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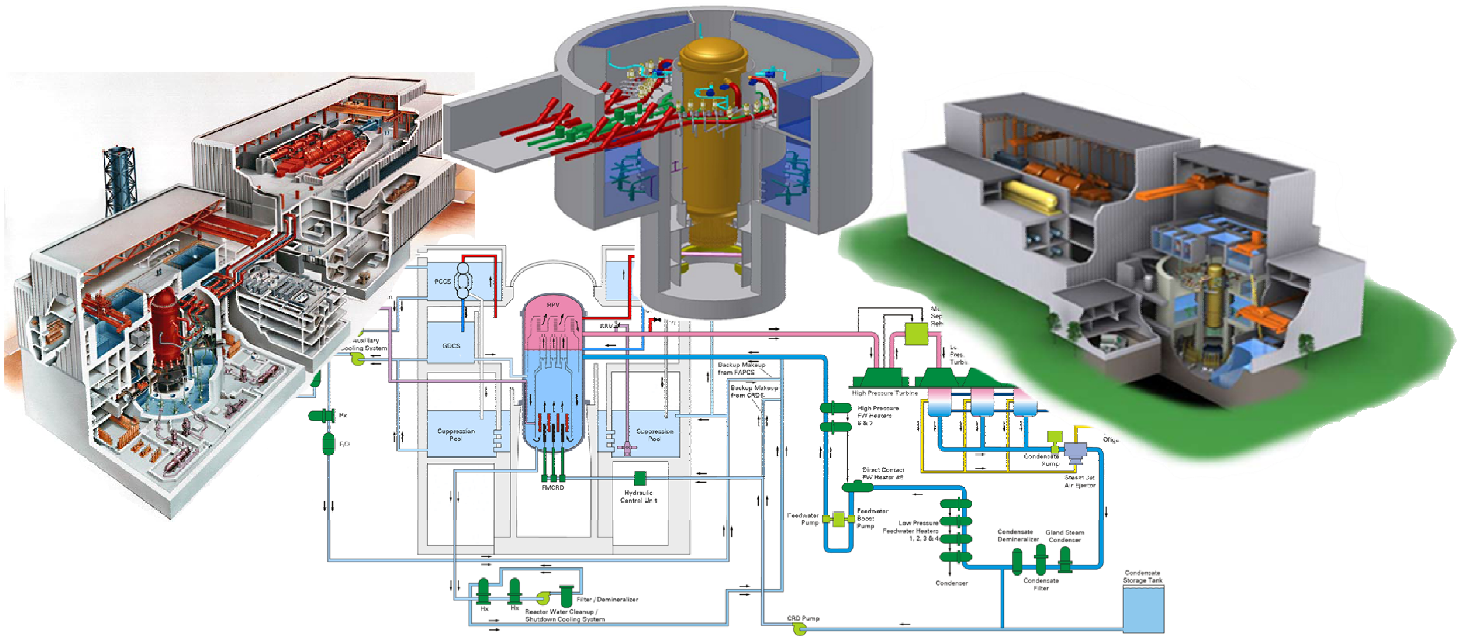

Part II
Introduction to Reactor Technology - BWR

Chapter 7.0, Reactor Protection System

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HUMAN RESOURCES TRAINING & DEVELOPMENT

Introduction to Reactor Technology

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

The information in this manual was compiled for NRC personnel in support of internal training and qualification programs. No assumptions should be made as to its applicability for any other purpose. Information or statements contained in this manual should not be interpreted as setting official policy. The data provided are not necessarily specific to any particular nuclear power plant, but can be considered to be representative of the vendor design.

The Introduction to Reactor Technology – BWR briefing manual outlines the differences between the Boiling Water Reactors (BWR), Advanced Boiling Water Reactor (ABWR), and Economic Simplified Boiling Water Reactor (ESBWR). The course is broken down into discussions on design features, facility and plant layout, containment systems, nuclear steam supply systems, control and instrumentation, safety systems, balance of plant systems, normal, abnormal, and emergency operations.

The content of this course was based on the content provided in the following references:

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

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

7.0 REACTOR PROTECTION SYSTEM

The purpose of the Reactor Protection System (RPS) is to initiate a reactor scram to:

- preserve the integrity of the fuel cladding,
- preserve the integrity of the reactor coolant system, and
- minimize the energy which must be absorbed following a loss of coolant accident

The functional classification of the RPS is that of a safety related system. Its regulatory classification is reactor trip system.

7.1 System Description

The reactor protection system is a fail safe system, composed of two independent trip channels, A and B, each made up of two automatic scram logics and one manual scram logic (Figure 7.0-1). Trip channel A consists of reactor automatic scram logics Al and A2, along with the manual scram logic A3. Trip channel B consists of the same type of logic arrangement as trip channel A, designated Bl, B2 and B3. Each automatic scram logic receives inputs from at least one independent sensor monitoring each of the critical parameters. An unbypassed trip occurring in any trip logic(s) of trip channel A, together with an unbypassed trip occurring in any trip logic(s) of trip channel B, generates a complete reactor scram. Note that a trip of one trip channel, with the other trip channel not tripped, does not cause a reactor scram.

7.2 Component Description

The major components of the Reactor Protection system are discussed in the paragraphs which follow and are illustrated in Figure 7.0-1.

7.2.1 Power Supplies

The RPS receives power from two independent power supplies, RPS bus A and RPS bus B. Each bus is supplied normal power from a separate motor generator set. The motor generator sets are equipped with a high inertia flywheel to minimize the effects of momentary changes to the electrical supply of the motor generator set.

Alternate power is available to the RPS buses and is used when one of the motor generator sets is out of service. To prevent feeding both A and B RPS buses from the alternate power supply, an interlock is provided that will not allow both alternate supply breakers to be closed at the same time.

7.2.2 RPS Logic

The RPS is referred to as a dual channel protection system arranged in a one-out-of-two-twice logic scheme. Each channel is completely independent of the other. The RPS logic, Figure

7.0-1, consists of two separately powered trip channels. Each channel contains two automatic trip logics and one manual trip logic. The automatic trip logics of channel A are designated Al and A2 and both receive at least one input signal from the same monitored parameter. Thus, any monitored parameter supplying an automatic trip signal would have a minimum of four sensors.

An out-of-tolerance sensor (trip condition) in either automatic trip logic, Al or A2, would cause a trip in channel A. A trip condition in channel A would de-energize all of the A scram solenoid valves for each and every control rod. This condition is referred to as a half scram. Likewise, any sensor in channel B out-of-tolerance will cause a half scram. This type of logic arrangement is called one-out-of-two once.

To produce a reactor scram, both trip channels A and B must be in the trip condition. The overall logic is termed one-out-of-two-twice.

The manual trip logics A3 and B3 contain the operator initiated scram signals, such as manual scram buttons and reactor mode switch.

7.2.3 Scram Valve Arrangement

Each of the 137 control rods is equipped with two scram solenoid valves, Figure 7.0-1. The scram solenoid valves are normally in an energized, untripped condition, and control the air supply to the control rod drive scram inlet and outlet valves. The scram inlet and outlet valves open with spring pressure and close (normal position) with air pressure. The scram inlet valve controls the scram water provided to the control rod drive by the scram accumulator. The scram outlet valve aligns the top of the control rod drive piston to the scram discharge volume. A reactor scram is initiated when both scram solenoid valves are de-energized, venting the air from the scram valves. When spring pressure overcomes the air pressure, the scram inlet and outlet valves open. Opening of the scram inlet valve allows the stored energy of the scram accumulator to be felt on the bottom of the drive piston. Opening of the scram outlet valve aligns the top of the drive piston with the scram discharge volume, which is at atmospheric pressure. With 1500 psig of water pressure below the drive piston and atmospheric pressure above the drive piston a large differential pressure is created to force the control rod rapidly into the core.

Note that on loss of air pressure or electrical power a reactor scram would be initiated. This is the fail safe feature of the Reactor Protection system.

7.3 System Features

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

7.3.1 Mode Switch

There are four principal modes of the Reactor Protection system: SHUTDOWN, REFUEL, STARTUP/HOT STANDBY and RUN. Each operating mode has its own individual restrictions for safe reactor operation. A keylock mode switch is provided. Operators must ensure that all

applicable restrictions are imposed at the proper time and to ensure the transition from one mode to the next is also safe.

7.3.2 Scram Functions and Bases for Trip Settings

The following discussions cover the functional considerations for each parameter monitored by the RPS. Table 7.0-1 lists all reactor scram signals, basis and bypass conditions.

7.3.2.1 Neutron Monitoring System Trips

Provides fuel cladding protection against excessive power generation. This protection is accomplished by monitoring neutron flux to initiate a reactor scram.

7.3.2.2 High Reactor Pressure

High pressure within the nuclear system process barrier poses a direct threat of a reactor coolant system rupture and a core power excursion from void collapse. The scram counteracts a pressure increase by quickly reducing core fission heat generation. The high pressure scram also serves as a backup to the Neutron Monitoring system high flux scram.

7.3.2.3 Reactor Vessel Water Level Low

A low water level scram prevents power operation at water levels lower than those assumed in the safety analysis. Low water level in the reactor indicates the core is in danger of having inadequate cooling.

7.3.2.4 Turbine Stop Valve Closure

Closure of the turbine stop valve, with the reactor at power, can result in a significant addition of positive reactivity to the core as the nuclear system pressure rise collapses steam voids. The turbine stop valve closure scram, which initiates a scram earlier than either the neutron monitoring system or nuclear system high pressure, is required to provide a satisfactory margin below core thermal hydraulic limits for this category of abnormal operation transients. Although the nuclear system high-pressure scram, in conjunction with the pressure relief system, is adequate to preclude over-pressurizing the nuclear system, the turbine stop valve closure scram provides additional margin to the nuclear system pressure limit.

7.3.2.5 Turbine Control Valve Fast Closure

The turbine control valve fast closure scram is also called the generator load reject scram. A mismatch between generator power and the turbine power causes rapid closure of the control valves. This rapid closure results in a situation similar to a turbine stop valve closure. Therefore, this scram is provided for the same reasons as those discussed for a turbine stop valve closure scram.

7.3.2.6 Main Steam Line Isolation Valve Closure

Closure of main steam line isolation valves, with the reactor at power, can result in a significant addition of positive reactivity to the core as the nuclear system pressure rise collapses steam

voids. A main steam line isolation valve closure scram is required to provide a satisfactory margin below core thermal hydraulic limits for this category of abnormal operational transients.

7.3.2.7 Scram Discharge Volume High Level

The scram discharge volume receives the water displaced by the motion of the control rod drive pistons during a scram. Should the scram discharge volume fill up with water to the point where insufficient volume remains to receive water displaced during a scram, control rod movement would be hindered in the event a scram were required. To prevent this situation, the reactor is scrammed when the water level in the discharge volume attains a value high enough to verify that the volume is filling up, yet low enough to ensure that the remaining capacity in the volume can accommodate a scram.

7.3.2.8 Drywell Pressure High

High drywell pressure may indicate a break in the reactor coolant pressure boundary. It is, therefore, prudent to scram the reactor in such a situation to minimize the possibility of fuel damage and to reduce the energy transfer from the core to the coolant, which in turn minimizes the energy that the containment/suppression pool may be required to absorb. The high drywell pressure scram setting is selected to be as low as possible without inducing spurious scrams.

7.3.2.9 Mode Switch in SHUTDOWN

The mode switch provides appropriate protective functions for the condition in which the reactor is to be operated. The reactor is to be shut down with all control rods inserted when the mode switch is in SHUTDOWN. To enforce the condition defined for the SHUTDOWN position, placing the mode switch in the SHUTDOWN position initiates a reactor scram. This scram is not required to protect the fuel or nuclear system process barrier, and it bears no relationship to minimizing the release of radioactive material from any barrier. The scram signal is removed after a short time delay, permitting a scram reset which restores the normal valve lineup in the control rod drive hydraulic system.

7.3.2.10 Manual Scram Buttons

Two manual scram pushbuttons are provided to allow the operator to scram the reactor in advance of imminent trips and follow up automatic scrams.

7.3.2.11 Reset Circuit

Once a scram has occurred and the condition causing the scram has been corrected, a manual reset is required to begin the process of returning the reactor plant to a normal condition. A single reset switch is provided for this purpose.

Three conditions are necessary to reset a scram signal:

- The scram signal(s) must all be cleared or bypassed.
- Ten seconds must have elapsed since the scram was initiated.

- The reset switch must be momentarily placed in both reset positions.

A ten second time delay function is provided to allow the slowest control rods to be fully inserted into the reactor core prior to being able to reset a scram.

Table 7.0-1, Reactor Protection Scram Signals

Scram Signal	Signal Bypass	Probable Cause	Reason for Scram
Low Reactor Water Level	None	Abnormal Operational Transient or line break	Protect fuel cladding from inadequate cooling
NMS-IRM INOP	Mode switch in RUN	Low voltage, card unplugged or switch misaligned	Protect fuel cladding integrity
NMS-IRM High High	Mode switch in RUN	Failure to up range IRM's or to short of a reactor period	Protect fuel cladding against excessive power and short period
NMS-APRM Down scale & Companion IRM Up scale.	Mode Switch not in Run	Not monitoring Reactor power level	Protect fuel cladding integrity
NMS-APRM INOP	None	Too few LPRM inputs, card unplugged or switch misaligned	Protect fuel cladding integrity
NMS-APRM High High (Fixed 15% or 120%)	None	Abnormal Operational Transient	Protect fuel cladding from excessive power
NMS-APRM High High (Flow biased)	Mode switch not in RUN	Abnormal Operational Transient	Protect fuel cladding from excessive power

Table 7.0-1, Reactor Protection Scram Signals

Scram Signal	Signal Bypass	Probable Cause	Reason for Scram
MSIV Closure	Mode switch not in RUN	Any MSIV closure signal	Protect fuel cladding against positive $\Delta K/K$ insertion from void collapse
Turbine Stop Valve Closure	<30% Turbine First stage pressure.	Any Turbine Trip	Protect fuel cladding against positive $\Delta K/K$ insertion from void collapse
Turbine Control Valve Fast Closure	<30% Turbine First stage pressure.	Generator Load Rejection	Protect fuel cladding against positive $\Delta K/K$ insertion from void collapse
High Reactor Pressure	None	Abnormal Operational Transient	Protect reactor coolant pressure boundary integrity
High Drywell Pressure	None	Line break in Drywell	Minimize energy SP must absorb, prevent re-criticality
Scram Discharge Instrument Volume High Level	Keylock switch in “Bypass” and mode switch in SHUTDOWN or REFUEL	Leaking scram outlet valves or any other scram just happened	Allows RPS to scram while the ability still exists

Table 7.0-1, Reactor Protection Scram Signals

Scram Signal	Signal Bypass	Probable Cause	Reason for Scram
Manual Push Buttons	None	Manual scram push buttons depressed	Allows manual scram whenever operator deems prudent
Mode switch in SHUTDOWN	When 10 second timer times out	Mode switch was placed in SHUTDOWN	Enforce shutdown conditions defined for “SHUTDOWN” mode

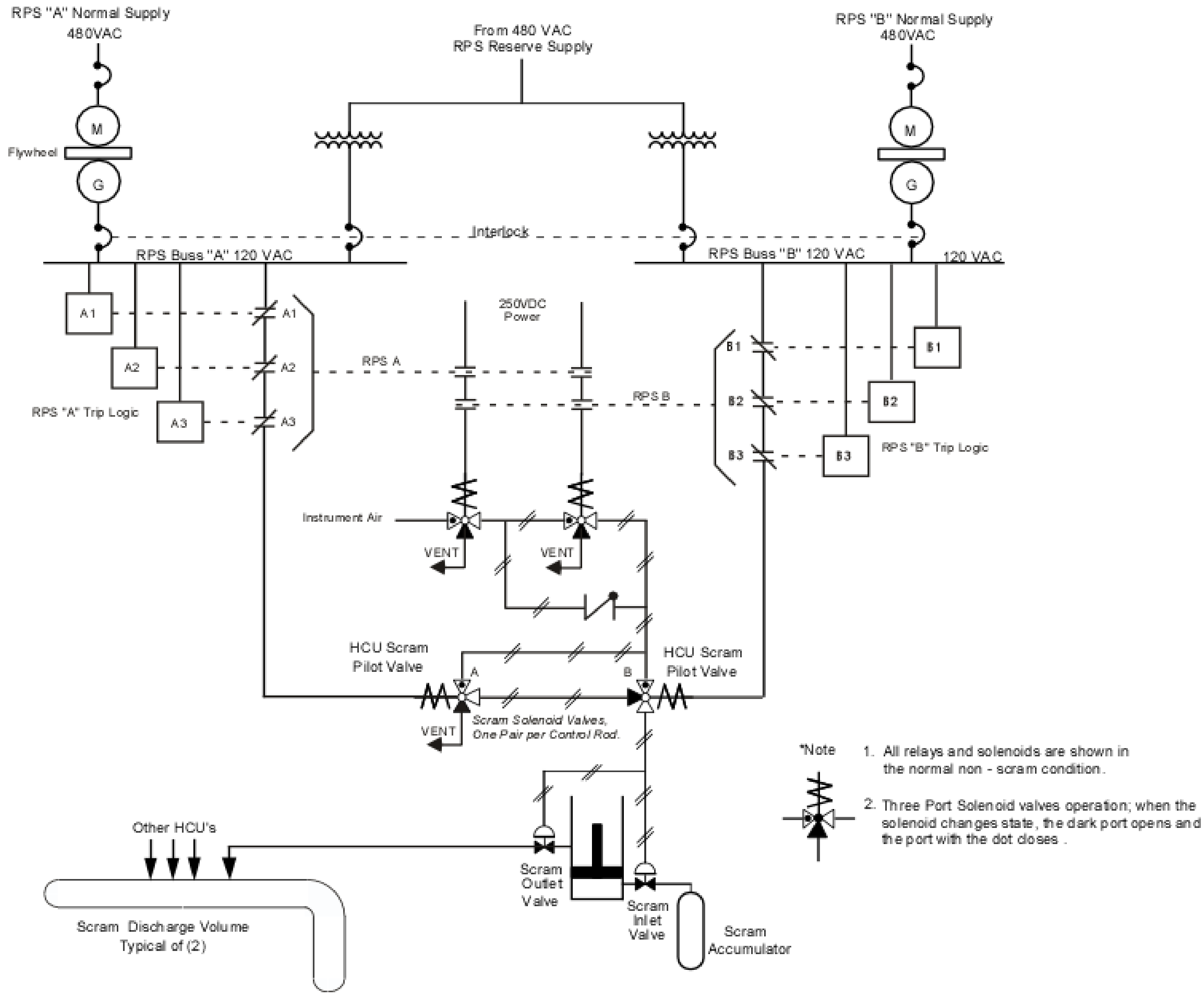

Figure 7.0-1, Simplified Reactor Protection System