## 4.6 Functional Design of Reactivity Control Systems

### 4.6.1 Information for Control Rod Drive System

The control rod drive mechanism (CRDM) and operation of the control rod drive system are described in subsection 3.9.4. Figure 3.9-4 provides the details of the control rod drive mechanisms. Figure 4.2-8 provides the configuration of the driveline, including the control rod drive mechanism. No hydraulic system is associated with the functioning of the control rod drive system. The instrumentation and controls for the reactor trip system are described in Section 7.2. The reactor control system is described in Section 7.7.

The control rod drive mechanisms are contained within an integrated head package located on top of the reactor vessel head as described in subsection 3.9.7. This assembly provides the support required for seismic restraint in conjunction with the attachment of the control rod drive mechanisms to the reactor vessel head. An outer shroud and the seismic restraint structure isolate the control rod drive mechanisms from the effects of ruptures of high-energy lines outside the shroud, and from missiles. The shroud also is used to direct air from the cooling fans past the control rod drive mechanisms. The cooling system maintains the temperatures of the coils in the control rod drive mechanisms below the design operating temperature. The integrated head package provides the proper support and required separation for electrical lines providing power to the control rod drive mechanisms and signals from the rod position sensors.

The line for the reactor head vent system is located among the control rod drive mechanisms and is supported by the integrated head package. This line is pressurized to reactor coolant system pressure and considered to be a high-energy line. This line is constructed to the appropriate requirements of the ASME Code. Figure 3.9-7 shows elements of the integrated head package surrounding the control rod drive mechanisms.

### 4.6.2 Evaluations of the Control Rod Drive System

Rod control systems of the type used in the AP1000 have been analyzed in detailed reliability studies. These studies include fault tree analysis and failure mode and effects analyses. These studies, and the analyses presented in Chapter 15, demonstrate that the control rod drive system performs its intended safety-related function – a reactor trip. The control rod drive system puts the reactor in a subcritical condition when a safety-related system setting is reached with an assumed credible failure of a single active component.

The essential elements of the control rod drive system (those required to provide reactor trip) are isolated from nonessential portions of the rod control system by the reactor trip switchgear, as described in Section 7.2. The essential portion of the control rod drive system is shielded from the direct effects of postulated moderate- and high-energy line breaks by the integrated head package. The dynamic effects of pipe ruptures do not have to be considered for those pipes that satisfy the requirements for mechanistic pipe break, as outlined in subsection 3.6.3.

The reactor vessel head vent lines and instrumentation conduits are one inch nominal diameter or smaller. Breaks in lines of this size do not have to be postulated for dynamic effects, pressurization, and spray wetting. The pressure boundary housing of the control rod drive mechanisms is constructed to the requirements of the ASME Code and a break in this pressure boundary is not credible.

The only instrumentation required of the control rod drive mechanism and supporting systems to operate safely is the rod position indicator. A break in the cables connected to the rod position indicators would neither preclude a reactor trip, nor would it result in an unplanned withdrawal of a rod assembly. A break in the power cable to the control rod drive mechanism coils results in a drop of the rod assembly. Information on the pressure and temperature of the control rod drive mechanisms and surrounding areas is not required for safe operation. The design pressure and temperature of the control rod drive mechanism housing is the same as the reactor coolant system, which is protected by safety valves. Overheating of the control rod drive mechanism coils due to a failure of the cooling system would in the worst case result in a drop of one or more rod assemblies. The reactor and reactor protection system is designed to accommodate and protect against rod drop events. Additional information is provided in subsection 3.9.1, and Sections 7.2, and 15.4.

### 4.6.3 Testing and Verification of the Control Rod Drive System

The control rod drive system is extensively tested prior to its operation. These tests may be subdivided into five categories:

- Prototype tests of components
- Prototype control rod drive system tests
- Production tests of components following manufacture and prior to installation
- Onsite pre-operational and initial startup tests
- Periodic in-service tests

These tests, which are described in subsection 3.9.4.4 and Sections 4.2 and 14.2, are conducted to verify the operability of the control rod drive system when called upon to function.

### 4.6.4 Information for Combined Performance of Reactivity Systems

As indicated in Chapter 15, there are only three postulated events that assume credit for reactivity control systems, other than a reactor trip to render the plant subcritical. These events are the steam-line break, feedwater line break, and small break loss of coolant accident. The reactivity control systems in these accidents are the reactor trip system and the passive core cooling system (PXS). Additional information on the control rod drive system is presented in subsection 3.9.4. The passive core cooling system is discussed further in Section 6.3.

No credit is taken for the boration capabilities of the chemical and volume control system (CVS) as a system in the analysis of transients presented in Chapter 15. Information on the capabilities of the chemical and volume control system is provided in subsection 9.3.6. The adverse boron dilution possibilities due to the operation of the chemical and volume control system are investigated in subsection 15.4.6. Prior proper operation of the chemical and volume control

system has been presumed as an initial condition to evaluate transients. Appropriate technical specifications promote the correct operation or remedial action.

The AP1000 instrumentation and control system includes a diverse actuation system (DAS). This system provides for automatic control rod insertion, turbine trip, passive residual heat removal heat exchanger start, core makeup tank start, isolation of critical containment penetrations, and start of the passive containment cooling system as appropriate upon conditions indicative of an anticipated transient without scram or other failure of the plant control and reactor protection system. This system is diverse and independent from the reactor trip system from the sensor through actuation devices.

In addition to the above, the AP1000 plant systems provide for operator response to an anticipated transient without scram (ATWS) event that includes core reactivity control followed by core decay heat removal. Core reactivity control is provided by a manual trip of the control rods, insertion of the control rods, the chemical and volume control system, or by the core makeup tank injection. The decay heat removal can be performed by the startup feedwater system or the passive residual heat removal system.

### 4.6.5 Evaluation of Combined Performance

The evaluations of the steam-line break, the feedwater line break, and the small break loss of coolant accident, which presume the combined actuation of the reactor trip system and the control rod drive system and the passive safety injection, are presented in subsections 15.1.5 and 15.2.8 and Section 15.6. Reactor trip signals and signals to actuate passive safety features for these events are generated from functionally diverse sensors. These signals actuate diverse means of reactivity control; that is, control rod insertion and injection of soluble neutron absorber.

Non-diverse but redundant types of equipment are used only in the processing of the incoming sensor signals into appropriate logic which initiates the protective action. This equipment is described in Sections 7.2 and 7.3. In particular, protection from equipment failures is provided by redundant equipment and periodic testing. Effects of failures of this equipment have been extensively investigated. Reliability studies, including failure mode and effects analysis for this type of equipment verify that a single failure does not have an adverse effect upon the engineered safety features actuation system. Adequacy of the passive core cooling system performance under faulted conditions is verified in Section 6.3.

In addition to the automatic actuations provided for by the diverse actuation system, that system also provides for manual actuation of the reactor trip.

The probability of a common mode failure impairing the ability of the reactor trip system to perform its safety-related function is extremely low. However, analyses are performed to demonstrate compliance with the requirements of 10 CFR 50.62. These analyses demonstrate that safety criteria would not be exceeded even if the control rod drive system were rendered incapable of functioning during anticipated transients for which its function would normally be expected. The evaluation demonstrates that borated water from the core makeup tank shuts down the reactor with no rods required, and the passive residual heat removal system provides sufficient core heat removal.

### 4.6.6 Combined License Information

This section has no requirement for additional information to be provided in support of the Combined License application.