4.0 Reactor

4.1 Summary Description

The reactor assembly consists of the reactor pressure vessel (RPV), pressure-containing appurtenances (including Control Rod Drive System (CRD) housings), incore instrumentation housings, and the head vent and spray assembly plus the reactor internal components described in Subsection 4.1.2. Figures 5.3-2a, 5.3-2b, and Table 5.3-2 show the arrangement of the reactor assembly components. A summary of the important design and performance characteristics is given in Subsection 1.3.1. Loading conditions for reactor assembly components are specified in Subsection 3.9.5.2.

4.1.1 Reactor Pressure Vessel

The RPV includes the reactor internal pump (RIP) casing and flow restrictors in each of the steam outlet nozzles, and the shroud support and pump deck which form the partition between the RIP suction and discharge. The RPV design and description are covered in Section 5.3.

4.1.2 Reactor Internal Components

As described in Subsection 3.9.5.1, the major reactor internal components include:

(1) The core (fuel, channels, control blades and instrumentation)

(2) Core support structure (including the shroud, top guide and core plate)

(3) Shroud head and steam separator assembly

(4) Steam dryer assembly

(5) Feedwater spargers

(6) Core flooding spargers

Except for the Zircaloy in the reactor core, these reactor internals are stainless steel or other corrosion-resistant alloys. The fuel assemblies (including fuel rods and channel), control blades, shroud head and steam separator assembly, and steam dryers and incore instrumentation dry tubes are removable when the reactor vessel is opened for refueling or maintenance.

4.1.2.1 Reactor Core

Important features of the reactor core are:

(1) The bottom-entry cruciform control rods, which were first introduced in the Dresden-1 reactor in April 1961, have accumulated millions of hours of service.

(2) Fixed incore fission chambers provide continuous local power range neutron flux monitoring (LPRMs). A guide tube in each incore assembly provides for a traversing incore probe (TIP) for calibration and axial detail. Startup range neutron monitors (SRNMs) are located at fixed locations between the LPRMs as shown on Figure 4.1-1. The incore location of the startup range instruments provides coverage of the large reactor core. All incore instrument leads enter from the bottom and the instruments are in service during refueling. Incore instrumentation is presented in Subsection 7.6.1.

(3) As shown by experience obtained at Dresden-1 and other BWR plants, utilizing the incore flux monitor system, the desired power distribution can be maintained within a large core by proper control rod scheduling.

(4) The fuel channels (a) provide a fixed flow path for the boiling coolant, (b) serve as a guiding surface for the control rods, and (c) protect the fuel during handling operations.

(5) The mechanical reactivity control permits criticality checks during refueling and provides maximum plant safety. The core is designed to be subcritical at any time in its operating history with any one control rod fully withdrawn and the other control rods fully inserted.

(6) The selected control rod pitch represents a practical value of individual control rod reactivity worth, and allows adequate clearance below the pressure vessel between CRD mechanisms for ease of maintenance and removal.

(7) The reactor core is arranged as an upright circular cylinder containing a large number of fuel cells and is located within the core shroud inside the reactor vessel.

4.1.2.1.1 Fuel Assembly Description

The fuel assembly description is provided in Section 4.2.

4.1.2.1.2 Fuel Assembly Support and Control Rod Location

A few peripheral fuel assemblies are supported by the core plate. Otherwise, individual fuel assemblies in the core rest on fuel support pieces mounted on top of the control rod guide tubes (CRGTs). Each guide tube, with its orificed fuel support, bears the weight of four assemblies and is supported by a CRD penetration nozzle in the bottom head of the reactor vessel. The core plate provides lateral support and guidance at the top of each CRGT and directs the reactor recirculation into the orificed fuel support and through the fuel assemblies. The top guide, mounted on top of the shroud, provides lateral support and guidance for the top of each fuel assembly. The reactivity of the core is controlled by cruciform control rods and their associated mechanical hydraulic drive system. The control rods occupy alternate spaces between fuel assemblies. Each independent drive enters the core from the bottom, and accurately positions its associated control rod during normal operation with an electric motor-driven ball screw. Scram hydraulic pressure acts on the hollow cylinder to exert several times the force of gravity to insert the control rod during the scram mode of operation. Bottom entry allows optimum power shaping in the core, ease of refueling, and convenient drive maintenance.

4.1.2.2 Shroud

Detailed information on the shroud is provided in Subsection 3.9.5.1.1.1.

4.1.2.3 Shroud Head and Steam Separators

Detailed information on the shroud head and separators is presented in Subsection 3.9.5.1.2.1.

4.1.2.4 Steam Dryer Assembly

Detailed information on the steam dryer assembly is presented in Subsection 3.9.5.1.2.3.

4.1.3 Reactivity Control Systems

4.1.3.1 Operation

The control rods perform dual functions of power distribution shaping and reactivity control. Power distribution in the core is controlled during operation of the reactor by manipulation of selected patterns of rods. The rods, which enter from the bottom of the near cylindrical reactor core, are positioned to counterbalance steam voids in the top of the core and effect significant power flattening.

These groups of control rods, used for power flattening, experience a somewhat higher duty cycle and neutron exposure than the other rods in the control system.

The reactivity control function requires that all rods be available for either reactor “scram” (prompt shutdown) or reactivity regulation. Because of this, the control rods are mechanically designed to withstand the dynamic forces resulting from a scram. They are connected to bottom mounted, electro-hydraulically actuated drive mechanisms which allow either electric motor-controlled axial positioning for reactivity regulation or hydraulic rapid scram insertion. The design of the rod-to-drive connection permits each blade to be attached or detached from its drive without disturbing the remainder of the control system. The bottom-mounted drives permit the entire control system to be left intact and remain operable for tests with the reactor vessel open.

4.1.3.2 Description of Control Rods

A description of the control rods is provided in Section 4.2.

4.1.3.3 Supplementary Reactivity Control

The core control requirements are met by use of the combined effects of the movable control rods, supplementary burnable poison, and variation of reactor coolant flow. Descriptions of the supplementary burnable poison are presented in Sections 4.2 and 4.3.

4.1.4 Analysis Techniques

4.1.4.1 Reactor Internal Components

Computer codes used for the analysis of the internal components are as follows:

(1) SAP4G07

(2) ANSYS

(3) SEISM03

Detail descriptions of these programs are given in the following subsections.

4.1.4.1.1 SAP4G07

SAP4G07 is a general-purpose finite element computer program used to perform stress, dynamic, and seismic analyses of structural, mechanical and piping components. Dynamic analyses can be done using direct integration or mode superposition. Response spectrum analysis (a mode superposition method) can include multiple support excitation.

4.1.4.1.2 ANSYS

ANSYS is a general-purpose finite element computer program designed to solve a variety of problems in engineering analysis.

The ANSYS program features the following capabilities:

(1) Structural analysis, including static elastic, plastic and creep, dynamic, seismic and dynamic plastic, and large deflection and stability analysis.

(2) One-dimensional fluid flow analysis.

(3) Transient heat transfer analysis, including conduction, convection, and radiation with direct input to thermal-stress analyses.

(4) An extensive finite element library, including gaps, friction interfaces, springs, cables (tension only), direct interfaces (compression only), curved elbows, etc. Many of the elements contain complete plastic, creep, and swelling capabilities.

(5) Plotting—Geometry plotting is available for all elements in the ANSYS library, including isometric and perspective views of three-dimensional structures.

(6) Restart Capability—The ANSYS program has restart capability for several analyses types. An option is also available for saving the stiffness matrix once it is calculated for the structure, and using it for other loading conditions.

ANSYS is used extensively in GE for elastic and elastic-plastic analysis of the reactor pressure vessel, core support structures, reactor internals, fuel and fuel channel.

4.1.4.1.3 SEISM03

SEISM03 is a GE proprietary computer program for non-linear dynamic analysis. The method uses basic mass, spring, damper, gap, and coupling elements in a direct integration approach to solve non-linear dynamic analysis. This is the main dynamic analysis engineering computer program (ECP) for fuel lift load analysis. Other programs used in conjunction with SEISM03 are:

(1) CRTFI

The CRTFI program uses, as input, the scaled or composite horizontal acceleration time histories at the mid fuel and end fuel positions to determine (1) the clamping forces to be applied to the analysis model friction elements, (2) the scram uplift forces on a bundle, (3) inertial forces of the fuel in order to obtain reaction forces on both ends of the fuel, and (4) fuel-center deflection and uplift forces due to scram.

(2) SEPRE

This ECP is a pre-processor for SEISM. It takes the output from CRTFI and phases the input time histories of all loads with the basic load time histories. SEPRE also converts all input loads to the format required for input to SEISM.

(3) SEPST

This ECP is the SEISM post-processor. SEPST condenses the SEISM output data into a form which is more practical to interpret. It determines and prints the initial values, the maximum and minimum values for all components, and the times of their occurrence. In addition, it generates the response time history plots of selected components.

4.1.4.2 Fuel Design Analysis

The fuel design analysis models are discussed in Section 4.2.

4.1.4.3 Reactor Systems Dynamics

The analysis techniques and computer codes used in reactor systems dynamics are discussed in Reference 4.1-1.

4.1.4.4 Nuclear Analysis

The analysis techniques are discussed in Section 4.3.

4.1.4.5 Neutron Fluence Calculations

Neutron vessel fluence calculations were carried out using a two-dimensional, discrete ordinates, Sn transport code with general anisotropic scattering.

This code is the most widely used two-dimensional, discrete ordinated code for solving various radiation transport problems. The program will solve both fixed source and multiplication problems. Rectangular (XY, or RZ) and polar (R, θ) geometry are allowed with various boundary conditions. The fluence calculations incorporate, as an initial starting point, neutron fission distributions prepared from core physics data as a distributed source. Anisotropic scattering was considered for all regions. The cross sections were prepared with 1/E flux weighting polynominal expansion matrices for anisotropic scattering but did not include the resonance self-shielding factors.

4.1.4.6 Thermal–Hydraulic Calculations

The thermal-hydraulic models are discussed in Section 4.4.

4.1.5 References

4.1-1 *Stability and Dynamic Performance of the GE BWR*, NEDO-21506, January 1977.

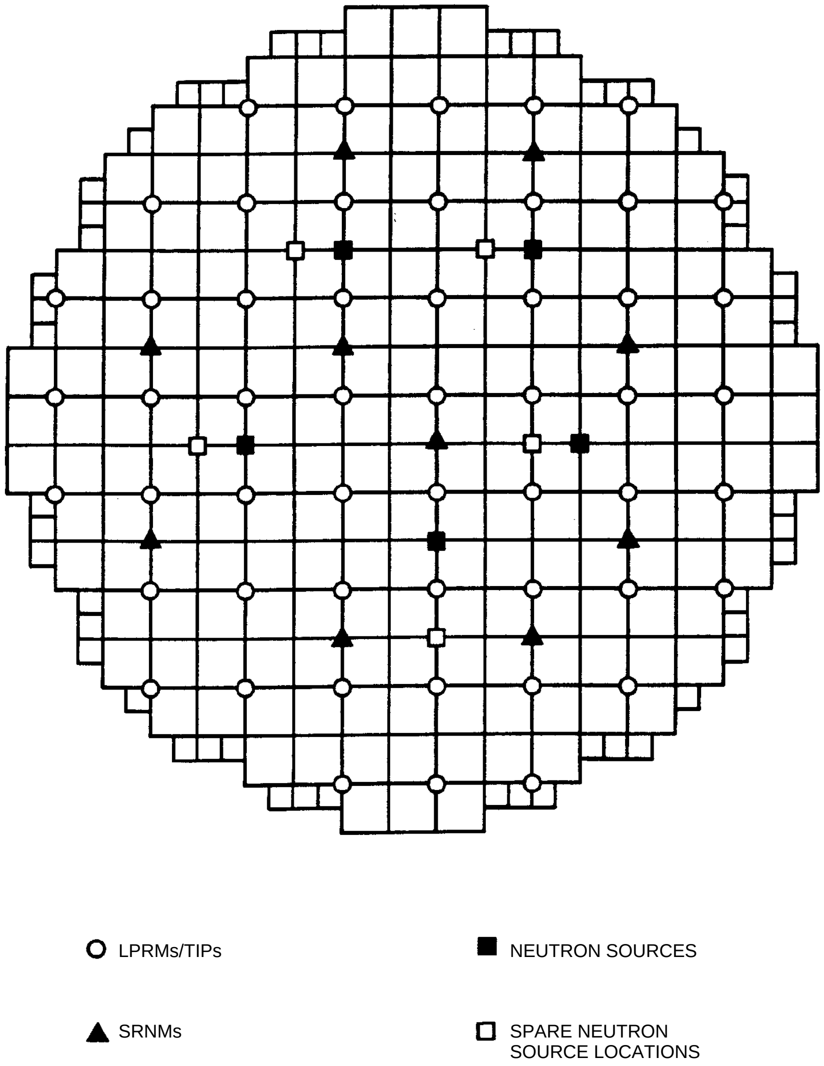

Figure 4.1-1 Core Configuration with Location of Instrumentation