4.0 REACTOR

4.1 SUMMARY DESCRIPTION

➔(DRN 01-1103, R12; 02-1477, R12; EC-9533, R302)
The reactor is of the pressurized water (PWR) type using two reactor coolant loops. A vertical cross-section of the reactor is shown in Figure 4.1-1. The reactor core is composed of 217 fuel assemblies and 87 control element assemblies, which provides for 236 fuel rod positions, consists of five guide tubes welded or bulged to spacer grids, and is closed at the top and bottom by end fittings. The guide tubes each displace four fuel rod positions and provide channels that guide the CEAs over their entire length of travel. In selected fuel assemblies, the central guide tube houses incore instrumentation.
🡐(DRN 01-1103, R12; 02-1477, R12)

The fuel is low enriched UO_2, in the form of ceramic pellets and is encapsulated in pre-pressurized Zircaloy, ZIRLO™, or Optimized ZIRLO™ tubes that form a hermetic enclosure.
🡐(EC-9533, R302)

The reactor coolant enters the upper section of the reactor vessel, flows downward between the reactor vessel wall and the core barrel, passes through the flow skirt where the flow distribution is equalized, and into the lower plenum. The coolant then flows upward through the core, removing heat from the fuel rods, exits from the reactor vessel and passes through the tube side of the vertical U-tube steam generators where heat is transferred to the secondary system. The reactor coolant pumps return the coolant to the reactor vessel.

➔(EC-9533, R302)
Figure 4.1-2 shows the reactor core cross section and certain dimensional relationships between fuel assemblies, fuel rods, and CEA guide tubes.

➔(EC-1020, R307)
The original reactor vessel closure head (ORVCH) was replaced. The replacement reactor vessel closure head (RRVCH) is identical in design to the ORVCH in all its major dimensions and functions. The main differences are the elimination of four unused control element drive mechanism (CEDM) penetrations and the replacement of Alloy 600 nozzle material (Ni-Cr-Fe) with a material that is less susceptible to primary water stress corrosion cracking (PWSCC). The use of stainless steel or Alloy 690 in place of Alloy 600 reduces the likelihood of PWSCC. The head nozzles are Alloy 690 construction, and the ICI Quickloc II flange adaptor is stainless steel.
🡐(EC-1020, R307)

The reactor internals support and orient the fuel assemblies, control element assemblies, and in-core instrumentation, and guide the reactor coolant through the reactor vessel. The reactor internals also absorb static and dynamic loads and transmit the loads to the reactor vessel flange. They will safely perform their functions during normal operating, upset, emergency, and faulted conditions. The internals are designed to safely withstand forces due to dead weight, handling, temperature and pressure differentials, flow impingement, vibration, and seismic acceleration. All reactor components are considered Category I for seismic design. The design of the reactor internals limits deflection where required by function. The stress values of all structural members under normal operating and expected transient conditions are not greater than those established by Section III, Subsection NG, of the ASME Pressure Vessel Code. The effect of neutron irradiation on the materials concerned is included in the design evaluation. The effect of accident loads on the internals is included in the design analysis.
🡐(EC-9533, R302)

Reactivity control is provided by two independent systems - the control element drive system and the Chemical and Volume Control System (CVCS).

The control element drive system controls short term reactivity changes and is used for rapid shutdown. The CVCS compensates for long term reactivity changes and can make the reactor sub critical without the benefit of the control element drive system. Design of the core and the Reactor Protect System prevents fuel design limits from being exceeded for any single malfunction in either of the reactivity control systems.

➔(DRN 01-1103, R12; 02-1477, R12)
The standard control element assemblies consist of five poison rods assembled in a square array, with one rod in the center. The rods are connected to a spider structure that couples to the control element drive mechanism (CEDM) shafting.

The Waterford 3 core originally contained 91 CEAs, of which 83 were full length and eight contained only a part length poison column. Of the 83 full length CEAs, 79 were standard five element design and 4 were four element CEAs (did not have a center poison rod). The four element CEAs each spanned two fuel assemblies at the core periphery's major axes.

At the end of Cycle 11, the 4 four element CEAs were removed from the core internals and the 8 part length CEAs were replaced with standard five element design CEAs.

Commencing with Cycle 12, the Waterford 3 core will have a total of 87 CEAs, all of the standard five element design.
🡐(DRN 02-1477, R12)

➔(EC-2800, R307)
The CEAs are positioned by magnetic jack control element drive mechanisms mounted on the reactor vessel head. Beginning with Cycle 19, a replacement reactor vessel closure head will be installed equipped with 87 CEDM nozzles and 87 replacement CEDMs. The replacement CEDMS are of similar construction as compared to the original CEDMs. The replacement CEDMs have fewer welded/assembled parts (3 versus 4) and incorporate other design improvements such as the use of improved electrical wiring and pressure boundary materials that are more resistant to stress corrosion cracking.
🡐(DRN 01-1103, R12; EC-2800, R307)

The maximum reactivity worth of the CEAs and the associated reactivity addition rate are limited by system design to prevent sudden large reactivity increases. The design restraints are such that reactivity increases do not result in violation of the fueled limits, rupture of the reactor coolant pressure boundary, or disruption of the core or other internals sufficient to impair the effectiveness of emergency cooling.
➔(EC-9533, R302)
Boric acid dissolved in the coolant is used as a neutron absorber to provide long term reactivity control. In order to reduce the boric acid concentration required at beginning-of-operating conditions, and thus the moderator temperature coefficient, burnable poison rods are provided in certain fuel assemblies. The poison is boron carbide dispersed in aluminum pellets; the pellets are clad in Zircaloy, ZIRLO™, or Optimized ZIRLO™ to form rods that are similar to the fuel rods.
🡐(EC-9533, R302)
A three batch fuel management scheme is employed, where 40-50 percent of the core assemblies are replaced at each refueling. The batch average burnup will be about 45,000 MWD/MTU over the three cycle life of the fuel. Sufficient margin is provided to ensure that peak burnups are within acceptable limits.

➔(EC-9533, R302)
The nuclear design of the core ensures that the combined response of all reactivity coefficients in the power operating range to an increase in reactor thermal power yields a net decrease in reactivity.
🡐(EC-9533, R302)
Control element assemblies are moved in groups to satisfy the requirements of shutdown, power level changes, and operational maneuvering. The control system is designed to produce power distributions that are within the acceptable limits of overall nuclear heat flux factor (F_Q) and departure from nucleate boiling ratio (DNBR). The Reactor Protection System and administrative controls ensure that these limits are not exceeded.

➔(DRN 01-1103, R12)
Axial xenon oscillations, should they occur, can be manually controlled by CEAs, using information provided by the nuclear instrumentation.
🡐(DRN 01-1103, R12)
The core originally contained two plutonium 238-beryllium neutron sources for initial and subsequent start-ups. The neutron sources were removed prior to cycle 7 startup. However, the core design has startup and operational capability without the sources.

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Design of the reactor internals is discussed in Subsections 3.9.5 and 4.5.2; fuel assembly design is discussed in Section 4.2; nuclear design of the core is discussed in Section 4.3; and the thermal and hydraulic design is discussed in Section 4.4. Summary lists of significant core parameters are presented in Tables 4.2-1, 4.3-1, and 4.4-1. A tabulation of the analysis techniques, load conditions, and computer codes utilized in the analyses of various reactor internal components is presented in Table 4.1-1. Appendix 4.3A provides an update of the information above with respect to the current fuel cycle.
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→(EC-9533, R302)

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←(EC-9533, R302)

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TABLE 4.1-1 (Sheet 1 of 3) Revision 307 (07/13)

ANALYSIS TECHNIQUES

Internal Components	Description	Analysis Technique	Computer Code
Core Support Barrel	Axial and Lateral Loads	Shell Analysis Beam Analysis	ASHSD[1] SHOCK[2] STARDYNE[3,4]
	Dynamic Buckling	Shell Analysis	SAMMSOR[5] - DYNASOR
Upper and Lower Core Support Barrel Flanges	Lateral Loads Axial Loads & Bending Moments	Finite Element Analysis	SAAS[6] NAOS[7]
Lower Support Structure Beams	Lateral Loads	Plane Grid Structure Analysis Simply Supported Beams	STRUDL II[8]
Columns	Axial Loads Bending Loads	Column Analysis	SHOCK[2] STARDYNE[3,4]
Upper Guide Structure	Lateral Loads	Beam Analysis	SHOCK[2]
CEAs	Axial Loads	Column Analysis	STARDYNE[3,4]
Beam Structure	Uniform Lateral Loading	Plane Grid Structure	STRUDL II[8]
Support Plate Flange	Axial Loads	Finite Element Analysis	SAAS[6]
	Bending Moments	NAOS(7)	
Core Shroud	Thermal & Pressure Loading	Finite Element Analysis	ANSYS[9]
CEDM ➔(EC-2800, R307) 🡐(EC-2800, R307)	Pressure, Fatigue and Thermal Loads	Finite Element Analysis	SAAS[6]
	Seismic Loading	Framed Structure	ANSYS[9]
➔(EC-1020, R307) CEDM and R.V. Nozzles 🡐(EC-1020, R307)	Thermal Loading	Relaxation Analysis	ANSYS[9]
➔(EC-2800, R307) CEDM Omega Seals 🡐(EC-2800, R307)	Pressure, Thermal Rotational and Displacement Loadings	Finite Element Analysis	ANSYS[9]

TABLE 4.1-1 (Sheet 2 of 3)

ANALYSIS TECHNIQUES

Internal Components	Description	Analysis Technique	Computer Code
Fuel Assembly	Seismic	Lumped Mass-Spring-Damper	SHOCK[2]
	Lateral Vertical	(Direct numerical Integration, Non-Linear/Linear Capability)	
	Loss-of-Coolant Accident Lateral Vertical	(Springs From Beam Stiffness Coefficients)	
Fuel Rod	Thermal-Mechanical	Generalized plane strain analysis including thermal, mechanical and creep effects solved by finite difference techniques	FATES[16]
Fuel Assembly	DNB Calculation	Open core	TORC[12,13,14]
Fuel Assembly, Structure, Reflector	Few-group cross-section generation for diffusion codes		CEPAK[15]
CEA Control Rod Fingers	Effective diffusion theory constants for diffusion codes	Match extrapolation lengths on outer surface to those based on tabulated capture probabilities	CERES[15]
Burnable Poison Rod	Effective diffusion theory constants for diffusion codes	Sequences of HAMMER, DTF-IV and M0807 based on relative reaction rates	HADTMO[15]
Fuel Assemblies and Reactor Core	Static and depletion dependent reactivities, flux, nuclides, power distributions in one, two, and three dimensions	Diffusion-depletion using PDQ-7 and HARMONY programs but with modifications to allow various feedback options	PDQX[15]

TABLE 4.1-1 (Sheet 3 of 3)

ANALYSIS TECHNIQUES

Internal Components	Description	Analysis Technique	Computer Code
Reactor Core	Static and time dependent one dimensional (axial) studies, with control rod motion	Diffusion code using up to 140 distinct regions with variable mesh intervals. Feed-back, Eigenvalue searches and power shaping searches	QUIX[15]
Reactor Vessel and Vessel Internals	Fast neutron flux and fluence	Combination of discrete ordinate transport and point kernel codes using core power distributions from PDQ-X	ANISN-SHADRAC[15]
Reactor Core	Xenon stability analysis	Linear modal analysis employing the funda-mental and first harmonic modes	HILLAMA[15]