3.9.4 Control Rod Drive System

The control rod drive system (CRDS) consists of the control rods and the related components which provide the means for mechanical movement. The CRDS extends to the coupling interface with the rod cluster control assembly (RCCA). However, as stated in Section 3.9.4 of the Standard Review Plan, for electromagnetic systems designs such as the CRDS, the description in this section is limited to the control rod drive mechanism (CRDM).

The following GDC apply to the CRDS:

- GDC 1 and 10 CFR 50.55a establish requirements for the quality standards to be applied to the CRDS. The specifications and design requirements for the CRDS are consistent with the quality group classification, in accordance with RG 1.26, as described in Section 3.2.

- GDC 2 establishes requirements for the CRDS to withstand the effects of an earthquake. The seismic classification of the CRDS, in accordance with RG 1.29, is provided in Section 3.2.

- GDC 14 establishes requirements for the reactor coolant pressure boundary (RCPB) portion of the CRDS. The CRDS is designed to provide a barrier to the release of fission products to the containment through the design of the control rod drive housing and the related components that are part of the RCPB.

- GDC 26 establishes requirements for the redundancy and capability of the reactivity control systems. As described in Section 3.1.3, the reactivity control systems for the U.S. EPR are the RCCAs, which are inserted into the core by gravity, and the chemical shim (boric acid) system. Further information on the RCCAs is provided in Chapter 4 and Chapter 7. Boric acid concentration control is described in Section 9.3.4.

- GDC 27 establishes requirements for the combined reactivity control system capability. The CRDS is one of the reactivity control systems relied on during normal operation and anticipated operational occurrences to control reactivity changes so that the fuel design limits are not exceeded. As described in Section 3.1.3, the U.S. EPR maintains the core subcritical under anticipated conditions with margin for contingencies. The means to accomplish this are described in detail in Chapter 4 and Chapter 9.

- Pursuant to GDC 29, the CRDS, in conjunction with the reactor protection systems, is designed to have an extremely high probability of accomplishing its safety functions in the event of anticipated operational occurrences. Further information concerning the design of the protection and reactivity control systems is found in Chapter 4 and Chapter 7.

3.9.4.1 Descriptive Information of CRDS

The CRDS includes the CRDMs and the rod cluster control assemblies (RCCA), which have absorber material over the entire length of the control rods. Further descriptions of the CRDS are provided below and in Section 4.6, while additional information on the RCCAs is in Section 4.2.

3.9.4.1.1 Control Rod Drive Mechanism

The CRDMs (see Figure 3.9.4-1—Control Rod Drive Mechanism Assembly) are mounted on top of the reactor pressure vessel (RPV) head. They are based on a proven design that has been in use for over 30 years.

The material requirements for the pressure boundary portions of the CRDMs are in Section 5.2.3, non-pressure boundary potions of the CRDMs are in Section 4.5.1, and the RCCA material requirements are in Section 4.2.2.9. Additional characteristics of the CRDMs are provided in Section 4.1.

The CRDMs use an electromagnetic jack design. The electromagnets are energized and either insert or withdraw the RCCAs in a controlled manner to control the core power level and distribution. The CRDMs consist of the following subassemblies, which are described in further detail below:

- Drive rod assembly (non pressure boundary).
- Pressure housing (pressure boundary).
  - Flange, nuts, and necked-down bolts (pressure boundary).
  - Latch unit (non pressure boundary).
- Coil housing assembly (non pressure boundary).

During a reactor trip, the CRDMs insert the drive rod and the attached RCCA by force of gravity. During normal operation, the CRDMs insert and withdraw the RCCAs and hold them in any selected step position within the positioning range. The pressure boundary portions of the CRDM are designed for a 60 year life. The CRDMs are designed to provide provisions for replacement of components during the life of the plant. Each CRDM is a self-contained unit that can be fitted or removed independently.

3.9.4.1.1.1 Drive Rod Assembly

The drive rod assembly is the connecting link between the latch unit and the RCCA. It consists of a hollow rod with transverse grooves in the upper section over the required travel length. The grooves receive the latches to hold or move the drive rod. The drive rod is coupled to the RCCA by a mechanical coupling at the bottom end.

The principal component of the coupling is a two-segment, split coupling clamp. The lower splined part snaps into the mating grooves of the RCCA top hub. The disconnect button, disconnect rod, and locking button provide positive locking of the coupling to the RCCA, yet permit the drive rod to be disconnected remotely.

3.9.4.1.1.2 Pressure Housing

The pressure housing encloses the moving parts of the CRDM. The pressure housing is attached to the RPV CRDM head adaptor flange via a flange that is tightened using necked-down bolts and nuts and is sealed using metallic gaskets. The pressure housing, flange, and bolting form part of the RCPB.

The pressure housing consists of two main sections, the latch unit section and the position indicator section, and forms a thimble-like extension to the RPV closure head. The latch unit section of the pressure housing contains the latch unit and the flange used to connect the pressure housing to the head adaptor flange of the RPV. The position indicator section is a capped tubular section that contains the drive rod in the fully withdrawn position.

The flange connection is equipped with two conical gaskets, each designed to withstand the operating pressure. Due to their conical shape, the gaskets increase in outer diameter and decrease in inner diameter when the pressure housing is mounted to the nozzle flange. As a result, the edges of the conical gaskets provide support in the corner radii of the flange and of the pressure housing, which are then sealed hermetically as the result of local plasticization of the gasket material.

The pressure housing is equipped with a displacement limiter which protects the CRDM from large displacements during earthquakes, and prevents the CRDM from contacting other CRDMs, as described in Section 5.4.14.

3.9.4.1.1.3 Latch Unit

The latch unit (see Figure 3.9.4-1) is located inside the lower section of the pressure housing and is used to control the position of the drive rod. It converts the magnetic forces generated by the coils outside the pressure housing into motion. The latch unit consists of a central sleeve (guide tube) as the load-bearing member, latch carriers with latches, stationary poles, and armatures. Between the stationary poles and armatures, springs are installed which guarantee the armatures will drop from the stationary poles in a certain amount of time. The armatures cause a movement of either of the two latch groups or cause the 0.4 in lifting motion of one of the latch groups. The latches grip into the grooves of the drive rod and, through a defined control cycle, move the drive rod by 0.4 in at each step. With this defined control cycle, the drive rod can be extracted from, or inserted into, the core.

3.9.4.1.1.4 Coil Housing Assembly

The coil housing assembly consists of a holding coil, gripping coil, lifting coil, a plug connector for the DC power supply to the operating coils, and a second plug connector for transmitting the signals from the position indicator coils. The coil housing assembly is combined with the position indicator coils and a sheet steel casing to form a single assembly that can be removed from the pressure housing. The CRDMs do not require forced air cooling because the sheet steel casing is arranged around the position indicator coils so that a chimney effect generates natural convection.

The material used in the latch unit section of the pressure housing is martensitic stainless steel, which is ferromagnetic. Ferromagnetic materials exhibit permanent magnetic properties, which reduces the magnetic resistance of the magnetic circuit. The field produced outside of the pressure housing in the working coils moves the armatures of the latch unit inside the pressure housing. The lower magnetic resistance makes it possible to significantly reduce the necessary coil current without a significant loss of magnetic forces between the armature and its adjacent pole. Therefore, the temperature of the CRDM pressure housing is reduced and natural air convection cooling is possible.

The position of each RCCA is measured by an analog and a digital position indicator system located on the outside of the position indicator section of the pressure housing. Additional coils are installed to indicate the top and bottom limit positions to permit detection of those limits.

Drive rod and RCCA movements are controlled by the energizing sequence of the operating coils. The lifting armature is influenced by the magnetic fields of the lifting and gripping coil so that reciprocal magnetic interference occurs between them.

3.9.4.1.2 Operation of the Control Rod Drives

During operation, the drive rod in each control bank (see Section 7.7.2) is held in place when the gripping coil is energized. When the signal is given to lift the drive rod, the coils are energized in the sequence described in Table 3.9.4-1—Control Rod Withdrawal Sequence. This sequence describes the lifting of the drive rod by one step (0.4 in) starting from the rest position in which only the gripping coil is energized. The sequence is controlled by a timing sequencer that interrupts the power supply to the operating coils in the sequence shown in the table. The drive rod is lowered one step by following a similar step sequence. The sequence described in Table 3.9.4-1 is repeated to raise or lower the drive rod the desired number of steps.

When a reactor trip signal occurs, the operating coils are de-energized. This causes the armatures to drop, retracting the latches from the drive rod grooves and allowing the drive rod and the RCCA, which contains 24 control rods, to drop into the reactor core under gravity. Toward the end of the travel path, the RCCA is decelerated by means of a hydraulic dashpot, and residual energy is absorbed by the spring in the RCCA spider hub.

3.9.4.2 Applicable CRDS Design Specifications

The design, fabrication, examination, testing, inspection, and documentation of the pressure boundary parts of the CRDS are in accordance with the ASME Boiler and Pressure Vessel Code, Section II (Reference 1) and Section III (Reference 2) for Class 1 vessels. The pressure-retaining components and the attachments of the pressure housing assembly are classified as an "appurtenance" as specified in the ASME Code, Section III, Subsection NCA. The requirements of the ASME Code, Section III, Division I, Subsection NB apply to those portions of the pressure housing that form a pressure-retaining boundary, and ASME Code, Section III, Division 1, Subsection NF applies to the displacement limiter. Classification of the pressure retaining portions of the CRDS is addressed in Section 3.2.2.

Materials used in the pressure boundary section are described in Section 5.2.3 and non-pressure boundary portions of the CRDS are described in Section 4.5.1. The CRDM pressure housing, which is part of the RCPB, is designed in accordance with the requirements of 10 CFR 50.55a, ASME Codes, and applicable standards. The pressure housing meets the stress requirements for design and transient conditions specified for Class 1 components in the ASME Code, Section III. The ASME Code requirements do not apply to the non-pressure boundary components of the CRDS. For those materials which do not have established stress limits, the limits are based on the material specification mechanical property requirements.

The CRDM pressure housing is designed for the preservice and inservice inspection requirements of the ASME Code, Section XI (Reference 3). Welding is performed in accordance with the ASME Code, Section III, Division I, Subsection NB. The CRDMs are also designed to prevent brittle fracture in accordance with the ASME Code, Section III, Division I, Appendix G, Article G-1000.

The operating coils of the CRDM assembly do not provide a safety function and are not part of the RCPB. Failure to supply power to the operating coils does not result in a condition that would prevent the rods from inserting into the core, therefore the CRDMs fail in an acceptable condition. The CRDM bolting is designed in accordance with the ASME Code, Section III, Appendix E as addressed inSection 3.13. Additional information on compliance with codes and code cases for the RCPB is provided in Section 5.2.1.

3.9.4.3 Design Loads, Stress Limits, and Allowable Deformations

The CRDMs are designed for the conditions specified below.

- Design pressure of 2550 psia.

- Operating pressure of 2250 psia.
- Design temperature of 664°F.
- Operating temperature of 482°F.

The CRDMs are designed to withstand the loading combinations and loading values specified in Section 3.9.3. The ability of the CRDMs to withstand these loads is verified using acceptance methods that indicate the primary stresses meet the requirements of the ASME Code, Section III, Division I, Subsection NB.

Loading combinations, system operating transients, and stress limits are further described in Section 3.9.3. The analyses that are performed for the loading combinations described in Section 3.9.3 demonstrate that the allowable stress limits are satisfied and verify the design margin. These analyses, in conjunction with the testing described in Section 3.9.4.4, verify that the actual design conforms to the design criteria and that design limits have not been exceeded.

In addition to the loading requirements mentioned above, the CRDMs are designed with the ability to overcome a stuck rod condition. Design requirements are also established for clearances in the CRDM latch assembly, the latch arm, the coil assembly, and the coil fit in the coil housing. These clearances account for the thermal expansions of the various CRDM components, and are verified during testing as described in Section 3.9.4.4. Additionally, hydrostatic tests are required for ASME Code, Section III, Class 1 components to verify the integrity of the pressure housing.

As noted in Section 3.9.4.2, the ASME Code requirements do not apply to the non-pressure boundary components of the CRDM, which include the latch and coil stack assembly. As a conservative approach, the minimum material properties at temperature are utilized for the non pressure boundary components. Maintaining structural integrity under the design loading conditions is the only design requirement for these components, however the ASME Code, Section III criteria will be used as guidelines for the allowable stresses. The NRC has found this approach acceptable in Section 3.9.4 of the Final Safety Evaluation Report Related to Certification of the AP1000 Standard Design (Reference 4).

3.9.4.4 CRDS Operability Assurance Program

The ability of the pressure housing components to perform throughout their design life, using the criteria of an operating life of 60 years, is confirmed by the primary stress analysis report required by the ASME Code, Section III.

To confirm the mechanical adequacy of the CRDS, a prototype testing program was created that integrates the CRDM and appurtenances, the CRDM drive rod, the CRGA, the RCCA, and the fuel assembly. The purpose of the tests is to demonstrate the correct mechanical functioning of a prototype of the complete control rod line with the CRDM. Operation of the CRDS and rod drops under various conditions are tested and measured. The prototype assembly is tested under simulated conditions of reactor temperature, pressure, and flow.

The first phase of the function tests are the performance tests, which verify the performance of the equipment under a broad range of conditions. Temperature, pressure, and flow rate conditions are tested for a complete assessment of the system behavior. The performance tests provide information for recording, adjusting, and optimizing the coil activation sequence to achieve reliable stepping operation. The performance tests also provide dynamic behavior assessment, including displacement and snapback tests with natural frequency measurements, and drop time measurements in perturbed geometries. These measurements help demonstrate that the entire system will operate as designed under seismic conditions. The performance tests also evaluate stepping operation dynamic characterization, including acceleration and stepping force measurements, and coupling forces.

After the performance tests, stability tests are conducted to demonstrate correct functioning over an appreciable amount of time. These tests consist of repeated stepping motions under nominal conditions, periodically interrupted with full height drops. An objective of these medium-term stability tests, which involve up to three million steps, is to verify the relative insensitivity of drop times to repeated stepping and drop operations.

The final set of prototype tests are endurance tests, with up to six million additional steps, to quantify the amount of time and the number of steps during which no appreciable mechanical damage is expected (i.e., fatigue and wear) that could alter the correct mechanical behavior. In addition to the performance, stability, and endurance testing performed on the prototypes, each CRDM has a series of production tests performed to verify the integrity of the pressure housing and the function of the CRDM. These tests include a hydrostatic test of each assembled CRDM in accordance with the ASME Code, Section III, Division I, Subsection NB to verify the pressure housing, and a functionality test.

In addition to the prototype testing program, tests are performed on the CRDMs to verify their function. These tests verify that the insertion and withdrawal times in the stepping mode meet the design requirements. Drop tests are performed to verify the mechanical functioning of the CRDMs.

Following installation of the CRDMs, preoperational tests are performed. These tests verify the correct sequencing of the operating coils and verify the design requirements are met for insertion, withdrawal, and drop times. A description of the initial startup test program is provided in Section 14.2.

To demonstrate correct operation of the CRDMs and acceptable core power distributions, partial-movement checks are performed on the RCCAs in accordance with the Technical Specifications. Additionally, periodic drop tests of the RCCAs are performed at each refueling shutdown to verify the ability to meet trip time requirements.

3.9.4.5 References

1. ASME Boiler and Pressure Vessel Code, Section II, “Materials,” The American Society of Mechanical Engineers, 2004.

2. ASME Boiler and Pressure Vessel Code, Section III, “Rules for Construction of Nuclear Power Plant Components,” The American Society of Mechanical Engineers, 2004.

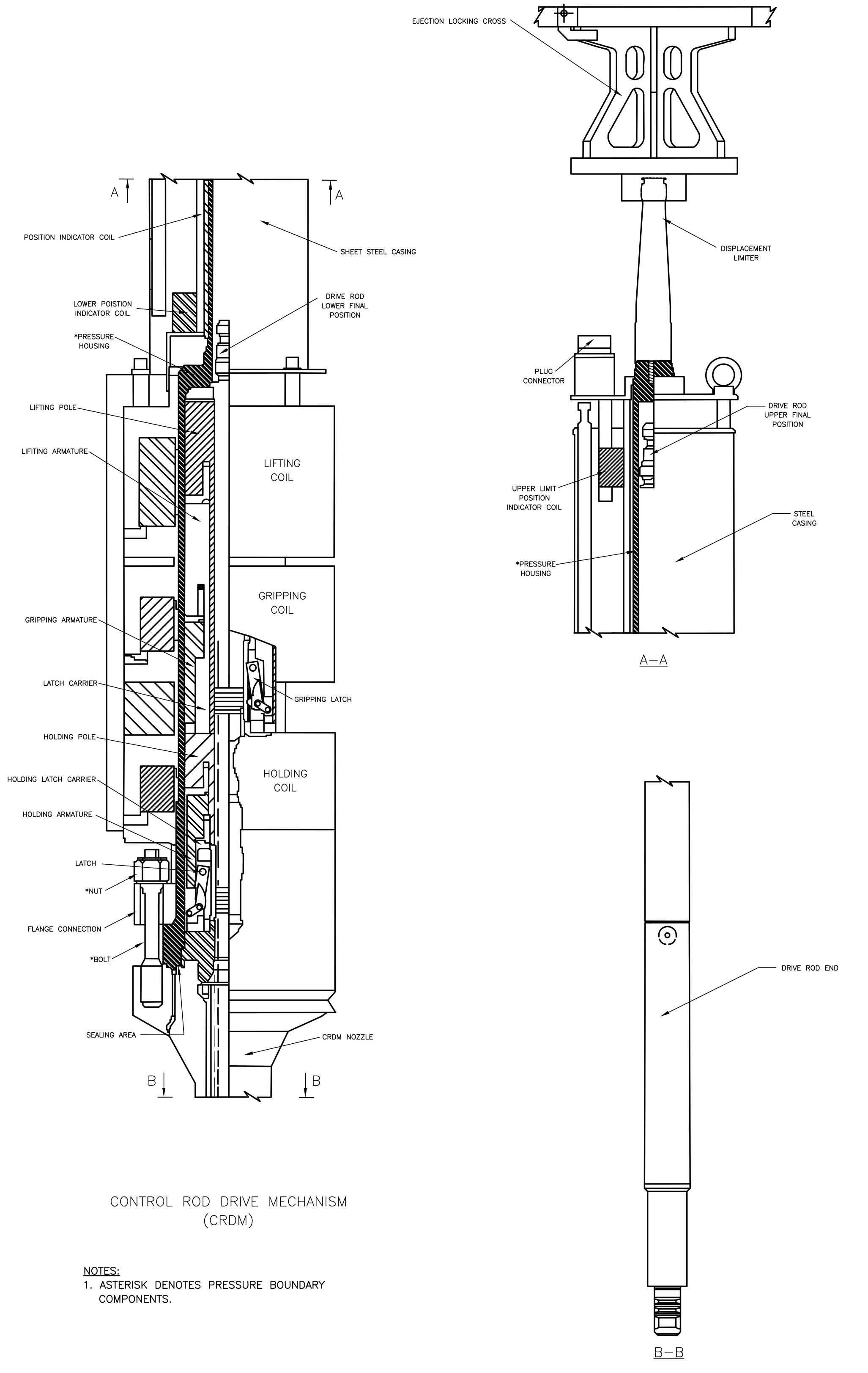
3. ASME Boiler and Pressure Vessel Code, Section XI, “Rules for Inservice Inspection of Nuclear Power Plant Components,” The American Society of Mechanical Engineers, 2004.

4. NUREG-1793, “Final Safety Evaluation Report Related to Certification of the AP1000 Standard Design,” U.S. Nuclear Regulatory Commission, September 2004.

Table 3.9.4-1—Control Rod Withdrawal Sequence

Step	Operating Coil Energizing Sequence	Latch Unit Response
1	Gripping coil is energized	The rest position; the drive rod is on gripping latches.
2	Lifting coil is energized	The lifting armature lifts up the drive rod one groove pitch (0.4 in) by means of the gripping latches.
3	Holding coil is energized	The holding latches are engaged in a groove and the load is removed from the gripping latches by raising the holding armature.
4	Gripping coil is de-energized	The gripping armature drops down and withdraws the gripping latches from the groove.
5	Lifting coil is de-energized	The lifting armature drops down, thus reverting to its starting position.
6	Gripping coil is energized	The gripping latches engage into the next groove.
7	Holding coil is de-energized	The holding armature drops down, the load is transferred to the gripping latches, and the holding latches are withdrawn from the groove.
8	Repeat	The sequence described above (steps 2 through 7) is termed one cycle. The RCCA assembly moves approximately 0.4 in for each cycle. The RCCAs can be withdrawn at a variable rate. The maximum speed is 29.5 in per minute.

Figure 3.9.4-1—Control Rod Drive Mechanism Assembly



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