1.2 General Plant Description

This section includes a summary description of the principal design criteria, operating characteristics, and safety considerations of the U.S. EPR; the engineered safety features (ESF) and emergency systems; the instrumentation, control, and electrical systems; the power conversion system; the fuel handling and storage systems; the cooling water and other auxiliary systems; and the radioactive waste management system. This section also provides a general description of the plant site, the site criteria, the general plant arrangement, the plant arrangement criteria, and key features of each of the individual buildings.

A COL applicant that references the U.S. EPR design certification will identify those site-specific features of the plant likely to be of special interest because of their relationship to safety. The COL applicant will also highlight items such as unusual site characteristics, solutions to particularly difficult engineering, construction problems, and significant extrapolations in technology represented by the site specific design.

1.2.1 Principal Design Criteria, Operating Characteristics, and Safety Considerations

The U.S. EPR is an evolutionary four-loop Pressurized Water Reactor (PWR). Section 1.1 identifies the power output for the U.S. EPR. The primary system design, loop configuration, and main components design are similar to those of currently operating PWRs, thus forming a proven foundation for the design. The U.S. EPR contains unique design features, such as four redundant trains of emergency core cooling, a Containment and Shield Building, and a core melt retention system for severe accident mitigation. Compliance with 10 CFR 50, Appendix A, General Design Criteria (GDC) is described in Section 3.1. Conformance with Regulatory Guides and the Standard Review Plan is described in Section 1.9. A listing of the key operating parameters is provided in Section 1.3.

The U.S. EPR design philosophy is based on the following objectives:

- Reduce core damage frequency (CDF).
- Reduce large release frequency (LRF).
- Mitigate severe accidents.
- Protect critical systems from external events.
- Improve human-machine interface (HMI).
- Extend response times for operator actions.
- Reduce radiological consequences and accident initiator frequencies.

- Produce favorable transient plant behavior.
- Simplify safety systems and divisional separation.
- Eliminate common mode failures by physical separation and diverse backup safety functions.
- The plant design objective is 60 years. The design provides for the replaceability of major components, including the steam generators.
- Increase redundancy and arrangement of the redundant trains into separated divisions. The divisional separation is also extended to supporting features such as cooling water, power supply and instrumentation and controls (I&C). In the event of a loss of one division by an internal hazard, the remaining divisions provide at least one full system capacity, taking into account a single failure.
- Produce low sensitivity to failures, including human errors, by incorporation of adequate design margins; automation and extended times for operator actions; high reliability of the devices in their expected environment; and protection against common mode failures.
- Reduce sensitivity to human errors by optimized I&C systems and information supplied by state-of-the-art operator information systems.
- Consider operating experience in the design phase to simplify and optimize operation.

The safety design of the U.S. EPR is based primarily on deterministic analyses complemented by probabilistic analyses. The deterministic approach is based on the "defense-in-depth" concept which comprises four levels:

1. A combination of conservative design, quality assurance, and surveillance activities to prevent departures from normal operation.
2. Detection of deviations from normal operation and protection devices and control systems to cope with them. This level of protection supports the integrity of the fuel cladding and the reactor coolant pressure boundary (RCPB) to prevent accidents.
3. ESFs and protective systems that are provided to mitigate accidents and consequently to prevent their evolution into severe accidents.
4. Measures to preserve the integrity of the containment and enable control of severe accidents.

Low probability events with multiple failures and coincident occurrences up to the total loss of safety-grade systems are considered in addition to the deterministic design basis. Representative scenarios are defined for preventing both core melt and large releases in order to develop parameters for risk reduction features. The design uses a

probabilistic approach to define these events and assess the specific measures available for their management. Consistent with international and U.S. probabilistic safety objectives, the CDF is less than 10^{-5}/reactor-year, including all events and all reactor states. Additionally, the overall mean LRF of radioactive materials to the environment from a core damage event is less than 10^{-6}/reactor-year.

Innovative features result in the low probability of energetic scenarios that could lead to early containment failure. Design provisions for the reduction of the residual risk, core melt mitigation, and the prevention of large releases are as follows:

- Prevention of high pressure core melt by high reliability of decay heat removal systems, complemented by primary system overpressure protection (OPP).
- Primary system discharge into the containment in the event of a total loss of secondary side cooling.
- Features for corium spreading and cooling.
- Prevention of hydrogen detonation by reducing the hydrogen concentration in the containment at an early stage with catalytic hydrogen recombiners.
- Control of the containment pressure increase by a dedicated severe accident heat removal system (SAHRS) consisting of a spray system with recirculation through the cooling structure of the melt stabilization system.
- Collection of leaks and prevention of bypass of the containment.

External hazards (e.g., explosion pressure wave (EPW), seismic events, tornado-generated missiles, wind, fire) and aircraft hazards have been considered in the design of Safeguard Buildings and the hardening of the Shield Building.

1.2.2 Site Description

The U.S. EPR is a standard plant design that can be built on a site with parameters as described in Section 1.3 and in Table 1.3-1—U.S. EPR Comparison with Similar Facilities. These site parameters relate to the seismology, hydrology, meteorology, geology, heat sink, and other site-related aspects that form the basis for the U.S. EPR design. Figure 1.2-1—3-Dimensional Conceptual Configuration of U.S. EPR Buildings, Figure 1.2-2—U.S. EPR Cutaway, and Figure 1.2-3—Plant Configuration, show the layout and configuration of a generic U.S. EPR. General Arrangement drawings of the following structures are identified below:

Reactor Building, Safeguards Buildings, Fuel Buildings, Emergency Power Generating Buildings, Essential Service Water Building Plan – Section 3.8.

Nuclear Auxiliary Building – Figures 1.2-4 through 1.2-17.

Radioactive Waste Processing Building – Figures 1.2-18 through 1.2-27.

Turbine Building – [[Figures 1.2-28 through 1.2-48.]]

Access Building – [[Figures 1.2-50 through 1.2-58.]]

A COL applicant that references the U.S. EPR design certification will provide a site-specific layout figure. A COL applicant that references the U.S. EPR design certification will provide site-specific general arrangement drawings for the Turbine Building and Access Building.

1.2.3 Plant Description

1.2.3.1 Introduction to the U.S. EPR Design and Building Arrangement

1.2.3.1.1 Overview

The U.S. EPR is furnished with a four-loop, pressurized water, reactor coolant system (RCS). This system consists of a reactor vessel that contains the fuel assemblies, a pressurizer (PZR) with control systems to maintain system pressure, one reactor coolant pump (RCP) per loop, one steam generator (SG) per loop, associated piping, and related control and protection systems.

The RCS is located in the Reactor Building. The Reactor Building is an integrated structure consisting of an inner Containment Building, an outer building called the Shield Building, and an annular space between the two buildings that separates them. The Containment Building is a post-tensioned concrete cylinder lined with steel. The Shield Building is a cylindrical reinforced concrete structure. The Reactor Building is surrounded by four Safeguard Buildings and a Fuel Building (see Figures 1.2-1, 1.2-2, and 1.2-3). The internal structures and components within the Reactor Building, Fuel Building, two of the Safeguard Buildings, and the plant control room are protected against external and aircraft hazards. The other two Safeguard Buildings have a lower level of protection, but they are located on opposite sides of the Reactor Building, which limits damage from an external event to a single safety division.

Redundant safety systems (one in each Safeguard Building) are physically separated into four divisions, which protect the individual integrity of the electrical and mechanical safety systems. The four divisions of safety systems are consistent with an N+2 safety concept. With four safety divisions, one division can be out of service for maintenance, and one division can fail to operate, while the remaining two divisions are available to perform the necessary safety functions even if one of the two remaining becomes inoperable due to the initiating event.

In the event of a loss of offsite power (LOOP), each safeguards division is powered by a dedicated emergency diesel generator (EDG). The four EDGs are housed in two

separate reinforced concrete buildings; the two EDGs in each building are in separate locations within the building. In addition to the four safety-related diesels, two independent non-safety-related station blackout (SBO) diesel generators are available to power essential equipment during an SBO event (i.e., a LOOP with coincident failure of all four EDGs).

Additional safety systems and features are located in and around the RCS and the Reactor Building. Water storage for safety injection is provided by the in-containment refueling water storage tank (IRWST). Also located inside containment, below the reactor pressure vessel (RPV), is a dedicated spreading area for molten core material following a postulated worst-case severe accident. Furthermore, the fuel pool is adjacent to the Reactor Building in a dedicated building to simplify access for fuel handling during plant operation and handling of fuel casks. Two divisions of redundant, safety-related cooling systems provide fuel pool cooling.

The ultimate heat sink (UHS) consists of four division-related and independent mechanical draft cooling towers connected to the essential service water system (ESWS) through intake and discharge paths, with water storage basins associated with each cooling tower.

1.2.3.1.2 Buildings and Arrangement

The Nuclear Island (NI) includes the Reactor Building, Safeguard Buildings, and the Fuel Building, all of which are located on a common basemat. The Nuclear Auxiliary Building, two Emergency Power Generating Buildings, the Radioactive Waste Processing Building, and the UHS structures are located on individual basemats. Additionally, an Access Building is provided, which includes functions such as the health physics area, access control, and personnel facilities (showers, locker rooms). The Access Building is further described in Section 3.7.2. Figure 1.2-1 and Figure 1.2-3 show the general layout of the major U.S. EPR Buildings. Note that any building dimensions in these figures are for information only.

Both the structural design and physical arrangement of the U.S. EPR buildings provide protection from both external and internal hazards. Physical separation protects each safety system division against the propagation of internal hazards (e.g., fire, high-energy line break, flooding) from one division to another. Safety-related buildings are also designed to withstand the effects of the safe shutdown earthquake (SSE) and a tornado.

Protection of the U.S. EPR against external hazards (including aircraft impact) is provided by the following design features:

- A hardened concrete shell protects Safeguard Buildings 2 and 3, the Reactor Building, and the Fuel Building.

- The main control room (MCR) and the remote shutdown station (RSS) are located inside the protected Safeguard Buildings 2 and 3.
- The inner structures of the Reactor Building, Safeguard Buildings 2 and 3 and the Fuel Building are not connected to the protection shells, which isolates the consequences of an aircraft hazard.
- Safeguard Buildings 1 and 4 are physically separated, limiting damage to one division.
- The main steam and feedwater valve stations are physically separated into two pairs, so that one pair remains operable in the event of an external or aircraft hazard.
- Safety-related systems located in other buildings, such as emergency diesels, ESWS, and UHS, are protected by physical separation.

Physical separation also protects the [[Turbine Building and Switchgear Building. The Turbine Building houses the components of the steam condensate main feedwater cycle, including the turbine-generator. This building is located in a radial position with respect to the Reactor Building, but is independent from the NI. The Turbine Building is further described in Section 3.7.2. The Switchgear Building, which contains the power supply, the instrumentation and controls (I&C) for the balance of plant, and the SBO diesel generators, is located next to the Turbine Building and is physically separate from the NI. The Switchgear Building is shown in Figure 1.2-3.]]

Reactor Building Structure

The Reactor Building is located at the center of the NI. The Reactor Building consists of a cylindrical reinforced concrete outer Shield Building; a cylindrical, post-tensioned concrete inner Containment Building with a 0.25 inch thick steel liner; and an annular space between the two buildings. The Shield Building protects the Containment Building from external hazards. The Containment Building contains the RCS and portions of its associated structures, systems, and components. In the event of a design basis accident, the Containment Building retains radioactive material and can withstand the maximum pressure and temperature resulting from the release of stored energy. General arrangement drawings of the Reactor Building are provided in Section 3.8.

The Reactor Building is designed to withstand internal accidents as well as external hazards. The design of the Reactor Building, Containment Building, containment internal structures, and Shield Building is described in Section 3.8.

Safeguard Buildings

There are four Safeguard Buildings, each containing one of the redundant safety system divisions. The arrangement of these buildings achieves physical separation of

the systems that they house: Safeguard Buildings 1 and 4 are located on opposite sides of the Reactor Building; Safeguard Buildings 2 and 3 are housed together in a hardened concrete enclosure. The Safeguard Buildings are designed to withstand internal accidents as well as external and aircraft hazards. The Safeguard Building design is described in Section 3.8.4. Safeguard Buildings 2 and 3 interior structures, systems, and components are further protected from the impact forces of an aircraft hazard by structural decoupling from the outer hardened walls above the basemat elevation.

The Safeguard Buildings are located adjacent to the Reactor Building and contain the following:

- Component cooling water system (CCWS).
- Emergency feedwater system (EFWS).
- Safety injection system and residual heat removal (SIS/RHR).
- SAHRS (Safeguard Building 4).
- MCR in Safeguard Building 2 and RSS in Safeguard Building 3.
- Equipment for I&C and electrical systems of the NI.
- Safeguard Building ventilation and safety chilled water systems.

In the event of a release of radioactivity, each building can be isolated and air can be circulated through a filter system. Release of radioactivity to the ground water is prevented by isolating water release points. The design of the Safeguards Buildings is described in Section 3.8.

Fuel Building

The Fuel Building, which houses fuel storage and handling equipment, is part of the NI and is on a common basemat with the Reactor Building and the Safeguard Buildings. The operating compartments and passageways in the Fuel Building are separated from the equipment compartments, valve compartments, and the connecting pipe ducts in the building. Areas of high radioactivity are shielded from areas of low or no radioactivity. The spent fuel pool is also located in the Fuel Building. This configuration simplifies cask loading outside the containment during plant operation and provides sufficient spent fuel capacity without enlarging the containment.

The Fuel Building is enclosed by a hardened concrete protection shield, which prevents damage to the building from external hazards. The Fuel Building interior structures, systems, and components are further protected from the impact forces of an aircraft hazard by structural decoupling from the outer hardened walls above the

basemat elevation. Building isolation and filtering occurs in the event of a release of radioactivity inside the building. The Fuel Building is described in Section 3.8.4.

Nuclear Auxiliary Building

The Nuclear Auxiliary Building is located on a separate basemat and contains additional non-safety-related systems, including:

- Reactor boron and water makeup system.
- Fuel pool cooling and purification system.
- Gaseous waste processing system.
- Portions of the steam generator blowdown system.
- Nuclear auxiliary building ventilation.

The Nuclear Auxiliary Building is designed so that it will not impact any safety-related structures in the event of an SSE. Physical separation is also incorporated within the building; the operating compartments and passageways are completely separated from equipment compartments, valve compartments and the connecting pipe. Shielding facilities separate areas of high radioactivity from areas of low or no radioactivity. The interaction of the Nuclear Auxiliary Building with Seismic Category I structures is described in Section 3.7.2.

Emergency Power Generating Buildings

The Emergency Power Generating Buildings (EPGB) house the EDGs and related electrical, I&C, and heating, ventilating and air conditioning (HVAC) equipment. These buildings are designed to withstand internal accidents and are located on opposite sides of the NI; thereby providing physical separation for protection against external hazards. Each EPGB contains two redundant divisions including the EDGs for emergency power supply. The two redundant EDGs and related equipment within each building are protected against internal hazards by physical separation. The EPGBs are described in Section 3.8.4.

Radioactive Waste Processing Building

The Radioactive Waste Processing Building is used for the collection, storage, treatment, and disposal of liquid and solid radioactive waste and is adjacent to the Nuclear Auxiliary Building. The building contains all the systems required for liquid and solid radioactive waste processing.

The Radioactive Waste Processing Building is supported on a reinforced-concrete slab foundation which is separated from the adjacent foundation of the Nuclear Auxiliary Building. The radioactive waste building design prevents exceedance of the offsite

radiological release limits in the event of an SSE or other hazard. Isolation of the building is provided if radioactivity is released inside the building. The interaction of the Radioactive Waste Processing Building with Seismic Category I structures is described in Section 3.7.2.

Ultimate Heat Sink Structure

Four division-related and independent mechanical draft cooling towers serve as the UHS for the U.S. EPR. Each division has an ESWS Pump Building located with the respective cooling tower structure. The UHS is arranged with two of the four divisions located on opposite sides of the Reactor Building. The UHS is described in Section 9.2.5. The design of the ESWS Pump Buildings is described in Section 3.8.4.

1.2.3.2 Reactor Coolant System

The RCS configuration is a conventional four-loop design. The RPV is located at the center of the Reactor Building and contains the fuel assemblies. The reactor coolant flows from the RPV through the hot leg pipes to the SGs and returns to the RPV via the cold leg pipes, which contain the RCPs. The PZR is connected to one hot leg via a surge line and to two cold legs by spray lines. The RCS is described in further detail in Chapter 5.

1.2.3.2.1 Reactor Pressure Vessel

The RPV is the main component of the RCS. The vessel is cylindrical, with a welded hemispherical bottom and a removable flanged hemispherical upper head with gasket. The RPV is made of low-alloy steel, with the internal surface covered by stainless steel or NiCrFe alloy cladding for corrosion resistance. This unit is designed to provide the volume required to contain the reactor core, the control rods, the heavy reflector, and the supporting and flow-directing internals. The RPV nozzles are the fixed point of the RCS.

The RPV has four inlet nozzles and four outlet nozzles located in a horizontal plane just below the reactor vessel flange but above the top of the core. Coolant from the cold legs enters the vessel through the inlet nozzles and flows down through the annulus formed by the space between the core barrel and the reactor vessel inner wall. At the bottom of the vessel, the coolant is deflected to pass up through the core to the outlet nozzles. Heated reactor coolant leaves the RPV through four outlet nozzles, flowing into the hot legs and toward the SGs.

The cylindrical shell of the RPV consists of two sections, an upper and a lower part. To minimize the number of large welds, which require frequent in-service inspections, the upper part of the RPV is machined from a single forging and fabricated with eight nozzles. Because the nozzles are welded to an axis-symmetric ledge machined out from the forged flange shell, most of the reinforcement needed for the nozzle design is

provided by the vessel material itself. Therefore, the nozzles used in this design are the “set-on” type, which require a less substantial weld than would otherwise be required.

The RPV closure head consists of the closure head dome and the closure head flange, two single-piece forgings that are welded together by a circumferential weld. The closure head flange consists of a shaped forging with holes for the closure studs. The lower face of the flange is clad and locally machined to form two grooves in which two metallic gaskets are located.

The closure head is provided with penetrations for:

- Adapters for the control rod drive mechanisms (CRDM).
- An adapter for a dome temperature measurement probe.
- Adapters for neutron, temperature, and reactor vessel water level instrumentation.
- An adapter for a vent pipe that is welded to the head dome and penetrates the RPV closure head.

The lower part of the RPV body is made of two cylindrical shells at the reactor core level: one forged transition ring and one forged bottom head dome. The bottom head is a spherical shell connected to the RPV body through the transition ring. There are no penetrations in the bottom head.

The RPV is described in Section 5.3 and the RPV internals are further described in following paragraphs and in Section 3.9.5.

1.2.3.2.2 Reactor Pressure Vessel Supports

The RPV is supported by pads located on the bottom of the eight nozzles for the reactor coolant loops. Each nozzle has its own support pad which rests on a support ring, also part of the RPV support structure. This arrangement is capable of withstanding the forces caused by design basis and beyond design basis severe accidents.

1.2.3.2.3 Reactor Pressure Vessel Internals

The RPV internals consist of two primary sections (i.e., the upper internals and the lower internals). Coolant from the cold legs enters the RPV through the inlet nozzles and flows down through the annulus formed by the space between the core barrel and the RPV inner wall, and into the lower plenum below the lower support plate (LSP). The flow is then directed through the LSP and into the core region. After leaving the core, the heated reactor coolant passes through the upper core plate (UCP); then bypasses through and around the control rod guide tubes and the support columns to

reach the outlet nozzles. The flow in the core is channeled by the heavy reflector, which fills the space between the outline of the core and the internal diameter of the lower support assembly shell. Further details are provided in Section 3.9.5.

1.2.3.2.4 Pressurizer

The PZR consists of a vertical cylindrical shell, closed at both ends by hemispherical heads. The PZR is supported by three brackets welded to the lower cylindrical shell. The brackets rest on a supporting floor and allow free radial and vertical thermal expansion of the PZR. Lateral restraints prevent rocking in the event of an earthquake or a pipe break. The PZR is connected to the RCS by a surge line that connects to one hot leg. The surge line PZR nozzle is located at the bottom of the PZR and is connected vertically.

The PZR is equipped with electric heater rods. The heater rods are installed vertically through the lower head. The heater rods are used to increase the PZR pressure and consequently the RCS pressure.

The spray system inside the PZR consists of three separate nozzles welded laterally near the top of the upper cylindrical shell. Two nozzles are provided for the normal spray lines connected to cold legs, and one nozzle is provided for the auxiliary spray line connected to the chemical and volume control system (CVCS). The spray heads at the end of the spray lines inject spray flow in the steam space of the PZR to reduce PZR pressure and consequently RCS pressure.

The upper head of the PZR has four large nozzles, one for each of the three safety valve connections on the upper head and one for the pressurizer depressurization system (PDS) line used for severe accident mitigation. The three safety valves are spring pilot-actuated during normal operation, receiving input from dedicated impulse lines connected to the PZR upper head. The manway used for access to the PZR is located on the upper head. A small nozzle used for venting is also installed on the upper head.

The PZR is described in further detail in Section 5.4.10.

1.2.3.2.5 Steam Generators

The four SGs are vertical shell, natural circulation, U-tube heat exchangers with integral moisture separators. Each SG is supported by four support legs hinged to ball-jointed brackets or clevises. The ball joints allow the SG to move freely when the RCS temperature changes. Lateral supports restrain SG thermal movement during normal operation and for design basis events. The tube material is Alloy 690, which is highly resistant to corrosion.

Reactor coolant flows inside the inverted U-tubes, entering and leaving nozzles located in the hemispherical bottom channel head of each SG. The bottom head is divided into inlet and outlet chambers by a vertical partition plate extending from the tube sheet to the inside surface of the bottom channel head. The heat conveyed by the reactor coolant is transferred to the secondary water through the tube walls of the tube bundle. On the secondary side, the feedwater is directed to the cold side of the tube sheet by an annular skirt, in which the feedwater distribution ring injects feedwater.

The SGs are described in further detail in Section 5.4.2.

1.2.3.2.6 Reactor Coolant Pump

The RCPs are vertical, single-stage, shaft-sealed units, driven by air-cooled, three-phase induction motors. The RCP unit is a vertical assembly consisting of (from top to bottom) a motor, a seal assembly, and the hydraulic pump. Reactor coolant is pumped by an impeller attached to the bottom of the pump rotor shaft. Coolant is drawn up through the bottom ring of the casing, then through the impeller, and discharged through the diffuser and an exit nozzle located in the side of the casing.

The RCP motor shafts are rigidly connected to the RCPs by bolted spool pieces. This configuration allows the shaft to be removed for maintenance without removing the RCP motor. The shaft is supported by three radial bearings: two oil bearings located in the RCP motor and a hydrostatic water bearing installed at the lower end of the diffuser in front of the impeller. An auxiliary hydrodynamic water bearing is located in the thermal barrier area to support RCP start, shutdown, and accident conditions. The axial thrust is constrained by a double-acting thrust bearing located at the upper end of the shaft below the flywheel. The oil that lubricates the upper radial and thrust bearings is cooled in a low pressure oil-water cooler attached to the motor frame. The oil that lubricates the lower radial bearing is cooled by a low-pressure water coil incorporated inside the oil pot.

The shaft seals are designed to seal at RCS pressures up to and including the RCS hydrostatic test pressure. The seals are located in a housing bolted to the thermal barrier (closure) flange. The RCP casing closure flange and motor support stand are jointly fitted to the casing by the casing studs.

The shaft sealing system consists of three water lubricated seals and a standstill seal. The shaft seal design provides redundancy so that failure of a single seal stage will not result in an uncontrolled loss of reactor coolant. This redundancy is accomplished by the first and second seals. The third seal provides leak tightness and prevents loss of reactor coolant through the standstill seal during normal RCP operation. The standstill seal system (SSSS) can be actuated after the RCP is at rest. The SSSS is composed of a metallic ring that acts as a piston. The metallic ring is moved upward by

nitrogen pressure and closes against a landing on the RCP shaft, creating a tight metal-to-metal seal.

The reactor coolant pumps are described in further detail in Section 5.4.1.

1.2.3.2.7 Reactor Coolant System Piping

The RCS piping in each of the four loops consists of a hot leg, a crossover leg, and a cold leg. The hot leg extends from the RPV to the SG; the crossover leg from the SG to the RCP; and the cold leg from the RCP to the RPV. The piping material is austenitic stainless steel. The pipes are forged; the elbows are also forged and either machined from the forging or bent by induction.

The RCS piping is described in further detail in Section 5.4.3.

1.2.3.3 Engineered Safety Features and Emergency Systems

1.2.3.3.1 Safety Injection/Residual Heat Removal System

Emergency core cooling is performed by the safety injection system/residual heat removal system (SIS/RHRS). The SIS/RHRS performs normal shutdown cooling, as well as emergency coolant injection and recirculation functions to maintain reactor core coolant inventory and provide adequate decay heat removal following a LOCA. The SIS/RHRS also maintains reactor core inventory following a main steam line break (MSLB).

The SIS/RHRS consists of four independent divisions, each providing injection capability from an accumulator pressurized with nitrogen gas, a medium head safety injection (MHSI) pump, and a low head safety injection (LHSI) pump. These pumps are located in the Safeguard Buildings. The LHSI pumps also perform the operational functions of the RHRS. Each of the four SIS/RHRS divisions is provided with a separate suction connection to the IRWST. Each pump is provided with a miniflow line routed to the IRWST. The LHSI pump miniflow also provides cooling and mixing of the IRWST.

In the injection mode, the MHSI and LHSI pumps take suction from the IRWST and inject water into the RCS through nozzles located in the cold leg piping. In the long term following a LOCA, the LHSI discharge can be switched to the hot legs to limit the boron concentration in the core, thus reducing the risk of crystallization in the upper part of the core.

In RHR mode, suction is taken from the hot leg of the RCS, and enters the LHSI pump for the respective train. The coolant is pumped through the LHSI heat exchanger where residual heat is transferred to the CCWS and eventually to the UHS. The coolant is then returned to the RCS via the cold leg injection nozzle.

The SIS/RHRS is described in further detail in Sections 6.3 and 5.4.7.

1.2.3.3.2 In-Containment Refueling Water Storage Tank

The function of the IRWST is to hold an amount of borated water sufficient to flood the refueling cavity for normal refueling. The tank maintains this water at a homogeneous concentration and temperature. The IRWST is also the safety-related source of water for emergency core cooling in the event of a LOCA; it is also a source of water for containment cooling and core melt cooling in the event of a severe accident. During a LOCA, the IRWST collects the discharge from the RCS, allowing it to be recirculated by the SIS.

The IRWST is described in further detail in Section 6.3.

1.2.3.3.3 Emergency Feedwater System

The EFWS supplies water to the SGs to maintain water level and remove decay heat following the loss of normal feedwater resulting from design basis events. The EFWS removes heat from the RCS, which is initially transferred to the secondary side via the SGs and then discharged as steam via the main steam relief train (MSRT).

The EFWS is described in further detail in Section 10.4.9.

1.2.3.3.4 Core Melt Stabilization System

The U.S. EPR is equipped with a dedicated core melt stabilization system (CMSS) for molten core debris up to and including the total inventory of the core, internals, and lower RPV head. The functional principle of the CMSS is to spread the molten core debris over a large area and stabilize it by quenching it with water. Spreading increases the surface-to-volume ratio of the melt to promote fast and effective cooling and limit further release of radionuclides into the containment atmosphere. This allows for transformation of the molten core into a coolable configuration.

The U.S. EPR core melt stabilization concept has two main phases:

1. Temporary retention and accumulation of the molten fuel mixture in the reactor cavity.

2. Flooding, quenching, and long-term cooling of melt in the lateral spreading compartment.

The relocation of the melt from the reactor cavity into the spreading area is initiated by the opening of a retention gate centered in the lower portion of the cavity. This gate, which isolates the reactor cavity from the spreading compartment, consists of a steel framework enclosed by an aluminum outer layer and covered with a layer of sacrificial concrete. The concrete gate cover is an integral part of the sacrificial layer

in the cavity and has approximately the same thickness as the rest of the layer. The retention time in the pit is primarily driven by the thickness of this concrete cover and not by the delay-to-failure time of the gate after melt contact.

The spreading compartment is a dead-end room which is isolated from the rest of the containment. It is also protected from sprays, leaks, or other kinds of spillage. Because there is no direct water inflow into this compartment, the spreading area is dry at the time of the melt arrival.

The molten core debris is ultimately retained in a shallow crucible. The bottom and sides of the crucible are assembled from individual elements of a cast iron cooling structure. The cooling structure is covered with a layer of sacrificial concrete, which provides protection against thermal loads resulting from melt spreading as well as a sufficient delay to allow the cooling elements to be flooded prior to the initial contact between the molten core debris and the metallic cooling structure.

Prior to core melt, the motorized isolation valves of the passive flooding lines have to be opened. The passive melt stabilization process is then enabled. When the melt enters into the spreading area, spring-loaded valves are opened by a thermal actuator, initiating a controlled gravity-driven flow of water from the IRWST. The incoming water fills a central supply duct underneath the spreading area where it enters the system of parallel channels formed by finned cooling structure elements. The water continues to rise along the sidewall of the cooling structure and pours onto the surface of the melt from the circumference. Water overflow continues until the spreading room and IRWST are balanced, resulting in the submersion of the spreading area and transfer channel as well as a portion of the reactor cavity, thereby stabilizing any residual core debris in those areas.

The CMSS is described in further detail in Section 19.2.

1.2.3.3.5 Severe Accident Heat Removal System

The SAHRS is used in the event of a severe accident to control the containment pressure and achieve long-term cooling of the IRWST and the molten corium in the spreading compartment. The SAHRS performs the following functions:

- Provides containment spray function to rapidly control containment pressure and temperature following passive melt stabilization.
- Provides long-term containment pressure and temperature control through operation in the recirculation mode.
- Transfers residual heat from the containment atmosphere to the IRWST during a severe accident to control the containment pressure and temperature.

- Removes fission products from the containment atmosphere during a severe accident.
- Transfers residual heat from the spread melt to the IRWST during a severe accident.
- Transfers residual heat from the IRWST to the UHS via an intermediate, dedicated cooling system, during a severe accident or during a beyond design basis event without core melt in which all other RHR capability has failed.

The SAHRS consists of a dedicated suction line from the IRWST and a pump and heat exchanger located in a dedicated room in one of the Safeguard Buildings. The secondary side of the containment spray heat exchanger is cooled by the CCWS.

The SAHRS is described in further detail in Section 19.2.

1.2.3.4 Instrumentation and Control Systems

The functions of plant I&C systems are:

- Control and monitoring of the plant systems functions during normal conditions.
- Control of plant functions that provide corrective measures should the plant deviate from normal operating conditions.
- Control of limitation functions that provide corrective measures to avoid protective actions.
- Control of protection functions that mitigate the consequences of a design basis event, up to reaching a controlled, stable state following the detection of the event.
- Control and monitoring of post-accident functions that mitigate the consequences of a design basis event and bring the plant from the controlled state to the safe shutdown state.
- Control of functions that mitigate the consequences of a beyond design basis event, including SBO and severe accident.

A summary description of basic DCS architecture and systems is provided below. The I&C systems are described in further detail in Chapter 7.

Classification

The I&C functions and equipment are categorized as safety related (Class 1E) and non-safety related, according to their importance to safety. Portions of the I&C systems and equipment needed to perform a given I&C function are classified according to the highest class functions they must perform.

Description of the DCS Architecture

The DCS architecture fulfills the operational, licensing, and safety requirements to operate the plant and perform protective functions.

The DCS includes the following systems:

- Protection system (PS).
- Safety automation system (SAS).
- Diverse actuation system (DAS).
- Process automation system (PAS).
- Priority and actuator control system (PACS).
- Reactor control, surveillance, and limitation (RCSL) system.
- Process Information and Control System (PICS).
- Safety Information and Control System (SICS).
- Signal Conditioning and Distribution System (SCDS).

1.2.3.5 Electrical Systems

1.2.3.5.1 General

The electrical distribution system for the U.S. EPR operates at 60 Hz, with offsite power provided through a site specific transmission grid. The AC power distribution system uses three voltage levels; 480 V, 6900 V, and 13.8 kV. The switchyard provides the point of interconnection between the external grid and the U.S. EPR power systems. At least two independent transmission lines into the switchyard are provided. During plant power operation modes, power from the main generator is supplied to the main grid through the switchyard. [[For operational flexibility and reliability, the switchyard is configured in either a breaker-and-a-half or double breaker scheme.]] Further information on the switchyard is provided in Section 8.2.

The electrical distribution system is described in further detail in Section 8.1.

1.2.3.5.2 Offsite Power

Offsite power is provided from the switchyard to the onsite power systems through four three-winding auxiliary transformers. Two of the transformers are for safety-related power and two are for non-safety-related power. Two emergency auxiliary transformers provide the source for the onsite safety-related (Class 1E) buses of the emergency power supply system (EPSS). Each of these transformers will normally

supply two of the four safety divisions, but each is sized to supply all four divisions in the event of a failure. Two normal auxiliary transformers provide power to the onsite non-safety buses of the normal power supply system (NPSS). These transformers are sized to supply all non-safety loads required for operation with only one transformer in operation.

The offsite power system is described in further detail in Section 8.2.

1.2.3.5.3 Onsite Power System

The onsite electrical distribution system consists of the EPSS and the NPSS. The system design maintains independence between the EPSS and the NPSS auxiliary transformers. This configuration prevents the Class 1E EPSS from being adversely impacted by transients or equipment failures on the normal auxiliary transformers or any non-Class 1E buses.

The EPSS is arranged in a four-division configuration consistent with the four division safety system concept. The EPSS is designed to power the loads necessary to shut down the reactor safely, keep it in a shutdown condition, remove residual and stored heat, and prevent excessive release of radioactive substances under accident conditions. In the event of LOOP, each division is provided with an EDG to supply power to the system. Each EPSS division can also be supplied by a station blackout diesel generator through the non-safety-related NPSS buses. Each division of the EPSS has an uninterruptible power supply (UPS) rated for two hours of operation.

The NPSS is also arranged in a four-train configuration. The NPSS distributes power to the non-safety loads on the NI and Turbine Island (TI). A UPS system with batteries rated for 12 hours of operation is provided for loads on the TI and the NI for station blackout and severe accident mitigation. An additional two train UPS system with two hour rated batteries is provided for non-safety-related loads on the TI.

The onsite power system is described in further detail in Section 8.3.

1.2.3.6 Power Conversion Systems

1.2.3.6.1 Turbine-Generator

The turbine-generator (TG) converts the thermal energy supplied by the main steam system into electrical energy. It is designed for base load operation, but has load change characteristics compatible with the I&C system which coordinates TG and reactor operation. The TG is designed to accept a sudden loss of full load without exceeding design overspeed.

The turbine design presented in Section 10.2 consists of an 1800-rpm single-flow high-pressure element and a single-flow intermediate-pressure element (HP/IP) in a

common casing and three double-flow low-pressure elements in tandem. Moisture separation and reheating of the steam are provided by two, combined moisture separator reheater (MSR) assemblies. The generator is coupled directly to the turbine shaft. The generator has a hydrogen cooled rotor and a water cooled stator. It is equipped with a collector for the static excitation system directly coupled to the generator shaft.

The TG is described in further detail in Section 10.2.

1.2.3.6.2 Main Steam System

The main steam system (MSS) routes the steam produced in the four SGs through individual lines to the high pressure (HP) turbine stop valves. Each main steam line has a main steam isolation valve (MSIV) located just outside containment. A bypass line is provided around each MSIV for warming the piping system downstream of the valve during startup. Overpressure protection on each main steam line is provided by a MSRT and two main steam safety valves (MSSV). Each MSRT consists of a quick-opening main steam relief isolation valve (MSRIV) and a downstream main steam relief control valve (MSRCV).

During power operation, steam flow is a function of turbine load. In the case of an imbalance between turbine load and core power, excess steam is dumped to the condenser via the turbine bypass valves. Upon turbine trip, the reactor trips and the MSS removes residual heat by steam dump to the condenser via the turbine bypass or to the atmosphere via the MSRT until RHRS entry conditions are reached.

The MSS is described in further detail in Section 10.3.

1.2.3.6.3 Condensate and Feedwater System

The condensate and feedwater system (CFS) extends from the condenser through the LP feedwater heaters, de-aerator/feedwater tank, the main feedwater pumps, the HP feedwater heaters, main feedwater isolation valves, main feedwater control valves, and up to the SG main feedwater inlet nozzles. During normal power operation, the feedwater supply to the SGs is provided by the CFS. A dedicated pump, with associated valves and controls, is provided for startup and shutdown operation of the plant.

The CFS is described in further detail in Section 10.4.7.

1.2.3.7 Fuel Handling and Storage Systems

Fuel storage consists of both new and spent fuel storage areas, as described in Sections 9.1.1 and 9.1.2. Fuel storage and handling systems include the following features:

- Storage of new and spent fuel outside the containment.
- Long-term storage capacity, including full core offloading during an outage.
- Fuel assemblies transferred to and from containment using a transfer tube.
- Fuel transfer tube isolated during plant operation.
- Fuel cask loading conducted at the bottom of the loading pit using a dedicated cask loading device.

Fuel handling systems are described in further detail in Section 9.1.4. Fuel pool cooling is described in further detail in Section 1.2.3.8.4 and Section 9.1.3.

1.2.3.8 Cooling Water and Other Auxiliary Systems

1.2.3.8.1 Chemical and Volume Control System

The chemical and volume control system (CVCS) is the interface system between the high-pressure RCS and the low-pressure systems in the Nuclear Auxiliary Building and Fuel Building. The primary functions of the CVCS are letdown, charging, and RCP seal water.

The letdown/charging process is used to control the chemistry of the RCS fluid. The letdown portion of the system receives water from the RCS, where it passes through a heat exchanger that heats the charging flow prior to flow back into the RCS. After passing through the heat exchanger, the letdown flow is cooled and depressurized. It is then sampled, purified, degassed (if necessary), and hydrogenated. The letdown fluid is directed to the charging pump suction, with a small portion diverted to the volume control tank (VCT) to maintain the boron concentration in the VCT in chemical equilibrium with the RCS. The charging pumps take suction from the letdown line, as well as the VCT, and increase the fluid pressure so that it will flow into the RCS. Before flowing into the RCS, a portion of the charging flow is diverted to the four RCPs for shaft seal water. Any leakage past the seals is directed to the VCT where it is used to maintain the CVCS inventory.

In addition to its primary functions, the CVCS maintains the RCS inventory by controlling the PZR level. The CVCS also maintains and adjusts the RCS boron concentration to control reactor power level variations resulting from expected reactivity changes. Also, the CVCS is the source of fluid for the auxiliary PZR spray.

The CVCS is an operational system and is not required for the mitigation of design basis accidents. However, the CVCS may be used to preclude the use of safety systems during minor transients (such as boron dilution events). The system is normally in continuous operation during all modes of plant operation.

The CVCS is described in further detail in Section 9.3.4.

1.2.3.8.2 Component Cooling Water System

The CCWS consists of four separate safety-related divisions corresponding to the four Safeguard Buildings. The CCWS permits heat transfer from safety-related systems and operational cooling loads to the UHS via the ESWS under all operating conditions. Non-safety headers of this system are automatically isolated from the safety-related branches in the event of an accident.

The CCWS performs the following functions:

- Heat removal from the SIS/RHR to the ESWS.
- Heat removal from the fuel pool cooling system (FPCS) to the ESWS while fuel assemblies are located in the spent fuel storage pool.
- Cooling of the thermal barriers of the RCP seals.
- Heat removal from two divisions of the safety chilled water system.
- Cooling of the SAHRS by a dedicated cooling train (this function is used for severe accident mitigation).

The CCWS is described in further detail in Section 9.2.2.

1.2.3.8.3 Essential Service Water System/Ultimate Heat Sink

The supply of ESW is designed to provide cooling water during normal, transient, and accident operating conditions for the safe operation and orderly shutdown of the plant. The ESWS consists of four separate divisions that provide cooling water to the CCWS and EDG heat exchangers from the UHS. Each division includes a pump, discharge piping from the pump to the parallel CCWS and EDG heat exchangers, and outlet piping from the heat exchangers to the UHS. The ESWS pumps are located in separate train-related buildings. Piping connecting the ESWS pumps to the CCWS and EDG heat exchangers is routed to provide physical train separation in the yard and Safeguard Buildings. An internal hazard affecting one train does not affect the other train.

The safety function of the ESWS is to cool the CCWS and EDG heat exchangers. In addition to the four safety-related trains, the ESWS also has one non-safety-related dedicated train that cools the dedicated CCWS.

The UHS dissipates heat rejected from the ESWS during all modes of plant operation. The UHS for the U.S. EPR consists of four train-related mechanical draft cooling towers connected to the train-related ESWS pumps. The ESWS is described in further detail in Section 9.2.1. The UHS is described in further detail in Section 9.2.5.

1.2.3.8.4 Fuel Pool Cooling and Purification System

The fuel pool cooling and purification system consists of the FPCS and fuel pool purification system (FPPS). The FPCS cools the spent fuel pool (SFP). The FPPS provides purification of the Fuel Building pool and Reactor Building pool compartments and is used to transfer water between the various pool compartments, the IRWST, and other make-up water sources.

The FPCS has two separate and independent trains, each consisting of two pumps installed in parallel, a heat exchanger cooled by the CCWS, and associated piping and valves. The pipe penetrations to the SFP are above the water level that must be maintained over the spent fuel, while providing the required pump suction head. The pipes that penetrate the pool are equipped with siphon breakers to limit water loss resulting from a leak in the piping system.

Both trains of the FPCS are located in the Fuel Building and are installed on either side of the SFP, which provides adequate separation in the event of an internal hazard. Both FPCS trains are powered from separate emergency buses, each backed by an EDG.

The FPPS includes two purification pumps that operate in parallel. One pump is used for Fuel Building pool purification and the other pump for Reactor Building pool purification. Headers provided upstream and downstream of the purification pumps allow for the alignment of each pump to either building. This system contains two purification paths: one is part of the FPPS and the other is part of the coolant purification system. The FPPS path consists of a pre-cartridge filter, a mixed-bed ion exchanger, and a post-cartridge filter installed in series. The purification return pipes enter the pools from above the water level and are equipped with siphon breakers. The purification supply lines, except for the ones from the SFP, exit the bottom of the pool compartments. These pipes contain isolation valves that are powered from emergency buses, while the rest of the system is supplied by a normal power supply.

The FPCS is described in further detail in Section 9.1.3.

1.2.3.8.5 Heating, Ventilation, and Air Conditioning Systems

The HVAC systems maintain acceptable conditions (temperature, pressure, filtration, and fresh air flow rate) during all operating modes for the MCR and other equipment rooms to maintain their habitability, and for the equipment rooms to allow the operation of safety-related systems. Several HVAC systems for the U.S. EPR also function to contain radioactive substances and reduce radioactive releases to the environment for normal operating modes, transients, and abnormal events. These HVAC systems include the:

- Containment ventilation system.

- Annulus ventilation system.
- Safeguard Building controlled area ventilation system.
- Fuel Building ventilation system.
- MCR air conditioning system.
- Nuclear Auxiliary Building ventilation system.
- Radioactive Waste Building ventilation system.

Additional information on the HVAC systems is provided in Section 9.4.

1.2.3.8.6 Fire Protection System

The U.S. EPR is designed for safe shutdown assuming equipment in any one fire area will be rendered inoperable by fire and that re-entry into the fire area for repair and operator actions is not possible. The control room and containment are excluded from this approach. An alternate shutdown capability exists that is physically and electrically independent of the control room. In containment, protection is provided for redundant shutdown systems, to the extent practicable, such that one shutdown division will be free of fire damage. In the remaining fire areas, the U.S. EPR contains sufficient redundant independent shutdown systems so that one shutdown division will be free of fire damage. Additionally, the design contains provisions so that smoke, hot gasses, or fire suppressant will not migrate into unaffected areas and adversely affect safe-shutdown capabilities.

The fire protection system includes the fire protection water supply system, yard piping, water sprinkler, standpipe and hose systems, foam systems, smoke detection and alarm systems, and fire barriers.

Fire detection systems are provided for areas that present a credible fire exposure or contain safety related equipment. The detectors give audible and visual alarm and annunciation in the control room. Where zoned detection systems are used in a given fire area, local solutions are provided to identify the detector zone that has actuated. Local audible alarms sound in the fire area and are distinctively unique so they will not be confused with any other plant system audible alarms.

The fire protection systems are designed to detect, control, and extinguish possible fires throughout the facility. Fixed suppression systems are provided based on the type of hazard(s) in the fire area, the impact on plant operation, and the potential for release of the suppression agent. In fire areas where the use of a water-based suppression system is the preferred means of suppression, pre-action or wet-pipe sprinkler systems are provided.

The fire protection system is described in further detail in Section 9.5.1.

1.2.3.9 Radioactive Waste Management Systems

The radioactive waste management systems provide the equipment necessary for controlled treatment and preparation for retention or disposal of liquid, gaseous, and solid wastes produced as a result of reactor operation. The liquid waste processing system collects, processes, and recycles reactor grade water, removes or concentrates radioactive constituents, and processes them until suitable for reuse or for processing in the solid radwaste system. The gaseous waste processing system removes fission product gases from the reactor coolant and contains these gases during normal plant operation. The solid radwaste system receives, processes, packages, and stores solid radioactive wastes generated until shipment offsite.

The radioactive waste management systems are described in further detail in Chapter 11.

Figure 1.2-1—3-Dimensional Conceptual Configuration of U.S. EPR Buildings

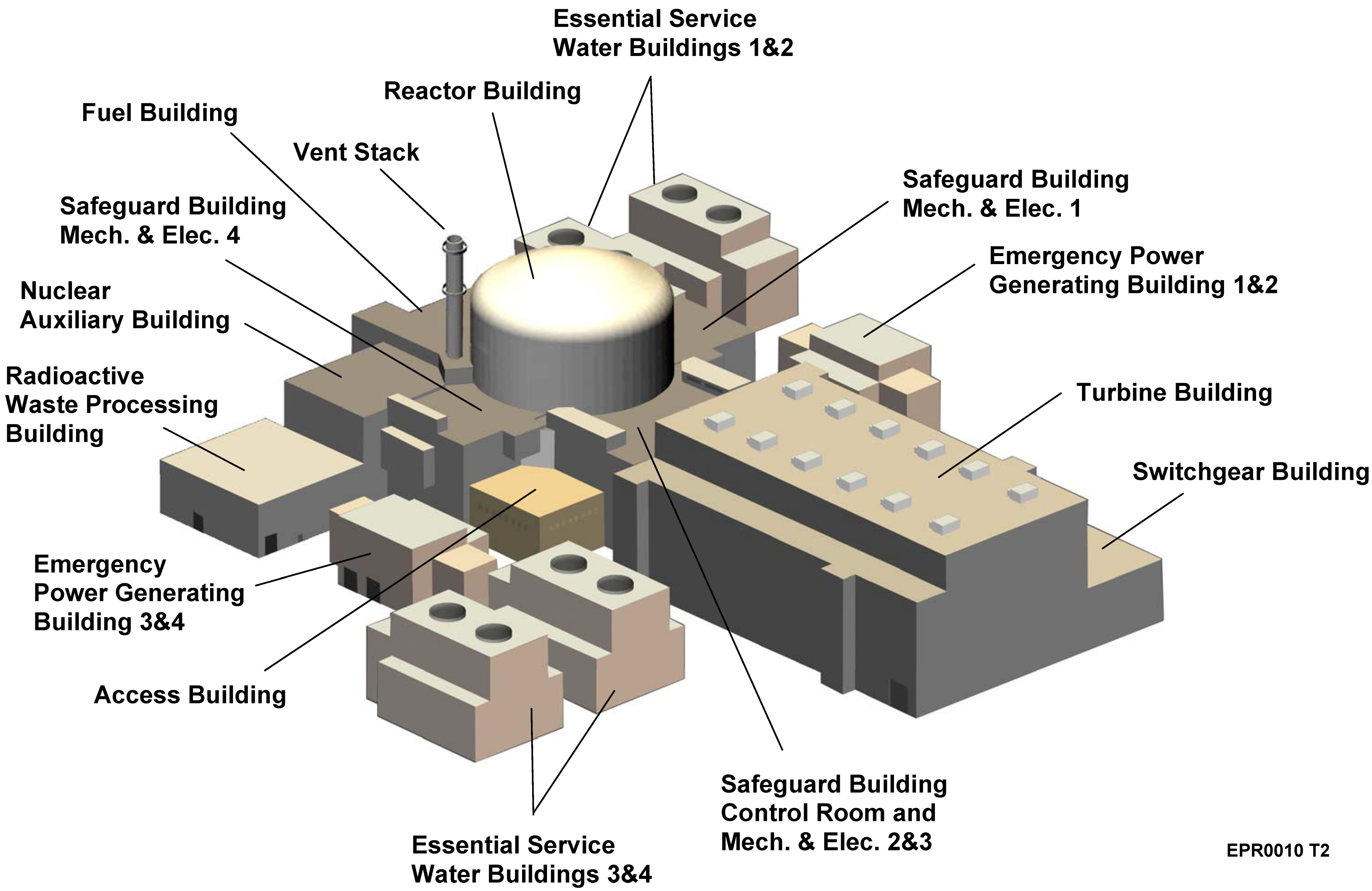

Figure 1.2-2—U.S. EPR Cutaway