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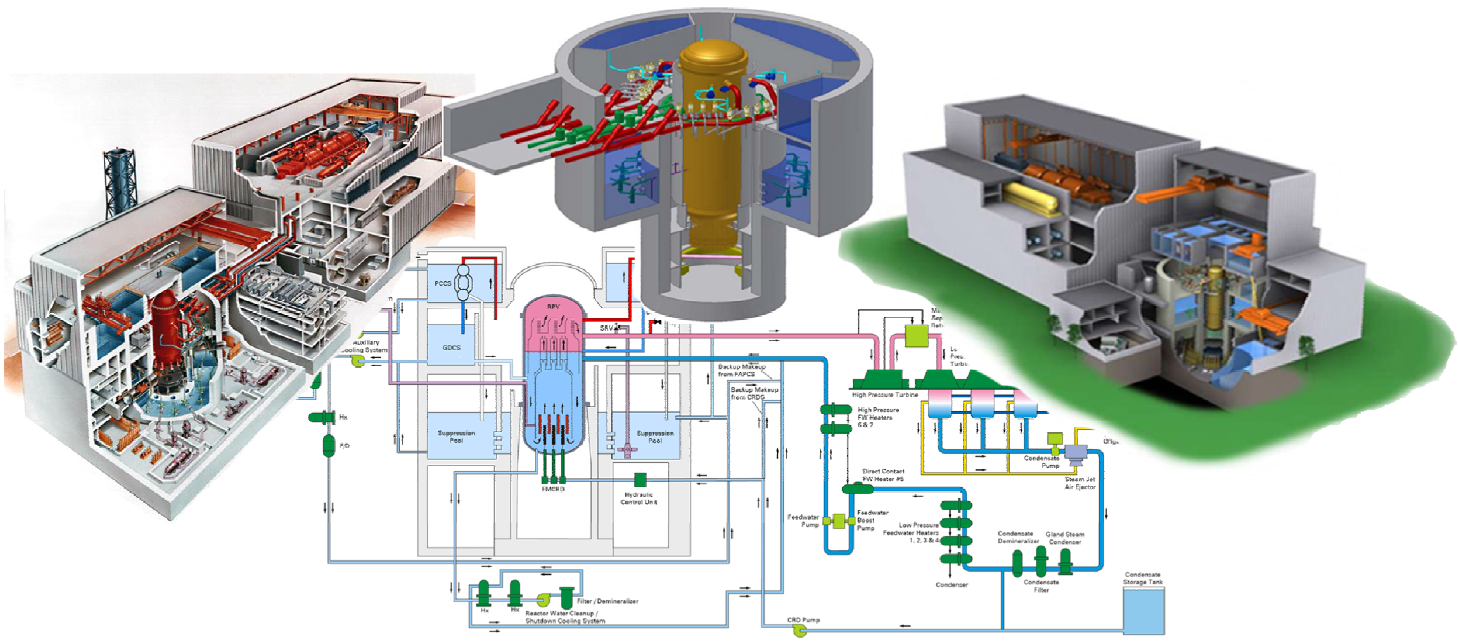

Part II

Introduction to Reactor Technology - BWR

Chapter 11.0, Reactor Operations

HRTD

Human Resources Training & Development

UNITED STATES

NUCLEAR REGULATORY COMMISION

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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Table of Contents

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

11.0 REACTOR OPERATIONS

Detailed written operating procedures for all modes of plant operation are prepared prior to the initial startup and critical testing period. Appropriate changes in these procedures are made during the startup test program. The following is a discussion of the general operating procedures that are used for plant startup, power operation, and shutdown. This information is presented to indicate the general method of operation.

The order to startup the reactor for power operation, or to shutdown for maintenance or refueling, is issued by the plant senior plant management. The load schedule during power operation is issued by the load dispatcher’s office with concurrence from the plant. To support these operations, the shift management schedules the startup or shutdown of various systems and components as required by issuing the necessary orders to the control room personnel.

The following sections describe the sequence of general plant operations during startup, power operation and shutdown.

11.1 COLD STARTUP PROCEDURES

Prior to cold startup, pre-startup check lists are completed on all systems required to support startup and power operation. Included in these checks are the following: operational checks of safety related systems to ensure their availability, nuclear steam supply and balance of plant system valve and switch lineups, and from control room panels switch lineups.

The shutdown cooling mode of the Residual Heat Removal (RHR) system is secured and the recirculation pumps are started running at minimum speed. The Condensate and Feedwater system is prepared to supply water to the reactor vessel. This includes bringing chemistry into specification by recirculating water through the condensate demineralizers. A vacuum is drawn in the main condenser to aid in the removal of noncondensable gases and to establish the main heat sink.

11.1.1 Approach to Critical and Pressurization of the Reactor

The reactor mode switch is placed in the startup position, and control rods are withdrawn, using the Reactor Manual Control system. While following a very specific pull sequence. Control rod withdrawal continues until criticality, a self-sustaining chain reaction is achieved. The time, rod position, reactor period and reactor water temperature are then recorded.

After neutron flux measurement overlap with the Intermediate Range Monitors (IRM) has been demonstrated, the Source Range Monitor (SRM) detectors are withdrawn from the core.

After the reactor is critical, a positive reactor period is established to raise power to the heating range. The IRMs are ranged upward as required to maintain the proper on-scale readings. The power increase continues until heating power is reached. At this point control rod withdrawal is governed by the heatup rate usually about 90°F/hr. The 90°F/hr heatup rate is a procedural limit. The Technical Specification limit is l00°F/hr. Control rod withdrawal is constrained to an approved sequence such that control rod positions remain symmetrical and the reactivity worth of a given rod is minimized.

As reactor water temperature increases, the coolant expands, causing the reactor vessel level to increase. In order to maintain a constant level during heatup, water must be removed from the reactor vessel. The Reactor Water Cleanup system (RWCU) is aligned to reject water to the main condenser or to the Liquid Radwaste system. It is usually more desirable to reject the excess water to the condenser in order to minimize the water processing load on the Liquid Radwaste system. This evolution continues until rated temperature and pressure are reached.

As temperature increases above 212°F the reactor vessel begins to pressurize. At about 100 psig, the Reactor Core Isolation Cooling (RCIC) system and the High Pressure Coolant Injection (HPCI) system, low steam pressure isolation is reset, and the steam lines to auxiliary steam loads such as Reactor Feedwater Pump (RFP) turbines and Steam Jet Air Ejectors (SJAEs) are warmed.

As pressure approaches 150 psig, the Electro Hydraulic Control (EHC) system pressure regulator would start to open bypass valves. To avoid bypassing steam to the main condenser and to allow plant pressurization, the pressure setpoint is increased to 920 psig.

At about 350 psig, a Reactor Feed Pump is started and placed in service. At about 450 psig, the SJAEs are placed in service to maintain a vacuum in the main condenser. Also at this time, the main turbine is reset and prepared for starting.

As pressure reaches 920 psig, the bypass valves begin to open to control reactor pressure at the EHC system pressure setpoint. Control rods are withdrawn to increase power, which results in further opening of the bypass valves. When power reaches 5% to 12%, the reactor mode switch is shifted to the “RUN” position, and the IRMs are fully withdrawn. Control rods continue to be withdrawn until 2 to 3 bypass valves are open, representing sufficient steam flow to roll the main turbine and provide minimum loading following synchronization to the grid. At about this time, the Feedwater Control system is placed in automatic.

11.1.2 Startup and Synchronization of the Generator

A turbine acceleration rate is chosen, depending upon various turbine temperatures, and the turbine is rolled to synchronous speed. The generator is then synchronized to the transmission system, and the generator output breakers are closed.

As the operator now increases load on the generator by using the load selector to open the control valves, the bypass valves automatically close to maintain a constant reactor pressure. This is all accomplished using the EHC system.

Once all bypass valves are closed, a further increase on the load selector performs a setpoint adjustment only, and the load selector is set to the final expected power level.

As control rods are withdrawn, reactor power and pressure increase. As reactor pressure increases, steam throttle pressure also increases which causes the EHC system to open the control valves more, increasing turbine steam flow and hence generator power.

11.1.3 Increase of Power to Rated

Control rod withdrawal is used to increase power to approximately 60%. When approximately 60% power is reached, the control rods have been withdrawn to what is called a 100% or "target" rod pattern. This rod pattern, in turn, yields 100% reactor power when recirculation flow is increased to 100%.

The power increase from 60% to 100% is accomplished by increasing recirculation flow. The Recirculation Flow Control system is aligned with the individual loop controllers in master manual control. Recirculation flow is then increased to near 100% with the master flow controller.

During the increase to rated power, additional support equipment is started as necessary; i.e., additional condensate, condensate booster, reactor feed pumps or condensate demineralizers, etc.

11.2 POWER OPERATION

After the generator is synchronized to the transmission grid and producing a substantial output, reactor power output is changed to meet the grid system requirements by adjustment of control rod position, manual adjustment of reactor recirculation flow, or a combination of these two methods.

11.2.1 Control Rod Adjustment

Withdrawing a control rod reduces neutron absorption and adds positive reactivity. Reactor power then increases until the increased steam formation just balances the change in reactivity caused by the rod withdrawal. The increase in boiling rate tends to raise reactor pressure, causing the EHC system pressure regulator to open the turbine control valves sufficiently to maintain a programmed throttle pressure. When a control rod is inserted, the reverse effect occurs.

11.2.2 Recirculation Flow Control

Reactor power output can be varied over a power range of approximately 40% of rated power, by adjustment of reactor recirculation flow, which maintains a near uniform power distribution. Reactor power change is accomplished by using the negative void coefficient of

reactivity. An increase in recirculation flow temporarily reduces the volume of steam in the core by sweeping away the voids (steam bubbles). This addition of reactivity to the core causes reactor power level to increase. The increased steam generation rate then returns the steam volume in the core to approximately its original value, and a new constant power level is established. When recirculation flow is reduced, reactor power is reduced in a similar manner.

During initial power operation, the operating curve or power/flow map is established relating reactor power to recirculation flow. The first point of the curve is full flow and rated power. When a rod pattern is established for this point, recirculation flow is reduced in steps, at that rod pattern, and the relationship of flow to power is plotted for steady state conditions. Other curves are established at lower power ratings and other rod patterns as desired. During operation, reactor power may be changed by flow control adjustment, rod positioning, or a combination of the two, while adhering to established operating curves.

Although control rod movement is not required when the load is changed by recirculation flow, the long term reactivity effects of fuel burn-up must be compensated for by control rod adjustment.

Operating personnel are engaged in many activities during normal power operation. The following list includes some of the most typical activities:

- routine data taking and writing of operational logs
- routine system instrument and valve tests
- special periodic operational tests

Manipulation of control rods and recirculation flow to maintain a balanced flux distribution, accommodate major changes in load demand and ensure optimum plant performance.

Evaluation of abnormal conditions, and taking required action to minimize potentially dangerous effects on equipment and systems.

- sampling of process steam and water
- surveillance of plant equipment for proper operation, including making of necessary adjustments and minor repairs

Confining radioactive contamination to the smallest possible area and preventing contamination of personnel areas.

11.3 NORMAL SHUTDOWN

A plant shutdown is accomplished by essentially reversing the steps described in Sections 11.0.1 and 11.0.2, cold startup and power operation.

Preparation for plant shutdown involves testing of systems required to maintain cold shutdown and other equipment checks such as the turbine oil systems, flushing of the Residual Heat Removal system (shutdown cooling piping).

Reactor power is reduced from 100% to approximately 60% by using the Recirculation Flow Control system. This requires adjusting the master flow controller to reduce recirculation pump speed to minimum.

Control rods are now inserted in reverse of the withdrawal sequence to obtain a reactor power of approximately 10%. At this time, the IRM detectors are inserted, and the reactor mode switch is transferred to the startup position.

Generator load is reduced to a minimum and the turbine generator is separated from the transmission system. Turbine steam flow is picked up automatically by the bypass valves. Control rod insertion continues until all rods reach the full in position. Reactor cooldown is commenced by withdrawing steam from the reactor via the bypass valves and maintaining vessel inventory using a reactor feed pump. A cooldown rate of 90°F/hr. is established.

When reactor pressure has been reduced to approximately 50 psig, the shutdown cooling mode of the RHR system is initiated and is used to cool the nuclear system down to a temperature of 150°F.

The reactor shutdown is essentially complete. Some plant shutdowns may require flooding of the reactor vessel. This is normally done using a condensate pump and would be necessary if the plant was going into refueling operations.