized) and will receives a shut signal from containment isolation system channel A.

13.4.2 System Operation

The rotary air compressor is normally available for service at all times. The other air compressors are placed in a standby mode with one compressor selected as the lead (will start first on low air pressure). In the event of a loss of the operating compressor or during heavy load demands, the lead compressor will automatically start (header pressure 105 psig). If pressure continues to drop, the second standby compressor will come on the line (header pressure 103 psig). The third standby compressor will automatically start on a header pressure of 100 psig. The compressor control system regulates the compressor air intake to match the amount of compressed air used. This minimizes the amount of compressor starts and stops required to maintain pressure. The sequence of compressor starts can be varied to permit equal operating time for all three reciprocating air compressors.

The discharge line for each air receiver is connected in parallel to a common header. The air then passes through the service and instrument air filters before entering the service air or instrument air headers. The service air header directs the distribution of service air to various outlets throughout the plant. The instrument air header directs the air from the filter outlet to the instrument air filter/dryer train. The filter/dryer train processes the air to the required cleanliness and dew point.

The service air line is provided with an isolation valve (CV-4467) that will automatically isolate the service air header when pressure falls below 80 psig. This arrangement is provided to direct all the compressed air to the instrument air header in the event of excessive demand. This feature is provided to preclude a complete loss of air should the normal starting sequence fail.

13.5 Summary

The service and instrument air systems supply low pressure air (125 psig) for several functions around the plant. The service air system is for general plant use. The instrument air system is used for operating pneumatic valves and instruments. Both the service and instrument air systems have the same supply.

The instrument air system has two parallel pre-filters, dual tower dryer units, and after-filters to supply it with clean dry air. Under normal operations, the rotary air compressor will supply all needs. When systems have heavy use, the other three compressors are available. Air operated safety-related valves (pressurizer power operated relief valves, steam supply valves to the turbine driven auxiliary feedwater pump, main steam isolation valves, and several fire protection system spray system valves) are provided with accumulators to supply air to the valves in the event of a failure of the instrument air system.

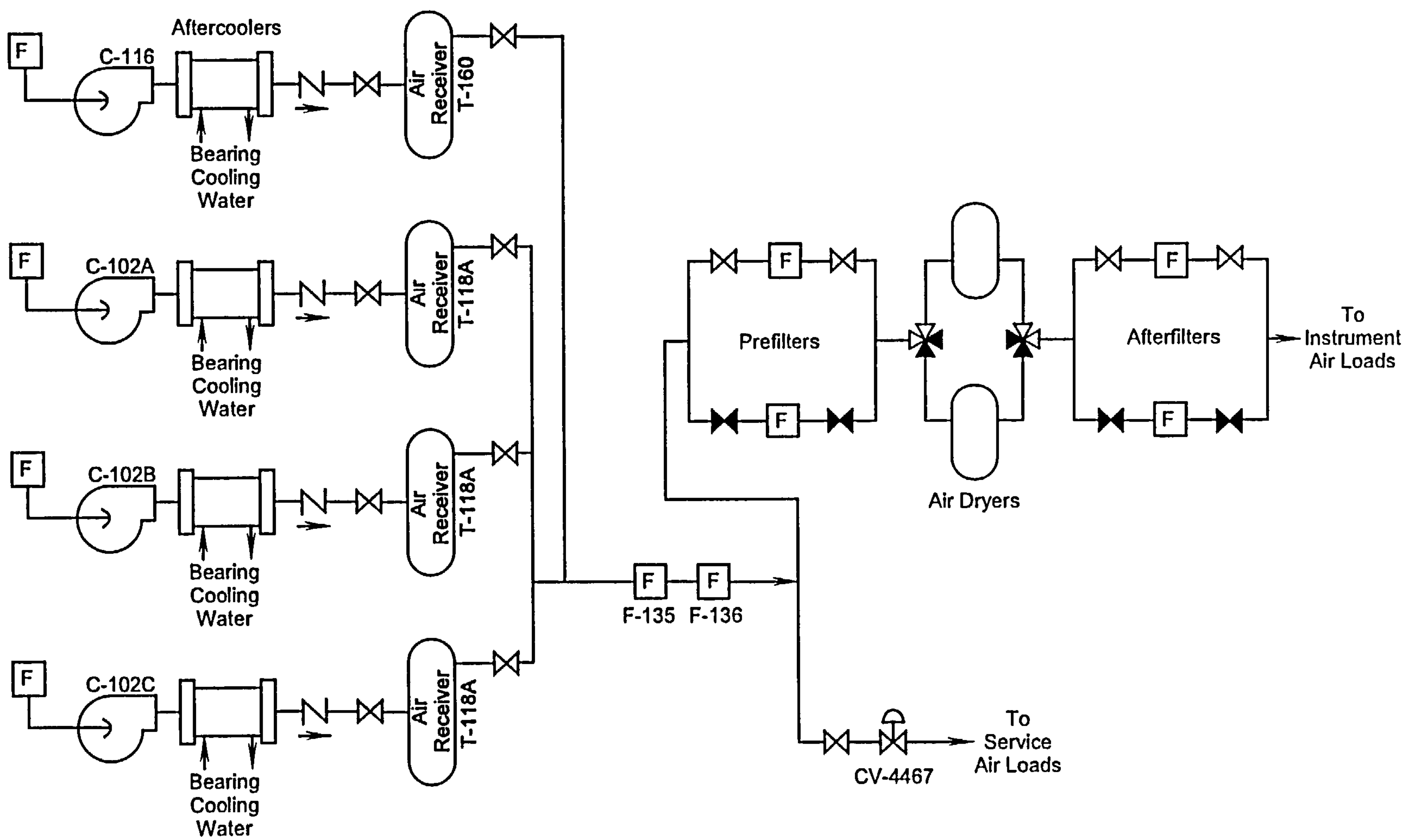

Figure 13-1 Instrument and Service Air

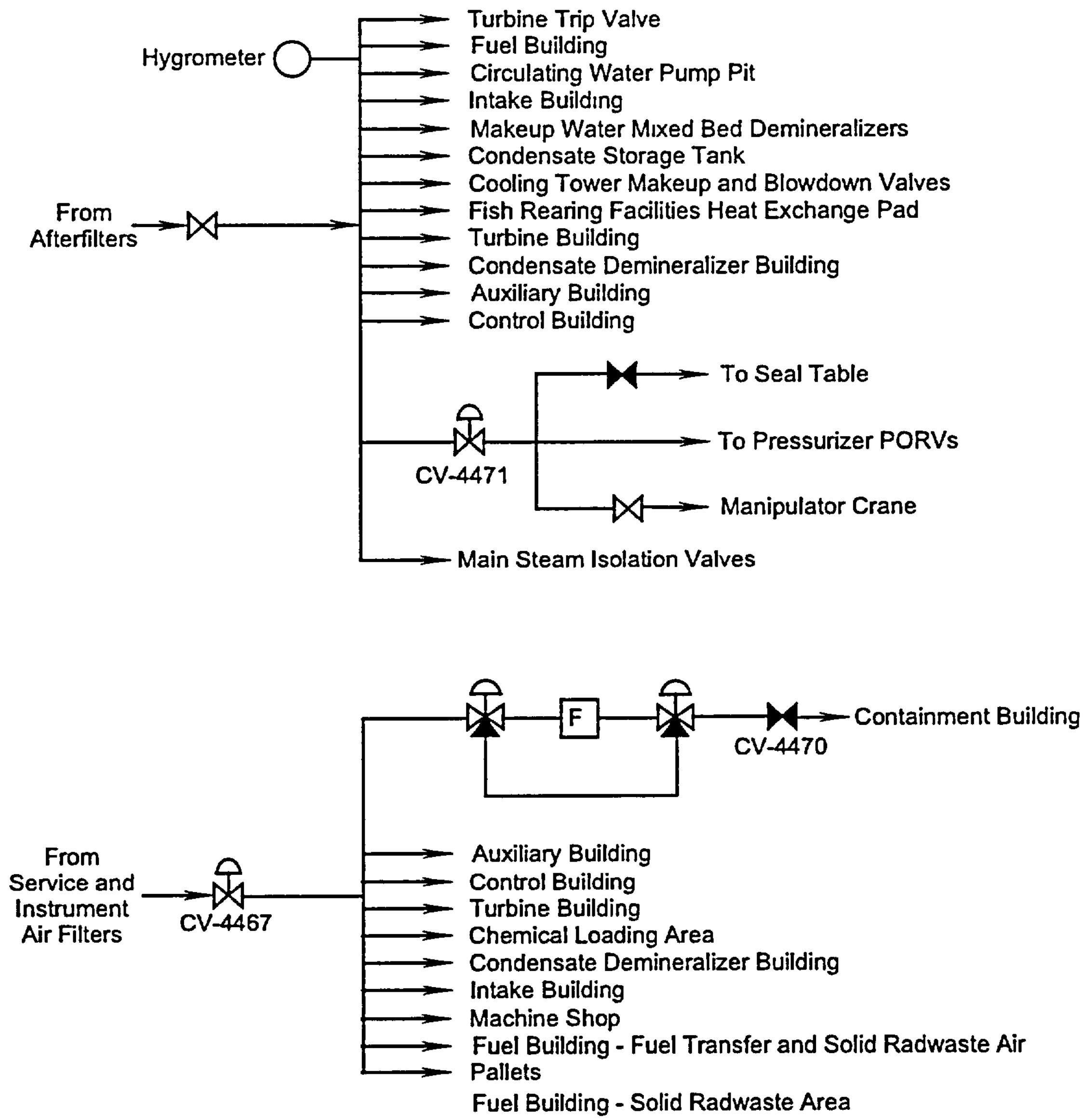

Figure 13-2 Instrument and Service Air Loads

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Chapter 14

COOLING WATER SYSTEMS

Section

Westinghouse Technology Systems Manual

Section 14.1

Generic Component Cooling Water System

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14.1 COMPONENT COOLING WATER

Learning Objectives:

1. State the purposes of Component Cooling Water (CCW).
2. List the loads served by CCW.
3. Explain how the design of CCW prevents the release of radioactivity to the environment.
4. Describe both methods of detecting leak-age into CCW.
5. Describe how CCW is protected against leakage in the thermal barrier heat exchangers.

14.1.1 Introduction

The purposes of component cooling water (CCW) are:

1. Remove heat from systems and components which may contain radioactive water.
2. Transfer the heat to the essential service water system.
3. Act as a barrier between radioactive systems and the environment.

The CCW system is used during all phases of plant operation, including shutdown and post accident. This system is sometimes referred to as a buffer system. It operates at a lower pressure than the radioactive systems which it cools and at a lower pressure than the system cooling it (essential service water section 14.2). The entire system is safety related and meets all seismic qualifications.

14.1.2 System Description

The component cooling water system (Figure 14.1-1) consists of two safety related cooling loops and a third service loop for non-safety loads. The system is Seismic Category I, and power supplies are Class 1E. The two safety related loops are independent and redundant. Each loop or train consists of two pumps, a heat exchanger, and a surge tank. The loops could be cross-connected, but for reliability they are operated independently. Each of the pumps are 100% capacity.

The entire CCW System is of the closed cycle type, with fluid continuously circulated through the system by the CCW pumps. Heat is removed from the system by the flow of essential service water through the tube side of the CCW heat exchangers. The closed cycle design assures a monitored intermediate barrier between the components handling reactor coolant system fluids and the ESW System. The closed cycle also permits use of a corrosion inhibitor in the system to protect the system water passages from corrosion. During normal operations, the Service Water (SW) System supplies the heat exchangers with cooling water, and during accident conditions, ESW from the ultimate heat sink is used as the cooling medium.

Emergency makeup water can be supplied directly to the pump suction header from the ESW System. Two valves, in series, supply each loop. HV-12 and 14 supply loop B and HV-11 and 13 supply loop A.

14.1.2.1 Safety Related Loops

The output of the CCW heat exchangers is directed to the safety loops. The loads in these loops consist of:

1. Safety injection pump oil coolers
2. Centrifugal charging pump oil coolers
3. Spent fuel pool heat exchangers
4. Residual heat removal pump seal coolers
5. Residual heat removal heat exchangers
6. Post accident sampling station coolers

Only one safety loop supplies the post accident sampling station. This is done with manual valves. The flow then goes through two motor operated valves, HV-72 and HV-73. Flow returns to the loop through HV-74 and HV-75. All four valves close on a safety injection signal, and a surge tank lo-lo level will close one supply and one return valve.

All safety loads are supplied during normal operations, except the RHR heat exchangers. The heat exchangers are supplied by opening HV-101 and HV-102 from the main control board.

14.1.2.2 Service Loop

The service loop (Figure 14.1-2) supplies non-safety loads and is connected to only one of the safety loops. The supply valves are HV-53 for loop A and HV-54 for loop B. The return valves are HV-15 and HV-16 for loops A and B respectively. Cross-connecting the loops will generate an alarm. There are three load groups supplied by the service loop:

1. Reactor containment loads
2. Auxiliary building loads
3. Radwaste building loads

The reactor containment loads are the heat exchangers on the reactor coolant pumps and motors, excess letdown heat exchanger, and reactor coolant drain tank heat exchanger. The supply header is common for all these loads, but the thermal barrier heat exchangers have a separate return header.

All penetrations close on a containment phase B isolation signal. One of the containment isolation valves on the thermal barrier heat exchanger return header will close on a high flow signal to protect the system from overpressure if a leak occurs in the heat exchanger. Upstream of the penetration, each reactor coolant pump has its own return valve which closes on high flow, but the setpoint is lower than the common valve. This way a leak in one heat exchanger may not affect the other pumps.

The auxiliary building loads are the letdown heat exchanger, the seal water heat exchanger, and the positive displacement charging pump cooler. These loads may be individually isolated by local manual valves.

The radwaste building loads include waste gas compressors, evaporator coolers, and hydrogen recombiners. A safety injection signal will close all supply and return valves. Lo-lo level in a surge tank or high flow in the radwaste supply header will close supply and return valves.

14.1.3 Component Descriptions

14.1.3.1 Pumps

There are four 100% capacity CCW pumps, two in each loop. Pumps A and C supply the A loop, and pumps B and D supply the B loop. The pumps are single stage, centrifugal, horizontally mounted pumps with a capacity of 11,025 gpm at 82 psig discharge pressure.

The motors are 700 HP induction type and are powered from 4160 Vac vital distribution busses. A and C are powered from one train, while B and D are powered from the other. During normal operation, one pump in each loop is running, with the backup pump in auto. After a 4 second delay, the standby pump will start on low discharge pressure. A safety injection signal will send a start signal to the A and B pumps after 5 seconds and to C and D at 10 seconds if the associated pump did not start.

14.1.3.2 Heat Exchangers

The CCW heat exchangers are on the discharge side of the pumps. They are rated at 77.2 x 10^6 BTU/hr, enough capacity for all loads including RHR during plant cooldown. CCW flows through the shell side, and essential service water flows in the tubes.

Temperature of CCW is controlled by bypassing some flow around the heat exchangers using TV-29 and TV-30. These valves will close on a safety injection signal.

14.1.3.3 Surge Tanks

Each loop has a surge tank which serves as an expansion volume for temperature changes or leakage into or out of the system. It also provides net positive suction head for the pumps. The tanks are vented to the atmosphere, and the vent valves close on high radiation in the heat exchanger bypass lines. A relief valve set at 150 psig protects the tank from overpressure, and a vacuum breaker protects against a collapse. CCW is a closed system, and chemicals are added to inhibit corrosion. Makeup water is provided by the demineralized water system. Level transmitters start and stop automatic makeup and provide indication of leakage in or out of the system.

14.1.4 System Features and Interrelationships

14.1.4.1 Safety Injection Signal

A safety injection signal will start pumps A and B. Pumps C and D will start only if their associated pump does not start. Heat exchanger bypass valves will close so all flow goes through the heat exchangers. Also, radwaste building loads and post accident sampling station are isolated from CCW.

14.1.4.2 Phase "B" Isolation

All service loop loads supplied the component cooling water system, located inside the containment structure, are isolated on a phase B isolation signal.

14.1.4.3 Cooldown

Two trains of CCW are needed to cool the plant to cold shutdown in 20 hours. One train could achieve cold shutdown, but more time is required. Two pumps may be required in the train supplying the service loop because of the RHR heat exchanger load.

14.1.4.4 Leak Detection

The CCW System is operated at low pressure so that any leakage in a heat exchanger would leak into the CCW and cause a rise in surge tank level. If the leakage is radioactive, it would be detected by the radiation elements in the heat exchanger bypass lines.

14.1.5 PRA Insights

The Component Cooling Water System, (CCW) at some sites, is a major contributor to Core Damage Frequency, (79% at Zion, and 31% at Sequoyah). This is due to its role in reactor coolant pump seal cooling and cooling of equipment in the Emergency Core Cooling Systems. RCP seal cooling is provided by the thermal barrier heat exchanger and the normal charging seal injection. Both of these methods are dependent on CCW for pump seal cooling.

A loss of CCW would result in a failure of the RCP seal and produce a seal LOCA. The Charging pumps and Safety Injection pumps are needed to supply injection to the core to makeup for the loss of inventory. Without CCW, they would fail due to overheating. The resultant unrecoverable inventory from the reactor coolant system would lead to core damage. Probable causes of failure of the CCW system are as follows:

1. Human error - At those sites such as Zion and Sequoyah where the CCW system is shared between units, failure to manually align the standby train after failure of the operating loop.
2. Loss of CCW pumps - The pumps fail to start, or fail to continue to run after starting, due to some common mode failure, such as loss of power.
3. Valves - Local fault of the heat exchanger outlet or bypass valves, or on some designs, a local fault of the header isolation valve to the ECCS pump coolers.
4. Piping - At Zion, the most significant failure is due to a rupture of the CCW piping. A review of the Probabilistic Safety Study, identified 30 pipe sections whose failure would lead to a loss of CCW.

PRA studies (Reactor Risk Reference Document NuReg-1150) on Importance Measures, have shown that the Component Cooling Water System can be a major contributor to both Risk Reduction, and Risk Achievement. Sequoyah-Risk Reduction Factor 450, Risk Achievement Factor, 120-630.

14.1.6 Summary

The CCW system is a closed loop, low pressure system designed to transfer heat from radioactive systems to the environment This system acts as a barrier between systems that may contain radioactive or potentially radioactive fluids and the environment. It provides these functions during normal plant operations, post accident operations, and during plant cooldowns. The component cooling water system is a safety system with two separate redundant trains, designed to be operational during all phases of plant operation.

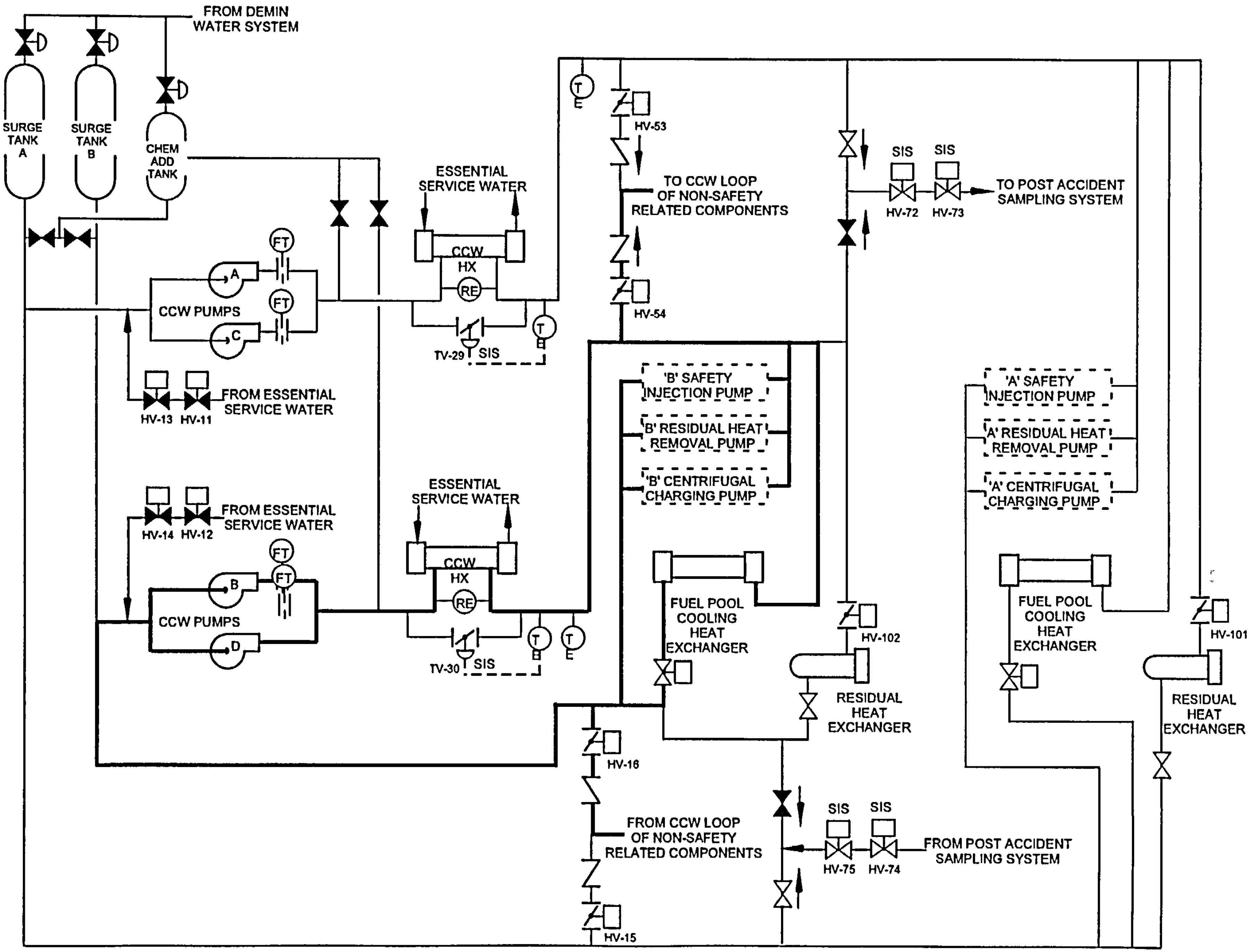

Figure 14.1-1 Component Cooling Water

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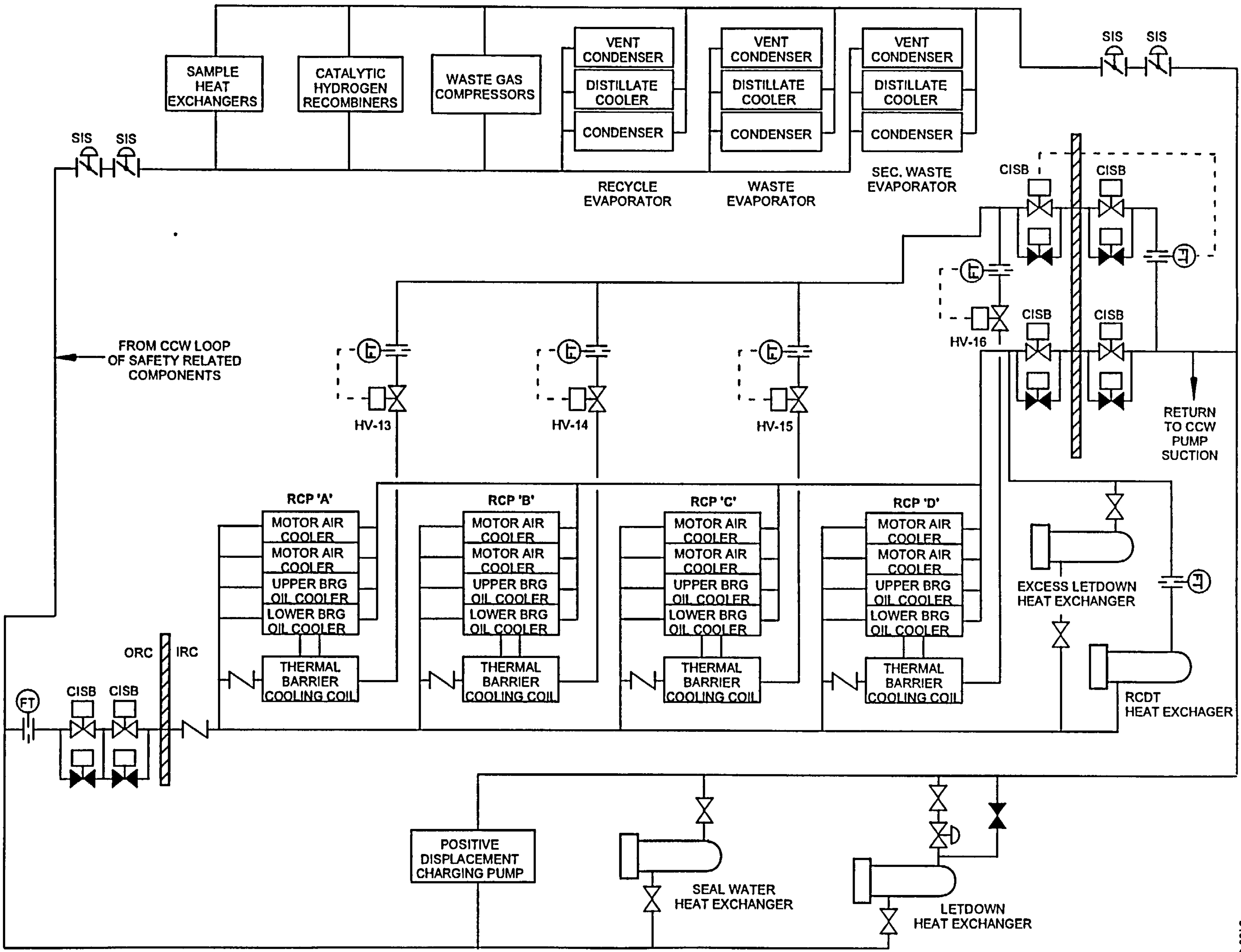

Figure 14.1-2 Component Cooling Service Loop

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Section 14.2

<u>Generic Service Water System</u>

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14.2 SERVICE WATER AND ESSENTIAL SERVICE WATER

Learning Objectives:

1. State the purposes of service water.
2. List two loads supplied by service water.
3. State the purposes of essential service water (ESW).
4. List four safety-related loads supplied by ESW.

14.2.1 Introduction

The purposes of the service water system are:

1. Provide cooling water to non-safety auxiliary components.
2. Supply the essential service water system during normal operations.

The purposes of the essential service water (ESW) system are:

1. Provide cooling water to safety related components following a LOCA or loss of offsite power.
2. Provide a backup source of water for auxiliary feedwater system (chapter 5.7 & 5.8), component cooling water system (Chapter 14.1), and the spent fuel pool (Chapter 14.4).

The essential service water system is used during all phases of plant operation. It is a safety related system, while the service water system is not safety related. During normal operations, the service water supplies ESW loads.

14.2.2 Service Water

The Service Water System as shown in Figure 14.2-1 has three pumps that take a suction on the cooling tower basin, and discharge through strainers to its loads, and back to the cooling tower. Normally, only two pumps are running, with the third pump in standby. The discharge valves operate automatically, opening when the pumps start and closing when the pumps stop. The pumps are vertical centrifugal pumps with a capacity of 17,500 gpm at 100 psig discharge pressure. They are located in the circulating water pump house and are powered from the service load buses. The loads supplied are:

1. Essential Service Water (ESW)
2. Closed cooling water heat exchangers
3. Turbine building chiller condensers
4. Steam packing exhauster
5. Air compressor and after cooler
6. Generator hydrogen coolers
7. Generator stator water cooler system coolers
8. Turbine-generator lube oil coolers
9. Boron thermal regeneration system chiller
10. Steam generator blowdown heat exchanger
11. Condenser vacuum pump seal water coolers

During normal operations service water supplies essential service water through valves HV-23 and HV-25 for A train, and HV-24 and HV-26 for B train. The return flow is through HV-39 and HV-41 for A train, and HV-40 and HV-42 for B train.

All of these valves will close to isolate ESW from service water on a safety injection signal or a loss of offsite power.

14.2.3 Essential Service Water (ESW)

The Essential Service Water System (ESW) (Figure 14.2-2) is a safety system with two independent and redundant loops. Each train has one pump with a discharge strainer, piping, and two mechanical draft cooling towers. The two trains could be cross connected, but are normally kept independent.

During normal operations, the ESW pumps are idle, with service water supplying ESW loads. A safety injection signal or loss of offsite power will isolate service water from ESW and start ESW pumps. The ESW pumps are vertical centrifugal pumps with a capacity of 15,000 gpm at 142 psig discharge pressure and are powered from the vital Class 1E electrical distribution system.

The water supply for ESW is the ultimate heat sink, a large enough supply to provide cooling for 30 days without the need for makeup. Safety grade mechanical draft cooling towers are used to help satisfy the 30 day requirement. The loads supplied by ESW are:

1. Component cooling water heat exchangers
2. Diesel generator coolers
3. Containment air coolers
4. Pump room coolers
5. Air compressors and after coolers
6. Control building air conditioning condensers
7. Fuel building coolers

ESW is also the backup water source for auxiliary feedwater system. ESW is the emergency backup supply for component cooling water and the spent fuel pool.

14.2.4 Summary

The service water system is a non-safety system that supplies auxiliary equipment. It is also the supply to essential service water system during non-accident and normal power conditions.

The ESW system is a safety system that supplies equipment necessary for the safe shutdown of the plant following an accident. It consists of two redundant trains with an 100% capacity pump in each train. These pumps are normally idle, and start upon a safety injection signal or loss of offsite power. The normal water supply, service water, is then isolated from ESW.

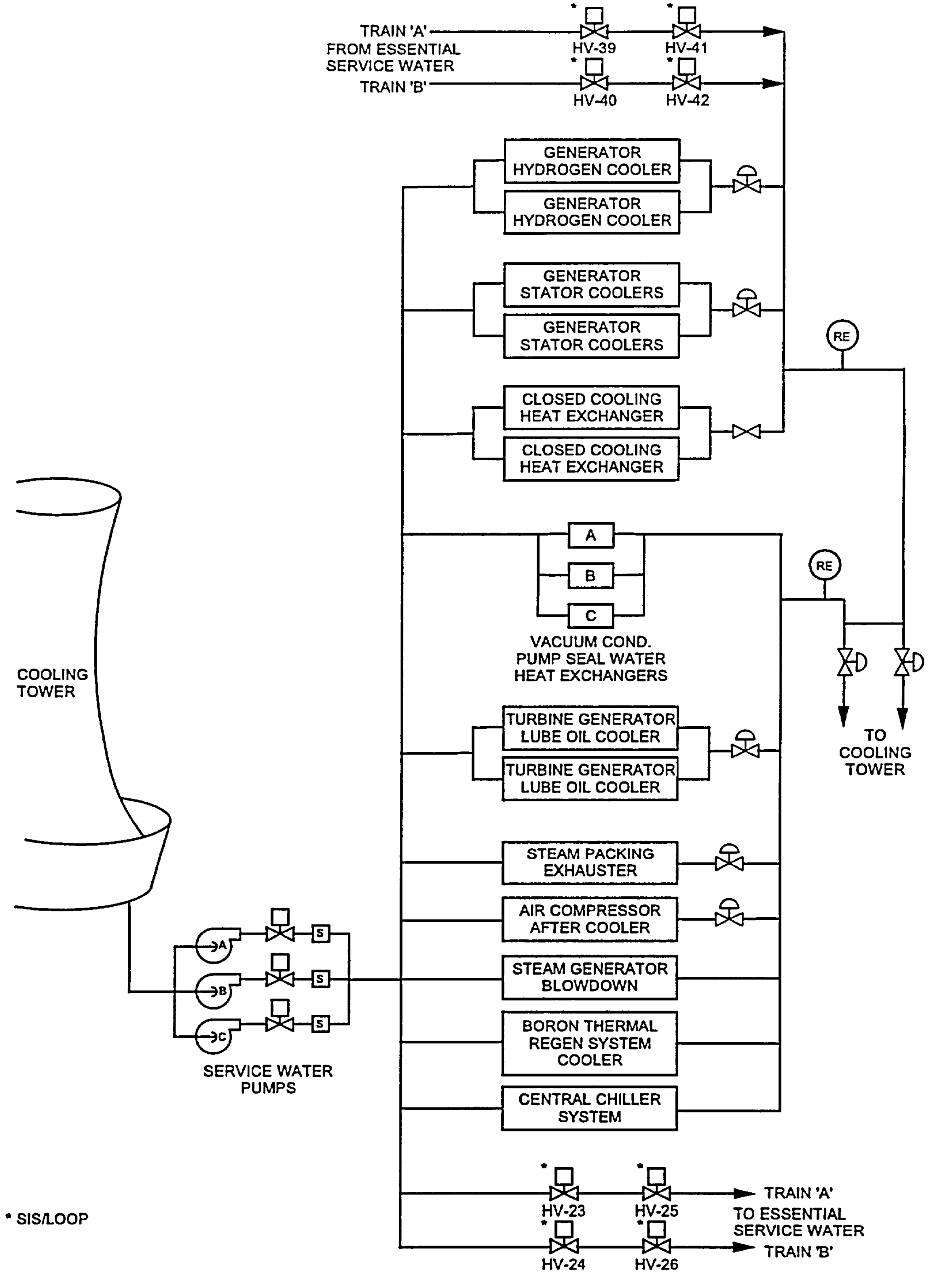

Figure 14.2-1 Service Water

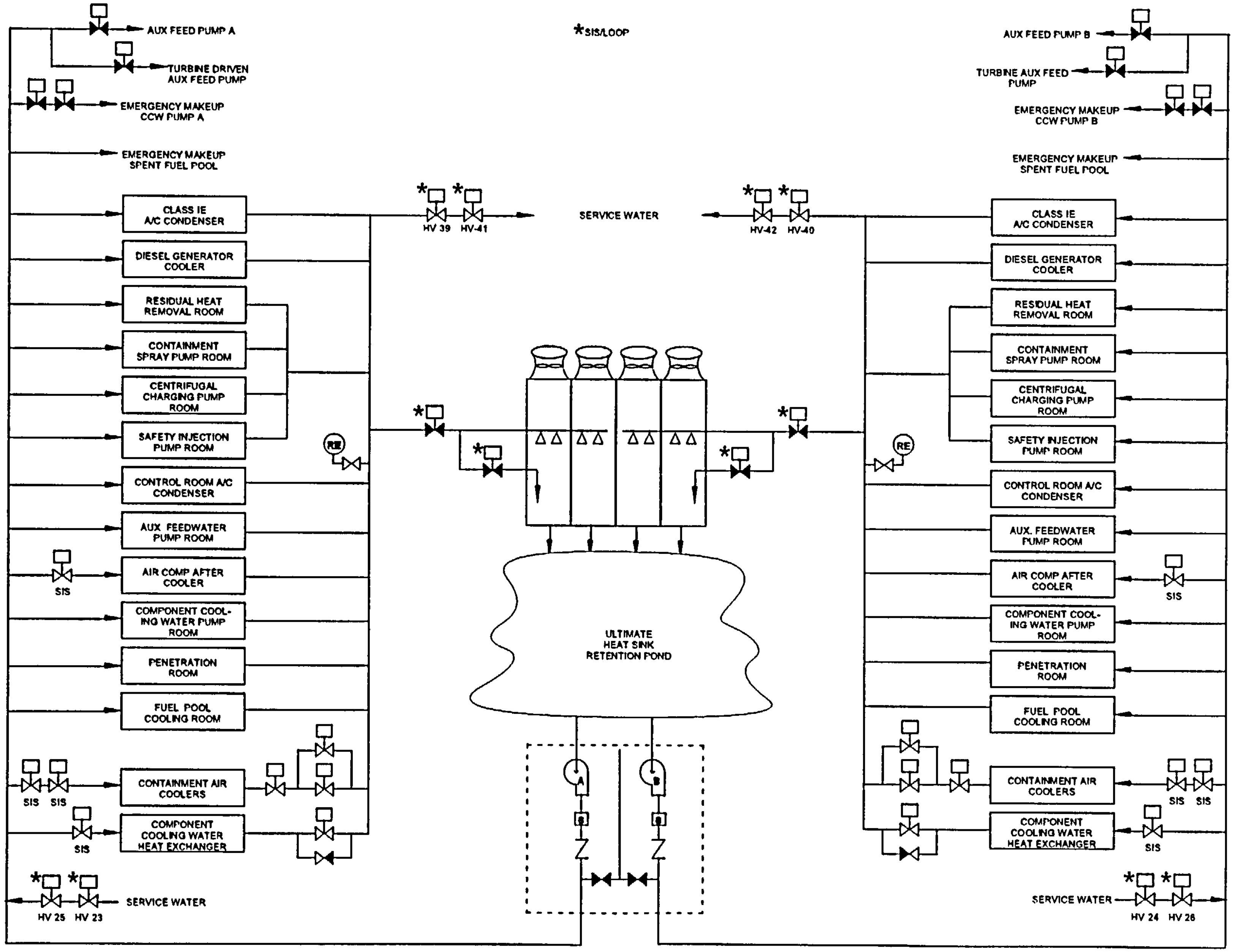

Figure 14.2-2 Essential Service Water

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Section 14.3

Generic Condenser Circulating Water System

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14.3 CONDENSER CIRCULATING WATER SYSTEM

Learning Objective:

1. State the purpose of the Condenser Circulating Water System.

14.3.1 Introduction

The primary purpose of the condenser circulating water system is to supply cooling water to the condensers of the main turbines. This system also provides water for auxiliary cooling equipment and provides an efficient means of rejecting waste heat from the power generation cycle into the ambient surroundings. In addition, due to its capacity and convenience, this system is used to dilute and disperse the potentially low-level radioactive waste from the blowdown of the steam generators.

14.3.2 System Description

The condenser circulating water system, as shown in Figure 14.3-1, consists of three circulating water pumps that take a suction on the pumping station forebay. The circulating water passes under a skimmer wall. The skimmer wall prevents trash from entering the intake channel and allows cooler subsurface water to flow into the forebay. The circulating water flows into the intake structure through trash racks and then through a traveling screen. The traveling screen has 3/8-inch square openings to trap smaller pieces of trash that may have gotten by the skimmer wall and the trash racks.

The intake structure has three pits. Each condenser circulating water pump has its own pit to take a suction from and discharges through an 84-inch conduit pipe. The individual conduits combine to form a 13'6" by 13'6" concrete supply conduit that runs to the condenser. The water makes one pass through the condenser with a resulting maximum temperature rise of 29.5°F, which is the limit imposed by Environmental Technical Specifications.

From the condenser, water flows from individual discharge lines into a 13'6" by 13'6" concrete discharge conduit that dumps the water into the discharge pond. The flow of water is then directed to the cooling towers via the cooling tower lift pumps or bypasses the lift pumps and is directed into the diffuser pond. From this point the water is directed back to the ultimate heat sink.

14.3.3 Component Descriptions

14.3.3.1 Circulating Water Pumps and Valves

The circulating water pumps are slow speed (250 rpm), vertical, single-stage pumps rated at 1750 horsepower. Each pump has a design capacity of 187,000 gpm with a design discharge head of 30 feet. The pump motors are powered from 4160 vac busses. The discharge valves are 84 inch butterfly valves. To prevent overheating the circulating water pump motor (overheating will occur if the pump is operated against it's shut off head for greater than one minute), the discharge valves are interlocked with the condenser circulating water pump start switches. Therefore, when a circulating water pump is started, its associated discharge valve opens.

14.3.3.2 Condenser

The main condenser is described in Chapter 7.2, section 7.2.3.1. A vacuum priming system takes a suction on the condenser shell water boxes to removed any non-condensible gases that may have accumulated in the upper region of the water box. This system is used to ensure that the uppermost condenser tubes are completely filled with water.

14.3.3.3 Cooling Towers

The shape of the cooling tower stack is circular in plan, and hyperbolic in profile. From a strictly thermodynamic point of view, the tower shape does not have to be hyperbolic. It could be cylindrical in shape. The momentum of entering air forms a vena contracta (as a fluid or gas flows past an orifice plate, the flow achieves its narrowest cross section some what down stream of the plane of the plate) whose dimensions vary with the ratio of the towers diameter to height of the air inlet of the base. Cooling tower designers taper the shell of the cooling tower to follow the diameter of the vena contracta, producing considerable savings in material and cost. Also the hyperbolic shape stiffens the concrete shell against wind forces.

Air flow through the hyperbolic tower is produced by differences in air density. In operation, heavier outside air is drawn in from around the base of the cooling tower. This air displaces the lighter saturated air in the tower, forcing it up and out the top of the tower. In fact, the cooling tower works like a conventional chimney except that water saturation rather than heat causes the changes in air density that are responsible for the air movement.

Unlike a mechanical-draft cooling tower whose fan moves a fixed volume of air regardless of its density, a hyperbolic unit's air flow varies with changing atmospheric conditions. Optimum performance is obtained when the air humidity is high. The higher the relative humidity the cooler the outlet water. Operation is satisfactory at a low relative humidity, but there is an economic limit to the lower level of application: about 35 percent relative humidity for design conditions. Below this relative humidity value, the size and the cost of the tower increases dramatically.

Many nuclear units use natural draft cooling towers to provide cooling for the condenser circulating water and the service water systems. In addition, to the cooling towers, water must be pumped into the basin of the cooling towers. This is accomplished with cooling tower lift pumps. These pumps (usually three or four pumps per cooling tower) are capable of supplying 187,000 gpm per pump.

14.3.4 System Features and Interrelationships

14.3.4.1 Condenser Tube Cleaning

The condenser tubes are cleaned by an Amertap system. This system using a non-clogging centrifugal pump, strainer screens, distribution piping, and a removable visual inspection port (for checking, removing and adding new balls) maintains the condenser tubes in a clean, polished form at all times. Elastic sponge rubber balls (slightly larger in diameter than the condenser tubes) are pumped into the condenser supply water boxes, forced through the condenser tubes, and then collected via screen traps in the discharge water boxes of the condenser. The balls are about the same density as water so they are evenly distributed among all the tubes. When the balls are too small to effectively clean the tubes, they are systematically removed from the system. During normal operation approximately 250-350 balls are replaced on a weekly basis. The total number of balls in the system is selected so that each condenser tube receives a ball on an average of every 5 minutes with approximately a single ball making four passes per minute through the condenser.

14.3.4.2 Modes of Operation

Due to Environmental Protection Agency guide lines, the temperature of the water being returned to the ultimate heat sink cannot be greater than 5.4 degrees F than the temperature of the water taken from the ultimate heat sink. With these guidelines in effect the condenser circulating water system is operated in one of the following three modes; open, closed or the helper mode.

In the Open Mode, circulating water bypasses the cooling towers and enters the diffuser pond for release directly to the river. Gates number one and two are closed while the diffuser sluice gate is open. Water is discharged from the diffuser pond to the ultimate heat sink via a corrugated metal discharge diffusion pipe. For a two unit site there would be two diffusion pipes. Sluice gates are provided, which allow one diffuser pipe to be closed off when only one unit is in operation.

When operating in the Closed Mode, circulating water is sent to the cooling towers. From the cooling towers the water flows through gate number 2 back to the pumping station forebay. Gate 1 and the diffuser sluice gates are closed. In addition, when operating in this mode, liquid radioactive waste cannot be discharged into the canal.

Finally in the Helper Mode, a portion or all of the circulating water is sent to the cooling towers before entering the diffuser pond. Gate number 2 is closed while gate number one is open and the diffuser sluice gate is open.

GATE POSITION TABLE			
COMPONENT	MODES		
	OPEN	HELPER	CLOSED
#1 GATE	CLOSED	OPEN	CLOSED
#2 GATE	CLOSED	CLOSED	OPEN
DIFFUSER GATE	OPEN	OPEN	CLOSED
LIFT PUMPS	OFF	ON	ON
BYPASS GATE	OPEN	THROTTLED	CLOSED

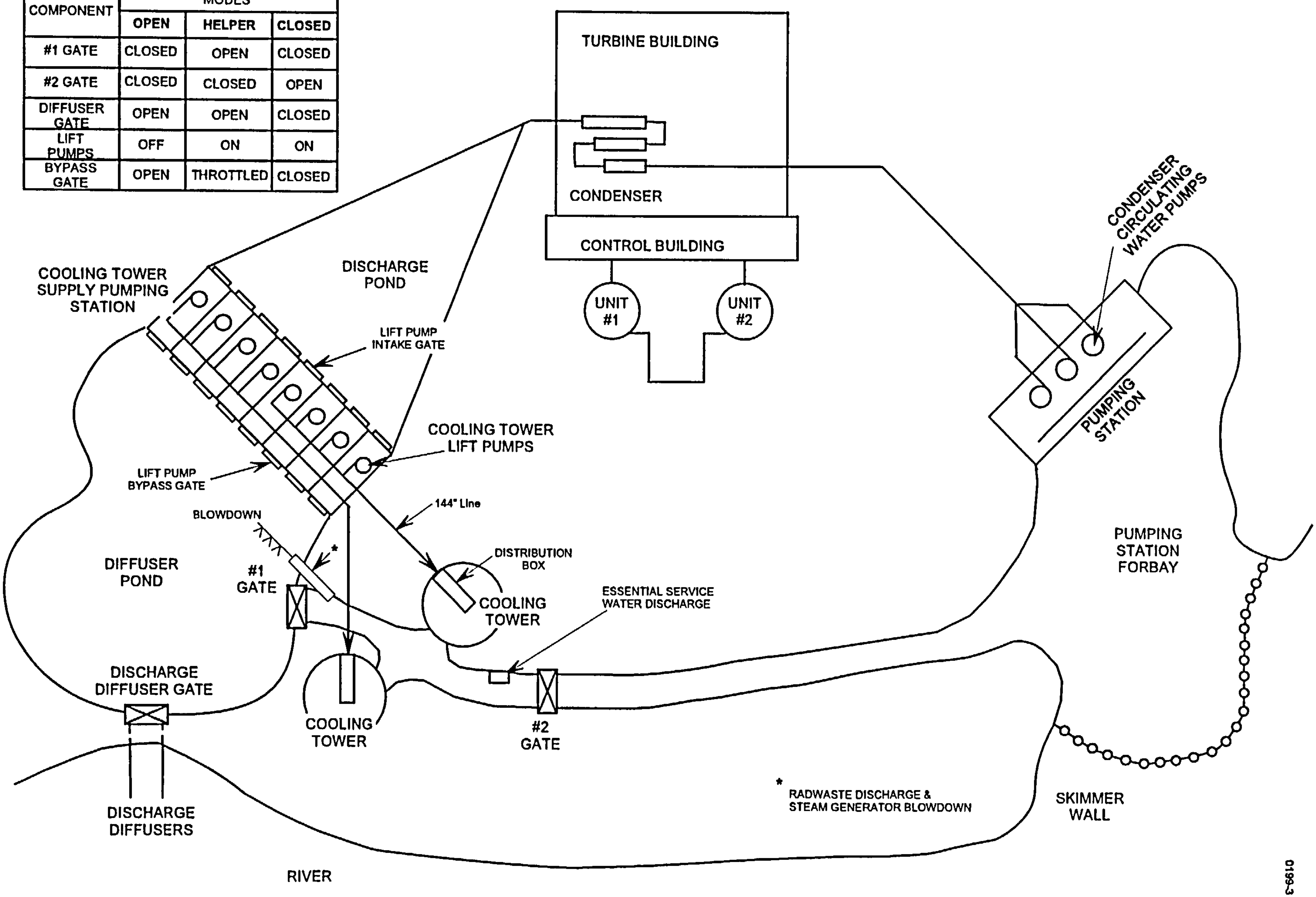

Figure 14-3.1 Circulating Water System

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Section 14.4

Spent Fuel Pool Cooling Water System

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14.4 SPENT FUEL POOL COOLING AND CLEANUP SYSTEM

Learning Objectives:

1. State the purposes of the spent fuel pool cooling and cleanup system.
2. Describe the design features of the spent fuel pool cooling and cleanup system which prevent inadvertently lowering the water level in the spent fuel pool.

14.4.1 Introduction

The spent fuel pool cooling and cleanup system is a closed loop system consisting of three subsystems: cooling, purification, and skimmer. The purpose of the cooling and cleanup system is to remove decay heat generated by the stored spent fuel and transfer this heat to the component cooling water system. This system continuously purifies, filters and maintains the optical clarity of the spent fuel pool, fuel transfer canal and the spent fuel cask pit. Finally this system maintains the water inventory in the spent fuel pool.

All nuclear reactor plants include a spent fuel pool for the wet storage of spent fuel assemblies. The methods used to provide cooling for the removal of decay heat from the stored assemblies vary from plant to plant depending upon the individual design. The safety function to be performed by this system in all cases remains the same; that is, the spent fuel assemblies must be cooled and remain covered with water during all storage conditions. Other functions performed by the system, but not related to safety, include water cleanup for the spent fuel pool, refueling canal, refueling water storage tank, and other equipment storage pools; and a means for filling and draining the refueling canal and the other storage pools. In addition, surface skimming is incorporated into the design to provide optically clear water in the storage pool.

To meet the above considerations, the spent fuel pool, surrounding structure, building and cooling and cleanup systems must meet, in part, the following 10 CFR Part 50, Appendix A, General Design Criteria (GDC):

1. GDC 2, "Design Bases for Protection Against Natural Phenomena"
2. GDC 4, "Environmental and Dynamic Effects"
3. GDC 61, "Fuel Storage and Handling and Radioactivity Control"
4. GDC 63, "Monitoring Fuel and Waste Storage"

Meeting the requirements of GDC 2, and GDC 4 provides assurance that the components of the spent fuel pool cooling and cleanup system will be designed to withstand the effects of expected natural phenomena (earthquakes, floods etc.), LOCA generated missiles, or damage caused by heavy loads, and still be capable of performing their intended safety functions. Meeting the requirements of GDC 61 provides assurance that components of the spent fuel pool cooling and cleanup system will be inspected, tested, shielded and provided with containment, confinement, and residual heat removal capability to ensure that the system is capable of performing its intended safety function. Finally GDC 63 ensures these systems are provided with monitoring and detection capabilities to perform there intended safety functions.

The spent fuel pool cooling and cleanup systems as stated above must be designed to Seismic Category I specifications. However, the entire cooling and cleanup system need not be designed to seismic Category I requirements provided that the makeup system, and the building ventilation and filtration systems are designed to seismic Category I specifications. Also to ensure that the system meets the shielding requirement of GDC 61 the system must be designed so that in the event of a failure of the inlets, outlets, or any piping or drain lines inserted into the pool; the level in the pool cannot be inadvertently drained below a point approximately 3 m (10 ft) above the top of the active fuel. Therefore piping or any external lines extending into the pool must be equipped with siphon breakers, check valves, or other devices to prevent draining the spent fuel pool. Finally a seismic Category I makeup system and an appropriate backup method to add coolant to the spent fuel pool must be provided. The backup system need not be a permanently installed system, nor designed to seismic Category I specifications, but it must take water form a seismic Category I source.

The cooling and cleanup system described in this chapter is designed to perform the following functions:

1. Maintain the spent fuel pool water temperature ≤ 60°C (140°F) by removing the decay heat input from the maximum number of fuel assemblies less a full-core off-load (a total of 1215 assemblies), including the assemblies from the last refueling discharged 100 hours after shutdown. The decay heat load under these conditions is calculated at 20.1×10^6 Btu/hr. After 11 days the decay heat output drops to 13×10^6 Btu/hr which is within the capacity of the spent fuel pool cooling heat exchangers.
2. Maintain the spent fuel pool water temperature below 60°C (140°F) by using the residual heat removal system in the event that the pool contains the maximum number of fuel assemblies (1408 assemblies) including a complete core unloaded 150 hours following shutdown. The heat load under these conditions is calculated at 44.3×10^6 btu/hr.
3. Maintain cladding integrity if all forced cooling is lost.
4. Maintain purity and clarity of borated water in the spent fuel pool, the fuel transfer canal, the refueling cavity, and refueling water storage tank.
5. Supply normal and emergency makeup to the spent fuel pool.
6. Maintain sufficient cooling if a fuel assembly or other object is dropped in the spent fuel pool.

The spent fuel pool, the emergency makeup supply lines, and the lines connecting to the residual heat removal system are designed to Seismic Category I requirements. The remaining components and piping of the cooling and cleanup system designed to applicable industry codes and standards.

14.4.2 System Description

The basic flow path of the cooling system is shown in Figure 14.4-1. The system consists of two half-capacity pumps which take a suction on the spent fuel pool through a common strainer located approximately 15 feet below the surface of the pool, and discharge back to the pool through two half-capacity heat exchangers. The cooling loop return line discharges directly above the fuel assembly storage racks (about 27 feet below the surface of the normal level of the pool). The downward momentum and negative buoyancy of the cool discharged water carries the flow downward. The coolant flows beneath the storage racks and begins the process of natural circulation as it is heated and rises up through the stored spent fuel toward the suction strainer. The cooling loop is completed by natural circulation flow within the spent fuel pool. The cooling loop return line has a siphon breaker hole machined into the discharge line about seven feet below the normal level of the pool. This hole (siphon break) prevents inadvertent siphoning of the pool and ensures there is at least 10 feet of water (actually 17-ft in this particular design) is retained above the top of the active fuel.

The cooling loop contains connections to the residual heat removal system in the suction piping between the spent fuel pool and the cooling pumps, and in the return piping to the pool from the spent fuel pool heat exchangers. These connections make possible the substitution of a residual heat removal pump and its associated heat exchanger in place of the spent fuel pool cooling pumps and heat exchangers when the heat load exceeds the capacity of the spent fuel cooling system.

During refueling the entire core is off-loaded to the spent fuel pool. The spent fuel cooling system as designed, and discussed in this section, does not have sufficient capacity for decay heat removal under these conditions. Therefore, the system is aligned so that the "B" train of the residual heat removal system aids in the cooling of the spent fuel pool.

The purification subsystem consists of a branch line containing a pump, filter, demineralizer, and an after filter, as shown in Figure 14.4-1. The purification line branches off from the outlet of the spent fuel pool cooling heat exchangers. The purification pump diverts a small amount of coolant flow (~150 gpm) from the heat exchanger outlet through the purification filter and/or demineralizer before returning the coolant to the pool. The demineralizer is 90 ft^3 in size and contains about 50 ft^3 of HOH resin. The purification subsystem is designed to remove fission products and other contaminants from the coolant by chemical ion exchange. The purification loop also contains connections to the refueling water storage tank. This feature enables the purification subsystem to circulate and purify the contents of the refueling water storage tank if required.

Makeup water to the spent fuel pool is supplied from the demineralized water makeup system and compensates for the loss of coolant from the spent fuel pool due to evaporation. The normal makeup line has a siphon breaker hole machined into the supply line approximately seven feet below the surface of the normal water level in the spent fuel pool. Under worst case conditions, if loss of all forced cooling flow to the spent fuel pool occurs, and with an initial pool water temperature of 60°C (140°F), the water in the spent fuel pool would reach the boiling point in about 3.5 hours. The integrity of the spent fuel is assured under these conditions as the maximum calculated peak center line temperature of the fuel would be 135°C (275°F). Under these conditions the evaporation rate from a boiling pool would be approximately 90 gpm. If makeup water from the normal supply source is not available, inventory in the spent fuel pool could be recovered from an emergency source of water (service water system) which has the capability of supplying 200 gpm.

The skimmer subsystem improves water clarity and maintains transparency for underwater fuel handling. It consists of portable floating skimmers, a skimmer suction header, one skimmer pump and filter, and a return line to the spent fuel pool. Floating skimmers can be placed in the spent fuel pool, the cask loading pit, the fuel transfer canal, or the refueling cavity. The skimmer pump takes a suction from the pool surfaces through a floating screen and discharges it through the skimmer filter back into the pool. At some facilities the 5 micron filter elements have been removed from the filter unit due to ALARA concerns. At these units there is no filtration of the pool fluids. However, the skimmer screen does provide removal of debris or floating particulate on the pool surface.

14.4.3 Component Descriptions

14.4.3.1 Spent Fuel Pool

The spent fuel pool is a reinforced concrete structure with a seam-welded stainless steel plate liner. It is designed and built to seismic Category I specifications. The pool which contains about 390,000 gallons of coolant, measures 39 ft by 24 ft and is 40 ft deep. The depth of the pool is selected to maintain at least 23 feet of water above the top of a spent fuel assembly in the storage ranks, and at least 9.5 feet above the top of the active fuel during fuel transfer operations. This water barrier serves as a radiation shield, enabling the gamma dose rate at the surface of the pool to be maintained at or below 2.5 mrem/hr.

14.4.3.2 Spent Fuel Pool Cooling Pumps

Each spent fuel pool cooling pump is a half-capacity pump rated for 1500 gpm at a discharge pressure of 43 psig. Its function is to circulate spent fuel pool water through the heat exchangers and the pool. Each pump is a horizontal, single stage, centrifugal pump driven by a horizontal, 1770 rpm, induction motor rated for 60 hp, 480 vac, 60 hz. The pump casing, impeller, and shaft are constructed of stainless steel. Each pump is equipped with a vent to atmosphere and a casing drain to the clean waste receiver tank. Sealing water supply for the shaft seal is taken off the pump discharge and seal leakoff is returned to the pump suction.

14.4.3.3 Spent Fuel Pool Cooling Heat Exchangers

Each spent fuel pool heat exchanger is a shell and straight tube type heat exchanger with a design heat transfer capacity of 6.5×10^6 btu/hr. This heat removal capacity is based on a maximum service water temperature of 75°F. However, since the average service water temperature for the design discussed in this section is 53°F, these heat exchangers are capable of removing more heat than designed. Tube side fluid is spent fuel pool coolant and the shell side fluid is component cooling water. Both sides of this heat exchanger are single pass. The inlet tube side is equipped with a vent to atmosphere. The tube side inlet and outlets are equipped with drains to the clean waste receiver tank. Both tube and shell sides are designed for 1500 gpm, 150 psig, and 100°C (212°F). The tubes are constructed of stainless steel; the shell of carbon steel. The heat exchangers are half capacity and arranged in parallel.

14.4.3.4 Purification Pump

The spent fuel pool purification pump, develops the pressure head required to force flow through the purification demineralizer and filters. It is a horizontal, single stage, centrifugal pump driven by a 480-vac induction motor. Its capacity is 132 gpm with a maximum back pressure and a flow rate of 232 gpm with minimum back pressure.

14.4.3.5 Demineralizer

The spent fuel pool demineralizer removes fission products and other contaminants from the coolant by chemical ion exchange. The demineralizer is designed for 150 psig, 93°C (200°F), and a maximum flow rate of 250 gpm. Piping and valving is supplied to allow removal of spent resin. The demineralizer can be back-flushed to remove suspended particulate. In addition back flushing fluffs the resin removing any channels that may have formed which in turn increases the efficiency the demineralizer.

14.4.4 Summary

The purpose of the spent fuel pool cooling and cleanup system is to remove decay heat from fuel stored in the spent fuel pool. The system is provided with a demineralizer and filters to maintain the chemical purity and optical clarity of coolant in the refueling cavities, transfer canal, spent fuel pool, and refueling water storage tank. The spent fuel pool heat exchangers are cooled by component cooling water.

In order to prevent a single component failure from draining the pool and removing the shielding provided by the coolant; the pool is designed with:

1. no drains in the bottom of the pool (hence the pool cannot be inadvertently drained).
2. the cooling pumps taking a suction fifteen feet below the surface of the pool. An anti-siphon hole is bored into the suction piping to maintain a minimum of 12 feet of water above the fuel assemblies
3. the return line terminating near the top of the fuel racks. The return line, as the suction line, has an anti-siphon hole machined into it. Both holes are machined into their respective pipes at the same elevation.

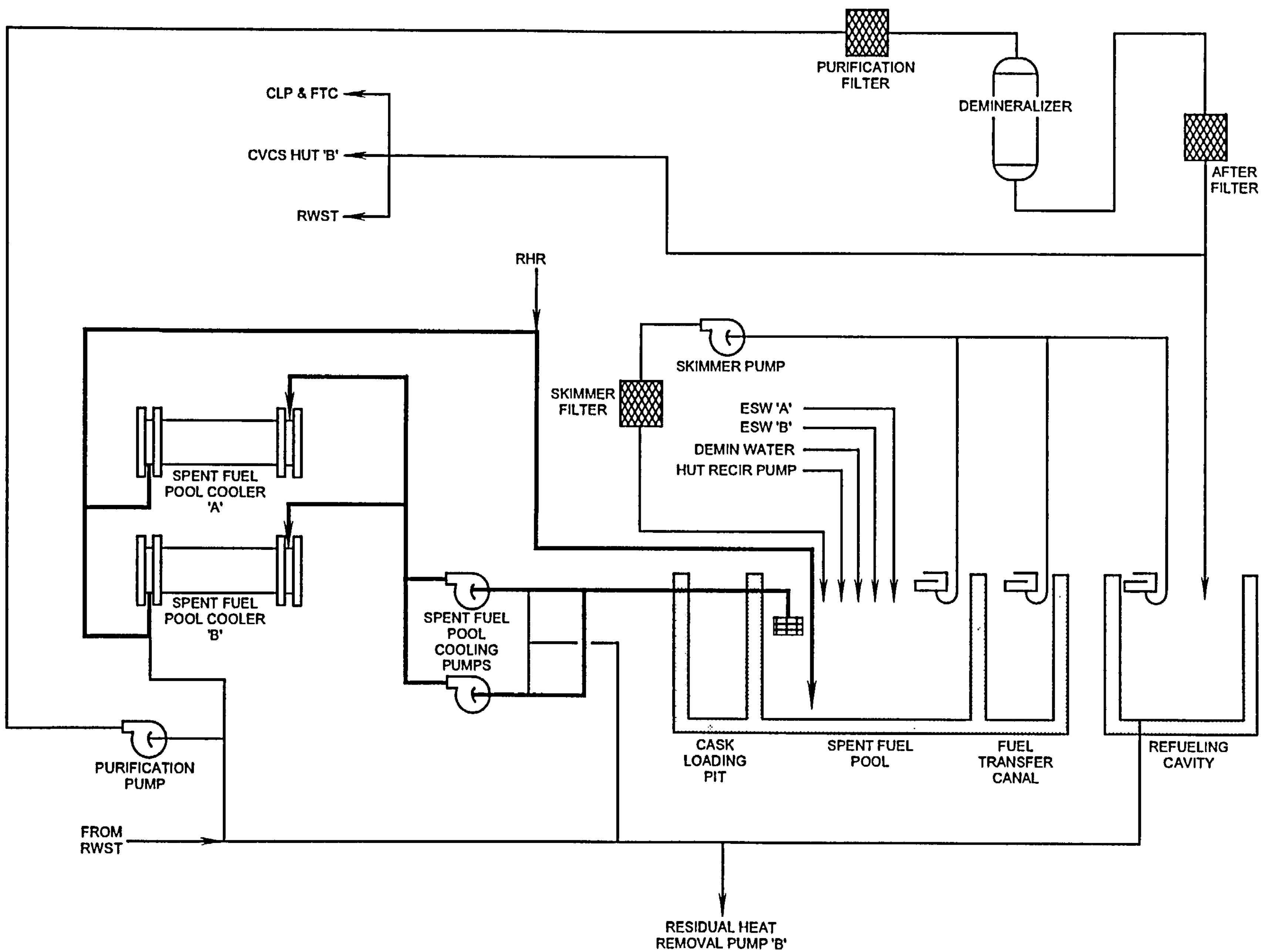

Figure 14.4-1 SFP Cooling and Cleanup System

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Section 14.5

TTC Simulator Component Cooling Water System

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14.5 COMPONENT COOLING WATER SYSTEM

Learning Objectives:

1. State the purposes of the Component Cooling Water (CCW) System.
2. List the loads served by the CCW system.
3. Explain how the design of the CCW system prevents the release of radioactivity to the environment.
4. Describe both methods of detecting leakage into the CCW system.
5. Describe how the CCW system is protected against leakage in the thermal barrier heat exchangers.

14.5.1 Introduction

During the course of normal operation, many of the processes fundamental to power production produce heat. To successfully achieve useful power production at the plant, the heat from various components must be removed. Many of these same components also contain radioactive fluids. Removing the heat produced by various plant systems while maintaining the release of these radioactive fluids to the environment to an absolute minimum is the function of the Component Cooling Water (CCW) System.

By virtue of their status as part of the emergency core cooling systems, some of the components cooled by CCW are more important than others. These include the residual heat removal pumps and heat exchangers, the charging, safety injection, and spray pumps, and the containment air coolers. They are needed by the plant during emergency conditions to remove heat. These components, as well as several others, are part of the Seismic Category I loops. The rest of the loads cooled by CCW are not critical to the successful outcome of any major emergency situations. These loads are part of the Seismic Category II loop.

As component cooling water flows through both these loops, it picks up thermal energy and rejects it, but not directly to the environment. CCW is a closed system which transfers heat to the service water system for ultimate disposal. As such, it provides a monitored intermediate barrier to the release of radioactive fluids which might leak from the components it cools. The service water system transfers heat absorbed from the CCW system to the ultimate heat sink.

14.5.2 System Description

As shown in Figure 14.5-1, the CCW system is a closed loop system. There are three CCW pumps that take suction from a main header, one for the A train, one for the B train, and a swing pump that can be valved in to supply either side. During normal operation, one pump in each train is running to supply all loads, with one train supplying nonessential loads.

The CCW pumps discharge to a main header that delivers flow through two heat exchangers, one per train. The component heat load of the CCW system is rejected to the service water system which is flowing through the tube side of the heat exchangers. Freshly cooled water from the outlet of the heat exchangers goes to a header for delivery to the various cooling loops. Because the service water system is more subject to fouling, its use on the tube side reduces the opportunity to foul.

There are two Seismic Category I trains that supply water to various Engineered Safety Function

(ESF) loads. These trains also provide flow to other plant loads in the containment and auxiliary building. Several branches are taken off the main header to accomplish this.

The first branch in each Seismic Category I train, as shown in Figure 14.5-2, delivers flow to the following ESF loads located in the auxiliary building:

1. Safety injection pump seal coolers,
2. Containment spray pump seal coolers,
3. Residual heat removal pump mechanical seal coolers,
4. Residual heat removal heat exchangers, and
5. Positive displacement charging pump lube oil coolers (Train A load).

A second Seismic Category I branch supplies cooling water to four containment air coolers in each train.

There is a third Seismic Category I branch in each train. These loads, as shown in Figure 14.5-3, are automatically isolated during Phase B containment isolation signal or a Phase A containment isolation signal with CCW surge tank low level. In the A train, CCW is supplied to two reactor coolant pumps and the excess letdown heat exchanger. The B train CCW supplies the other two reactor coolant pumps. There is a motor-operated valve in the return line from the thermal barrier heat exchanger of each reactor coolant pump that will automatically close on high flow (100 gpm) that would result from a leak in the heat exchanger. This would protect the CCW system from the high pressure of the reactor coolant system.

A fourth Seismic Category I load in the B train that is also isolated during containment isolation supplies the seal water and letdown heat exchangers.

During a safety injection sequence, valves in the suction and discharge lines of both trains close to provide train isolation. When these valves close, they also remove the flow to the Seismic Category II loop, which is supplied by a common header supplied from both trains. The loads on the Seismic Category II (nonessential) loop are as follows:

1. Spent fuel pool heat exchangers,
2. Boric acid evaporator packages,
3. Waste gas compressor and compressor aftercooler,
4. Primary sample conditioning panel, and
5. Fill and flushing supply to the chemical addition tank.

Return flow from the various loads comes back to the main suction header from which the CCW pumps receive their supply. It is to this same header that makeup water to the system is delivered from the demineralized water storage tank. There are two CCW makeup pumps (one per train) that supply the makeup water. There is also an emergency makeup supply to each pump from the service water system which is provided for when the demineralized water storage tank is not available.

The CCW System is equipped with a surge tank in each train to absorb system volume changes. There is a single chemical addition tank to service both trains. The chemical addition tank is used to add corrosion inhibiting chemicals to maintain system integrity.

14.5.3 Component Descriptions

14.5.3.1 CCW Pumps

The CCW pumps are horizontally mounted, single-stage, double suction, centrifugal pumps, each capable of delivering up to 11,500 gpm with a head of 140 ft. Electrical power is supplied from 4.16-kv vital buses A1 and A2. Each pump is designed to provide 100 percent of water requirements during normal operation and 100 percent of requirements for each train during abnormal conditions or plant cooldown.

One pump (A) is aligned directly to train A, and the other (B) is aligned directly to train B. The third pump (C) can be lined up into either train by opening normally locked-closed cross connect valves. During normal plant operations, one pump and heat exchanger are in operation in each train, with one train supplying cooling to Category II loads. The C pump is isolated and serves as an installed spare. Power to the C pump can be supplied from either bus A1 or A2 through a manually operated transfer switch. To maintain the required channel separation and independence, the transfer switch is constructed so that the two power supply sources can never be connected in parallel. Controls for the switchgear breakers feeding the C pump are interlocked such that when the A pump is running, the C pump breaker on bus A1 cannot be closed; it can only be closed when the A pump breaker is in the disconnect or test position and the transfer switch is in the channel A position. Similarly, the C pump can be run from bus A2 only when the B pump breaker is racked out in the disconnect or test position, and the transfer switch is in channel B position. If the C pump is running in place of either the A or B pump and the A or B pump breaker is racked in to the connected position, the C pump breaker will trip open, unless it is operated in local mode with its remote control switch in "pull-to-lock". The transfer switch position does not affect breaker closure, but it will determine if the pump is aligned to the breaker and receives power when the breaker is closed. This arrangement minimizes the chances that the normally operating pump and the standby pump are supplied from the same bus and maintains electrical channel separation. This arrangement also helps prevent the placing of two CCW pumps on one emergency diesel generator during loss of normal and preferred power conditions.

The following signals will start the pumps automatically:

1. CCW surge tank level low-low,
2. Low service water system pressure (from opposite train),
3. Low differential pressure across opposite train CCW pump,
4. Low service water booster pump header pressure (from opposite train),
5. DBA sequencer (20 seconds), or
6. Normal shutdown sequencer (6.5 seconds).

Of these auto starts, only those by the DBA and normal shutdown sequencers will activate if the lockout relay has tripped.

The following conditions activate the pump control circuit lockout relay, and stop the CCW pumps:

1. Pump motor phase overcurrent,
2. Pump motor ground overcurrent,
3. Bus undervoltage, or
4. Standby (C) pump breaker will trip if the preferred pump (A or B) breaker is racked in to the connected position on the same bus

The A and B CCW pumps discharge through a 24-inch header that leads to the respective heat exchanger. The C pump discharges to a similar header that spans the discharge of the other two and is isolated by a single locked closed valve and check valve in series in the piping to either train. A temperature element in each train provides indication of CCW heat exchanger inlet temperature on the control board recorders.

14.5.3.2 CCW Heat Exchangers

The two identical CCW heat exchangers used are horizontal counterflow shell and straight tube type. Cooling flow is provided by the service water system and circulates through the tube side to minimize fouling of the heat transfer surfaces. The design inlet and outlet temperatures of the service water are 75°F and 95°F, respectively, at a design flowrate of 17,500 gpm. The component cooling water on the shell side is in counterflow with the service water. It is designed to enter at 153.3°F and exit at 120.0°F at a design flowrate of 10,500 gpm. Each heat exchanger has a heat transfer rating of 175 x 10^6 Btu/hr.

The CCW system was designed to operate under normal conditions with a maximum heat exchanger outlet temperature of 120°F to meet the design criteria for maintaining spent fuel pool temperatures and containment operating temperatures of 125°F and 120°F respectively. In order that the above temperatures be maintained, CCW flow to the residual heat removal heat exchangers must be reduced by throttling the inlet valves.

During normal full power operation, the CCW system is designed to operate with one CCW heat exchanger in use. The remaining heat exchanger would provide for 100 percent standby capacity if the operating heat exchanger became inoperable. Provision of two heat exchangers allows for maintenance on one heat exchanger while the other is in service.

A continuously operating automatic radiation detection system is provided in each train of the system. The radiation detectors are installed at the outlet of each CCW heat exchanger by a "strap on" externally mounted design. This system detects any ingress of radioactive material before the levels become potentially dangerous. The normal monitor readings come from background radiation levels since contaminated leakage to the system is not expected. The monitor provides an alert alarm when concentration levels reach 1.5 times background, positive indication of contaminated leakage to the system. An additional high alarm set at 430 cpm above background is provided to indicate the magnitude of the leakage.

CCW flow from the outlets of both heat exchangers enter an 18-inch train cross connect header from which all loads receive their flow. This header is divided into three sections by air-operated isolation valves CV-3287 and CV-3288. The two sections nearest the heat exchanger piping carry flow to the Seismic Category I loads. The piping between the isolation valves is where the Seismic Category II and the chemical addition tank piping attach. The air-operated return header isolation valves, CV-3303 and CV-3304 separate the Category I and Category II piping. Flow returns at the suctions of the CCW pumps. Valves CV-3287, 3288, 3303, and 3304 will automatically close on low-low level in the corresponding surge tank or a safety injection signal.

14.5.3.3 Surge Tanks

The two identical surge tanks are vertically mounted, carbon steel cylinders with hemispherical top and bottom heads. The tanks are connected to the Seismic Category I loops downstream of the CCW heat exchangers via a 4-inch line. The functions of the CCW surge tank are as follows:

1. Provide system net positive suction head (NPSH),
2. Prevent boiling in the system high points by keeping the system full and pressurized on the containment air cooler outlets,

3. Dampen pressure transients due to load changes or pump startup and shutdown,
4. Act as an expansion volume due to changes in the CCW temperature,
5. Monitor fluid system volume, and
6. Provide pressure relief through the safety relief valves.

Each surge tank has a capacity of 2000 gallons and the normal operating level is maintained between 45% and 60%. Water level in the tanks is monitored by level transmitters. A signal from each level transmitter also goes to operate a level switch which in combination with their paired pressure switches operate solenoid valves that supply and vent the nitrogen cover gas on the surge tanks.

A cover gas is used to maintain the NPSH of the CCW system. The plant nitrogen supply delivers gas to each surge tank through its pressure regulating valve to maintain pressure at 113 psig. A second pressure regulating valve in the vent line from each tank also helps regulate pressure by venting excess nitrogen to the dirty waste drain tank at 125 psig.

To achieve adequate pressure control in the surge tanks each pressure regulating valve comes equipped with a solenoid-operated bypass valve that is normally closed. These valves are operated by OPEN-RESET switches that spring-return to an unlabeled mid-position. In the switch mid-position the solenoid valves control pressure between 115 psig and 125 psig. This control is accomplished through inputs from the level transmitters and pressure transmitters on each tank. Control of the solenoid valves is as follows:

1. Inlet solenoid valves
   a. Open automatically if tank level is greater than 65% and pressure is less than 115 psig.
   b. Close automatically if pressure is greater than 120 psig.
2. Outlet solenoid valves
   a. Open automatically if level is less than 54% and pressure is greater than 130 psig.
   b. Close automatically if tank level is greater than 56% or pressure is less than 125 psig.

The valves can be opened manually at any time, provided a safety injection signal is not present. A safety injection signal will either close the valves or prevent them from opening. Following reset of the SI signal, the solenoid valve switches must be reset to permit their operation.

Overpressure protection for each tank is provided by two relief valves installed in a line off the tank vent. Both pressure relief valves will lift at 130 psig.

The level transmitters on the CCW surge tanks provide several functions in addition to the role they play in maintaining tank pressure. Functions of the level switches located at the surge tank are:

1. Starts the B CCW makeup pump when the B CCW surge tank level drops below 40% and stops the pump when level rises to above 56.6%.
2. Starts the A CCW makeup pump when the A CCW surge tank level drops below 40% and stops the pump when level rises to above 56.6%.
3. Starts the B CCW and B service water pumps when the B CCW surge tank level is $\leq 8.3\%$. Note that this instrument starts the C CCW and/or C service water pump if these pumps are in the standby mode.
4. Starts the A CCW and A service water pumps when the A CCW surge tank level is $\leq 8.3\%$. Note that this instrument starts the C CCW and/or C service water pump if these pumps are

in the standby mode.

5. Closes the B train CCW seismic category I/II isolation valves when the B CCW surge tank level drops below 8.3%.
6. Closes the A train CCW seismic category I/II isolation valves when the A CCW surge tank level drops below 8.3%.
7. Opens and closes the nitrogen supply solenoid valves and the relief solenoid valves for the B CCW surge tank. It also provides a signal to a B CCW surge tank level indicator and high level alarm in the control room.
8. Opens and closes the nitrogen supply solenoid valves and the relief solenoid valves for the A CCW surge tank. It also provides a signal to an A CCW surge tank level indicator and high level alarm in the control room.

14.5.3.4 CCW Makeup Pumps

The CCW makeup pumps are single-stage horizontal centrifugal pumps. Their maximum operating flow rate is 110 gpm at a maximum operating head of 250 ft. The pumps are powered from 480-vac ESF buses B25 and B26. Each trains makeup pump is automatically started and stopped by level switches in its corresponding surge tank.

The CCW makeup pumps normally take a suction from the Seismic Category II demineralized water storage tank. A Seismic Category I source of makeup water from the service water system is available for emergency use.

14.5.4 System Features and Interrelationships

14.5.4.1 Design Bases

The CCW system is designed to provide the required heat removal rates while maintaining system temperatures within the following limits:

1. CCW temperatures at the inlet of the residual heat removal heat exchangers not exceeding 120°F and 95°F, respectively, at the beginning and end of normal cooldown of the reactor coolant system from 350°F to 140°F as required to provide 20-hour cooldown capability.
2. CCW heat exchanger outlet temperatures under design basis accident conditions of <140°F maximum temperature to protect against degradation of the pumps served by the system.
3. Temperatures that are less than the boiling point corresponding to the minimum pressure that occurs in the system at the outlet of the containment air coolers under DBA conditions.

Maintaining the minimum required cooling water flow to the ESF equipment served by the CCW system is essential to ensure safe operation and safe shutdown of the plant. The ESF components of the CCW system are designed to meet Seismic Category I requirements and the single failure criteria. The components of the CCW system which serve the reactor coolant pumps, the excess letdown heat exchanger, the letdown heat exchanger, and the seal water heat exchanger are also designed to meet Seismic Category I requirements to assure the integrity of these components under the postulated maximum seismic loading conditions.

Water chemistry control of the CCW system is accomplished by addition of a corrosion inhibitor via the chemical addition tank. Use of corrosion inhibitors serves to protect the piping from corrosion to a degree sufficient to prevent long-term degradation of system capability. A slightly elevated pH is also desirable for corrosion control.

14.5.4.2 System Operation

Due to pump design, the mechanical seals on the CCW pumps are pressure and temperature sensitive. To ensure design life-span of the seals, the CCW pumps must have adequate flow to ensure minimal heat up of the fluid in the pump casing and limit the pressure. Therefore a flow limit of 3,000 gpm minimum per pump is required. During normal operations with all equipment aligned, this is not a direct concern. However, during Modes 4, 5, and 6, equipment may be secured or tagged out putting total flow into question. Since there is no direct flow indication for CCW, CCW must be aligned to the residual heat removal system heat exchangers (5,000 gpm each) to ensure adequate flow.

The controls of the CCW pumps are interlocked with the service water pumps so that the automatic startup of a CCW pump on low-low surge tank level causes automatic startup of the service water pump in the same train on which the CCW system is operating.

During the plant cooldown phase following initiation of normal plant shutdown, two CCW pumps are required to be in operation, and flow through both residual heat removal heat exchangers at ≥ 5000 gpm is required for 20-hour cooldown capability. The plant can be brought safely to the cold shutdown condition with one residual heat removal heat exchanger in operation, but this will require approximately 100 hours.

A Safety Injection Signal (SIS) causes actuation of ESF equipment as a result of postulated accident conditions. An SIS causes the following to occur:

1. Automatic startup of the standby CCW system train and its associated service water system train by the DBA sequencer.
2. Separation of the two Seismic Category I trains and isolation of the Seismic Category II parts of the system by automatic closure of valves CV-3287, CV-3288, CV-3303, and CV-3304.
3. Automatic operation of flow control valves MO-3293 and MO-3347 in the return headers to the open position to provide full flow through the containment air coolers.
4. Removes power from the surge tank nitrogen supply and vent valves. The valves must be reset following reset of the SIS to enable the solenoids to function.

An SIS causes a containment isolation Phase A signal. Automatic or manual initiation of a containment isolation signal causes automatic closure of isolation valves MO-3295 and MO-3319, which closes off the letdown heat exchanger and the seal water heat exchanger from the system. If a containment isolation Phase B signal should occur, or a CCW surge tank low level alarm (less than 18.3%) concurrent with a containment isolation phase A signal, the automatic closure of MO-3294, -3300, -3296, and -3320 will occur. This will isolate CCW to the RCPs and the excess letdown heat exchanger. This will require shutdown of all running RCPs until CCW can be restored. Operator action is not required for CCW to perform its required functions during the injection phase of an accident. When the recirculation phase is initiated, the operator must open the motor-operated valves on the inlet to the residual heat removal system heat exchangers.

14.5.5 PRA Insights

The CCW system at some sites is a major contributor to core damage frequency (79% at Zion, and 31% at Sequoyah.) This is due to its role in reactor coolant pump seal cooling and cooling of equipment in the emergency core cooling systems. Reactor coolant pump seal cooling is provided by the thermal barrier heat exchanger and the normal charging seal injection. Both of these methods are dependent on CCW for pump seal cooling.

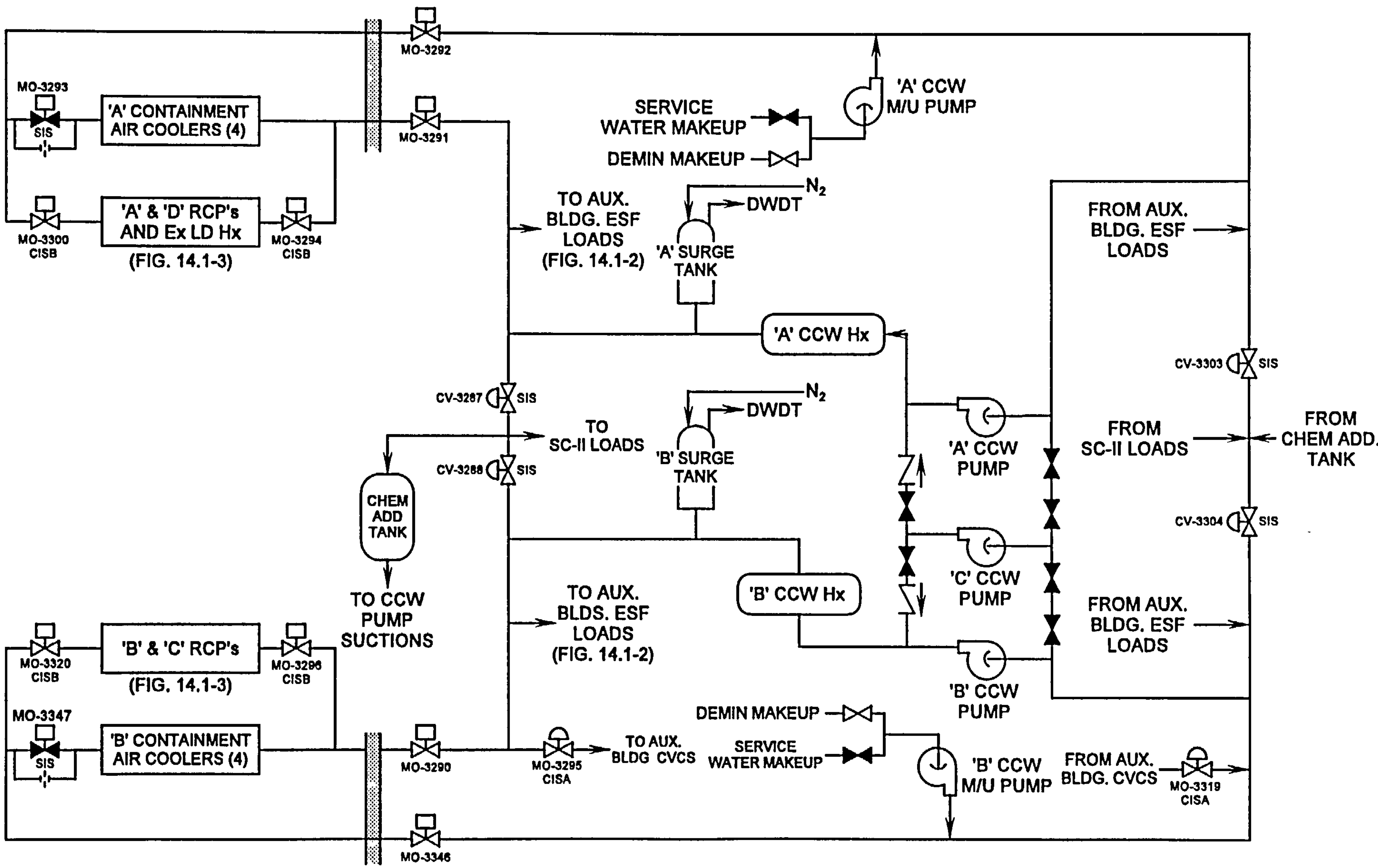
A loss of CCW may result in a failure of the reactor coolant pump seals and produce a seal LOCA. The charging pumps and safety injection pumps are needed to supply injection to the core to makeup for the loss of inventory. Without CCW, they may fail due to overheating. The resultant unrecoverable inventory from the reactor coolant system may lead to core damage. Probable causes of failure of the CCW system are as follows:

1. Human error - At those sites such as Zion and Sequoyah where the CCW system is shared between units, failure to manually align the standby train after failure of the operating loop.
2. Loss of CCW pumps - The pumps fail to start, or fail to continue to run after starting, due to some common mode failure, such as loss of power.
3. Valves - Local fault of the heat exchanger outlet or bypass valves, or on some designs, a local fault of the header isolation valve to the ECCS pump coolers.
4. Piping - At Zion, the most significant failure is due to a rupture of the CCW piping. A review of the Probabilistic Safety Study identified 30 pipe sections whose failure could lead to a loss of CCW.

PRA studies (Reactor Risk Reference Document, NUREG-1150) on importance measures, have shown that the CCW system can be a major contributor to both risk reduction and risk achievement. For example, the risk reduction factor for Sequoyah is 450 and the risk achievement factor is between 120 and 630.

14.5.6 Summary

The CCW system removes heat from various plant components during normal plant operation, plant cooldown, and post-accident conditions. This system serves as a monitored intermediate barrier between radioactive fluid systems and the ultimate heat sink. The CCW system has two surge tanks, three pumps, and two heat exchangers. It consists of two Seismic Category I safety trains and a common Seismic Category II non-safety loop. This system is an ESF system which enables two separate safety trains to operate during accident conditions. Makeup water to the system is available normally from demineralized water or from service water during emergency conditions.



DWDT = Dirty Waste Drain Tank

Figure 14.5-1 Component Cooling Water System

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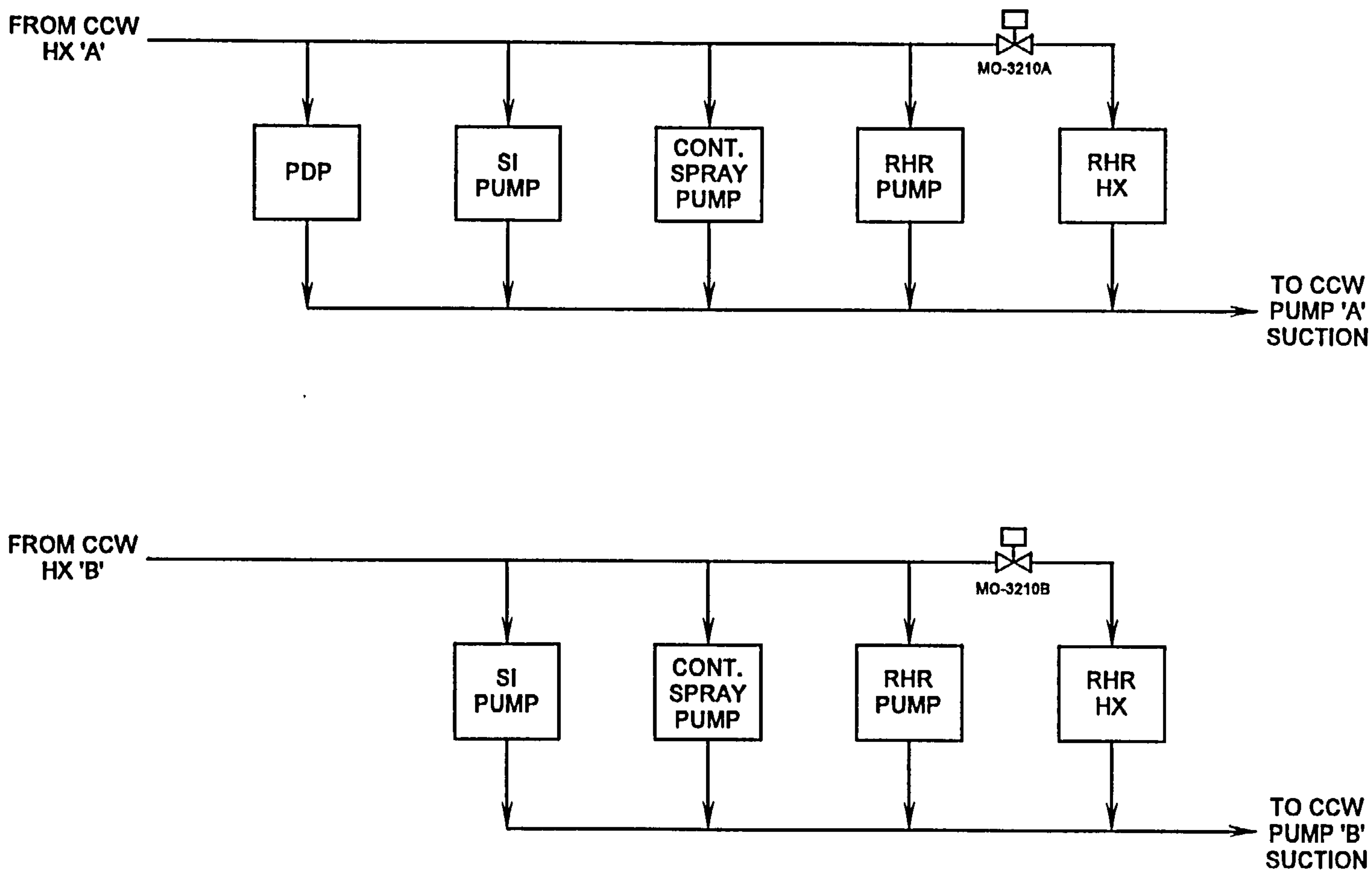

Figure 14.5-2 Auxiliary Building ESF Loads

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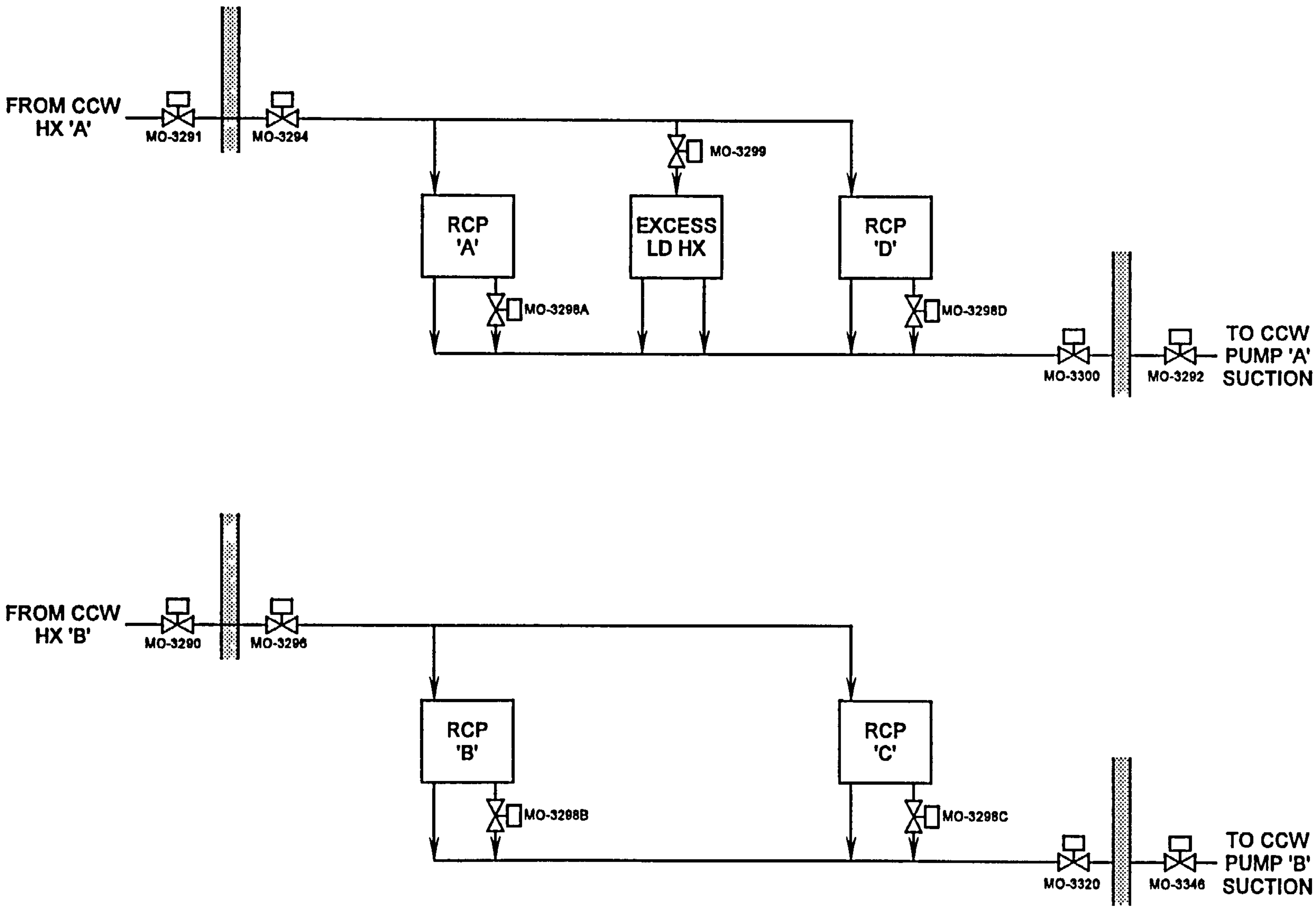

Figure 14.5-3 RCP Loads

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Section 14.6

TTC Simulator Service Water System

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14.6 SERVICE WATER SYSTEM

Learning Objectives:

1. State the purposes of the Service Water System (SWS).

2. List two non-safety related loads supplied by SWS.

3. List four safety related loads supplied by SWS.

14.6.1 Introduction

The Service Water System (SWS) shown in Figure 14.6-1 is an Engineered Safety Features (ESF) support system which supplies continuous cooling water to the power plant. It is used to cool safety and non-safety related components. The SWS serves two identical trains of ESF equipment, each consisting of one component cooling water heat exchanger, one emergency diesel generator, one train of room and pump coolers for ESF equipment, one auxiliary feed pump, and one component cooling water makeup pump, and spent fuel pool emergency makeup. Only one train of these components is required for safe shutdown of the plant following any of the postulated accident conditions. During accident or emergency conditions, flow to non-safety related components is isolated.

14.6.2 System Description

There are three service water pumps that take suction from the river at the intake structure. Trash racks, traveling screens, and a chlorination system protect the pump suctions from debris and marine growth. There is a pump for each of the A and B trains, and a spare swing pump that can be used to supply either side. The discharge of the service water pumps supplies the suction of the bearing lube water booster pumps. During the course of normal operation, the bearing lube water booster pumps provide bearing cooling flow to the service water pumps. If necessary, the service water pumps can supply their own bearing cooling water.

The discharge of the service water pumps goes through two independent Seismic Category I (safety related) flow paths (trains A and B). Each train supplies water to redundant safety related components. The service water pumps themselves supply a backup source of makeup water to the component cooling water system(makeup pump suction) and provide the normal source of cooling to the component cooling water heat exchangers. They also supply the suction of two service water booster pumps in each train. The service water booster pumps supply the rest of the Seismic Category I loads, which consist of the following:

1. Emergency diesel combustion air and jacket coolers,
2. Emergency makeup to spent fuel pool,
3. Emergency supply to the auxiliary feed pumps suction,
4. Essential room coolers,
5. Charging pumps bearing and gear oil coolers, and
6. Safety injection pumps bearing oil coolers.

The service water piping at the discharge of the booster pumps is divided into two trains by isolation valves that close with an engineered safety feature actuation signal or an emergency diesel generator load signal from the associated train. During normal operation the piping between these valves supplies the Seismic Category II (non-safety related) loads. The non-safety related loads consist of the following:

1. Bearing cooling water heat exchangers,
2. Isophase bus duct coolers,

3. Jockey fire pump suction,
4. Positive displacement charging pump room cooler,
5. Tank area cooler,
6. Reactor auxiliary building chillers,
7. Control building chillers,
8. Computer room air-conditioning condenser,
9. Electrical auxiliary room coolers,
10. Blowdown radiation monitor flush,
11. Steam generator blowdown heat exchanger,
12. Control building and maintenance shop chillers,
13. Water treatment system, and
14. Heater drain pump gland seal quenching water.

Another non-safety related load supplied by service water is the domestic water system. This load is supplied directly from the discharge of the service water pumps.

Both trains are required during normal operation, normal cooldown, and emergency diesel generator loading. Both trains available will allow a plant cooldown within 20 hours. One train is required during cold shutdown, ESF actuation, and safe shutdown and cooldown.

In the event the intake structure fails, water can be supplied to either train from the circulating water system or from portable pumping units via hose connections. The circulating water system supply can be returned to the cooling tower, or aligned to the discharge and dilution structure.

The river is used as the ultimate heat sink for the plant. The ultimate heat sink's principal safety functions is to dissipate residual heat after a normal reactor shutdown or following an accident that results in emergency shutdown conditions. In the event that the intake structure is lost, the cooling tower basin becomes the ultimate heat sink.

The design basis of the SWS is to provide sufficient heat removal capacity and reliability to safely operate, shutdown, and cooldown the plant and maintain it in a cold shutdown condition. Continuation of the minimum required cooling water flow to the safety related equipment, auxiliary feedwater system, spent fuel pool emergency makeup, and component cooling water emergency makeup is essential to assure safe operation and safe shutdown of the plant.

14.6.3 Component Descriptions

14.6.3.1 Service Water Pumps

The service water pumps are vertical centrifugal wet-pit pumps with a design flow rate of 21,750 gpm at a design head of 76 feet. Each pump is capable of delivering 20,000 gpm at 84 feet. The pump bearings are water lubricated with the exception of the grease packed suction bell bearing. Bearing lubrication is normally provided by the bearing lube water supply booster pumps. The pump impellers are made of stainless steel to resist corrosion.

The service water pumps take a suction from the river through the traveling water screens at the intake structure. Each pump is designed to supply 100 percent of the system flow requirements during each operating condition. Pump A is aligned directly to train A and pump B is aligned directly to train B. Pump C can be lined up to either train to replace either pump A or B by opening normally locked closed valves. During periods of single pump operation, one of the other two nonoperating pumps is lined up to the opposite train discharge header in standby. The third pump, not lined up to the system, serves as an installed spare.

Power is supplied to pump A from the 4.16-kv safeguards bus Al and to pump B from the 4.16-kv safeguards bus A2. Pump C can be supplied from either bus A1 or A2 through a manually operated transfer switch that transfers the motor feeders between the two buses. To maintain the required channel separation and independence, the transfer switch is constructed so that the two power supply sources can never be connected in parallel. Controls for the switchgear breakers feeding pump C are interlocked such that when pump A is running, the pump C breaker, racked in to the connected position on bus A1, cannot be closed. It can only be closed when pump A breaker is in the disconnect or test position. Similarly, pump C can be run from bus A2 only when pump B breaker is racked out to the disconnect or test position. Note that if pump C was operating on bus A1 (i.e., with its breaker shut) and the breaker for pump A was racked in to the connected position, pump C breaker would trip unless it is operating in local mode with its remote control switch in "pull to lock." The same holds for pump B and C operating on bus A2. The transfer switch position does not affect breaker closure, but it will determine if the pump runs when the breaker is closed. This arrangement ensures that electrical channel separation is maintained at all times, and also minimizes the chances of placing two service pumps on one emergency diesel generator during loss of normal power conditions.

There are six automatic start features for the service water pump. The first two auto start features require only that the pumps remote control switch be in auto. Given that the circuit breaker closing spring is charged, the pump will then start upon activation of either the DBA or normal shutdown sequencers. However, the four remaining auto start features listed below (3 through 6) require the pump selector switch to be in REMOTE, the control switch in AUTO, and breaker lockouts reset to start the service water pump A:

1. DBA sequencer - channel A,
2. Normal shutdown sequencer - channel A
3. train A CCW low surge tank level ($\leq$8.3%),
4. Train B service water system pressure low ($\leq$15 psig),
5. Train B CCW pump differential pressure low ($\leq$40 psid), or
6. Service water booster pumps B&D discharge header pressure low ($\leq$40 psig).

Operation of the B and C service water pumps is similar to that described for the A pump.

The discharge of the A and B service water pumps goes to the respective service water system trains through 30-inch supply piping. There is a 30-inch header across the two trains that accepts the discharge from the C pump and directs it to the appropriate train. Normally locked closed isolation valves are positioned to achieve this arrangement.

Several SWS loads are supplied directly from the discharge of the service water pumps. The domestic water system is one of those loads. Its supply comes from the Seismic Category II piping between valves CV-3804 and CV-3803. The other major loads supplied directly include strainer backwash flow, the CCW heat exchangers and the CCW emergency makeup supply. The rest of the flow from the service water pumps goes to the suction of the service water booster pumps.

14.6.3.2 Service Water Strainers and Backwash Pumps

Just downstream of where the system pressure is sensed there is a service water strainer in each train. The strainer is sized for a maximum flow rate of 30,000 gpm and a design rate of 20,000 gpm. The strainers are of the automatic self-cleaning multiple element type. They are designed to trap particles larger than 62.5 mils (1/16"). Normal SW flowpath is through the inlet, around the filter tube sheet, into the ends of the filters, and flow through the sides of the filters to the outlet.

Each strainer has a revolving dual backwash arm and drain valve that can be activated by a timer, high differential pressure across the strainer assembly, or manual (continuous) control. Backwash flowpath is from the outlet, through the sides of the filters, out the rotating dual backwash arm, and to the backwash pump or bypass valve to the discharge and dilution structure. The backwash arm is driven by a motor mounted on top of the service water strainer.

The service water strainer backwash pumps are located in the service water strainer pits. They are designed to increase backwash flow to 600 gpm vice 350 gpm bypass flow. The "start" position continuously runs the backwash pump and is the normal position. In the "auto" position, the backwash pump would receive start and stop signals from strainer differential pressure or by timer.

14.6.3.3 Service Water Booster Pumps

There are two service water booster pumps in each train that take their suction on the discharge of the service water pumps. The service water booster pumps are horizontal centrifugal pumps with a design flow of 2500 gpm at the design head of 120 feet. The service water booster pumps are powered from vital 480-vac motor control centers.

For a service water booster pump to be started either manually or automatically, it must first meet the permissive of greater than 10 psig service water pump discharge header pressure. The automatic starts and permissives vary from A&B pumps and C&D pumps and are as follows:

1. A and B pumps will auto start on any related train service water pump auto start. They will also auto start if the related train pump discharge decreases to less than 50 psig and their remote control switch is in auto after stop (green flagged).
2. C and D pumps will auto start on any related train service water pump auto start only if related train A or B pump is in pull-to-lock. They will also auto start if the related train pump control switch is in auto after start (red flagged) and its discharge decreases to less than 50 psig for greater than 3 seconds if their remote control switch is in auto after stop (green flagged). Also C or D will auto start if any related train service water pump auto starts, the related train pump discharge is less than 50 psig for greater than 3 seconds, and their remote control switch is in auto after stop (green flagged).

Two service water booster pumps are connected in parallel in each train to provide flexibility in meeting the system flow requirements of the various operating conditions. Each of these trains is designed to provide 100 percent of the design requirements during normal operation.

14.6.4 System Features and Interrelationships

14.6.4.1 Alternate Sources of Supply

There are two alternate methods of supplying water to the service water system in the event of failure of the intake structure. There is a single 30-inch line from the circulating water system that connects to each train of service water at the inlet and another at the outlet of the component cooling water heat exchangers. The return flow from the heat exchanger outlets go back to the cooling tower, or can be aligned to the discharge and dilution structure. Water can also be supplied through six 4-inch hose connections in each train that can be cross connected and supplied from the installed fire pumps. These connections are just upstream of the service water strainers in each train.

14.6.4.2 Intake Structure, Screen Wash and Chlorination Systems

Each of the three service water pumps is contained within its own concrete cubicle in the intake structure. The intake structure sits on the bank of the river. Intake structure design and a trash rack between the river and the suctions of the wet-pit type service water pumps keep out large debris.

Between the intake trash rack and the pump suctions there are traveling screens. The traveling screens are designed to keep smaller debris and marine life out of the suction of the service water pumps. The screens are kept clean by the screen wash system. This system employs two vertical pumps which take clean water that has already passed through the traveling screens and spray it through high velocity spray nozzles. The stationary spray nozzles wash the debris from the screens as they travel past. This cycle is automatically controlled by an adjustable timer that can provide up to 48 wash operations per day. There are also differential level controllers which will start a screen wash cycle whenever the levels on either side of the screen differ by more than six inches. It should be noted that no more than one service water pump may be in operation with one intake bay out of service.

Sodium hypochlorite is used for biofouling control of both service water and circulating water systems, supplied from a portable storage tank, through a metering valve, to the chlorine injectors. Sodium sulfite is used to neutralize the sodium hypochlorite at the discharge and dilution structure via the sodium bisulfate tank.

14.6.4.3 System Operation

During normal SWS operation both trains of service water are in operation. The intake structure screen wash and chlorination system and one bearing lube water pump are placed in operation. Each train of service water has one service water pump and one service water booster pump running with both trains aligned to Seismic Category II loads.

During normal single-pump operation, the system will automatically shift to operation on the other pump under the following conditions:

1. Loss of pressure of the operating service water pump discharge header,
2. Loss of pressure of the associated booster pumps' discharge header, or
3. Low differential pressure across the operating component cooling water pump.

The loads cooled by service water can normally receive flow from either train via the normally open (train A and B) isolation valves. Thus, during normal operations, both trains of service water are cross connected at their cooling loads.

Pressure switches at the discharge header of the associated service water pump prevent manual or automatic startup of the booster pump until sufficient pressure exists to prevent damage to the associated booster pump. However, it should be noted that the pressure switches are upstream of the service water strainer. If the strainers became clogged, the pressure switches would see adequate discharge pressure from the operating service water pump. The booster pumps would then start with inadequate suction pressure.

The service water booster pumps are electrically interlocked with the associated service water pump such that an automatic startup of train A service water pump will cause an automatic startup of the A booster pump. If the A booster pump fails to start automatically, as indicated by inadequate booster pump discharge header pressure, the C booster pump will start following a three second time delay.

During the plant cooldown phase following initiation of normal plant shutdown, two service water pumps are required to be in operation. Full flow through both component cooling water heat exchangers is required for 20-hour cooldown capability. The plant can be safely cooled down by one heat exchanger, but this will require a time period considerably longer than 20 hours.

During periods of cold shutdown for maintenance and/or refueling, one train of the SW system remains in operation. Flow through one component cooling water heat exchanger is required at all times during plant shutdown for removal of residual heat from the reactor coolant system. Two booster pumps may be required, depending on the operating equipment required to be cooled. During cold shutdown, the reactor coolant system is aligned to the residual heat removal system for decay heat removal. Flow through the residual heat removal heat exchanger is cooled by component cooling water, which is cooled by the service water system.

A safety injection signal will initiate an automatic startup of both emergency diesel generators. The safety injection signal causes the following to occur:

1. Automatic startup of the standby service water train,
2. Separation of the two safety related trains and isolation of the non-safety related parts of the system by automatic closure of valves CV-3720A & B, CV-3714, CV-3725, CV-3803 and CV-3804, and
3. Initiation of water flow to the emergency diesel generator heat exchangers by automatic opening of valves CV-3712A & B.

Loss of off-site power, with normal on-site power sources unavailable, causes automatic startup of the emergency diesel generators. When the emergency diesel generators are providing the sole source of power to the 4160-vac emergency buses (A1 and A2), service water realigns the same as after a safety injection signal.

14.6.5 Summary

The service water system is an ESF support system essential to maintain safe operation and shutdown of the plant. During normal plant operation it supplies safety and non-safety related components. During emergency conditions, the non-safety related portions of the system are isolated from the safety related portions to ensure plant integrity is maintained.

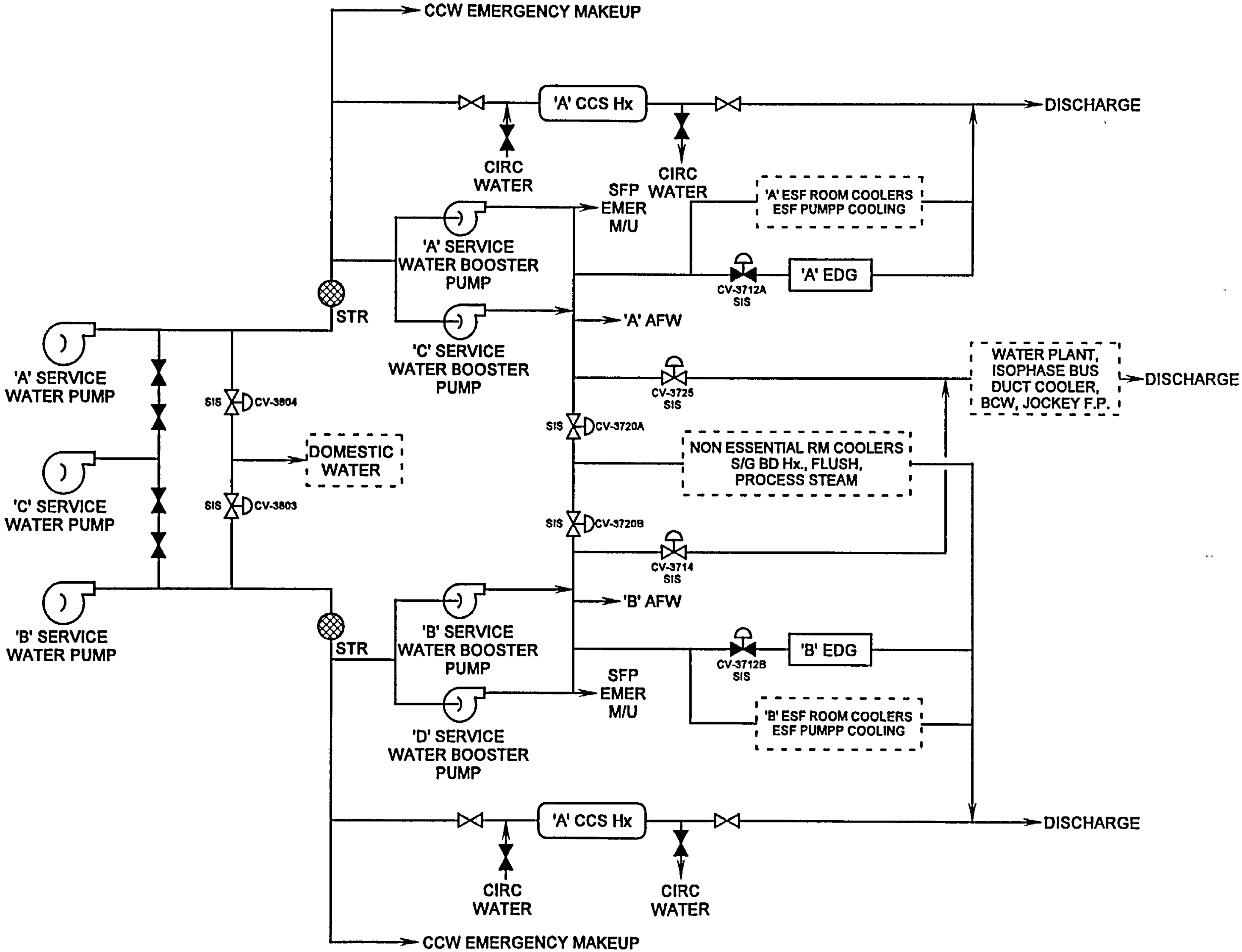

Figure 14.6-1 Service Water System

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Section 14.7

<u>TTC Simulator Circulating Water System and Turbine Building Cooling Water System</u>

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14.7 CIRCULATING WATER SYSTEM AND TURBINE BUILDING COOLING WATER SYSTEM

Learning Objective:

1. State the purposes of the circulating water system and turbine building cooling water system.

14.7.1 Introduction

The Circulating Water System (CWS), as shown in Figure 14.7-1, provides cooling water for heat removal from the main condenser, the air ejector condensers, the turbine generator auxiliary coolers, and the feedwater pump turbine lube oil coolers. The CWS serves as the normal heat sink for the secondary plant and can also supply water in an emergency to the service water system. The CWS supplies water to the Turbine Building Cooling Water System (TBCW).

14.7.1 System Description

The CWS is designed to dissipate 7.92 x 10^9 btu/hr, which equals the total heat load from the main condenser and other components served by the system. The CWS supplies:

1. Cooling water for the main condensers,
2. Cooling water for the steam jet air ejector inter and after condensers,
3. Emergency water supply to the service water system,
4. Emergency water supply to the fire main,
5. Water supply to the turbine building cooling water system,
6. Return point for service water flow from the steam generator blowdown heat exchangers,
7. Water for the administration building and the shop and warehouse heating systems,
8. Cooling water for the circulating water pump lube oil coolers, and
9. Heating water for the fish rearing facility.

The TBCW supplies cooling water to:

1. Turbine generator lube oil coolers,
2. Steam packing exhauster,
3. Steam generator turbine feed pump lube oil coolers,
4. Generator stator coolers,
5. Exciter air cooler,
6. Generator hydrogen gas coolers, and
7. Condensate demineralizer building.

The circulating water system and the turbine building cooling water system consist of two circulating water pumps, a cooling tower, two turbine building cooling water booster pumps, two cooling tower makeup pumps and various component heat exchangers. Since the CWS requires the addition of sulfuric acid to minimize scale buildup, a pH-controlling acid addition system is provided.

The circulating water pumps circulate the water from the cooling tower basin through the main condenser and back to the cooling tower. The pumps also supply water to the steam jet air ejector inter and after condensers, the turbine building cooling water system, and the fish rearing facility system.

The turbine building cooling water booster pumps take a suction on the circulating water pump discharge lines and deliver cooling water to the two turbine-generator lube oil coolers, the steam packing exhauster, the main generator exciter air cooler, the four main generator hydrogen coolers, the two main generator stator coolers, the four turbine feed pump lube oil coolers, and miscellaneous loads in the condensate demineralizer building. The cooling water then rejoins the circulating water at the main condenser discharge.

The cooling tower cools the circulating water using a counter flow, natural draft arrangement. Due to system impurities, a continuous blow-down is performed on the circulating water system. This inventory loss, combined with losses due to evaporation and drift, requires two cooling tower makeup pumps which take water from the cooling tower makeup reservoir section of the discharge and dilution structure and deliver it to the suction of the circulating water pumps.

14.7.3 Component Descriptions

14.7.3.1 Circulating Water Pumps

The two circulating water pumps are single stage, horizontally split, centrifugal pumps which supply the necessary head for system flow. Each pump can supply 210,000 gpm at a design head of 100 feet. The pumps are powered from the 12.47-kv buses H1 and H2. Each pump shaft is sealed at each casing exit point by a self-supplied stuffing box (gland) that has filters, heat tracing, throttle valves, and flow sight glasses. The pumps are located outside, in the circulating water pump pit. A common lubricating oil system is shared by the two pumps.

14.7.3.2 Cooling Tower

The cooling tower cools the circulating water returning from the various components served by the CWS and TBCW systems. The hyperbolic tower, designed for strength alone, is evaporative in design and contains no fans. The air flow within the shell is created by the density difference between atmospheric air and the hotter air inside the tower. The counter flow design provides a highly efficient heat transfer mechanism since the coolest air contacts the coolest water initially. The heat transfer process occurs in the fill section of the tower.

The cooled water falls into the cooling tower basin, passes through a set of double screens in the basin outlet and to the suction of the circulating water pumps. The cooling tower basin has a capacity of 5.2×10^6 gallons.

The spray header can be bypassed to allow warmup of the CWS on startup or to maintain the proper temperature during cold weather operation. Bypass flow is controlled by a 72 inch, motor operated, butterfly valve located near the tower basin. There are no interlocks associated with this valve, though only one CWS pump should be in operation with the valve open.

14.7.3.3 Cooling Tower Makeup Pumps

The cooling tower makeup system uses two makeup pumps in conjunction with a flow control valve to supply water to the CWS pump suction header to makeup for losses. Water is lost from the system due to evaporation, blowdown, and drift. The makeup pumps take a suction on the makeup section reservoir of the discharge and dilution structure. This bay receives water from the discharge of the service water pumps after passing through the component cooling water heat exchangers, and is ultimately derived from the river.

The makeup pumps are 450 horsepower, turbine-type pumps rated at 18,000 gpm at a design head of 75 feet. They are powered by the 4.16-kv buses A5 and A6.

14.7.3.4 Motor Operated Valves

The valves which will be discussed here are the CWS pump suction and discharge valves, the discharge cross-connect valve, and the condenser outlet valves. These valves are all 96-inch, motor-operated, butterfly valves.

The pump suction valve is interlocked with the CWS pump. The suction valve must be full open to start the pump and the pump will trip if the suction valve is not full open. When a pump is energized, the respective pump suction valve cannot be closed.

The CWS pump discharge valve does not have its own control switch. Starting a CWS pump sends a signal to open the pump discharge valve. If the discharge valve is not fully open within two minutes, the pump will trip. Stopping the pump will send a closing signal to the discharge valve motor operator. The pump will stop when the discharge valve reaches the fully closed position. An auto trip of the pump will also initiate discharge valve closure.

The cross-connect valve is interlocked to prevent the valve from being opened with both pumps in operation. If one discharge valve and the discharge cross-connect valve are open, opening the other discharge valve will cause the cross-connect to close. If either discharge valve is open, then the cross-connect valve cannot be opened. This interlock prevents excessive circulating water pump reverse rotation which would occur during one pump operation with the cross-connect and both discharge valves open.

The condenser outlet valves are interlocked with the CWS pumps such that the associated condenser outlet valve must be at least 48° open any time the pump is running. A valve position of less than 48° will prevent the pump from starting and will trip the pump if running. These valves are also prevented from closing any time the CWS pump is running. This interlock prevents condenser tube over pressurization.

14.7.3.5 Chemical Injection

Chemicals are manually added to the circulating water on a routine basis to help eliminate algae buildup in the system. The system taps into the pump suction header through 6-inch piping. The chemicals pass through a diffuser section to ensure good mixing and dilution prior to injection. Chemical injection is automatically blocked whenever the CWS pumps are de-energized.

14.7.3.6 Turbine Building Cooling Water Booster Pumps

Two centrifugal booster pumps supply the turbine building cooling water system. Each booster pump is rated at 9100 gpm at a head of 50 feet. The pump shaft is sealed at each end by a gland, which is supplied with sealing water from its own discharge. The booster pumps are powered from 480-vac non vital load centers.

14.7.4 Summary

The CWS provides cooling water for heat removal from the main condenser, the air ejector condensers, the turbine generator auxiliary coolers, and the feedwater pump turbine lube oil coolers. The CWS serves as the normal heat sink for the secondary plant and can also supply water in an emergency to the service water system. The CWS supplies water to the turbine building cooling water system.

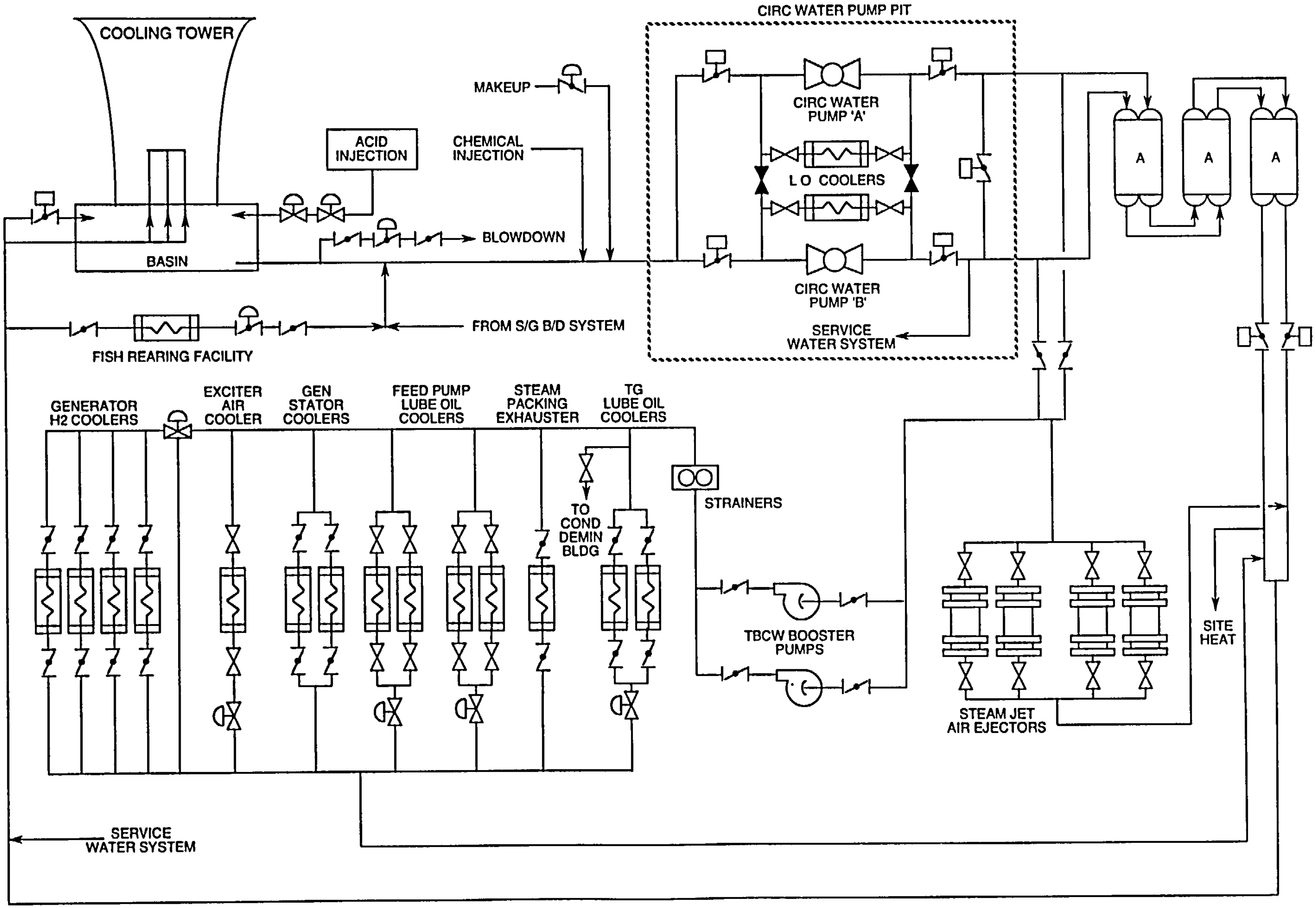

Figure 14.7-1 Circulating Water System

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Chapter 15

RADIOACTIVE WASTE MANAGEMENT

Section

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Section 15.0

Radioactive Waste Management

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15.0 RADIOACTIVE WASTE MANAGEMENT

15.0.1 Introduction

The purposes of the radioactive waste management systems are to collect, process and store radioactive waste. By meeting these purposes, the release of radioactive materials to the environment is minimized.

A major aspect of nuclear power plant operation is management of the radioactive waste generated as a by-product of nuclear power through activation or as fission product from nuclear power generation. Of all the problems associated with the nuclear power industry, probably none is so chronic, and its solution so controversial, as that of management of the radioactive wastes generated. Management of these wastes is complicated not only because of their diverse physical and chemical characteristics, but also because of the level and duration of containment required for some of the radioactive constituents.

The development of facilities and equipment to handle and process radioactive waste has provided the nuclear industry with the capability to treat, process, store, or dispose of the radioactive wastes within applicable regulatory requirements.

Appendix I of 10 CFR 50 requires consideration of population doses from discharged radionuclides at a much lower level than previously permitted. Design objectives are in the range of 3 to 10 mrem/year per reactor, hence any pertinent environmental radiation measurements will have to be extremely sensitive. It also requires the licensee to compute population doses on the basis of effluent measurements and calculational models of radionuclide release to the environment.

Successful operation stems from providing adequate storage, sufficient processing capacity, and flexibility in routing feed and process streams. Equipment redundancy and consideration of the requirement for sampling, operation, and maintenance, while maintaining radiation exposures to operating and maintenance personnel "as low as reasonably achievable" (ALARA), are an integral part of the design philosophy.

The formation of radioactive materials (Figure 15.0-1) occurs during the operation of a nuclear power plant. The concentration of radionuclides in the reactor coolant is a function of the reactor power level, the fuel burnup, type of fuel cladding, impurities and chemical additives in the reactor coolant, the reactor coolant volume, and the rate of reactor coolant purification. These radioactive materials will be in the form of solids, liquids, and gases and will be treated with different waste processing systems. There are basically three systems utilized in the management of radioactive wastes. These systems are:

Liquid Radioactive Waste (Section 15.1)
Solid Radioactive Waste (Section 15.2)
Gaseous Radioactive Waste (Section 15.3)

It is not the intent of this manual to present a "Standard System", for it is clearly recognized that there are many equipment combinations which meet the performance objective.

15.0.2 Overview of Waste

Radioactive waste is classified as either low-level waste (LLW) or high-level waste (HLW). LLW may be disposed of in burial facilities that are controlled by State Compacts. The compacts are responsible for providing for burial facilities, which are licensed in accordance with 10 CFR Part 61 which provides for burial approximately 30 meters from the surface. LLW is classified in terms of increasing radiological hazard and half-life as class A, B or C. Class B and C waste must be placed in a container that will provide for stability of the waste over 300 years. In addition, disposal of Class C waste requires protection against an inadvertent intruder for a period of 500 years due to the significance and duration of the radiological hazard. Due to the delayed development of LLW facilities, many licensees are using volume reduction techniques such as super compaction and incineration to reduce the volume of their solid radioactive waste. Liquid wastes are not acceptable for burial as LLW or HLW.

Examples of HLW included spent fuel and waste that is classified as greater than Class C. HLW cannot be buried at a LLW disposal facility. Disposal of HLW is to be conducted at a facility licensed to DOE by the NRC according to 10 CFR Part 60 which requires a suitable container and disposal in a geological repository. Presently DOE is evaluating the suitability of a site at Yucca Mountain in Nevada. Development of the HLW facility is funded by revenue from generation of electric power by reactor facilities into the Nuclear Waste Fund.

Temporary storage of HLW may be conducted using a monitored retrievable storage (MRS), which is a facility operated by DOE, or an independent spent fuel storage installation (ISFSI), which is operated by a private company. An ISFSI may be located at either a reactor licensees site, or at a separate location. Both a MRS and ISFSI facilities must be licensed by the NRC according to 10 CFR Part 72. This rule includes requirements for the storage facility as wall as requirements for the storage cask. Many utilities are developing facilities for above ground temporary storage of spent fuel as their spent fuel pool reach capacity.

In addition, 10 CFR Part 20 includes a provision for incineration of contaminated oil from power reactor facilities.

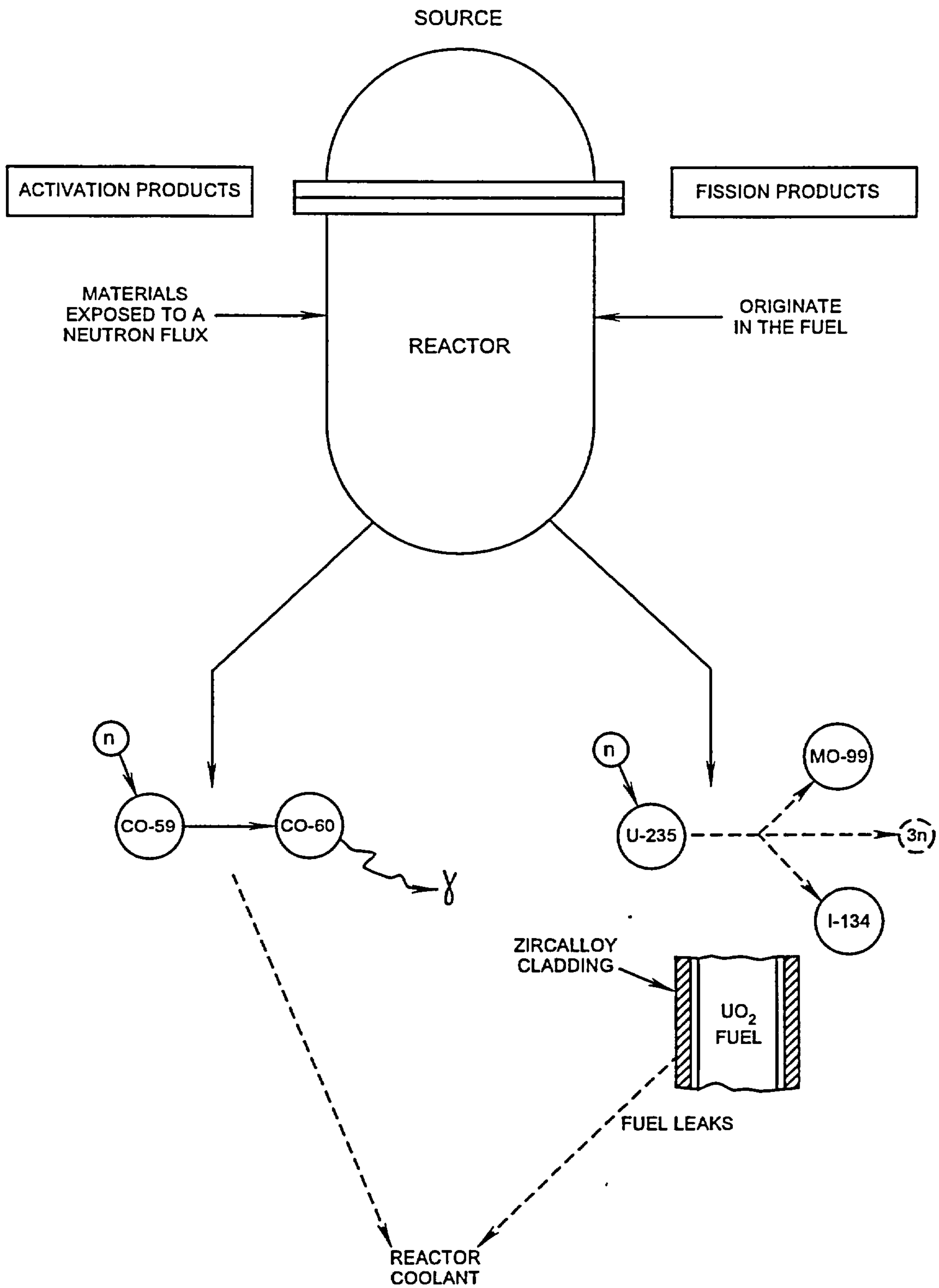

Figure 15.0-1 Sources of Radioactivity in the Plant

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Section 15.1

Liquid Radioactive Waste Processing Systems

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15.1 LIQUID RADIOACTIVE WASTE SYSTEMS

Learning Objectives:

1. Explain why liquid radioactive waste is separated into reactor grade and non-reactor grade.

2. List three inputs to the reactor grade waste subsystem.

3. List three categories of non-reactor grade wastes.

4. Briefly explain three liquid radioactive waste processing methods.

5. Define "decontamination factor" (D.F.).

15.1.1 Introduction

The liquid radioactive waste system (LRW) collects, stores, and processes radioactive, or potentially radioactive waste for recycling to the reactor coolant system (RCS) or for releasing to the environment. This system (Figure 15.1-1) begins at the interfaces with the reactor coolant pressure boundary, and the interface valve(s) in lines from other systems, or at those sumps and floor drains provided for liquid waste with potential of containing radioactive material. It terminates at the point of controlled discharge to the environment, at the point of interface with the waste solidification system, and at the point of recycle back to storage for reuse.

Provisions made to sample and analyze these liquids. Based on laboratory analysis, these wastes are either recycled for reuse, released under controlled conditions via the service water system, retained for further processing, or transferred to the solid waste system (Chapter 15.2) for solidification. The amount of liquid waste that enters the LRW is limited so that relatively small quantities of generally low level wastes are processed. To limit the input into the LRW, most of the water discharged from the RCS is processed by the boron recycle system (Section 4.1).

The liquids that are not processed by the boron recycle system will enter the LRW which is arranged to recycle as much water entering the system as practical. This is accomplished by segregation of equipment drains and waste streams to prevent the intermixing of the liquid wastes. The LRW consists of two main subsystems which process reactor grade and non-reactor grade effluents. In addition, the system is capable of handling drains which may contain reagents or chemicals and has the capability for the handling of spent demineralizer resins.

The LRW is designed so that at least two valves must be manually opened to permit discharge of liquids to the environment. One of these valves is normally locked closed. The discharge line also has a control valve that will automatically trip closed on high effluent activity level.

The LRW is constructed of materials that to meet the requirements of the system and applicable codes. In addition, all parts or components that may come in contact with borated water are fabricated of or are clad with stainless steel. Equipment and components within the LRW are located and arranged to reduce radiation exposure to plant personnel during operation and maintenance. All tanks and process equipment are shielded so that normally occupied areas are in a radiation field less than 2.5 mrem/hr. Process equipment is located and arranged to provide space for removal and replacement of components and the equipment itself. Process subsystems are arranged to reduce the length of piping runs. Process equipment, such as filters, ion exchangers and evaporators, are usually located in individual cells. Equipment is designed to facilitate rapid disconnection for removal, replacement and ease of in-place maintenance. Table 15-1 lists the Liquid Waste Systems at selected facilities.

15.1.2 System Description

15.1.2.1 Separation of Reactor Grade and Non-Reactor Grade Liquids

Liquid radioactive waste is collected in various tanks. The input to these tanks comes from various drains and is separated and treated as reactor grade and non-reactor grade liquids.

Reactor grade liquids are liquids whose tritium concentration is 10% or more of primary coolant tritium activity and can be processed for reuse as demineralized water or concentrated boric acid solution.

Non-reactor grade liquids are liquids having a tritium concentration of less than 10% of that of the primary coolant and due to their composition cannot be processed for reuse.

15.1.2.2 Reactor Grade Water (Recycle)

The recycle section is provided to process reactor grade water which enters the LWS. Deaerated, tritiated RCS water collected directly in the reactor coolant drain tank, Figure 15.1-2, may be routed directly to the boron recycle holdup tanks for processing in the boron recycle system or routed to the miscellaneous waste tank. Aerated and tritiated water is collected in the miscellaneous waste tank, Figure 15.1-3.

The systems used to process miscellaneous waste include ion exchange, evaporation, or equivalent processes. Evaporation is selected as a primary processing method as it is very efficient at reducing the amount of contaminated water with ionic and particulate contaminates. Various processing methods will be discussed in detail in section 15.1.3 in this chapter. The basic composition of the liquid collected in the miscellaneous waste tank is boric acid and water with some radioactivity. Liquid collected in this tank is evaporated to remove radio-isotopes, boron, and air from the water so that it may be reused in the RCS.

Evaporator bottoms are normally drummed (in the solid radioactive waste system) unless found acceptable for boric acid recycle. The condensate leaving the miscellaneous waste condensate polishing demineralizer enters the monitor tank. When a sufficient quantity of water has collected in the monitor tank, it is sampled to determine if it is suitable for recycle (to the primary water storage tank for reuse), discharge, or if it must be reprocessed in the LRW.

15.1.2.3 Non-Reactor Grade Water(Waste)

This waste category is designed to collect and process non-reactor grade liquid wastes. These include chemical wastes, detergent wastes, and secondary system wastes. The inputs to these tanks are gravity drains. Each of these collection points has a pump to recirculate the contents of the collection tank for sampling and for transferring the liquid for processing. After processing, the liquid is transferred to a monitor tank. The monitor tank has a pump to recirculate the contents of the monitor tank for sampling. Depending on the results of the sample, the monitor tank transfers the contents for discharge, recycle for reuse, or reprocessing.

Chemical Waste

Input sources include: radio chemistry laboratory drains, chemical cleaning waste, decontamination waste, and other liquid radioactive wastes which contain high concentrations of chemicals. The chemical waste may be treated separately, as shown in Figure 15.1-4, and transferred to the miscellaneous waste system, or transferred directly to the solid waste system.

Detergent Waste

Input sources, Figure 15.1-5, include: laundry, personnel decontamination, and other liquid radioactive wastes containing detergents and soaps. The detergent waste may be treated separately or processed directly in the Solid waste system. This system should be segregated from other waste collection systems to reduce operational problems with processing equipment.

Secondary System Waste

Input sources, Figure 15.1-6, include: steam generator blowdown, turbine building drains, and ion exchange spent regenerant solutions. The secondary system wastes may be treated separately, or in the event of primary to secondary leakage the turbine building drains and steam generator blowdown may be treated in the miscellaneous waste system. The ion exchanger spent regenerant solutions may be treated in the chemical waste system.

15.1.3 Processing Methods

Decontamination Factor is a term used to describe the efficiency of a processing method removing contaminants from a process stream. Decontamination factor (DF) is the ratio of the initial amount of activity in a stream to the final amount of activity in a stream following the treatment by a given process. Therefore, if a given process has a DF of 2, the final activity level is one half of the original activity. Decontamination factors for liquid waste processing are obtained by the selection and combination of a number of unit operations. At the present time, the principal unit operations for treating liquid radioactive waste are filtration, ion exchange, evaporation and reverse osmosis.

15.1.3.1 Filtration

Filtration is defined as the separation of undissolved particulate, suspended solids from a fluid mixture by passage of most of the fluid through a septum or membrane that retains the solids on or within itself.

Cartridge Type Filter

Cartridge filters, Figure 15.1-7, are designed with replaceable elements which are discarded when contaminated. These elements are usually constructed of pressed paper, matted fibers, or porcelain materials. In general, these types of elements are used in low pressure, low temperature systems.

Precoat Type Filter

Precoat filters, Figure 15.1-8, use elements designed as retainers to prevent a precoat material from being flushed downstream. The actual filtering of system contamination is accomplished by the precoat material. This type of filter is limited by temperature, flow, and pressure extremes. In addition, the large quantities of precoat material which must be disposed of can present significant problems in terms of handling and disposal.

Filters will remove radioactive particulates but have no effect on ionic removal. Therefore, filters are normally given a decontamination factor of 1.

15.1.3.2 Ion Exchange

An ion exchanger (demineralizer) is a device that uses a polyelectrolyte to exchange mobile ions of equal charge from the surrounding solution. The polyelectrolyte is essentially a plastic bead which has ions weakly attached to it, typically used is HOH type resin. When a liquid is passed across this bead, it will readily exchange the ions on the bead with ions of the same charge in the liquid. There are basically two types of resin beads, called cation and anion. The cation resin has a positive ion attached in the hydrogen (the H part of HOH resin) form. The anion resin has a negative ion attached in the hydroxide (the OH part of HOH resin) form. Generally, ion exchangers use a combination of these resins and are called mixed bed ion exchangers or demineralizers.

De-ionization with mixed bed ion exchangers is capable of producing a water of exceptional purity. On occasion, the effectiveness of an ion exchanger material may be impaired due to the accumulation of insoluble materials, such as oil or particulates, on the surface and the interior of the ion exchanger. It is best to avoid or minimize this fouling by the use of suitable pretreatment filtration.

The decontamination factor given to ion exchangers will vary from 1 to 100. This depends upon the conductivity of the solution, the location of the ion exchanger in the process stream, and if the ion exchanger is a single unit or in series with another ion exchanger.

15.1.3.3 Evaporation

Evaporation is the process by which a solution or slurry is concentrated via boiling the solvent. This process leaves most of the solids behind and the condensed steam is essentially pure water.

The basic operation of a waste evaporator is to receive a solution to cause boiling. This boiling causes radioactive gases to leave solution. These gases are collected and vented to the Waste Gas System. The steam generated due to boiling is collected, condensed, and treated as deaerated, essentially pure water, which can be recycled for reuse. The solution left behind in the evaporator bottoms is called the concentrate. The concentrate generally has a high concentration of radioactive material and this solution can be recycled for further processing, or most often, is transferred to the Solid Waste System for solidification.

Evaporation has a wide application in the nuclear industry for reducing waste volumes and for reducing the amount of radioactive nuclides in liquid effluents. It is usually used for radioactive wastes that require a high degree of separation and are not readily treated by low temperature operations such as filtration or ion exchange. In the design of evaporators for concentrating radioactive liquids, vapor separation is the most important factor as decontamination of the liquid is the main objective. Volume reduction is next and least important, the heating costs.

Evaporators can separate water from solids very effectively and a system decontamination factor of 10^4 to 10^5 is generally expected. However, for present generation waste evaporators to realistically achieve this decontamination factor, the flow rate must be very low, on the order of 15 gpm or less.

15.1.3.4 Reverse Osmosis

Reverse osmosis is a process that to oversimplify, acts as a molecular filter that can remove dissolved minerals, dissolved organics, biological and colloidal matter from water.

Osmosis is the natural process whereby pure water flows through a semipermeable membrane from a dilute solution into a more concentrated solution. This process will dilute the concentrated solution. Reverse osmosis is the process by which pressure is applied to the concentrated solution thereby forcing pure water to flow in the reverse direction through the semipermeable membrane.

The result of this process is that the concentrated solution will become more concentrated. Reverse osmosis has been found to be very effective in the treatment of detergent waste. The decontamination factor for the reverse osmosis unit is about 30 for the processing of detergent wastes. The decontamination factor for all other liquid wastes is 10.

15.1.4 System Interrelationships

15.1.4.1 System Decontamination Factor

As discussed in Section 15.1.2.1 through 15.1.2.4 there are various methods available for the processing of LRW. Usually the processing system employs several of these in series. To determine the decontamination factor for a given process stream the product of all the methods used in that stream is taken.

An example of this would be to take a hypothetical process stream and determine the system decontamination factor. This hypothetical system will consist of an inlet filter, evaporator, ion exchanger, and an outlet filter. The decontamination factors (DF) for each of these methods would be: inlet filter (1), evaporator (10^4), ion exchanger (10), and outlet filter (1).

To determine the system decontamination factor, the product of the above is taken:

$$1 \times 10^4 \times 10 \times 1 = 10^5$$

Therefore, the decontamination factor for this hypothetical process stream would be 100,000.

15.1.5 Summary

The liquid radioactive waste system is designed to collect, store, process and dispose of radioactive or potentially radioactive liquids. The liquids are collected by gravity drains and segregated into various tanks as reactor grade and non-reactor grade liquids. This segregation is necessary because the different grades of liquids must be processed by different methods.

There are different methods of processing these collected liquids. The processing methods include filtration, ion exchange, evaporation, and reverse osmosis. Normally, one or more of these processing units will be utilized in the process stream.

After processing, the liquid is transferred to monitor tanks. The liquid is sampled, and depending upon the results of the sample, will be recycled for reuse, reprocessed, or released to the environment.

It should be noted that the emphasis today is essentially zero discharge from the LRW to the environment. With this philosophy, the LRW is designed to: recycle as much liquid as possible; limit the amount of radioactivity released to the environment, and to limit the dose received by plant personnel. Therefore, greater emphasis has been placed on the decontamination factors for the process stream and volume reduction. Liquid that cannot be recycled (due to high activity, chemical composition, etc.) is transferred to the solid waste system for processing. After solidification this waste is placed in storage on site, or transported to a permanent burial facility.

Table 15.1-1
Liquid Waste Systems and Capacities

Plant Name	Chemical Drain	Laundry & Hot Shower	Reactor Cont. Drain	Spent Resin Storage	Waste Holdup	Waste Monitor
R.E. Ginna	375	2 @ 600	350	2 - ?	21,000	
Kewaunee	To H/U Tank	2 @ 700	350	1 - ?	24,490	
Point Beach 1 & 2	600*	2 @ 700	350	1 - ?	21,000*	
Prairie Island 1 & 2	600*	2 @ 700	350	1 - ?	24,490*	2 @ 10,000
Beaver Valley 1 & 2	?	2 @ 1,300*	350	1,400*	2 @ 5,000	
J. M. Farley 1 & 2	600	10,000*	350	2 @ 2,600*	1000	2 @ 5,000
Sharon Harris	?	2 @ 25,000*	350	2 - ?	25,000	
North Anna	?	?	?	1,100	2 @ 5,000	
H. B. Robinson	600	2 @ 600	565	300	24,000	
San Onofre	375	?	784	1 - ?	3 @ 52,000	2 @ 3,740
V. C. Summer	600	10,000	350	2,600	10,000	2 @ 5,000
Surry 1 & 2	?	?	?	2,019*	2 @ 2,390*	2 @ 3,000
Turkey Point	?	3 @ 600	350		2 @ 10,000*	2 @ 5,000
Byron 1 & 2	6,000*	4,000*	350	5,000*	?	2 @ 20,000
Braidwood	6,000*	4,000*	350	5,000*	?	
Calloway	600	10,000	350	?	10,000	2 @ 5,000
Catawba	600*	10,000	350		2 @ 5,000	2 @ 5,000
Commanche Peak	600*	10,000*	350	4,100*	10,000*	2 @ 5,000*
D. C. Cook	600*	2 @ 600*	350	300*	2 @ 25,000*	
Diablo Canyon	1,000	2 @ 1,000*	400	2 @ 15,000	2 @ 15,000	
McGuire 1 & 2	600*	10,000*	350	2 @ 5,000	5,000*	2 @ 6,080*
Millstone 3	To Hi Lvl Waste	To Lo Lvl Waste	350	3,200		2 @ 21,000*
Salem	600	2 @ 600*	565	300	2 @ 25,000	2 @ 25,000*
Seabrook 1 & 2			350			2 @ 25,000*
Sequoyah 1 & 2	600*	2 @ 600*	350	2,600*	24,700*	10,000*
Trojan	6,500		347	2,600		2 @ 15,322
Vogtle	600*	10,000*	350	2,600	10,000	2 @ 5,000
Wolf Creek	600	10,000	350	2,600	10,000	2 @ 5,000
Zion 1 & 2	12,500	2 @ 1,500	350	5,000	2 @ 30,000	6,000
* common to both units						

Table 15.1-2
Liquid Waste Evaporators and Miscellaneous Tanks

Plant Name	Waste Evaporator Capacity (gpm)	Waste Evaporator Concentrate Tank	Waste Evaporator Condensate Tank	Miscellaneous Tank	Comments
R.E. Ginna			2 @ 600		Ultra-filtration as a pre-filter for evaporator
Kewaunee	2 - ?		2 @ 1,000	Sump Tank 600	
Point Beach 1 & 2	1 - ?		1,000*	Sump Tank 600*	
Prairie Island 1 & 2	2 - 5		2 @ 1,000*	Sump Tank 600* Aerated	SGBD Demins not for Waste Handling
Beaver Valley 1 & 2	6	1,350*	2 @ 3,000*	Decon Drain 1,400*	
J. M. Farley 1 & 2	15	?	5,000	Floor Drain 10,000	
Sharon Harris	Fluid Bed Dryer	5,000		Floor Drains 4 @ 25,000	
North Anna	6 Clarifier		2 @ 1,500	Lo Level Waste 2 @ 11,250	
H. B. Robinson		925	2 @ 1,000	Waste Condensate 3 @ 11,250	
San Onofre	ion exh / gas stripper			Decon Drain 2,600	4 - 35 ft³ Waste Processing Demins
V. C. Summer		5,000	5,000	Floor Drain 10,000	
Surry 1 & 2	not used			Lo Level Waste 2 @ 2,875	5 - 10 ft³ Waste Processing Demins
Turkey Point	2 - 15				
Byron 1 & 2	3 - 30	6,400*	2,000*	Aux Bldg Floor Drain 2 @ 8,000	
Braidwood	3 - 30	6,400*	2,000*	Aux Bldg Floor Drain 2 @ 8,000	
Calloway			5,000	Floor Drain 2 @ 10,000	2 @ 5,000
Catawba	1 - 15	3,000	5,000	Floor Drain 10,000	Cont. Vent Unit Drain 5,000
Commanche Peak	1-15	5,000*	5,000*	Floor Drain 2 @ 10,000	Waste Dvaportor Floor Drain Rev. Osmosis - Laundry
D C. Cook	2 - 15 and 1 - 2	4,000*	2 @ 1,500*		

Table 15.1-2 (Continued)
Liquid Waste Evaporators and Miscellaneous Tanks

Diablo Canyon	Mobile Rad Waste	2,000		Floor Drain 2 @ 10,000 1 @ 30,000	Mobile Radwaste Purification (Chem Nuclear)
McGuire 1 & 2	1-15	3,000	5,000*	Floor Drain 2 @ 10,000	Cont. Vent Cond. Drain 4,000
Millstone 3	1-35			Lo Level Waste Drain 2 @ 4,000	
Salem				Concentrates Holding Tank 500	
Seabrook 1 & 2				Floor Drain 2 @ 10,000	
Sequoyah 1 & 2	1 - 30		3 @ 2,000*	Aux Bldg Sump 600*	Portable Filtration System (60gpm)
Trojan	1 -1 5	2 @ 15,322	1,300	Dirty Waste Drain 5,900	2 @ 15,322
Vogtle 1 & 2	1 - 15	2,000*	5,000	Floor Drain 10,000	2 @ 5,000
Wolf Creek		1,000	5,000	Floor Drain 10,000	
Zion 1 & 2	1 - 12		2 @ 8,000	Aux Bldg Sump 250	Spray Film Type Evaporator
* common to both units					

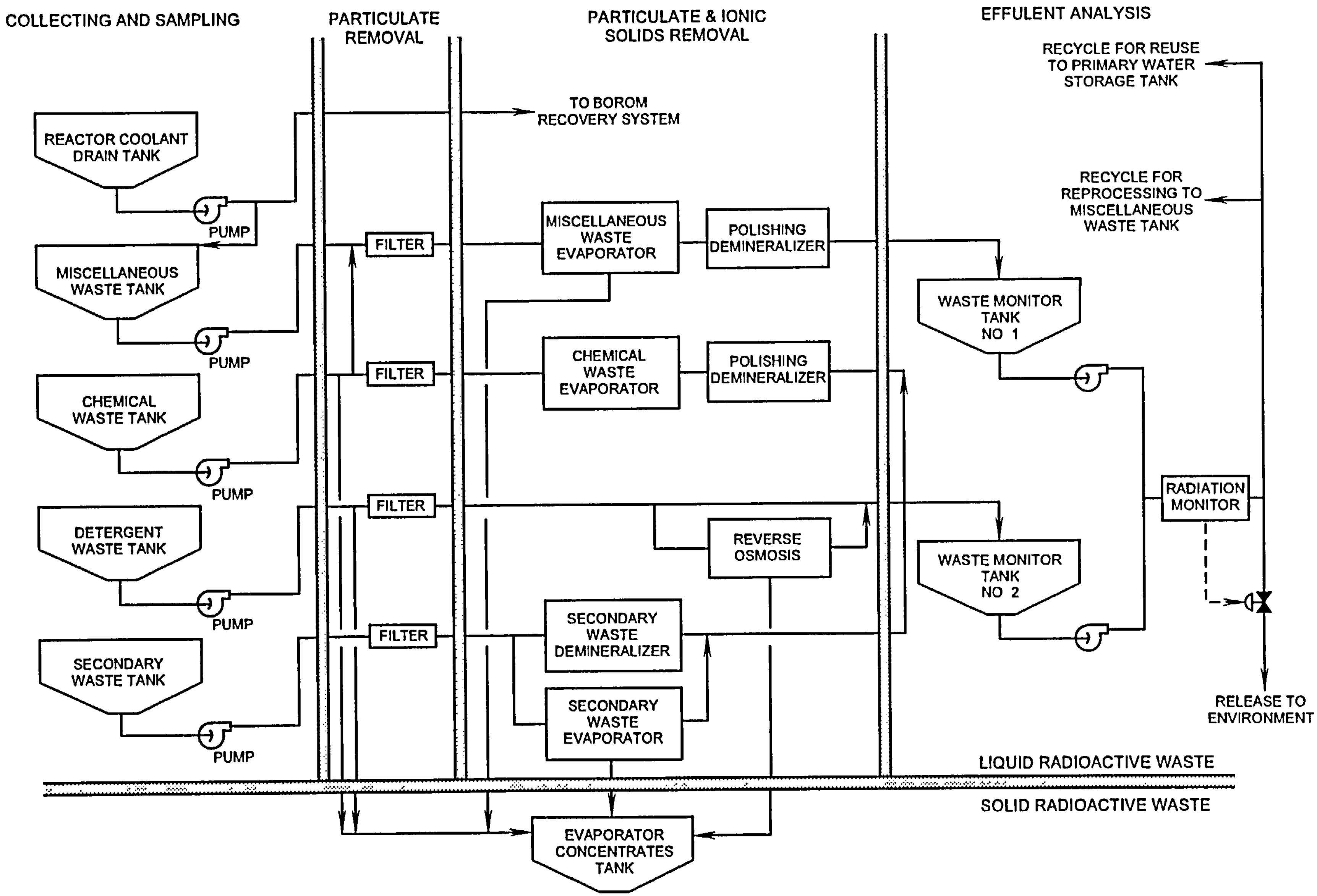

Figure 15.1-1 Liquid Radioactive Waste Processing System

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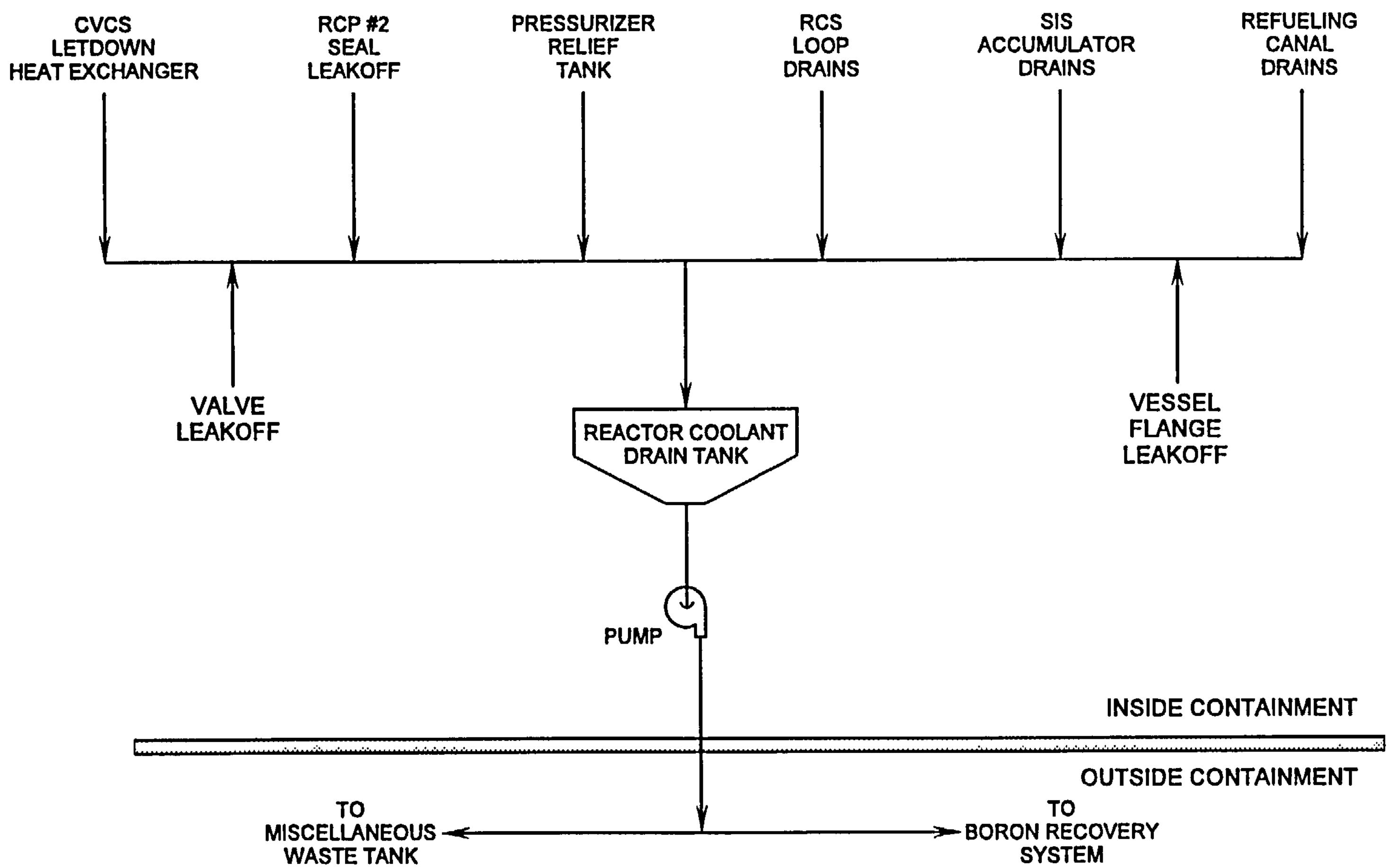

Figure 15.1-2 Deareated Reactor Grade Water System

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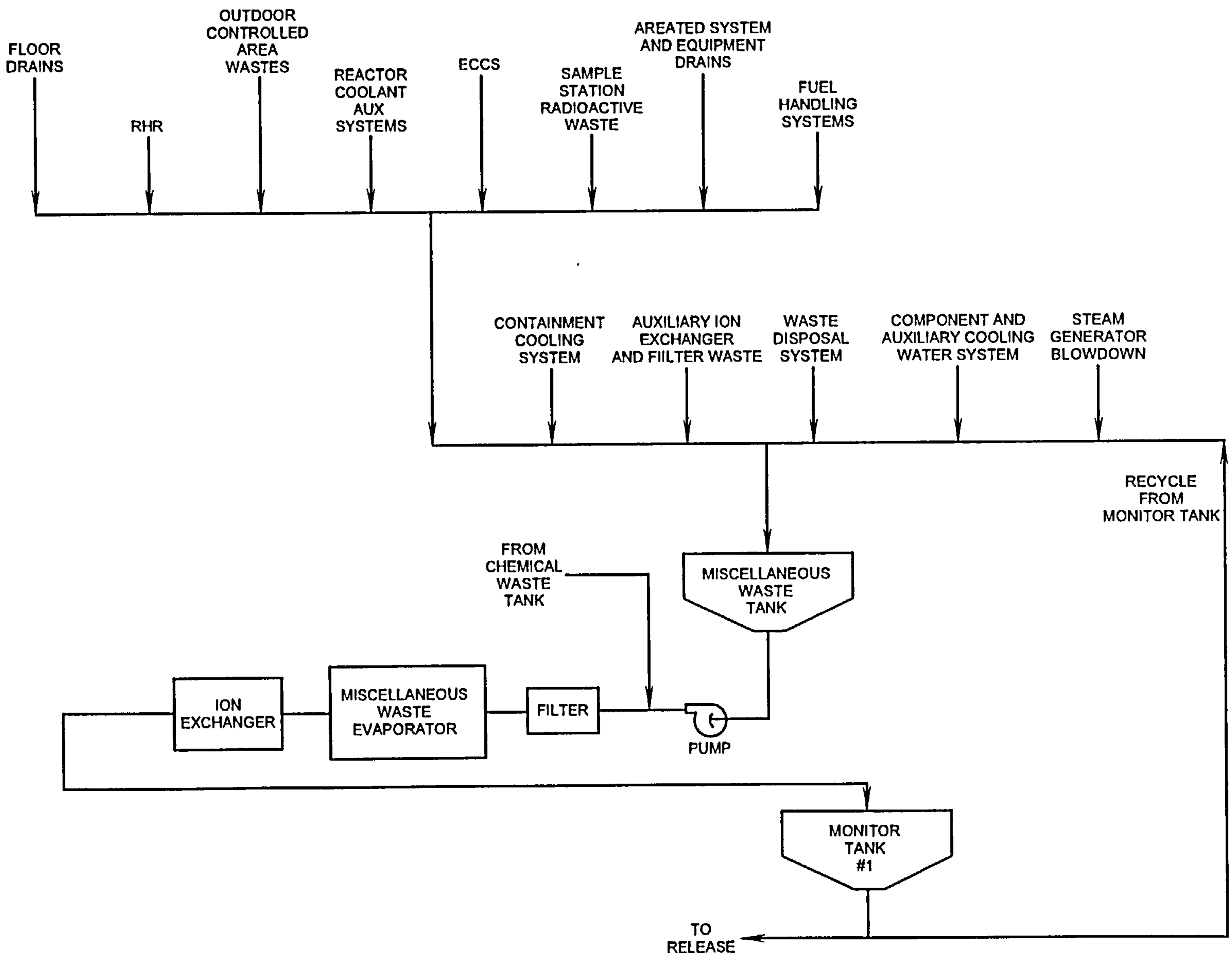

Figure 15.1-3 Miscellaneous Waste System

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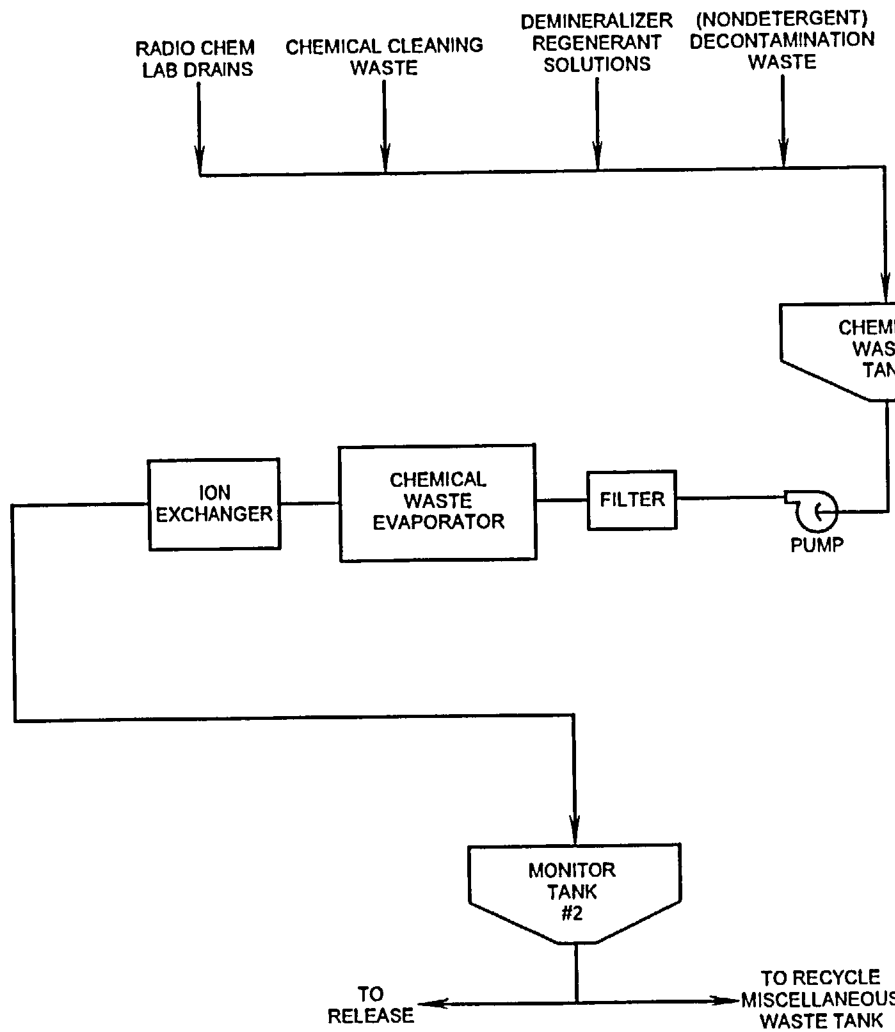

Figure 15.1-4 Chemical Waste System

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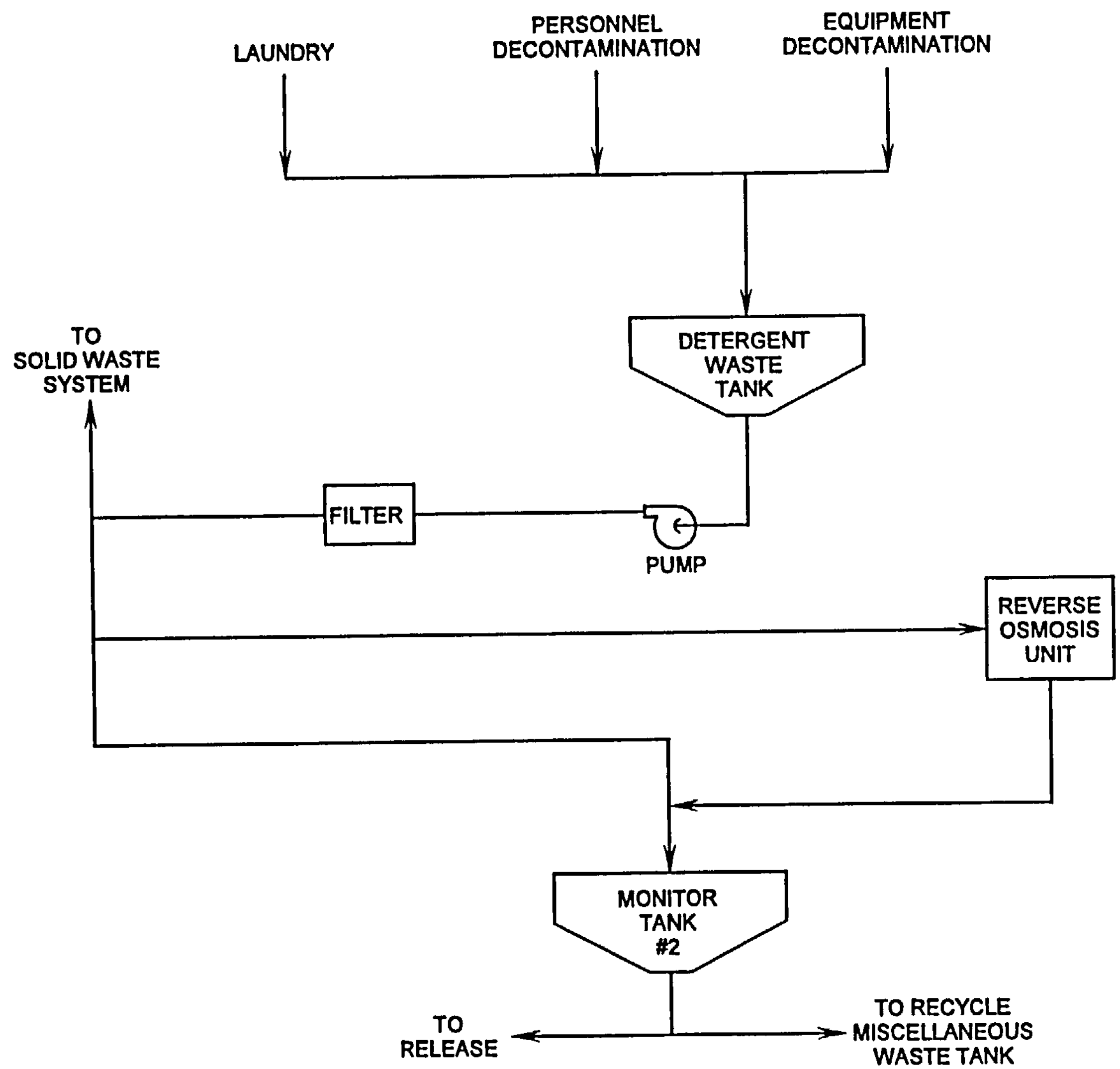

Figure 15.1-5 Detergent Waste System

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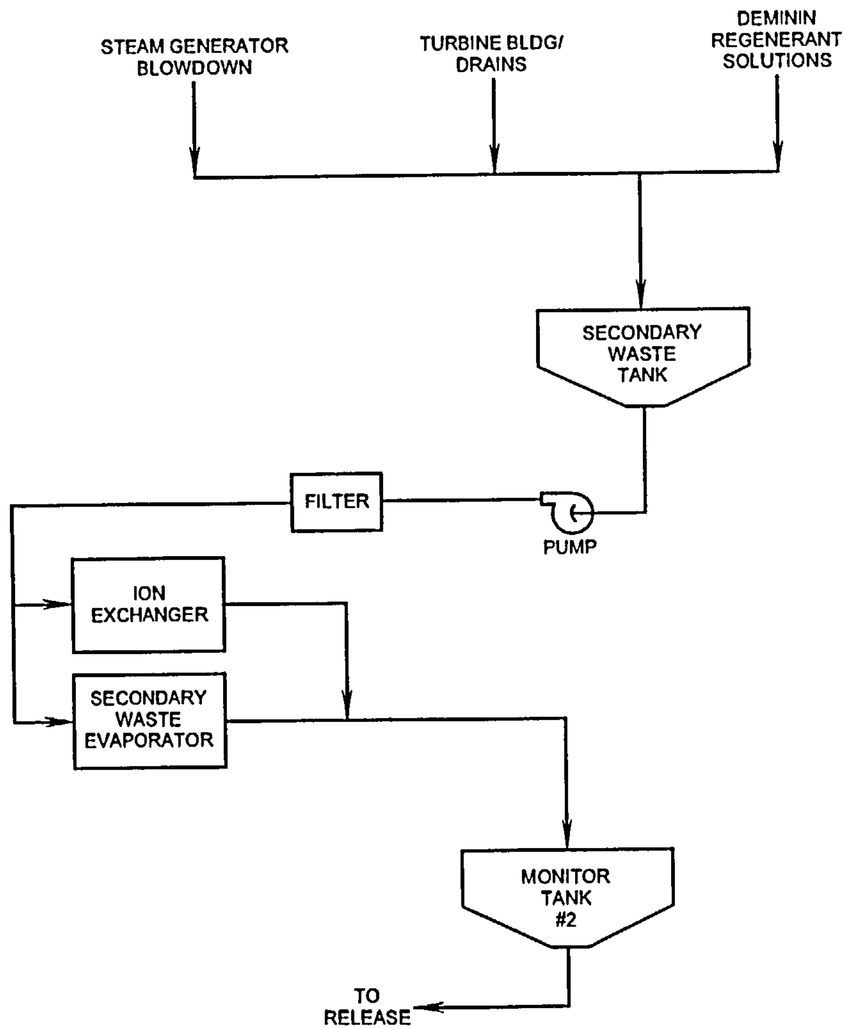

Figure 15.1-6 Secondary Waste System

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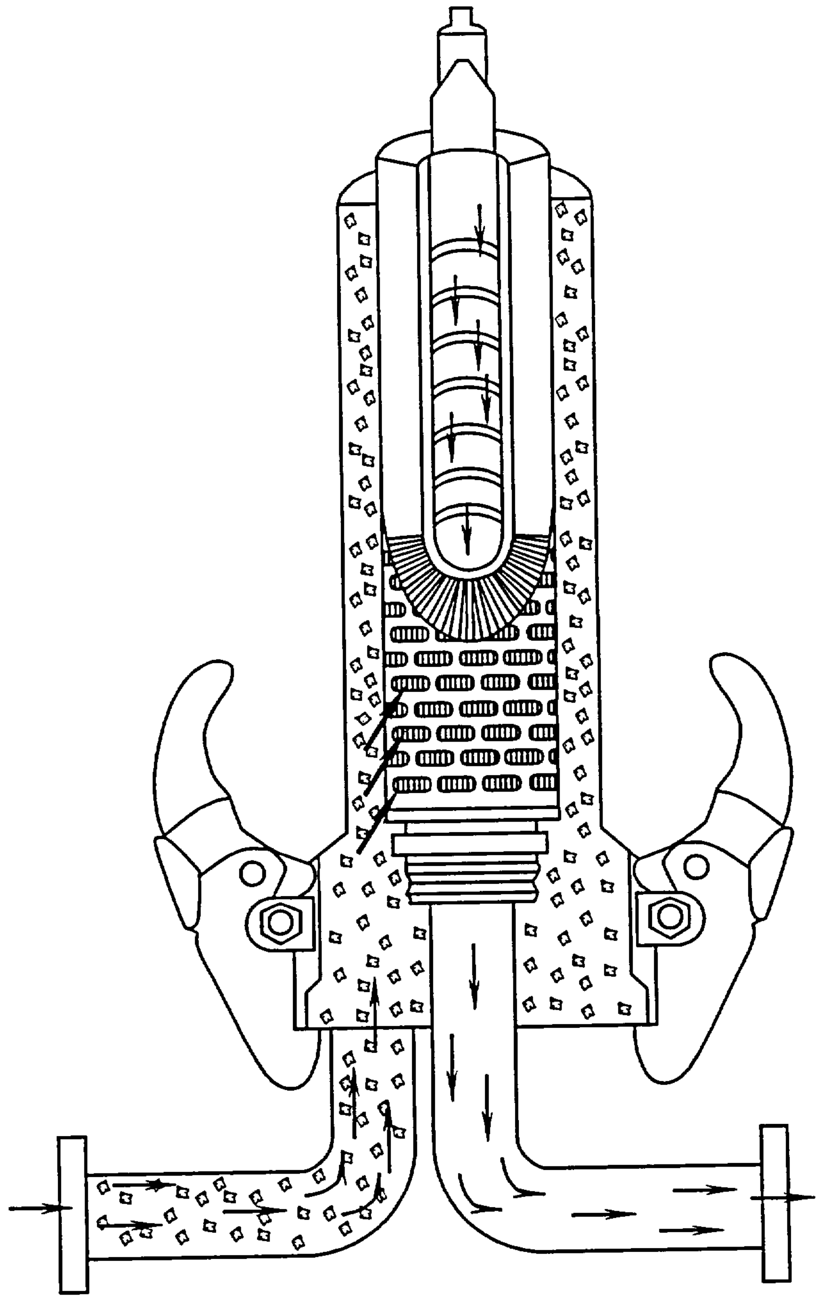

Figure 15.1-7 Cartridge Filter

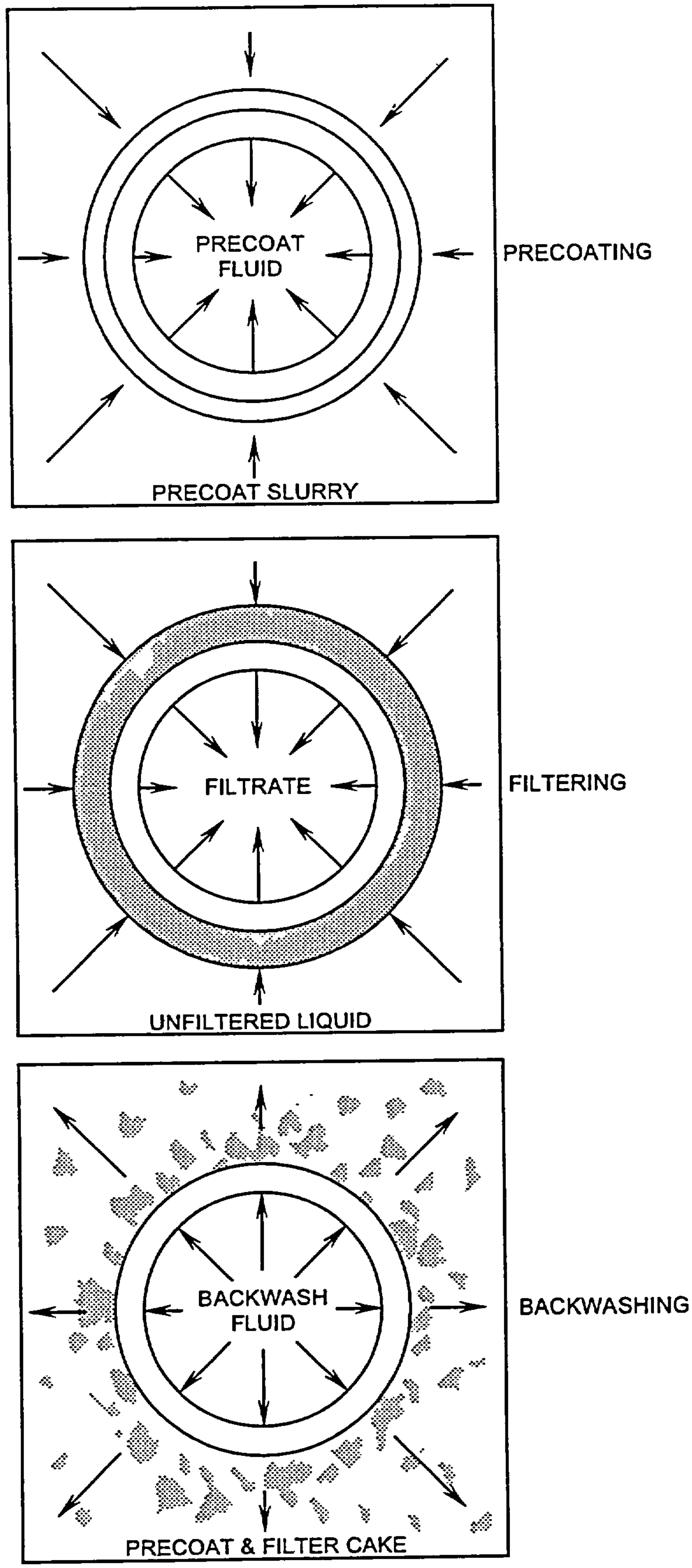

Figure 15.1-8 Precoat Filter

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Section 15.2

Solid Radioactive Waste Processing Systems

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15.2 SOLID RADIOACTIVE WASTE SYSTEMS

Learning Objectives:

1. List the two categories of solid radwaste.

2. Provide three examples of each category.

3. List and briefly describe two solidification systems.

15.2.1 Introduction

The most rapidly changing area in radioactive waste management today is that of solid radioactive waste processing. New solidification processes and agents are being used and more emphasis is being placed on volume reduction. Increasing concern for volume reduction is a result of the lack of adequate space in commercial shallow land burial grounds, and the spiraling cost of shipping and disposal.

A past study projected that the existing commercial burial ground would soon be filled to capacity, and burial facilities are experiencing difficulty handling the large number of waste shipments that are being received. This study predicted annual volumes of solid wastes that were well in excess of previous estimates and suggested that the capacities of most plants' solid radioactive waste systems (SRW) were under-designed by approximately a factor of two. It was this realization on the part of facility managements that caused the rush to add solid waste handling systems.

15.2.2 System Description

The materials destined for the SRW are grouped into two broad categories: wet wastes, which are the subjects of de-watering or volume reduction processes, and dry wastes, whose volumes are reduced primarily by compacting or baling (Figure 15.2-1). The most common techniques and processes in use or planned for the SRW are covered in this chapter. It should be understood that some volume reduction systems may not be covered and that these processing methods are strictly individual facility options. Various combinations of processing methods may be encountered at different plants.

Since all commercial burial sites prohibit the burial of liquids, the SRW must be designed to immobilize (solidify) wet waste into a free standing, monolithic form. To accomplish the objective of solidification, the SRW incorporates a number of discrete operations or subsystems. The treatment of the wet wastes may be broken down into five operations:

- waste collection
- waste pretreatment (de-water/volume reduction)
- solidification
- mixing/packaging; and
- container handling

The treatment of dry waste may be broken down into three operations:

- waste collection;
- mixing/packaging; and
- container handling

Table 15.2-1 lists the SRWs at selected Westinghouse facilities.

15.2.2.1 Wet Wastes

The term wet wastes refers to contaminated wastes having sufficient water content to allow them to be pumped to collection tanks for processing. Wet solid wastes are classified into four basic types:

- spent resin
- filter sludge
- evaporator concentrates and
- miscellaneous liquids

Spent resins

Spent resins result from liquid radwaste demineralizers, fuel storage pool coolant cleanup (Chapter 14.5), and reactor coolant cleanup (Chapter 4.1).

Filter Sludge

Filter sludge consist of spent filter and material from precoat filters and powdered resin from precoat filter/ demineralizers.

Evaporator Concentrates

Evaporator concentrates or evaporator bottoms result from the treatment of liquid radwaste evaporators. Evaporator concentrates consist of concentrated boric acid and radioactive particulate solutions.

Miscellaneous Liquids

Miscellaneous liquids are solutions that may contain a high concentration of chemicals that make this liquid difficult to process in the liquid waste system. The miscellaneous liquids generally will come from the chemical waste system.

15.2.2.2 Dry Wastes

Dry wastes are comprised of contaminated articles such as rags, disposable clothing, cleaning equipment, tools, disposable filter cartridges, and in some cases plant equipment.

Disposable filter cartridges present a different problem due to their moisture content and high radiation levels. Filter cartridges are treated as dry waste but are processed differently than the other dry waste materials.

15.2.2.3 Collection

Demineralizer resins and filter sludge are routinely collected in separate tanks which facilitates further treatment as they can be directed towards a specific waste process. Liquid waste, and decontamination solutions may be segregated during waste collection. Increasing the degree of waste segregation generally facilitates subsequent immobilization treatment.

15.2.3 Pretreatment Subsystems

Pretreatment is primarily directed towards reducing waste volume which reduces transportation and burial costs. Wet wastes, are generally in the form of slurries containing as much as 85% water. If this water can be removed and reused in the plant, the demands on the SRW will be greatly reduced. The following Table 15.2-2 illustrates the need for volume reduction.

Table 15.2-2
Volume Reduction

Process	55 gal drums/year
1. Drum packaging with cement, no de-water or volume reduction	~4500
2. Drum packaging with cement, and volume reduction	~500
*3. Drum packaging with urea formaldehyde polymer, no de-water or vol. red.	~2500
*4. Drum packaging with urea formaldehyde polymer, and volume reduction	~200
*5. Drum packaging with asphalt extrusion/evaporator process	~280

* Installed but not used at selected facilities

Various methods and options are available for the treatment of these wastes. The most common methods of pretreatment are decanting, centrifuge, evaporation, calcination, and filtration systems.

15.2.3.1 Decanting

The process of decanting (Figure 15.2-2), has been used for several years primarily to de-water resin slurries. The spent resin is flushed out of the ion exchanger into the spent resin tank. When it is time to process the spent resin, it will be pumped from the spent resin tank into the decant tank. This slurry is allowed to settle, with the resin beads dropping to the bottom of the decant tank. After settling, the decant arm, which is actually a movable pump suction tube, is lowered to just above the resin level. The position of the decant arm is determined by a sonic sensor, which can discern the resin water interface. The pump then switches the suction and discharge paths to take a suction on the bottom of the decant tank and discharges the de-watered resins to the mixing packing system for solidification.

15.2.3.2 Centrifuge Separation

Centrifuge separation is a method in which mechanically driven rotating devices use centrifugal force for separating substances of different densities. There are several types of centrifuges in use for de-watering radioactive waste. The most commonly found centrifuges are the tube and disk, ant the basket. The tube and disk type uses a rotational force to cause the solids to migrate to the tube wall, where they can be collected, and the clear liquid overflows the tube. The basket or filtering type forces liquid through a rotating screen which collects the solid and allows the clear liquid to flow through. Centrifuges are most commonly used to de-water resin slurries and precoat filter materials.

15.2.3.3 Evaporation

Evaporator have a wide range of uses in the management of radioactive wastes, and as explained earlier (Section 15.1.2.3), evaporators are effective in the volume reduction of wastes. There are many different types of evaporators in use that will meet the requirements of the SRW. The thin film evaporator is one type in use (Figure 15.2-3).

The advantage of the film evaporator (wiped film dryer) is its capability to evaporate to high waste product concentrations. The heating surface consists of a cylinder which contains a rotating blade or series of wipers, maintained at a fixed close clearance from the cylinder inner wall. The cylinder is externally heated by a steam jacket or other heat source. Liquid waste is fed into one end of the cylinder and agitated by the rotating blades which wipe the waste film from the heated cylinder. Partial evaporation from the film occurs quickly, and subsequent blade travel continuously redistributes the concentrate film as it progresses toward the discharge end of the cylinder.

The water product is discharged in the form of a liquid, slurry, or free flowing solid. this discharge material will then be solidified in another portion of the SRW.

15.2.3.4 Calciner System

Calcination is a high temperature process in which wastes are dried and thermally decomposed to form stable, non-fused compounds such as oxides. To date, much of the developmental work in calcination has been directed toward treatment of high level wastes. The end product from calcination represents minimum volume and can be powdery dusts, free flowing granular material, or a porous friable cake. In calcination systems, various liquid wastes are sprayed into a direct fired calciner vessel. Here the liquid flashes to steam, as the droplets come in contact with the vessel. Heat for this process is supplied by burning a combustible fluid. The dry calcined product is collected from the vessel and transferred to the solidification portion of the SRW.

15.2.3.5 Filtration

Solid waste products can be generated by filtration. Filtration systems commonly used in the pretreatment of wet wastes are reverse osmosis and precoat filters. These units were discussed in Sections 15.1.2.4 and 15.1.2.1 respectively. In reverse osmosis or precoat filtration, the impurities will be deposited on the membrane of the reverse osmosis unit or the precoat material of the precoat filter. Essentially pure water passes through these units and is collected in the monitor tanks where its ultimate disposal will be determined. During operation, the membrane or precoat material will become saturated with impurities. After saturation, the impurities along with the membrane or precoat material will be solidified.

15.2.4 Solidification

In this operation, the wet solid wastes are incorporated with a solidification agent to form a monolithic free standing solid. The basic solidification agent types are:

- Cement
- Urea-Formaldehyde
- Bitumen (Asphalt)
- Other polymer systems

15.2.4.1 Cement Systems

Cement is use to solidify free liquids by chemically binding the heavy liquid waste into a crystal like structure. Different mixtures and ratios of cement and additives are used depending upon the type of waste to be solidified. Cement has been commonly used as a solidification agent and is generally acceptable to all burial sites.

The optimum proportions of waste and cement and type of cement chosen will vary with the system type and its composition. Cement requires a minimum amount of water to obtain work ability. This minimum water to cement ratio is approximately 25% by weight for Portland Cement. The addition of too much water may result in a layer of free standing water on the surface of the solidified product. Boric acid and borate salts retard setting in Portland Cement. Therefore if sufficient quantities of borated water are added to the cement the set may be retarded to an extent that the cement may never harden. In the case of waste resins, filter sludge, and power, liquid waste or pure water may be added to form an acceptable mixture for good setting properties. To aid in the solidification process, sodium silicate is used as an additive to increase the waste/cement ratio. Sodium silicate is especially effective when the waste contains boric acid or borate salt solutions.

The two basic types of cement solidification systems are the drum tumbling mixing system and the in-line mixing system (Figure 15.2-4). The prime differences are in where the mixing of the cement and waste occurs. Advantages of cement as a solidification agent are its availability, low cost, fire resistance and well known characteristics. Disadvantages include post leach ability and problems with solidification if the correct waste/cement ratios are not maintained. All operations are carried out with remote handling equipment located in shielded areas. Automatic sequences simplify individual processes and reduce the possibility of operator errors. Special shielding arrangements have been established to improve access to equipment requiring routine maintenance.

15.2.4.2 Urea Formaldehyde Systems(Installed but not used)

Urea Formaldehyde (UF) resin is a liquid emulsion of urea and formaldehyde chemically combined to polymeric chains. This resin can be readily mixed with water. When an acid catalyst is added to the resin/water solution, a condensation mechanism occurs and a solid is formed. The water that was added to the resin is now entrapped on this solid polymer matrix. Several different acids may be used as the catalyst. Polymerization is pH dependent and the amount of catalyst necessary to produce a waste/UF mixture pH of approximately 1.5 must be determined for each waste processing batch. The resulting formulation will begin to gel within several minutes after the addition of the required quantity of catalyst and will generally form a free standing solid within thirty minutes. The polymerization reaction may, however, continue for several hours during which small quantities of acidic free standing water may be released. Figure 15.2-5 shows a simplified schematic of the UF process flow. As in the case with cement, the UF mixing process can be carried out either in an in-line mixer or directly in the burial container. In both cases, the catalyst is added last to avoid the problems associated with premature resin setting.

15.2.4.3 Asphalt Extrusion (Installed but not used)

Bitumen or asphalt is a mixture of high molecular weight hydrocarbons obtained as a residue in petroleum or coal tar refining. Several types of bitumen systems are available, but the direct distillation product is on of the most widely suggested for radwaste solidification. The asphalt extruder system reduces the volume of waste and caused solidification all in one step.

In this process (Figure 15.2-5), asphalt and either liquid or sludge wastes are continuously pumped into one end of a screw extruder which may contain one or multiple screws. The design and operation of the extruder is such that the asphalt and waste are intimately mixed and spread into a thin film on the heated surface of the extruder barrel. This mechanical processing together with the maintenance of a temperature of approximately 200 °C affects the almost complete (99.5%) evaporation of the water contained in the waste and provides a homogeneous product. The evaporated water is vented through sections called steam domes and passed through oil separators before being condensed. The number of domes needed varies depending on the size of the extruder needed to evaporated 99.5% of the water out of the waste input.

Evaporation rated from the various size extruders range from .25 gallons up to 50 gallons of water per hour. The asphalt waste mixture is discharged directly into the solidification containers at the end of the extruder and allowed to cool. The asphalt extruder system does have some specific problem areas. One being the oil carry over that can occur in the steam domes. This carry over would cause serious clean up problems. The second disadvantage of this system is that asphalt burns and there is some evidence that the incorporation of oxidizing agents increases the fire risk.

15.2.4.4 Polymer Systems

Binder 101 is a commercially available modified vinyl ester resin. For solid waste, the dry product is coated with solidification agents and solidified by cross linking of the polymer.

The solidification agent is blended with the quantity and type of promoter required by the pretested formulas at the filling station during the drum filling process. Catalyst in a stabilized condition is added to the drum via the in-drum mixer at the end of the drum filling process.

Stabilization of the catalyst permits it to be located in close proximity to the polymer for an indefinite period of time without catalysts. Catalyst is dispersed into the binder/promoter moisture during the verification phase that takes place with the drum processing enclosure during the drumming process. Because formation of the binder/waste stream mixture does not require high energy mixing, a temperature rise (less than 5 °F) due to mixing can be ignored. Quantities of binder, promoter, catalyst, and waste are determined by verification testing of the individual simulated waste stream.

The binder works as a solidification agent by surrounding the waste stream and physically entrapping it after polymerization. Generally, there is no chemical reaction between the waste stream and the solidification agent as there is with cement and liquid wastes. Once addition of the waste stream is complete, the reaction proceeds by first gelling and finally becoming a solid block. The cross linking reaction is exothermic. The exothermic reaction is not noticeable until the polymer waste mixture has gelled and begun to harden.

Solidification of this dry product requires that the dry product enter the drum at a temperature below 13 °F. Although at higher temperatures the viscosity is reduced which promotes mixing, the high temperatures have an adverse effect in that the polymerization process is accelerated.

15.2.5 Drumming

Prepared Department of Transportation (DOT) approved drums are placed in the drumming room. The waste product is transferred to the drums. After the proper amount of waste material has been added, the filling process is terminated. When the drums have been properly capped, they are transferred to a temporary storage area until shipment to a burial site. It should be noted that almost all steps in drumming process to storage are performed remotely.

15.2.6 Dry Waste Packaging

Contaminated articles such as rags, disposable clothing, cleaning equipment, tools , and in some cases, plant equipment are disposed of as dry waste. Most nuclear plants have a dry waste bailer or compactor to reduce the volume of loose dry waste prior to shipment to a licensed burial site. Disposable filter cartridges present a different problem due to abnormally high radiation levels. They are usually placed in special shielded casks for off-site disposal. The compaction, baling or casking operations that the dry wastes undergo are usually performed from remote locations.

15.2.3 Summary

Operating costs have risen to the level of several million dollars per year with no indication of leveling off. Therefore, much of the development and back fitting of the solid radioactive waste systems is directed toward reducing the total volume of packaged waste being shipped off-site. The SRW is designed to handle both wet and dry wastes.

Wet wastes may be de-watered by using various pretreatment system prior to solidification. The de-watered waste will then be solidified into a free standing form using some type of solidifying agent such as cement. Dry wastes are either bailed or compacted to reduce their volume. The drumming station is design to be remotely operated to limit the radiation exposure received by plant personnel.

Table 15.2-1
Solid Waste Processing Systems

Plant Name	Licensed Disposal Contractor	Solidification Agent	Catalyst Agent	Comments
R.E. Ginna	No	Cement		
Kewaunee	No			
Point Beach 1 & 2	No	Cement		
Prairie Island 1 & 2	No			
Beaver Valley 1 & 2	No	Cement		
J. M Farley 1 & 2	Yes	Cement		Hitman type disposable demineralizers. System is also used to process CVCS holdup tanks
Sharon Harris	No	Cement Vinyl Ester Polymer		Cement used for spent resins. VEP used for decanted dry salts
North Anna	Yes	Cement		UF system installed, not used.
H. B. Robinson	No	Cement		
San Onofre	Yes	Cement		
V. C. Summer	Yes	Cement	Sodium Bisulfate & Calcium Hydroxide	
Surry 1 & 2	Yes	Cement		Liquid Waste Demineralizer Subsystem
Turkey Point	No	Cement		
Byron 1 & 2	No	Cement		Cement used for liquid and resins. Polymer used for fluidized bed dryer salts from evaporator bottoms.
Braidwood	No	Cement		Cement used for liquid and resins. Polymer used for fluidized bed dryer salts from evaporator bottoms.
Calloway	No	Cement		Decant tank used to de-water resins and charcoal slurries prior to solidification.
Catawba	Yes	Cement		Mobile solidification unit
Comanche Peak	Yes			Mobile solidification processing skid ACTOR system (Topical Report ATC-132A)
D. C. Cook	Yes	Cement		
Diablo Canyon	Yes	Cement		Mobile Radwaste Purification System
McGuire 1 & 2	Yes	Cement		Waste Solidification pad. UF system installed not used
Millstone 3	No			Portable Solidification Unit
Salem	No	Cement		
Seabrook 1 & 2	Yes	Cement		Mobile Solidification contractor. Plant set up to use asphalt extruder

Sequoyah 1 & 2	Yes	Cement		Mobile Solidification System
Trojan	No	Tiger Lock (Cyanaloc-62)	Sodium Bisulfate	50 ft³ Disposable Liners
Vogtle	No	Cement		Cement used for liquid slurry wastes. Polymer used for dry product wastes from volume reduction system. Fluidized bed dryer produces dry product wastes
Wolf Creek	No	Cement		Decant tank used to de-water resins and charcoal prior to solidification.
Zion 1 & 2	No	Cement		

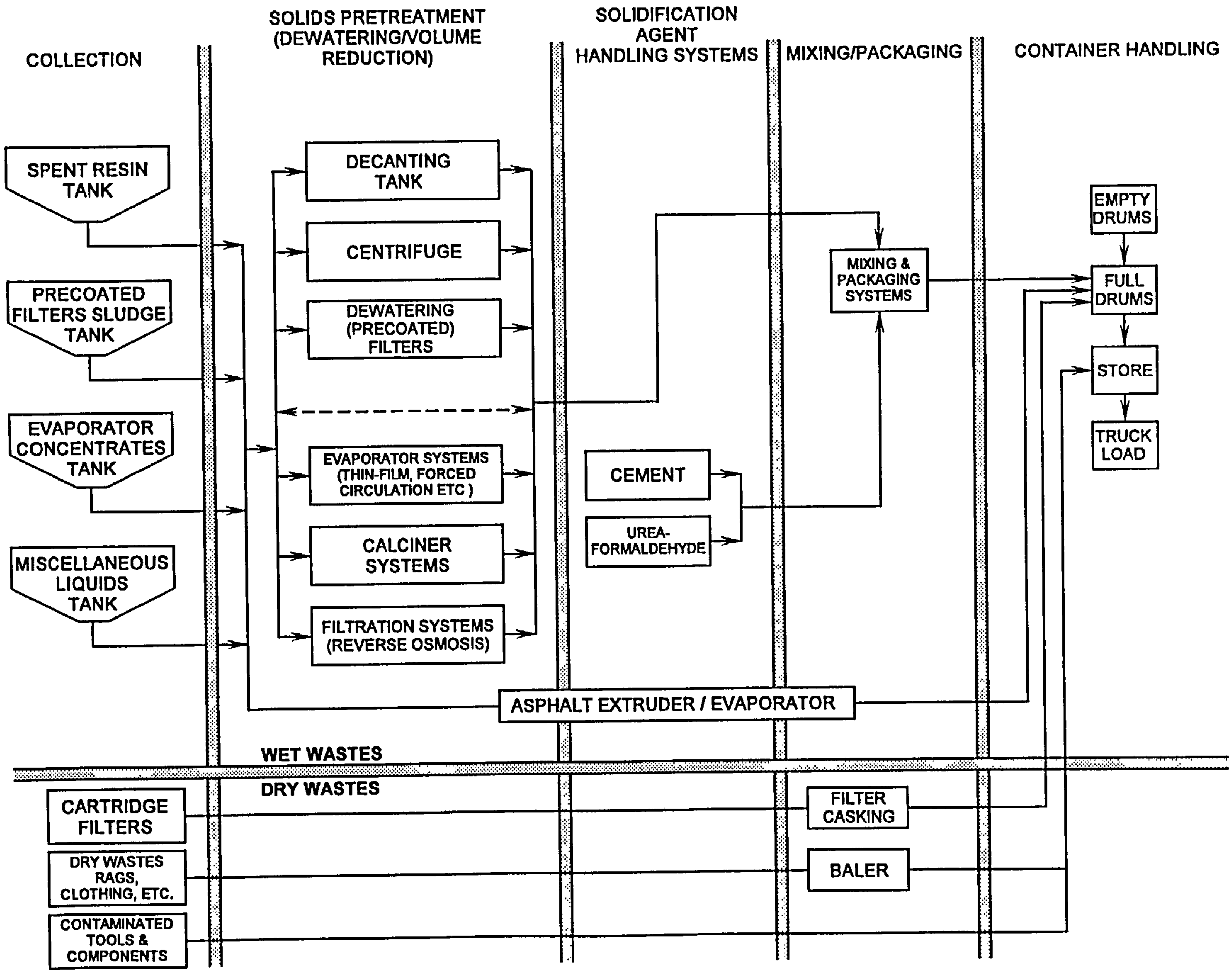

Figure 15.2-1 Solid Waste Processing Flow Diagram

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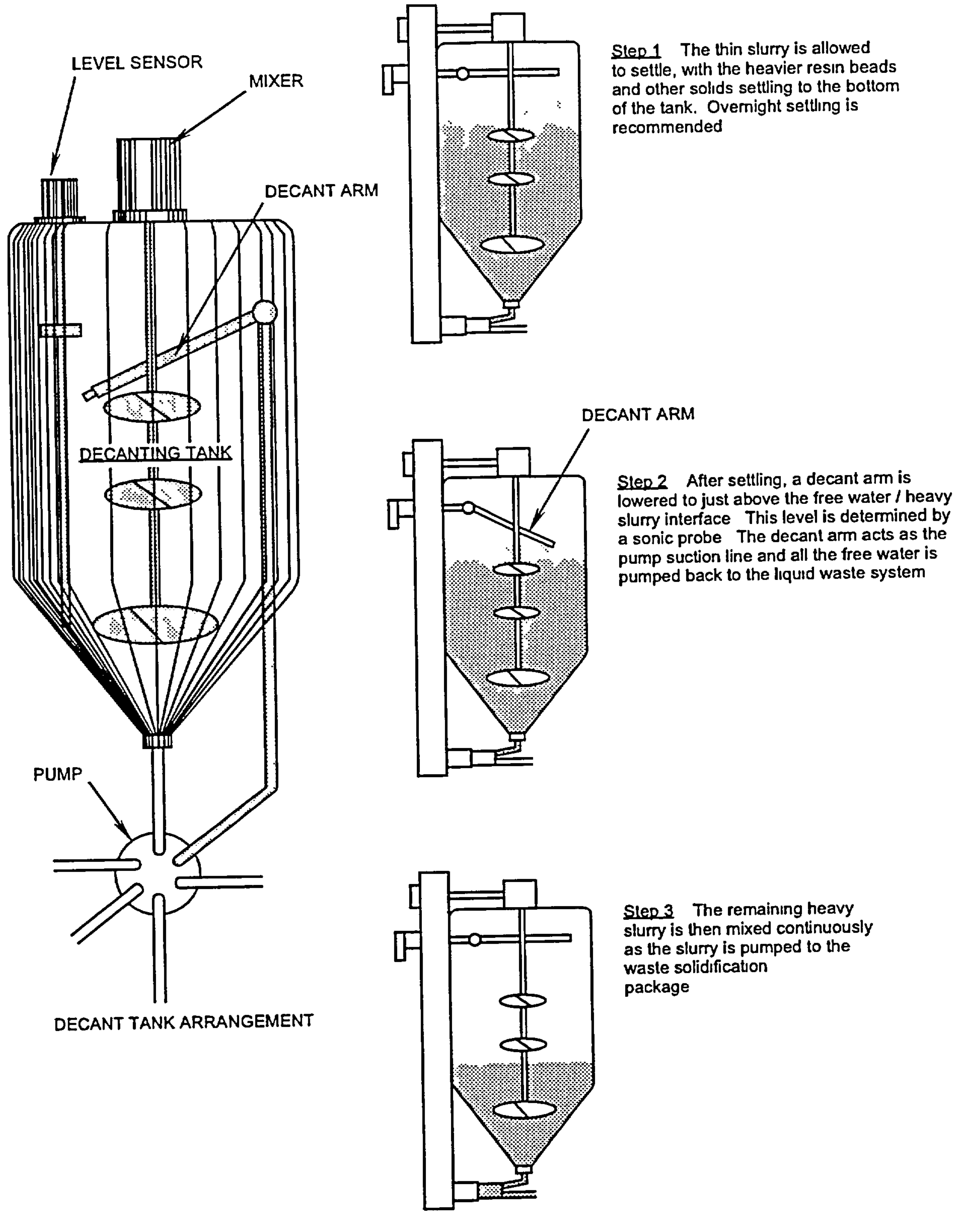

Figure 15.2-2 Decanting Tank System

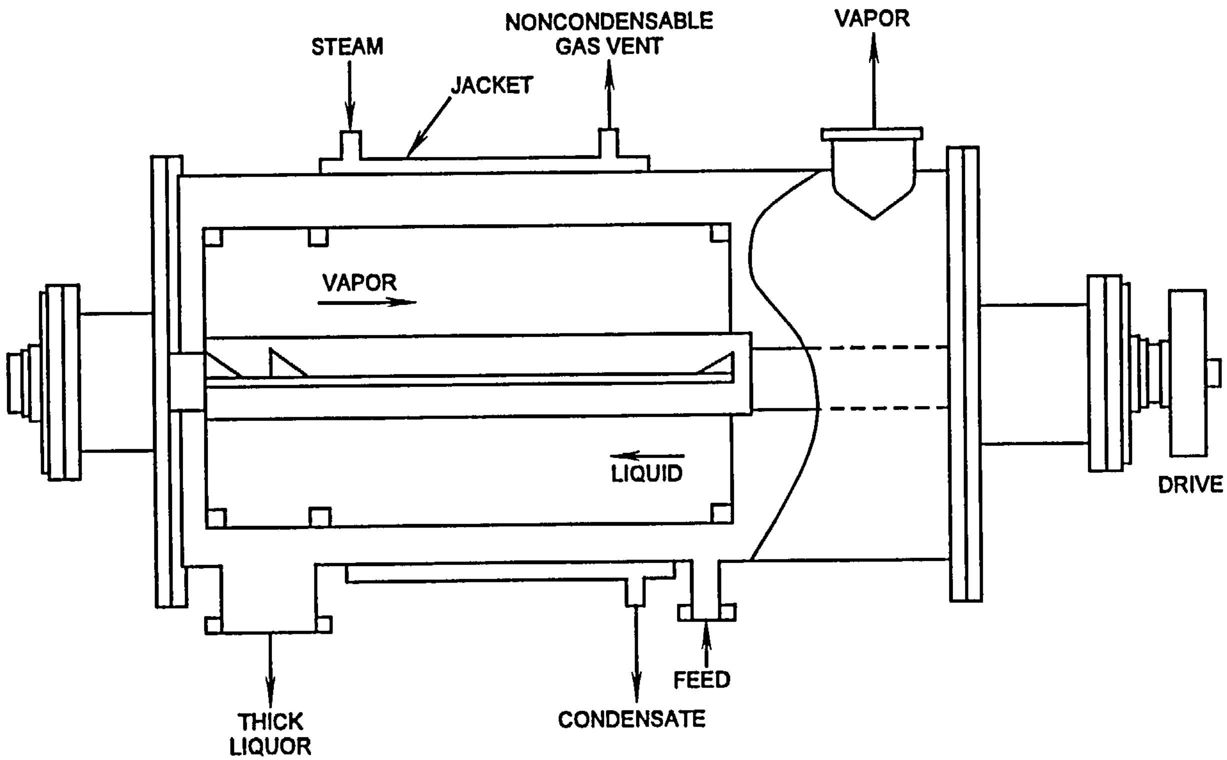

Figure 15.2-3 Wiped - Film Evaporator

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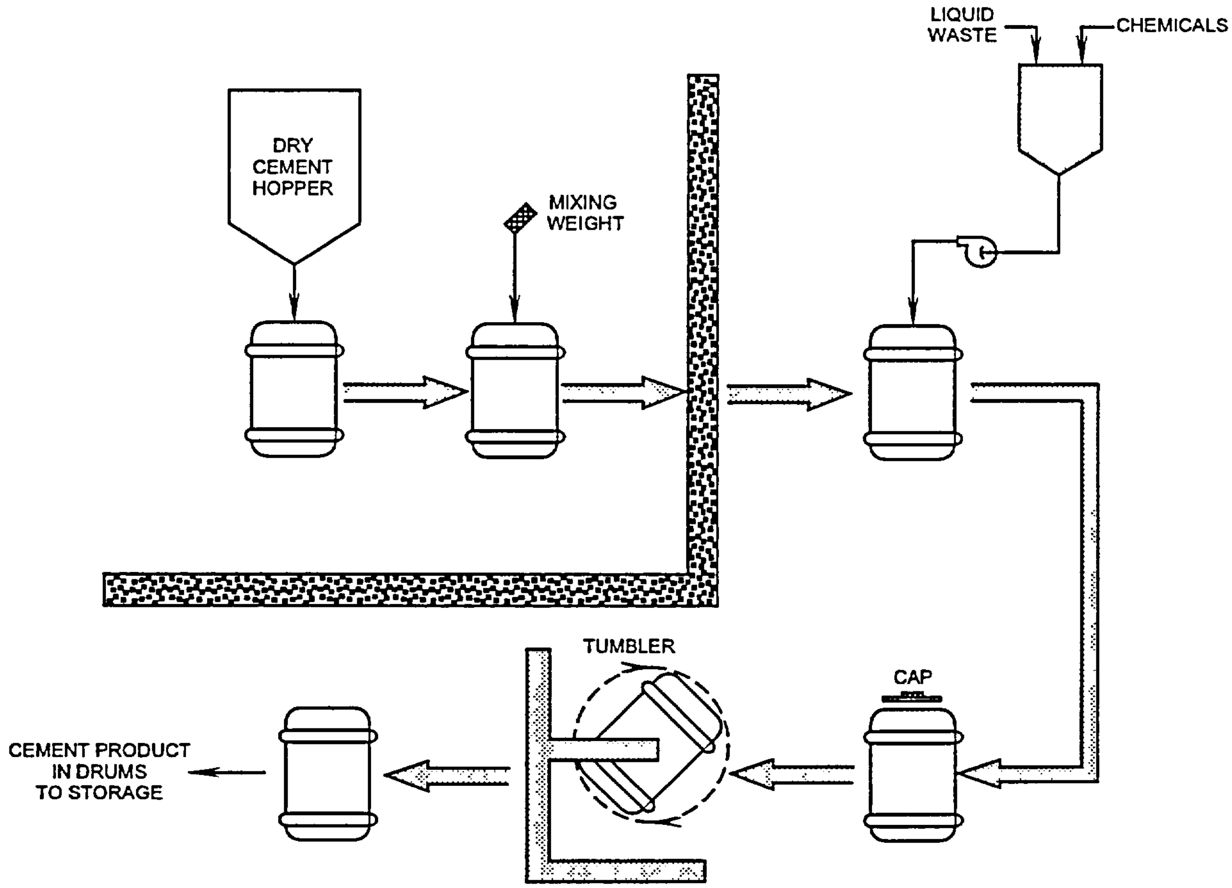
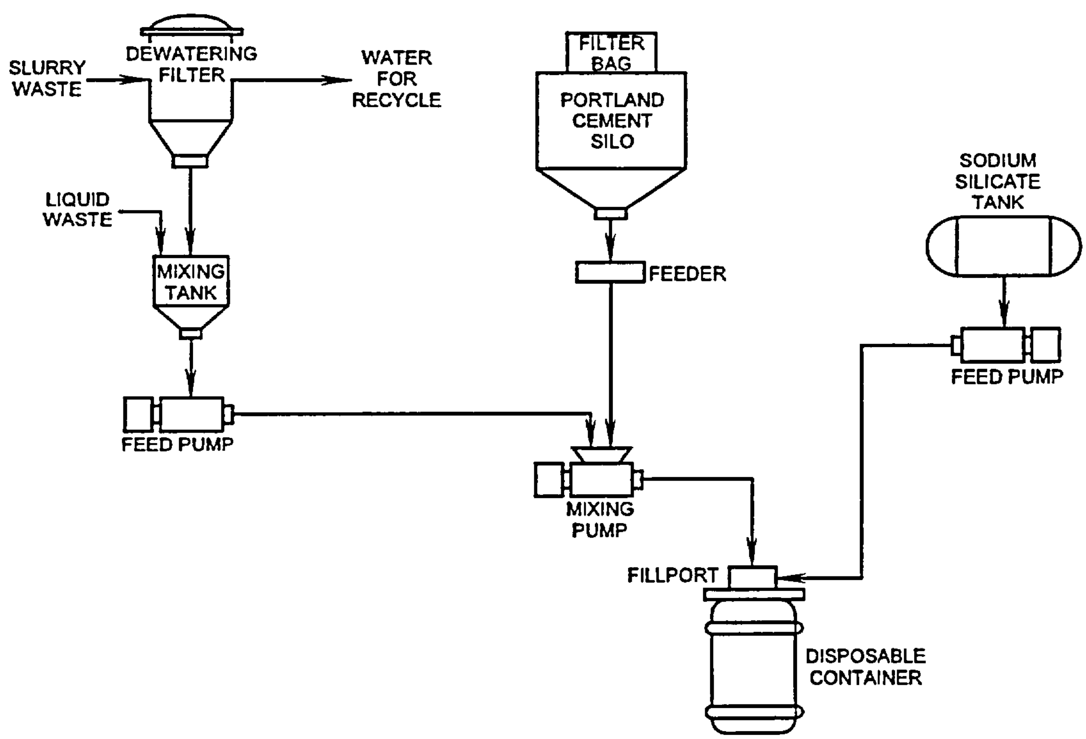
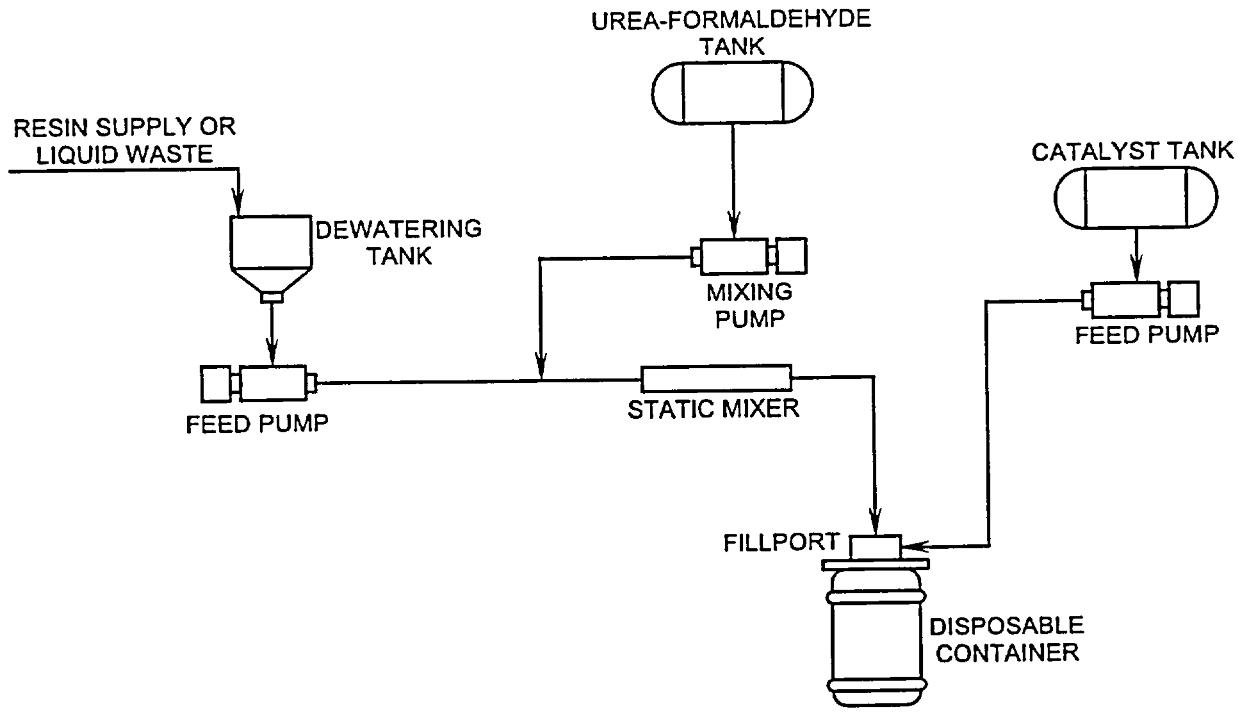


DRUM - TUMBLING CEMENT SYSTEM



IN - LINE MIXING PORTLAND CEMENT SYSTEM

Figure 15.2-4 Cement Systems



IN-LINE UREA-FORMALDEHYDE SOLIDIFICATION SYSTEM

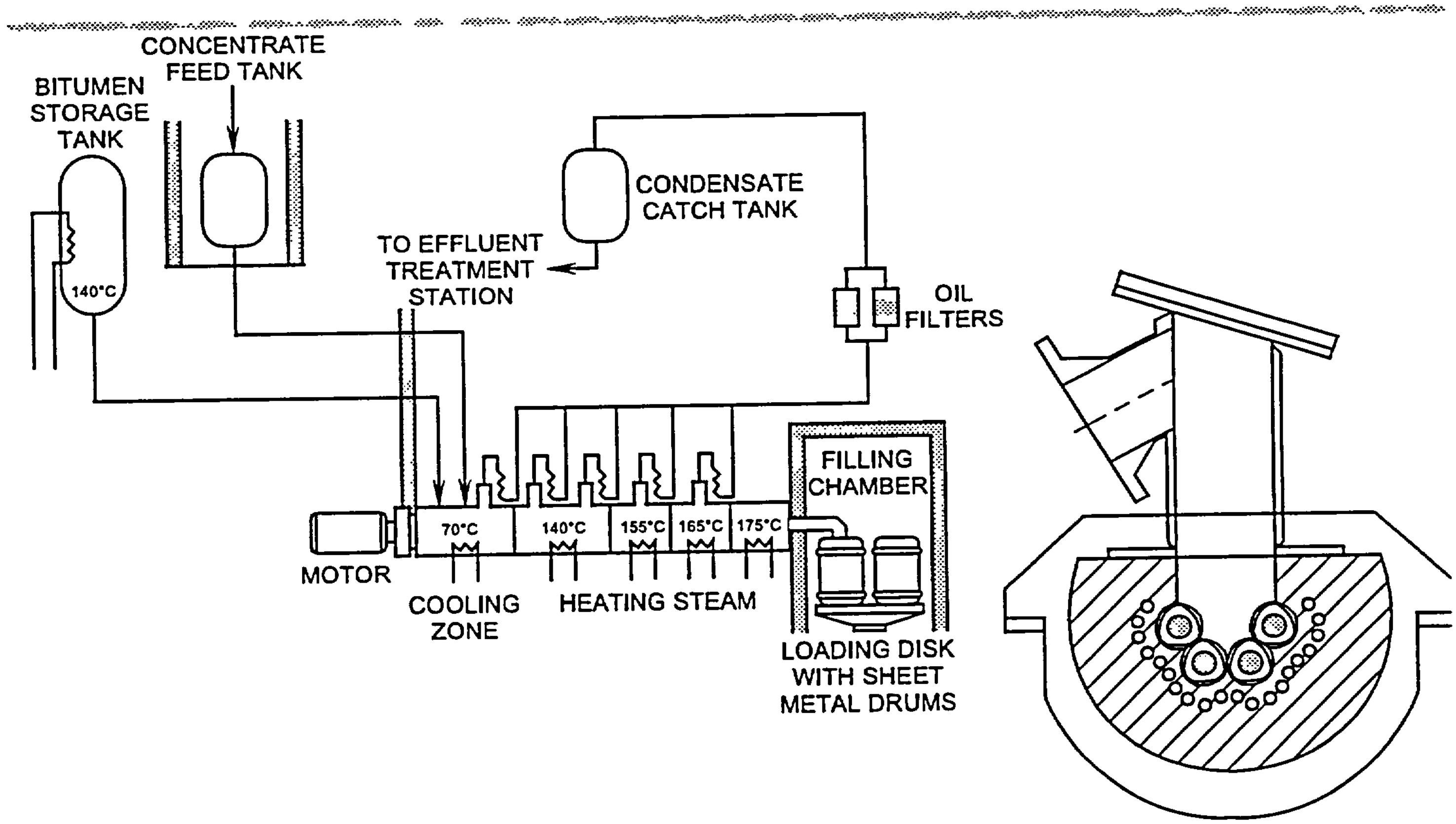


Figure 15.2-5 UF and Asphalt Solidification Systems

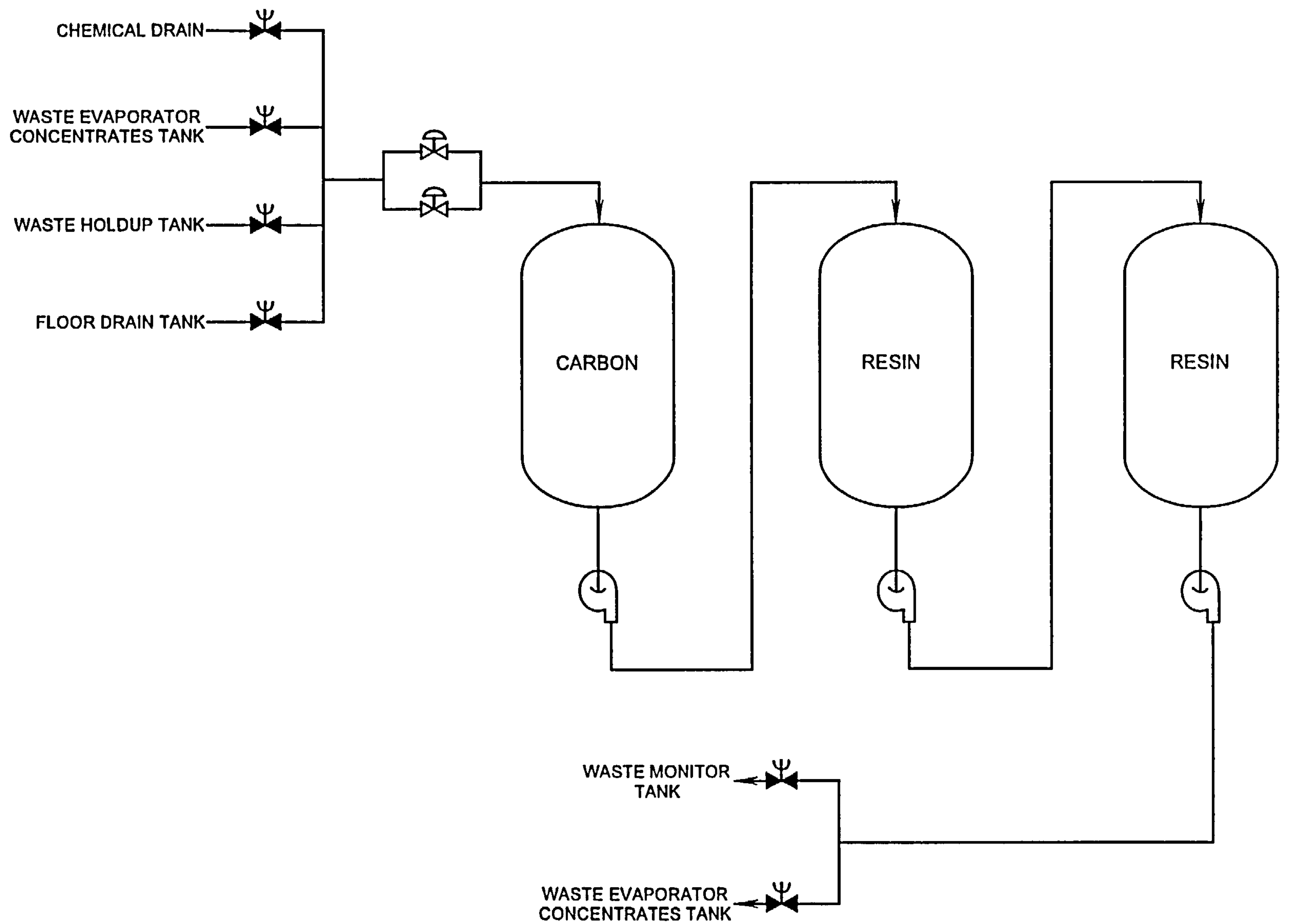


Figure 15.2-6 Three Tank Demineralizer System

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Westinghouse Technology Systems Manual

Section 15.3

<u>Gaseous Radioactive Waste Processing Systems</u>

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15.3 GASEOUS RADIOACTIVE WASTE SYSTEMS

Learning Objectives:

1. List both the principle volume contributors and radioisotope contributors to the gaseous radioactive waste system.

2. Explain the basis for the curie limit placed on a gas decay tank.

3. Explain the reasons for using cover gas.

15.3.1 Introduction

The gaseous radioactive waste system (GRW) begins at the point of discharge from plant components or systems designed to remove radioactive gases from the reactor coolant system and related auxiliary systems. The GRW terminates at the point of discharge into the plant ventilation exhaust system. Waste gases originate from several sources. These sources may be intermittent or continuous depending upon plant design. The gases processed by the GRW consist mainly of hydrogen and nitrogen with small amounts (by volume) of fission gases. Aerated gases are not processed to preclude the formation of explosive oxygen-hydrogen mixtures.

The radioactive gases of primary interest are xenon 133 (Xe-133) and krypton 85 (Kr-85) as these are the only gases present in significant amounts which have relatively long half lives. Waste gases are generally combined in the GRW for common treatment rather than separating the gases for separate treatment. There are a number of process designs which meet the performance objectives for gaseous waste systems and some of these different systems will be discussed in this chapter.

Each of these systems is designed to meet the following criteria:

1. Radioactive materials in gaseous effluents from the plant collectively meet the design objectives given in 10 CFR 50, Appendix I, and limits specified in 10 CFR 20.

2. Accidental release of radioactive material from a single component would not result in an off-site dose which would exceed the guidelines of 10 CFR 100. Radiation exposures to plant operation and maintenance personnel will be maintained "as low as reasonably achievable."

15.3.2 System Description

The GRW in use at most present generation pressurized water reactor facilities is designed to collect and store gaseous waste for radioactive decay prior to controlled release to the environment. These systems consist of a combination of the following items: a collection header into which the various sources of waste gas discharge, compressors to reduce the volume of the gas, recombiners to reduce the hydrogen concentration, charcoal beds for removal of iodine and tanks in which the pressurized gas is stored for decay prior to release. Provisions are also made to allow use of the stored gas as a cover gas for selected liquid holding tanks to prevent aeration of the fluids contained in these tanks. The various waste gas systems described in the following sections will be the storage and release, volume reduction, and charcoal adsorber systems. Table 15-3-1 lists the gaseous waste systems for selected Westinghouse facilities.

15.3.2.1 Storage and Release System

A simplified process flow diagram for the gaseous waste storage and release is shown on Figure 15.3-1. With this simplified system gases are vented from various components or systems into a vent header. The waste gas will flow to a surge tank and filter unit and then to the inlet of a gas compressor.

The waste gas is compressed and then stored in any one of several storage tanks called gas decay tanks. This gas may then be reused as a cover gas or released to the environment. The gas that is to be released to the environment will be stored in a decay tank for some period of time to allow for the decay of short lived radioactive gases.

A more detailed process flow diagram for a typical storage and release GRW is shown on Figure 15.3-2. The GRW is essentially a closed loop system in which the gas held in the gas decay tanks may be released to the environment after a specified decay time, or be returned as a cover gas to various tanks that vent to the vent header. This cover gas is used to minimize the aeration of liquids contained in these tanks and to prevent the entry of oxygen into the GRW. This could cause explosive mixtures of hydrogen and oxygen to occur. Generally the last decay tank to receive gas will be the first decay tank used to supply the cover gas. This provides for the maximum decay time prior to releasing the gas to the environment. The various components or systems that may vent to the vent header are as follows:

- Volume Control Tank
- Holdup Tanks
- Reactor Coolant Drain Tank
- Pressurizer Relief Tank
- Chemical and Volume Control System
- Gas Stripper
- Boric Acid Evaporator
- Waste Evaporators
- Volume Control Tank Gas Sampler
- Gas Analyzer Return

These tanks and components will vent nitrogen, hydrogen and trace amounts of fission gases to the vent header. The waste gases collected by the vent header, as described in the previous paragraph, will flow to the suction of the waste gas compressors. One of the two gas compressors is in continuous operation with the second unit in standby to act as a backup for peak load conditions or failure of the operating unit. From the compressor, gas flows through coolers to one of several gas decay tanks.

The control arrangement of the gas decay tank inlet header is designed with sufficient flexibility to allow the operator to align several tanks to perform different evolutions at the same time; such as, one tank being pressurized, one tank in standby, one tank supplying cover gas and one tank releasing its contents to the environment. For example; as shown on Figure 15.3-2, the gas decay tanks can be aligned with one tank being pressurized by the compressor (Tank 1). Another tank will be placed in standby so when the tank receiving gases from the compressors is pressurized to some specified set point the inlet valve to the pressurized tank will close. This will actuate an alarm to alert the operator so that a new standby tank may be selected. The last tank pressurized will now be aligned to be used as cover gas (Tank 3) as explained earlier in this section.

If the stored gas has decayed sufficiently in a decay tank (Tank 2), it may be released to the environment. Prior to the release the gas must be sampled and analyzed to determine the total amount of activity to be released. After analysis the gas can then be released to the plant vent at some controlled rate through a radiation monitor. If a high activity is indicated in the plant vent during the release an automatic valve in the discharge line will close.

15.3.2.2 Volume Reduction System

The volume reduction system is essentially the same type of system as the storage and release system (15.3.1.1), the difference being a device is incorporated into the system to reduce the volume of waste gas. This volume reduction is accomplished by a recombiner system to remove the hydrogen in the waste gas stream, and by re-using the nitrogen collected in waste gas. Since hydrogen and nitrogen comprise the major portion of the volume of waste gas, this will result in a much smaller volume of gas to be stored. Although the system has the capability for discharge to the environment after decay, it is anticipated that no scheduled releases will be necessary over the forty year life of the plant.

The volume reduction system for processing waste gas consists mainly of a closed loop comprised of two waste gas compressors, two catalytic hydrogen recombiners, and gas decay tanks to store the fission product gases. The process flow diagram is shown on Figure 15.3-3.

The GRW, with recombiners, removes fission gases from plant components and contains them indefinitely to eliminate the need for regularly scheduled discharges.

By continuous degassification of the reactor coolant at the volume control tank (VCT), the GRW also functions to reduce the escape of radioactive gases during maintenance operations or unavoidable equipment leaks. The design is based on continuous full power operation with all fission gaseous leakage into the coolant associated with the 1% failed fuel criteria for the 40 year life of the plant.

Although the system is designed to eliminate regular atmospheric discharge of waste gases, disposal of radioactive gas may become necessary at some time during the plant life. Therefore, the system includes provisions to sample and isolate each of the gas decay tanks.

The GRW is a closed loop comprised of two waste gas compressors, two catalytic hydrogen recombiners, four gas decay tanks for normal power service, and two gas decay tanks for service at start-up and shutdown.

During normal power operation, nitrogen gas, with contained fission gases, is circulated around the GRW loop by one of the two compressors. Fresh hydrogen gas is continuously introduced to the VCT, where it is mixed with fission gases which are stripped from the reactor coolant into the tank gas space by the VCT letdown line nozzle. The VCT is, in turn, continuously vented into the circulating nitrogen stream in the waste gas loop. Note that VCT pressure is determined by the hydrogen supply pressure regulator and not by the VCT purge flow regulator.

The resulting mixture of nitrogen, hydrogen and fission gases is pumped by one of the two compressors to one of the two catalytic hydrogen recombiners where enough oxygen is added to reduce the hydrogen to a low residual level.

The waste gas enters a recombiner package through a pressure regulator which absorbs inlet fluctuations and maintains a constant downstream pressure of 30 psig. Gas then flows through an electrical heater which maintains 200 - 220 °F to prevent condensed water from reaching the catalyst surface. Following the heater, oxygen is added and then the gas stream enters the catalyst bed where reaction between hydrogen and oxygen takes place.

The hot effluent stream from the reactor vessel enters the cooler-condenser where its temperature is reduced to 140 °F or less. This two phase mixture enters a high efficiency separator-mist extractor where liquid particles are removed.

Now free of entrained particles, process gas is discharged from the moisture separator into the gas system through a flow control valve. The gas is then routed through a gas decay tank, and sent back to the compressor suction to complete the loop circuit. Gas decay tanks 1 through 4 will be alternated so that the gaseous activity (as indicated on waste gas processing monitor RE-13) is distributed evenly among the tanks.

When gas decay tank pressure reaches about 20 psig, the recombiner back pressure control valve (flow control valve) will be full open so that no more adjustment can be made. To allow operation of the system to continue, the line-up of the system is changed to the "high pressure mode", where flow is from a compressor to a gas decay tank to a recombiner. This mode is suitable for operation up to 100 psig tank pressure, and it is also used during shutdown and startup operations with the shutdown tank set aside for this purpose.

When the residual fission gases and the hydrogen contained in the reactor coolant must be removed in preparation for a cold shutdown, VCT purge is increased to 1.2 scfm until the following criteria are met.

1. RCS hydrogen concentration is less than 5 cc/kg, and

2. RCS Xe-133 activity is less than 1.0 mCi/cc.

At this time, the gas decay tank which was in service during power operation is valved out and one of the shutdown tanks is valved in. During the first plant cold shutdown, fresh nitrogen is charged to the VCT to strip hydrogen from the RCS. The resultant accumulation of nitrogen in the shutdown tank is accomplished by allowing tank pressure to increase. During subsequent shutdowns, however, there is no additional accumulation since the gas from the first shutdown can be reused.

Gas decay tanks 1 through 4, which are used during normal operation, are designed to contain significantly higher concentrations of fission gases than those used during shutdown. Therefore, relief discharges (not shown) from tanks 1 through 4 are relieved into one of the shutdown tanks (150 psig). The shutdown tanks in turn relieve directly to the plant vent header (100 psig) (not shown).

Since the system is designed to operate with no regularly scheduled discharge over the 40 year plant life, extreme care must be taken to minimize the addition of any gases other than those which the system can process and remove. Contributors in order of importance include:

- B-10 (n,α) Li-7 reaction
- impurities in bulk hydrogen and oxygen
- Stable and long lived fission produce gases

The system just described uses a continuous purge of the VCT. There is a refinement to this system that some plants may utilize. This refinement is the use of chemical and volume control system gas stripper in lieu of the continuous purge of the VCT.

15.3.2.3 Charcoal Adsorber Systems

Another type of gaseous waste management system which may be interfaced with pressurized water reactors is the charcoal adsorber design. This design accomplishes holdup for decay of fission gases by adsorption on a charcoal bed with subsequent release to the environment.

The charcoal adsorber systems are not often used on present generation pressurized water reactors and will probably comprise only a small percentage of the systems applied with future facilities. A simplified process flow diagram of a

PWR ambient charcoal system is shown on Figure 15.3-4.

The ambient charcoal system will collect waste gases in the vent header in the same way as the previously mentioned GRWs. The gas will flow to a surge tank and filter unit to the inlet of a compressor. The compressor will transfer the waste gas to the charcoal adsorber beds where the radioactive gases will be held up for some period of time. The gases will then pass through a filter unit to be released into the plant vent.

A typical GRW using ambient charcoal is shown on Figure 15.3-5. Gases vented to the vent header are collected in the waste gas surge tank. These gases are dehumidified (moisture removed) by the gas refrigerant dryers. The gas is then filtered by the ambient temperature charcoal adsorbers. The hydrogen or nitrogen in the gas stream will pass through the adsorber beds while the xenon, krypton and any iodine present will be adsorbed. The charcoal beds are designed to delay xenon isotopes and krypton isotopes for minimum amount of time as explained in Section 15.3.3.4. In addition, an iodine decontamination factor of 10^6 is obtained during passage through the charcoal beds.

After passing through the adsorber beds, the hydrogen, nitrogen and delayed fission products are processed through the waste gas compressors to the waste gas receiver tank, from which they are discharged to the environment through a radiation monitor. Provisions are also included for the recycle of the purified gas stream to act as a cover gas. The normal mode of operation, however, is to discharge the gas stream directly into the plant vent. There are several variations of this system with the major difference in design being the temperature maintained in the adsorber beds. Refrigerated systems operator around 0 to 20 °F in the adsorber beds, this increases the efficiency and holdup times of the adsorber. Cryogenic systems operate at extremely low temperatures whereby the fission gases are liquefied, collected and stored on site.

15.3.3 Component Description

15.3.3.1 Waste Gas Compressors

Two compressors are normally provided for removal of gases to the gas decay tanks from all equipment that contains or can contain radioactive gases. These compressors are usually of the water-sealed, centrifugal, displacement type. The operation of the compressors is automatically controlled by the compressor inlet pressure. While one unit is in operation, the other serves as a standby for unusually high flow or failure of the first unit. The design discharge pressure of the compressor is 110 psig and the design flow rate at 10 psig is 40 cubic feet per minute.

15.3.3.2 Gas Decay Tanks

Welded carbon steel gas decay tanks are provided to contain compressed waste gases (hydrogen, nitrogen, and fission gases). The total number of gas decay tanks will vary from plant to plant. These tanks have a design pressure of 150 psig and have a volume typically of 600 cubic feet.

The quantity of radioactive material contained in each decay tank is limited by the plants Technical Specifications to insure that in the event of an uncontrolled release of a single tank (such as tank rupture), the resultant total body exposure at the exclusion area boundary will not exceed 500 mrem. This quantity of activity (equivalent to Xe-133) in a single gas decay tank varies depending upon plant location and population density. Technical Specifications activity levels for a single gas decay tank for various plants are listed below:

- Zion 22,000 curies
- Crystal River 47,000 curies
- Sequoyah 50,000 curies
- Calvert Cliffs 53,500 curies
- Callaway 250,000 curies

15.3.3.3 Recombiners

Two catalytic hydrogen recombiners are normally provided. Normally one recombiner is operated, and this operation may be continuous or on a batch basis. The other unit will be reserved for standby. The recombiner is designed for a pressure of 150 psig and a flow rate of 50 cubic feet per minute. The catalyst (such as aluminum palladium or nichrome) has a design life of approximately 15 years. The catalytic recombiner accepts a preheated waste gas mixture containing nitrogen, hydrogen and fission gases. Oxygen is then added to this gas mixture. As this gas flows through the catalyst, a chemical reaction takes place combining the oxygen and hydrogen to form a water vapor. This water vapor is then condensed and removed from the system.

To insure that the oxygen content in the GRW is as low as practical. The recombiner will operate lean on oxygen, thereby insuring that all the oxygen is reacted. Therefore, there will be a trace amount of hydrogen at the outlet of the recombiner. As a result of this process whereby hydrogen is removed, the quantity of the gas in the GRW tends to remain constant, except for an accumulation of small quantities of fission product gases.

15.3.3.4 Charcoal Adsorber Beds

The charcoal adsorbers are cylindrical tanks that hold a bed of adsorption material. The material used for this purpose is generally activated charcoal (freed from adsorbed matter by heating). This material is selected because it is especially effective in an adsorption process due to the great surface area presented by its porous structure. Adsorption is a process that takes place at the surface of a solid (activated charcoal) that is in contact with another medium (waste gas) resulting in an accumulation of molecules (krypton, xenon, iodine, etc.) from that medium. The activated charcoal will only retain these gas molecules for some period of time. It is this adsorption process that allows for the decay of short lived radioisotopes and will pass the long lived radioisotopes after a certain holdup or delay time.

The charcoal adsorption waste gas system is essentially the same type of system as the off gas system utilized by the boiling water reactors. The holdup time or adsorption resident time of the adsorption system will depend on various factors such as the type of adsorption material, amount of adsorption material, temperature (lower temperatures increases holdup time), flow rate and moisture content of the waste gas flowing through the beds. The lower the temperature, flow rate and moisture content of the waste gas (nitrogen, hydrogen and fission gases) flowing through a given bed, the higher the adsorption resident time of that bed.

15.3.4 System Interrelationships

15.3.4.1 Gas Analyzer

An automatic gas analyzer is provided to monitor the concentrations of oxygen and hydrogen in the various systems and tanks where an explosive mixture of oxygen and hydrogen might occur. Upon indication of a high oxygen level, provisions are made to purge the equipment to the Gaseous Waste System with an inert gas.

The process flow diagram of the waste gas analyzer system is shown on Figure 15.3-6. The sample gas will come from one of the many possible sample points and flow into the suction of the low pressure, low volume sample pumps (2 pumps in series). From the sample pumps discharge, the gas will split into two flow streams.

One of the flow streams will supply the oxygen analyzer and the other the hydrogen analyzer. After the gas flows through the analyzers, it will flow to the GRW inlet on vent header. The gas analyzer normally sequences through each of the sample points but may be selected to skip any combination of points or to continuously sample a single point of interest. If the oxygen concentration exceeds a preselected limit (~2%), an alarm is initiated to alert the plant operators. This will provide adequate time to locate and isolate the air in-leakage before an explosive concentration is reached.

Provisions are made to periodically calibrate the analyzer using a known zero gas (nitrogen) and a known span gas (80% hydrogen, 18% nitrogen and 2% oxygen). By using these known gases the analyzers can be calibrated to give an accurate reading from the various sample points.

15.3.5 Summary

Waste gas processing systems will treat waste gases that are comprised of nitrogen, hydrogen and trace amounts (by volume) of fission gases. The objective of the various systems presented is to collect and store (holdup) the waste gas prior to a controlled release to the environment. This holdup time will allow for the decay of short lived radioisotopes. Therefore, the fission gases that will be released are comprised mostly of krypton and xenon. Volume reduction is being incorporated in newer plants to increase this holdup time. Volume reduction is accomplished with the use of hydrogen recombiners which will reduce the total amount of waste gases to be stored.

Table 15.3-1
Gaseous Waste Processing Systems

Plant Name	Waste Gas Compressor (scfm)	Gas Decay Tanks (cu.ft.)	Catalytic Recombiners (scfm)	Comments
R.E. Ginna	2 -	4 - (470)		
Kewaunee	2 -	4 - (470)		
Point Beach 1 & 2	2 - (1.2)	4 - (525)*		Gas stripper system used in CVCS letdown. Cryogenic gas separation system used for volume reduction.
Prairie Island 1 & 2	3 -*	9 - (470)* lo level 6 - (470)* hi level	2 - (30)* one per loop	Low level tanks used for cover gas. High level tanks used for fission gas processing.
Beaver Valley 1 & 2	2 - (2)	3 - (132)		52 cr.ft. Waste gas surge tank. 4 Charcoal Beds
J. M. Farley 1 & 2	2 - (40)	6 - (600) nor. Ops. 2 - (600) s/u & s/d	2 - (50)	
Sharon Harris	2 - (40)	6 - (600) nor. Ops. 2 - (600) s/u & s/d	2 - (50)	
North Anna	2 - (1.5)*	2 - (462)	2 - (50)	
H. B. Robinson	2 - (2)	4 - (525)		
San Onofre	1 - (2 4) 1 - (4.5)	3 - (125)		14.7 cu.ft. Waste Gas Surge Tank
V. C. Summer	2 - (40)	6 - (600) nor. Ops. 2 - (600) s/u & s/d	2 - (50)	
Surry 1 & 2		2 (434)	Installed not used	15.7 cu.ft. Waste Gas Surge Tank
Turkey Point	2 - *	6 - (525)*		
Byron 1 & 2	2 - (40)*	6 - (600)*		
Braidwood	2 - (40)*	6 - (600*		
Calloway	2 - (40)	6 - (600) nor. Ops. 2 - (600) s/u & s/d	2 - (50)	
Catawba	2 - (40)	6 - (600) nor. Ops. 2 - (600) s/u & s/d	2 - (50)	
Comanche Peak	2 - (40) 2 - (600)	8 - (600) nor. Ops., s/u & s/d	2 - (50)	
D. C. Cook	2 - (40)*	8 - (600)*		
Diablo Canyon	3 - (40)	3 - (705)*		
McGuire 1 & 2	2 - (40)	8 - (600) nor. Ops. 2 - (600) s/u & s/d	2 - (50)	
Millstone 3		Process Gas Receiver		Letdown degassifer 120 gpm capacity 2 - 13,560 # Charcoal Beds
Salem	2 - (40)	4 - (525)		

Seabrook 1 & 2	2 - (1.2 - 11.3)			5 - 1,600 # Charcoal Beds
Sequoyah 1 & 2	2 - (40)*	9 - (600)*		
Trojan	2 - (39)	4 - (600)		
Vogtle	2 - (40)	7 - (600) nor. Ops. 2 - (600) s/u & s/d	3 - (50)	29 cu.ft. Waste Gas Surge Tank
Wolf Creek	2 - (40)	6 - (600) nor. Ops. 2 - (600) s/u & s/d	2 - (50)	
Zion 1 & 2	2 - (40)*	Cement		

* common to both units

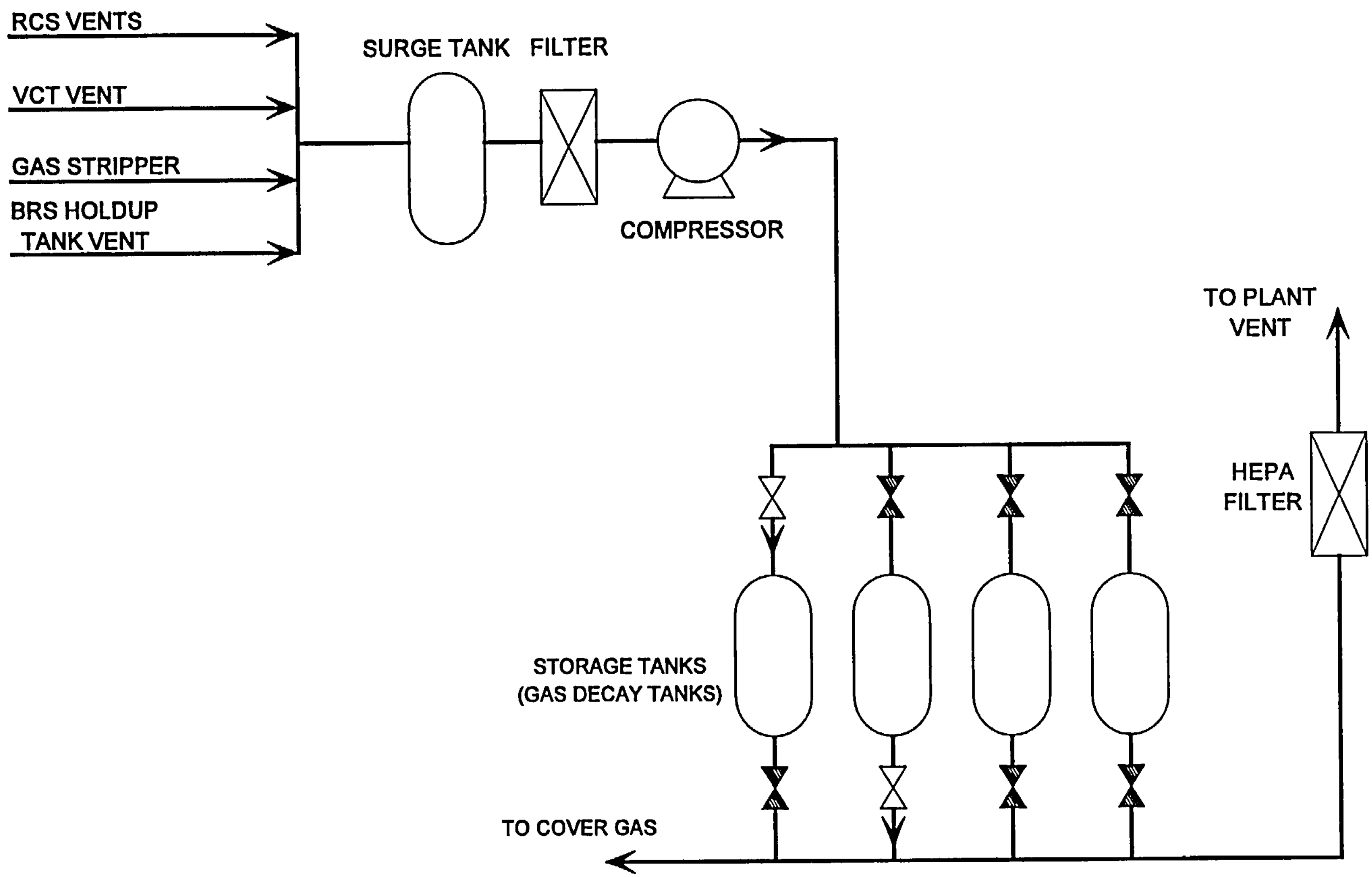

Figure 15.3-1 PWR Storage and Release - Waste Gas Decay Tank

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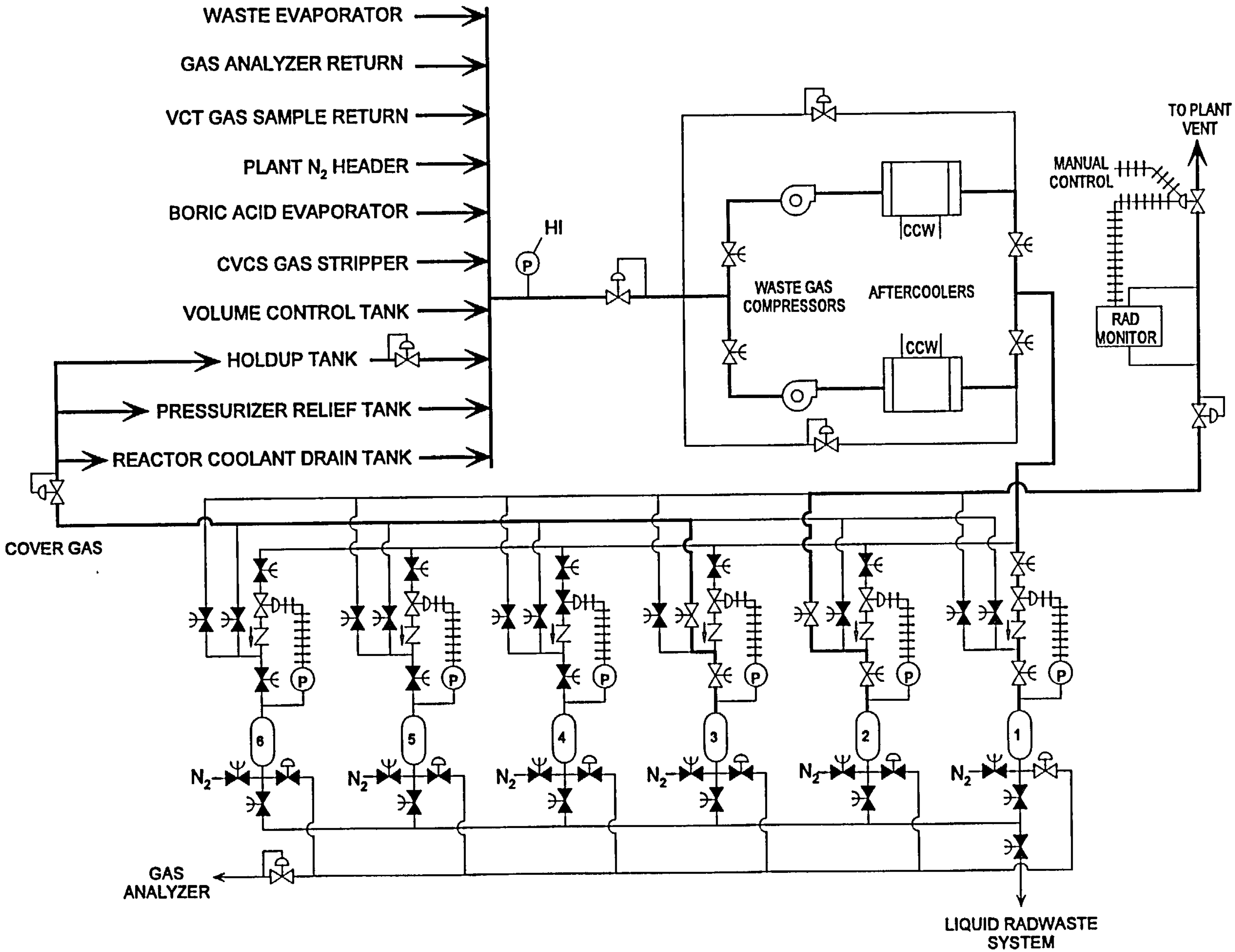

Figure 15.3-2 Gaseous Waste Processing System

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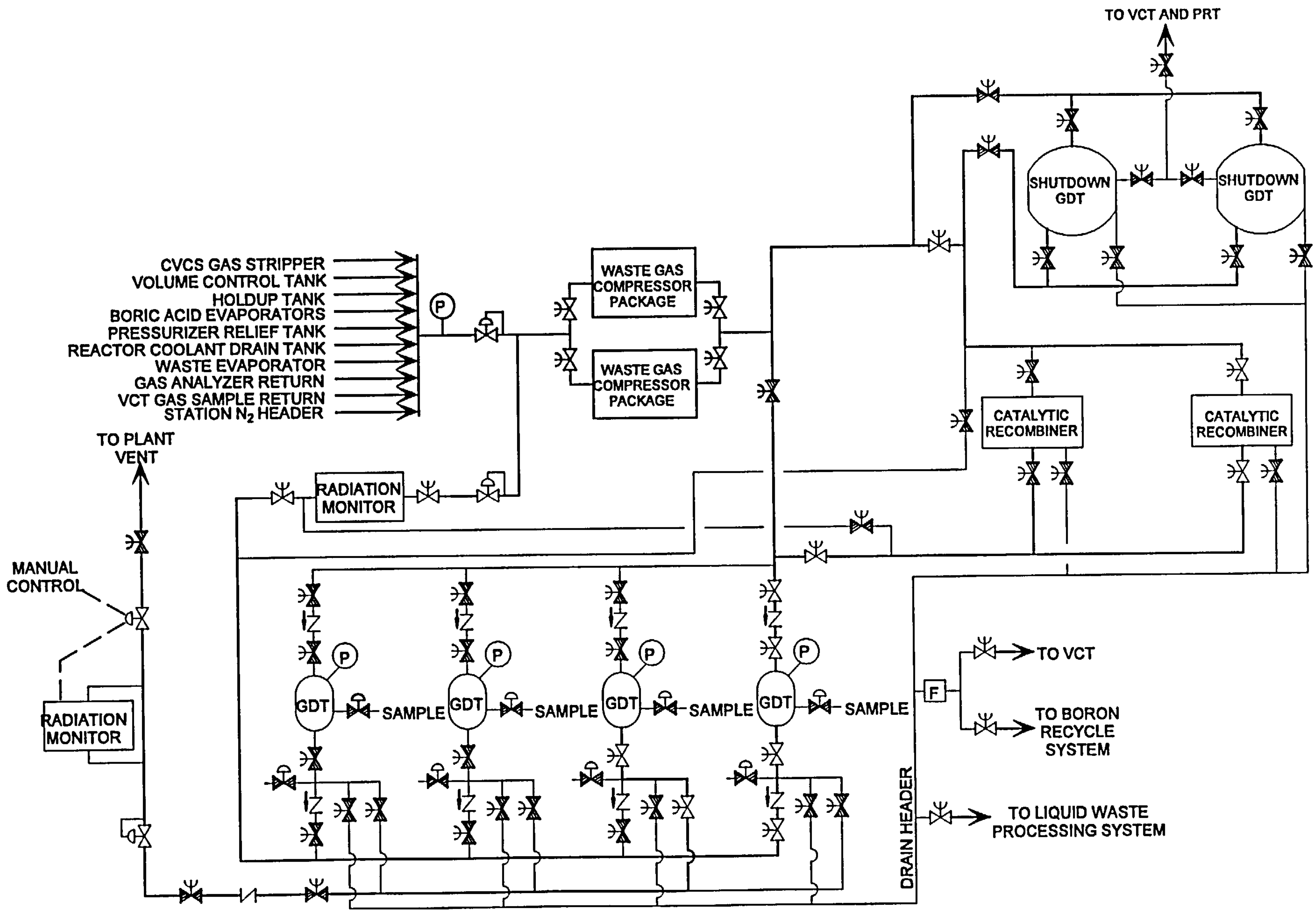

Figure 15.3-3 Gaseous Waste Processing with Recombiners

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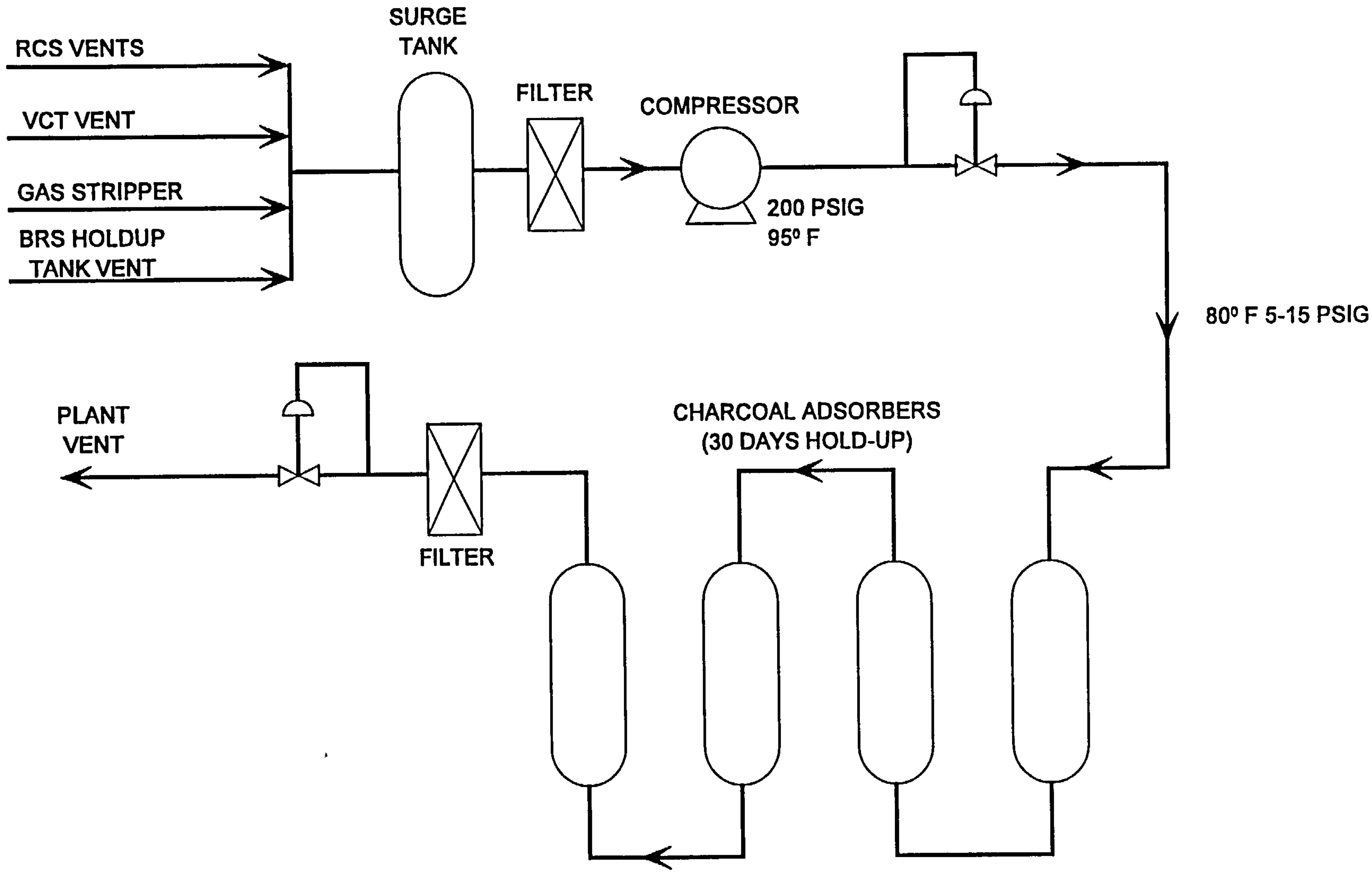

Figure 15.3-4 PWR Ambient Charcoal

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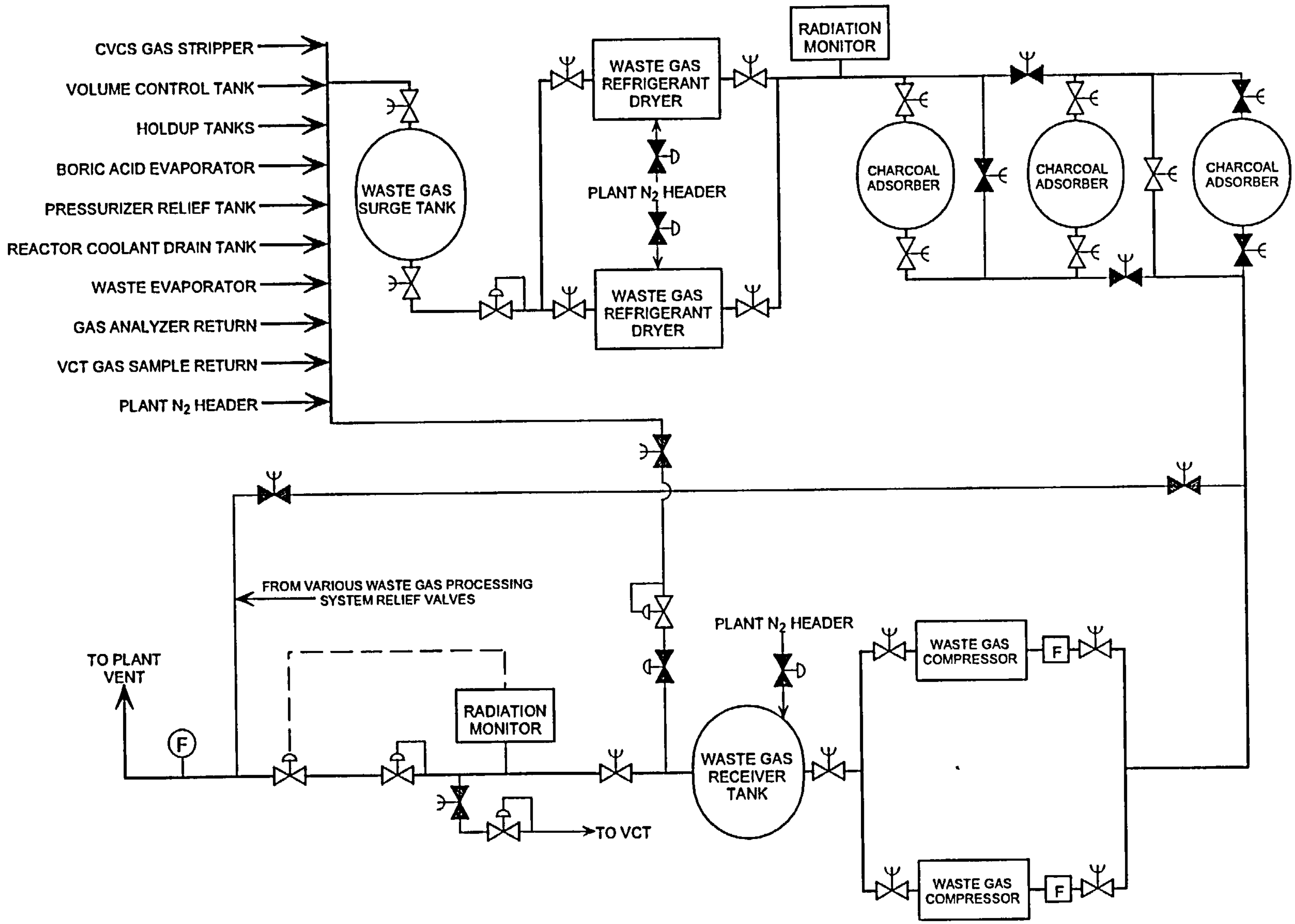

Figure 15.3-5 Gaseous Waste Processing System with Ambient Charcoal

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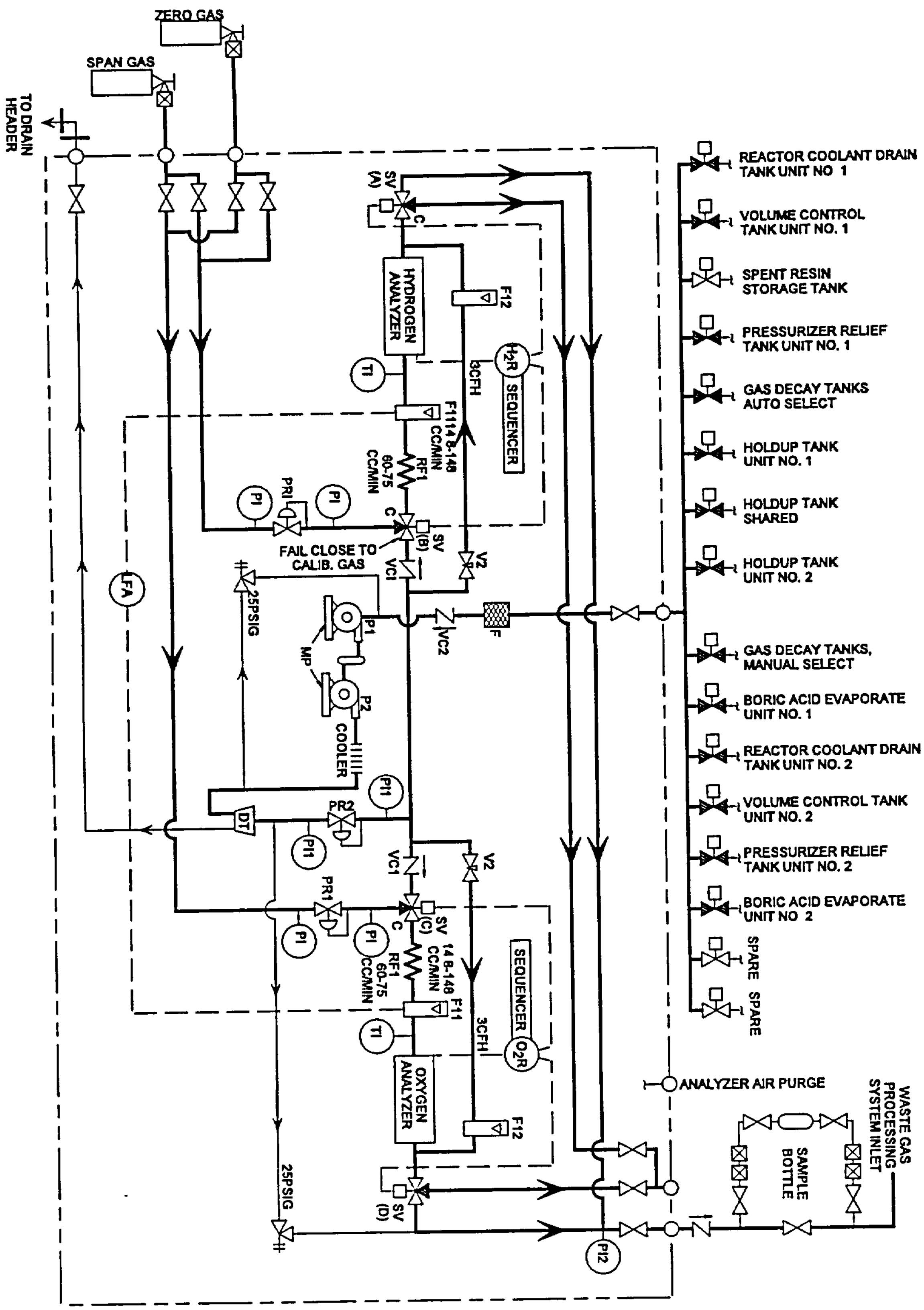
Figure 15.3-6 Gas Analyzer System



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