10.2 Turbine-Generator

This section describes the turbine-generator (TG) for the U.S. EPR.

The TG converts the thermal energy supplied by the main steam supply system (MSSS) into electrical energy.

The TG package interfaces with the MSSS at the high pressure (HP) turbine stop valves. It interfaces with the condensate and feedwater system at the low pressure (LP) turbine exhausts to the condenser, at the turbine extraction connections to the feedwater heaters, and at the moisture separator reheater (MSR) condensate and drain tank outlet connections to feedwater heaters and drain coolers. The generator terminals and enclosure connect to the isolated phase buses and ducts. The TG control system interfaces with the plant process automation system (PAS).

10.2.1 Design Bases

The TG performs no safety-related functions and therefore has no nuclear safety-related design bases.

The TG principal design features include:

- The TG is designed for base load operation. The design of the TG has provisions for load follow operation for future consideration.
- The TG is capable of a load step (increase or decrease) of 10 percent of rated load below a 50 percent power level or a ramp rate (increase or decrease) of 5 percent per minute of actual load when the power level is in the range of 50 to 100 percent, without necessitating a turbine trip.
- The TG is designed to trip automatically under abnormal conditions.
- The TG load change characteristics are compatible with the instrumentation and control system which coordinates TG and reactor operation.
- The TG is designed to accept a sudden loss of full load without exceeding design overspeed.
- The TG is designed to permit periodic testing of steam valves important to overspeed protection, emergency overspeed trip circuits and several other trip circuits under load.
- The failure of any single component does not cause the rotor speed to exceed the design speed.
- The reheat stop and intercept valves are capable of closure concurrent with the HP turbine stop valves, or of sequential closure within an appropriate time limit, to make sure that turbine overspeed is controlled within acceptable limits.

- The valve arrangements and valve closure times are such that a failure of any single valve to close does not result in excessive turbine overspeed in the event of a TG trip signal.
- The TG is designed to provide proper drainage of related piping and components to prevent water induction into the turbine.
- The extraction steam check valves are provided at extraction connections and are capable of closing within an appropriate time limit to prevent reverse flow and maintain stable turbine speeds in the event of a TG trip signal.
- There is access to the TG equipment, including components and instrumentation associated with the overspeed protection system, during all operating conditions. Radiation shielding is not necessary in the TG area and is not provided.
- The TG provides extraction steam for seven stages of regenerative feedwater heating.
- The MSRs, MSR drain tanks, heat exchangers (except for generator hydrogen coolers), and vessels in TG auxiliary systems are designed to the requirements of ASME Boiler and Pressure Vessel (BPV) Code, Section VIII (Reference 1) (refer to Section 3.2). Turbine casings, internal components in the turbine, HP stop valves, HP control valves, reheat stop valves, intercept valves, generator casing, generator hydrogen coolers, and internal parts of the generator are designed to TG supplier standards.

10.2.2 General Description

The TG package is shown in Figure 10.2-1—Turbine Generator System. Performance characteristics are provided in Table 10.2-1—Performance Characteristics.

The design and valves wide open (VWO) heat balances are presented in Section 10.1 (see Figures 10.1-1 and 10.1-2).

The TG package consists of an 1800 rpm, single-flow high pressure (HP) and a single-flow intermediate pressure (IP) turbine in a common casing; and three double-flow low pressure (LP) elements in tandem. The generator has a hydrogen-cooled rotor and de-ionized water-cooled stator. The generator is directly coupled to the turbine shaft. It is equipped with a collector for the static excitation system directly coupled to the generator shaft. Moisture separation and reheating of the steam is provided between the HP turbine and IP turbine by two combined MSR assemblies. The MSRs have two stages of reheating.

10.2.2.1 Component Description

Table 3.2.2-1 provides the quality group and seismic design classification of components and equipment in the TG package.

10.2.2.1.1 TG Package Equipment

The TG package equipment includes the HP turbine stop and control valves, reheat stop and intercept valves, MSRs, MSR drain tanks, steam lead piping, cold reheat piping, hot reheat piping, TG control system, static excitation system and accessory equipment listed in Section 10.2.2.1.2. Table 10.2-2—Turbine-Generator Material Data, provides a list of material specifications for turbine-generator components.

HP/IP Turbine

This design features a combined HP/IP cylinder module, which contains the HP and IP steam paths in opposite flows, in a single-shell casing. The HP and IP steam inlets are located at the center of the module and the exhausts are at its two extremities.

HP Section

The HP section of the HP/IP module receives steam through four steam leads, one from each main steam control valve outlet. Normal operation utilizes full arc admission. The steam is expanded axially across the stationary and rotating blades. Extraction steam from the HP turbine at two locations supplies the sixth and seventh stages of feedwater heating and the heating steam to the first stage reheaters. HP turbine exhaust steam is collected in four cold reheat pipes. Most of the exhaust steam is routed to the MSR inlet, but part of it is diverted and supplies the fifth stage of feedwater heating.

IP Section

After removal of the water content and reheating in the MSRs, the steam is directed through four steam inlet pipes to the IP part of the HP/IP module, where it expands in stages of stationary and rotating blades. Extraction steam from the IP section of the HP/IP module supplies the third and fourth stages of feedwater heating.

LP Turbines

Each of the three LP turbines receives steam from the IP outlet, through two steam pipe headers, one on each side of the turbines, fitted with expansion bellows. The LP turbines are identical, double-flow turbines. The LP turbines are each composed of an inner structure and an outer casing. The inner structure supports the LP blade carriers and the LP bearings. The outer casing collects the steam exhausted from the last LP stages. The outer casing is installed independently of the inner casing and is welded to the condenser which is directly anchored to the foundation slab. The outer casing moves freely with condenser thermal movements. A flexible sealing ring provided at each extremity maintains vacuum tightness between outer casing and the inner LP structure. The inner LP casing is provided with a piping header that allows water to be injected into the exhaust structures and prevents an excessive temperature rise during no-load or low-load operation. Extraction steam from the LP turbines supplies the first and second stages of feedwater heating.

HP Main Stop and Control Valves

Four HP main stop and control valves admit steam to the HP turbine. The primary function of the main stop valves is to quickly shut off the steam flow to the turbine under emergency conditions. The primary function of the control valves is to control steam flow to the turbine in response to the turbine control system. Each control valve is operated by a single-acting, spring-closed servomotor opened by a high pressure fire-resistant fluid supplied through a servo valve. The stop and control valves close in approximately 0.30 seconds. Each HP stop valve contains a permanent steam strainer to prevent foreign matter from entering the control valves and turbine.

Reheat Stop and Intercept Valves

The reheat stop and intercept valves are arranged between the MSRs and IP turbine inlet. The IP steam inlet is controlled by four sets of two series-mounted individual valves. One valve fulfills a turbine protection function (stop valve) and the other, a control and protection function (intercept valve). The valves are butterfly-type valves. The disc of each valve can rotate 90 degrees, from closed to open position, by means of a servomotor. The stop and intercept valves close in approximately 0.30 seconds.

Generator

The generator is a four-pole machine directly driven by the turbine and supplies the step-up transformer with high voltage electrical output. The field winding is directly cooled by hydrogen gas. The stator winding is directly cooled by an internal circulation of de-ionized water (stator cooling water). The generator static excitation system is controlled by an automatic voltage regulator. The generator rotor is made from a solid alloy steel forging with high tensile strength. The slots for the field coils are milled in the central body of the rotor.

The frame, which constitutes the outer envelope, is made of an assembly of heavy welded steel plates, forming a cylindrical shell. The machine is gas tight and the hydrogen coolers are located in the frame itself. Hydrogen detectors are located around the generator hydrogen system to provide warning of a hydrogen leak. The generator hydrogen system is designed in accordance with NFPA 55 (Reference 2).

The generator auxiliaries include cooling system, gas supply and shaft sealing circuits.

Moisture Separator Reheaters

Two cylindrical-shell, combined MSRs are installed in the steam path between the HP and IP turbines. The MSRs dry and reheat the HP turbine steam exhaust. Cold reheat steam is piped into the bottom of the MSR. Moisture is removed in chevron type moisture separators, drained to the moisture separator drain tanks and then drained and pumped to the deaerator/feedwater storage tank. The dry steam passes across two stages of reheaters, which are supplied with turbine extraction steam (first reheating stage) and main steam (second reheating stage). The steam is then routed to the hot reheat stop valves/intercept valves, which are located upstream of the IP turbine inlet nozzles. The first stage reheaters drain via drain tanks to the HP heaters, and the second stage reheaters drain via drain tanks to the high pressure drain coolers. Safety valves are provided on the MSR for overpressure protection.

10.2.2.1.2 TG Accessories

The TG accessories include:

- Bearing lubrication oil system.
- Electro-hydraulic control system.
- Control valves for second stage reheater steam supply.
- Extraction check valves.
- Turbine drain system.
- Turning gear.
- Turbine gland sealing system.
- LP outer casing spray system.
- Hydrogen and carbon dioxide systems.
- Generator seal oil system.
- Stator cooling water system.
- TG supervisory instrument (TSI) system.

10.2.2.2 TG Foundation

The TG foundation structure is a spring-mounted support system that provides a low-tuned, turbine-pedestal foundation. The springs dynamically isolate the TG deck from the remainder of the structure in the range of operating frequencies, thus allowing for an integrated structure below the turbine deck. The structure of the LP module is designed so that the outer casing is independent from the inner casing (i.e., the LP outer casing is directly and rigidly attached to the condenser and a flexible seal ring maintains a vacuum tight connection between the outer casing and the LP inner casing). The LP inner casing and bearings are directly supported on the turbine pedestal.

The foundation design consists of a reinforced concrete deck mounted on springs and supported on columns and structural system that take the load from the table top to the Turbine Building foundation. The lateral bracing under the TG deck also serves to brace the building frame. This "integrated" design reduces the bracing and number of columns required in the building. Additionally, the spring-mounted design allows for dynamic uncoupling of the TG foundation from the substructure. The spring-mounted support system is much less site-dependent than other turbine pedestal designs because the soil structure is decoupled from turbine dynamic effects. The TG foundation consists of a concrete table top, while the substructure consists of supporting beams and columns. The structure below the springs is designed independent of vibration considerations.

10.2.2.3 Cycle Description

The main steam flows from the MSSS through the four combined main steam stop and control valves into the HP turbine. After expanding in the HP blading, the steam passes through the steam exhaust branches into the cold reheat piping system. Steam passes to each of the two MSRs in two cold reheat lines per MSR.

The first stage reheat steam is supplied from the first extraction from the HP turbine. The second stage reheat steam is supplied from the MSSS, including control valves to control and shut off the steam flow. Condensed steam from the second stage reheater is drained to a drain tank and then flows to the shell side of a drain cooler, which is the last stage of feedwater heating. Condensed steam from the first stage reheater is drained to a drain tank and then flows to the shell side of the No. 6 feedwater heaters. The moisture removed from the MSRs is drained to a drain tank, and then to the de-aerator.

Two extraction lines are connected to the HP turbine. The steam goes to the HP feedwater heaters No. 7 and No. 6, respectively. The steam passes from the two MSRs into the hot reheat piping system and then through four LP stop-intercept butterfly valve assemblies to the IP turbine.

The IP turbine has two extraction stages to LP feedwater heaters No. 4 and No. 3, respectively. Steam exhausts from the IP turbine outlets to the three LP turbines through two steam pipes.

Each LP turbine has three extraction stages to LP feedwater heaters No. 2 and No. 1.

No check valves are necessary in the last two extractions from the LP turbines because the pressure level in the associated feedwater heaters is low. An actuator assisted swing check valve is provided in each extraction stage, three through seven.

The turbine casings, turbine valves and turbine piping are provided with drain valves or traps for removing condensate during startup and transient operation.

The turbine shaft seals and the main steam valve glands are fitted with connections to the gland steam system.

10.2.2.4 Excitation System

The excitation system is static with a solid-state voltage regulator. Excitation power is obtained from dry type, indoor excitation transformers, which are directly connected to the main generator IPB. The brushgear includes the enclosure with coolers, filters, moisture control, brush holders and brushes; and the slip rings mounted on a generator shaft extension. The exciter rectifiers are arranged in a full-wave bridge configuration and protected by a series-connected fuse. The Turbine Building closed cooling water system provides cooling water to the brushgear air-to-water heat exchangers.

10.2.2.5 TG Control System

The TG control system is a fault-tolerant control system with the following features:

- Triple processors and two-out-of-three trip logic.
- Automatic synchronizing capabilities.
- Automatic TG startup and shutdown control system functions as well as separate automatic startup and shutdown functions for each individual auxiliary system. These automatic functions are separate and independent of each other.
- Automatic and manual controls in the control room to preheat the turbines, start and load the unit from no load to full load, adjust load during continuous operation, perform all normal (periodic) test functions, and unload the unit for shutdown. Automatic controls are based, in part, on thermal ramp rate, acceleration through critical speeds, rotor stress and heat soak (temperature gradient minimization) of cylinders, shells and rotors.
- Redundant communication paths between processors within the turbine control system.
- Digital speed governor.
- On-line redundancy in a hot standby arrangement for turbine governor processors.
- Redundant power supplies for processors, chassis, input/output (I/O) modules, and field devices with alarm notification of any malfunction.
- Two redundant communication paths for each turbine-generator package from the TG control system main control cabinet to the operator workstation.
- Two redundant communication paths within the TG control system connecting to the plant PAS.

- Provisions for manually initiated individual valve or valve pair on-line testing of the main steam stop, control, reheat stop and intercept valves.

Valve opening actuation is provided by the control oil (electro-hydraulic) system that is independent of the bearing lubrication system. Valve closing actuation is provided by springs and steam forces upon reduction or relief of hydraulic fluid pressure. The system is designed so that loss of fluid pressure for any reason leads to valve closing and subsequent turbine trip.

Steam valves are provided in series pairs. The stop valves are tripped by the trip system (overspeed and other trips); the control valves are modulated by the governing system and are also actuated closed by the trip system.

A COL applicant that references the U.S. EPR design certification will provide schematics and logic diagrams for the turbine control system.

10.2.2.6 Speed Control

Speed control is used during startup and has a minimum adjustable setpoint range of zero to 100 percent of rated speed. It has the following features:

- The speed governor for normal speed-load control fully closes the control and intercept valves at 103 percent of rated turbine speed.
- The maximum rotational speed attainable upon loss of a single normal governing device does not exceed 103 percent of rated turbine speed.

10.2.2.7 Load Control

Load control is used during normal operation and has a setpoint range of zero to 100 percent of maximum capability. Load control controls megawatts (MW) based on the plant MW setpoint signal provided by the PAS. It has the following features:

- Automatic controls to avoid unnecessary turbine trip and to permit subsequent operation at house load (i.e., load required to run station auxiliaries) in the event of a load rejection from 100 percent load.
- Automatic controls for fast valving to rematch the TG loads following a momentary (7 Hz or less) mismatch between generator load and generator power, without loss of synchronization during load mismatch transients, up to full power.

10.2.2.8 Valve Control

The flow of main steam entering the HP turbine is controlled by four stop valves and four governing control valves. Each stop valve is controlled by an electro-hydraulic actuator, so that the valve is either fully open or fully closed. The function of the stop valves is to shut off the steam flow to the turbine when required. Actuation of the emergency trip system devices closes the stop valves.

The turbine control valves are positioned by electro-hydraulic servo actuators in response to signals from their respective flow control unit. The flow control unit signal positions the control valves for wide-range speed control through the normal turbine operating range and for load control after the TG unit is synchronized.

The reheat stop and intercept valves, located in the hot reheat lines at the inlet of the IP turbines, control steam flow to the IP turbines. During normal operation of the turbine, the reheat stop and intercept valves are fully open. The intercept valve flow control unit positions the valve during startup and normal operation and closes the valve rapidly on loss of turbine load. The reheat stop valves close completely on turbine overspeed and turbine trip.

10.2.2.9 Overspeed Protection

A protective trip system is provided to quickly close the main stop, control, reheat stop and intercept valves in the event of an unsafe condition or to provide overspeed protection. The system is designed to minimize false and spurious trips during normal operation and allow testing of the trip system during operation. A power load imbalance function is provided, which compares turbine and generator load and initiates an appropriate momentary control valve closure when the turbine load exceeds the generator load by a specified amount.

The steam turbine has two redundant and diverse electrical overspeed systems that meet the single failure criterion. The two overspeed protection systems are redundant from the speed probes to the turbine trip relays. Both overspeed protection systems have three independent speed probes and processing modules acting on one of three electronic tripping channels. Each independent electrical overspeed trip system is designed and manufactured by a different vendor. Each vendor directly manufactures their system components (e.g., motherboards, sensors) and develops the software to transform the analog speed sensor signal into a digital signal. There are no common components or process inputs between the two systems. Each system will be installed in a separate cubicle with separate power sources. Figure 10.2-2—Overspeed Protection System Schematic shows the separate source of power supply to each system and how the sensors are treated by independent mothercards.

The trip block provides an interface between the electrical and hydraulic systems and consists of three trip solenoid valves. The three independent electronic channels energize three fail safe solenoid valves (trip by loss of power). Each solenoid valve acts on two hydraulic relays of the trip block in order to perform the hydraulic two-out-of-three trip voting. The turbine will be tripped when a least two solenoid valves are de-energized. An interruption and discharge of the fluid supply by the trip block will cause the high pressure and intermediate pressure valves to close by spring action. Figure 10.2-3—Turbine Trip Block Schematic provides a schematic of the trip block. Failure of the hydraulic tubing between the trip block and the valve actuator, or between the hydraulic fluid tank and the valve actuator will cause a loss of fluid pressure, which closes the valves. Thus, the trip block is designed fail safe, due to the fact that any failure (e.g., loss of power, loss of safety fluid pressure, fluid leak) will cause a steam turbine trip.

The primary electrical overspeed trip system fully closes the valves at about 110 percent of rated speed. An independent and redundant backup electrical overspeed trip circuit is provided to fully close these valves at about 111 percent of rated speed. The TG rotor is designed to withstand 120 percent of rated speed.

The actuation of the turbine protection system does not rely on components in the electro-hydraulic control system. Conversely, turbine trip initiation devices are not used for normal control of the unit.

Provisions for online testing of the emergency trip system, including individual trip devices, are provided.

After receipt of a trip signal, the hydraulic controllers for the main stop, control, reheat stop and intercept valves close off these valves quickly to preclude an unsafe turbine overspeed. The response of the controllers considers the residual steam in the piping between the valves and the turbine.

10.2.2.10 Turbine Supervisory Instrumentation

TSI monitors thermal, hydraulic and electrical parameters; controls equipment components; and initiates automatic alarms and automatic shutdown of the TG in the event of an unsafe condition. Monitoring instrumentation interfaces with the plant PAS. The following conditions initiate a turbine trip:

- Low bearing oil pressure.
- Low control oil (hydraulic fluid) pressure.
- High condenser back pressure.
- Turbine overspeed.
- Thrust bearing excessive wear.
- Remote trip (includes manual and reactor trips).
- Excessive ‘Time of Operation above No Flow Load’ (initiated by generator reverse power relay after time delay specified by turbine designer).
- Loss of speed signals.
- Journal bearing high vibration.

- LP turbines outer casing high temperature.

10.2.2.11 Other Protective Systems

Additional protective features of the turbine and steam system are:

- MSR safety relief valves.
- Rupture diaphragms on the LP turbine outer casings.
- Turbine water induction protection systems on the extraction steam lines.

10.2.2.12 Turbine Inservice Inspection and Testing

Major TG system components are readily accessible for inspection and are available for testing during normal plant operation.

The turbine inservice inspection and test program is used for the governor and overspeed protection system to provide reasonable assurance that flaws or component failures are detected in the overspeed sensing and tripping subsystems, main steam control and stop valves, reheat steam intercept and stop valves or extraction steam non-return valves; or any other condition that could lead to an overspeed condition above that specified by the design overspeed. The inservice inspection program for operability of the governor and overspeed protection system includes, at a minimum, the following provisions:

- For turbine governor and overspeed protection systems, at intervals of approximately three and one-third years, during refueling or maintenance shutdowns coinciding with the inservice inspection schedule required by the ASME BPV Code, Section XI, (Reference 3) for reactor components, at least one main steam stop valve, one main steam control valve, one reheat stop valve, one reheat intercept valve and one of each type of steam extraction valve are dismantled for examination. Visual and surface examinations of valve seats, disks and stems are conducted. Valve bushings are inspected and cleaned and bore diameters are checked for proper clearance. If any valve is shown to have flaws or excessive corrosion or improper clearances, the valve is repaired or replaced and other valves of that type are also dismantled and inspected.
- The main steam stop and control valves, reheat stop and intercept valves, and steam extraction no return valves are exercised monthly at 97% to 100% load and observations of the valve motions are made.
- The components of the electro-hydraulic governor system, as well as the primary and backup overspeed trip, are automatically tested when the turbine is in operation on a daily basis.

10.2.3 Turbine Rotor Integrity

Turbine rotor integrity is provided by the integrated combination of material selection, rotor design, fracture toughness requirements, inspections and tests. The combination results in a very low probability of rotor failure.

10.2.3.1 Materials Selection

Turbine rotors are made from vacuum melted or vacuum degassed Ni-Cr-Mo alloy steel by processes that minimize flaw occurrence and provide adequate fracture toughness. Tramp elements are controlled to the lowest practical concentrations consistent with good scrap selection and melting practice, and consistent with obtaining adequate initial and long-life fracture toughness for the environment in which the parts operate. The sulfur and phosphorous concentrations are specified below 0.020 percent (chemical product analysis), which is in accordance with specifications ASTM A470 (Reference 11) and ASTM A471 (Reference 4).

The chemical compositions and mechanical properties used for the turbine rotors are given in Table 10.2-3—HP Rotor, Table 10.2-4—IP Discs and Shaft End, and Table 10.2-5—LP Rotors.

A cast chemical analysis is performed on each rotor forging element. It shall conform to the requirements of the material specification.

Tensile test pieces and procedures are in accordance with the requirements of ASTM A370.

The turbine materials have the lowest fracture appearance transition temperatures (FATT) and highest Charpy V-notch (C_v) energies obtainable, on a consistent basis, from water quenched Ni-Cr-Mo material at the sizes and strength levels used. The processing is controlled to maintain the following:

- 50 percent FATT less than 0°F for the LP turbine rotors.
- Charpy V-notch energy at the minimum operating temperature of each LP rotor in the tangential direction greater than or equal to 60 ft-lbs.

The form, dimensions and procedure used for Charpy V-notch impact tests are in accordance with the requirements of ASTM A370. The average value for the Charpy V-notch impact strength obtained on the three test pieces shall not be lower than specified for the material. Not more than one individual value shall be below the specified value and no individual value shall be lower than 70 percent of the specified value.

Curves of Charpy V-notch absorbed energy and percentage crystallinity versus test temperature are plotted for FATT determination. The method of measurement of crystallinity conforms to the requirements of ASTM A370. The FATT is determined as the temperature corresponding to 50 percent crystallinity using a minimum of ten test pieces.

Table 10.2-2—Turbine-Generator Material Data, provides a list of material specifications for turbine-generator components. Actual material properties of turbine rotors are obtained through precise destructive tests of actual samples from each turbine rotor. A COL applicant that references the U.S. EPR design certification will provide applicable material properties of the turbine rotor, including the method of calculating the fracture toughness properties, after the site-specific turbine has been procured.

10.2.3.2 Fracture Toughness

As noted in Section 10.2.3.1, a suitable material toughness is obtained through the use of selected materials to produce a balance of adequate material strength and toughness and maintain a reasonable level of safety, while simultaneously providing high reliability, availability and efficiency during operation.

Stress calculations are performed taking into account centrifugal loads and thermal gradients, wherever applicable, on all major components (e.g., rotors, casings, blades). Fracture mechanics calculations are performed on the rotors taking into account the maximum acceptable size defect for U.S. standards. Calculations verify that the initial defect, after increasing due to fatigue during the equipment lifetime, does not propagate and remains non critical by a large margin as regards to brittle fracture.

The ratio of the fracture toughness, K_{lc} (as calculated from the material tests performed on the rotor) to the maximum tangential stress at speeds from normal to 120 percent of the rated speed, is at least 2 $\sqrt{in}$, at minimum operating temperature. Adequate fracture toughness to prevent brittle fracture during startup is verified by calculating startup curves specifying appropriate startup temperature and sufficient warm-up time.

The acceptance criteria for UT inspections are:

- 3 mm maximum for discs (depending on the areas).
- 5 mm maximum for shaft ends (depending on the areas).

Fracture toughness properties are calculated from material tests and can be obtained by any of the following methods:

- Testing of the actual material of the turbine rotor to establish the Klc value at normal operating temperature.

- Testing of the actual material of the turbine rotor with an instrumented Charpy machine and a fatigue precracked specimen to establish the Klc (dynamic) value at normal operating temperature. If this method is used, Klc (dynamic) is used in lieu of Klc (static) in meeting the toughness criteria.

- Estimating of K_{lc} values at various temperatures from conventional Charpy and tensile data on the rotor material using methods are presented in J. A. Begley and W. A. Logsdon, Scientific Paper 71-1E7-MSLRF-P1 (Reference 5). This method of obtaining K_{lc} is used only on materials which exhibit a well-defined Charpy energy and fracture appearance transition curve and are strain-rate insensitive.

- Estimating "lower bound" values of Klc at various temperatures using the equivalent energy concept developed by F. J. Witt and T. R. Mager, ORNL-TM-3894 (Reference 6).

A COL applicant that references the U.S. EPR design certification will provide applicable turbine disk rotor specimen test data, load-displacement data from the compact tension specimens and fracture toughness properties after the site-specific turbine has been procured.

10.2.3.3 High Temperature Properties

There is no influence on stress rupture properties because the maximum operating temperature, the basis for determining the design temperature of rotors, is below the re-crystallization and creep temperatures.

10.2.3.4 Turbine Rotor Design

The high pressure (HP) part of the high/intermediate pressure (HIP) rotor assembly is one forged section. The intermediate pressure (IP) part of the HIP rotor assembly consists of three forged sections. The HIP rotor assembly is a welded rotor consisting of four forgings. The rotors of the LP turbines are a welded rotor design.

The turbine assembly is designed to withstand normal operating conditions, anticipated transients, and accidents resulting in a turbine trip without loss of structural integrity. The design of the turbine assembly meets the following criteria:

- The design overspeed of the turbine is 120 percent of rated speed, which is higher than the highest anticipated speed resulting from a loss of load. The primary overspeed trip system fully closes the valves at about 110 percent of rated speed. An independent and redundant backup electrical overspeed trip circuit is provided to fully close these valves at about 111 percent of rated speed.

- The combined stresses in the low-pressure turbine rotor at design overspeed due to centrifugal forces and thermal gradients do not exceed 75 percent of the minimum specified yield strength of the material, or 75 percent of the measured yield strength in the weak direction of the materials if tensile tests are performed on the actual rotor material.

- The turbine shaft bearings are able to withstand any combination of the normal operating loads, anticipated transients and accidents resulting in a turbine trip.
- The natural critical frequencies of the turbine shaft assemblies between zero speed and 20 percent overspeed are controlled by design and during operation stages to minimize adverse effects to the unit during operation.
- The turbine rotor design facilitates inservice inspection of high stress regions.
- Stress corrosion cracking is considered as a degradation mechanism for crack growth.

10.2.3.5 Turbine Rotor Preservice Inspections and Testing

The following preservice inspections are performed during manufacture:

- Forged or welded rotors are rough machined prior to heat treatment.
- Each finished forged or welded rotor is subjected to 100 percent volumetric (ultrasonic), surface and visual examinations using procedures and acceptance criteria equivalent to those specified for Class 1 components in the ASME BPV Code, Section III (Reference 7) and Section V (Reference 8). Before welding or brazing, all surfaces prepared for welding or brazing are surface examined. After welding or brazing, all surfaces exposed to steam are surface examined, giving particular attention to stress risers and welds. Welds are ultrasonically examined (100 percent volumetric examination), equivalent to examinations in Reference 8. Each weld in the turbine rotor assembly is subjected to 100 percent examination in the radial, longitudinal, and tangential directions. Acceptance criteria shall be the most stringent between manufacturer's standards and ASME Code Section III, subsection NB-5300 (Reference 10).
- Each turbine rotor assembly is spin tested at 120 percent of normal operating speed.

10.2.3.6 Turbine Rotor Inservice Inspection Program Plan

A turbine rotor inservice inspection program detects rotor or disk flaws that can lead to brittle failure at or below design speed in the steam turbine rotor assembly. The turbine rotor inservice inspection program uses visual, surface and volumetric examinations to inspect components in the steam turbine rotor assembly. The inspections are performed during refueling outages on an interval consistent with the inservice inspection schedules in Reference 3 and the inspection intervals from the turbine manufacturer's turbine missile analysis provided by the COL applicant as described in Section 3.5.1.3. A COL applicant that references the U.S. EPR design certification will provide the site-specific turbine rotor inservice inspection program and inspection interval consistent with the manufacturer's turbine missile analysis.

Inservice inspection activities associated with the steam turbine rotor assembly include:

HP/IP Cylinder–Rotors (Including Couplings)

- Visual inspections (surface condition, traces of friction, shaft journals bearings, coupling flange and thrust bearing collar) equivalent to examination defined in Reference 3.
- Examination of the fillet radii between discs and shaft.
- Magnetic particle examination in the area of blade attachments.
- Check of balancing weights.
- Visual examination of the coupling bolt holes.

LP Cylinders–Rotors (Including Couplings)

- Visual inspections (traces of erosion, disc fillets, journals, gland seals and coupling flanges) equivalent to examination defined in Reference 3.
- Visual examination of the coupling bolt holes.
- Inspection of balancing weights.
- Visual inspection and magnetic particle examination in the area of blade attachments. If surface indications are detected, ultrasonic inspections will be performed.

10.2.4 Safety Evaluation

The TG is not safety-related and does not perform any safety-related functions.

The TG design satisfies general design criteria (GDC 4) relating to the protection of structures, systems and components (SSC) important to safety from turbine missiles. A failure in the TG package does not affect any structures, systems and components (SSC) important to safety and does not preclude safe shutdown of the reactor.

- The orientation of the U.S. EPR TG is favorably oriented because the containment and most of the safety-related SSC are located outside the low-trajectory hazard zone. Turbine missiles are addressed in Section 3.5.1.3.
- The TG design includes a redundant overspeed protection system, which terminates an overspeed event prior to reaching design overspeed.
- The TG package and associated piping, valves and controls are located completely within the Turbine Building. There are no safety-related systems or components located in the Turbine Building.
- Turbine speed is continuously monitored. Alarms are issued if specified limits are exceeded.

- The turbine and its auxiliaries are manufactured, erected, tested and operated in accordance with manufacturers standard practices and applicable U.S. codes to engender high reliability of systems and the mechanical integrity of the TG package.

Normally there is no radioactivity in this system. Radioactivity is only present as a result of primary to secondary leakage in the steam generators. If steam generator tube leakage occurs, the small amount of radioactivity which may be present in the secondary system is monitored and detected by the steam generator blowdown system (refer to Section 10.4.8) and in the exhaust air system from the main condenser evacuation system (refer to Section 10.4.2). Information concerning the radiological aspects of primary-to-secondary leakage is presented in Chapter 11 and Chapter 12.

10.2.5 References

1. ASME Boiler and Pressure Vessel Code, Section VIII, Division 1: “Rules for Construction of Pressure Vessels,” The American Society of Mechanical Engineers, 2004.

2. NFPA-55-05, “Standard for the Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders, and Tanks,” National Fire Protection Association, 2005.

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. ASTM A471-06, “Standard Specification for Vacuum-Treated Alloy Steel Forgings for Turbine Rotor Disks and Wheels,” American Society for Testing and Materials, 2006.

5. J. A. Begley and W. A. Logsdon, “Correlation of Fracture Toughness and Charpy Properties for Rotor Steels,” Scientific Paper 71-1E7-MSLRF-P1, Westinghouse Research Laboratories, 1971.

6. F. J. Witt and T. R. Mager, “Procedure for Determining Bounding Values on Fracture Toughness K_{Ic} at any Temperature,” ORNL-TM-3894, Oak Ridge National Laboratory, 1972.

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

8. ASME Boiler and Pressure Vessel Code, Section V: “Nondestructive Examination,” The American Society of Mechanical Engineers, 2004.

9. ASTM A370-05, “Standard Test Methods and Definition for Mechanical Testing of Steel Products,” American Society for Testing and Materials, 2005.

10. ASME Boiler and Pressure Vessel Code, Section III: "Rules for Construction of Nuclear Facility Components," Subsection NB-5300 Acceptance Standards, The American Society of Mechanical Engineers, 2004.

11. ASTM A470-05, "Standard Specification for Vacuum-Treated Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts," American Society for Testing and Materials, 2005.

Table 10.2-1—Performance Characteristics

Turbine-Generator	Details
Nominal Rating	1710 gross MW_e
Turbine type	Tandem compound, six flow
Operating speed	1800 rpm
Turbine throttle steam pressure	1089 psia
Throttle steam nominal moisture	0.42%
Moisture Separator/Reheaters (MSR)	
Number of MSRs per unit	2
Stages of moisture separation	1 with preseparator
Stages of reheat	2

Table 10.2-2—Turbine-Generator Material Data

Component	Nearest ASTM Designation
Stop Valve Bodies	A356:Gr2
Stop Valve Disc	X19CrMoVNbN11-1 No ASTM Equivalent
Stop Valve Seats	A336:F22, Class 3
Control Valve Bodies	A356:Gr2
Control Valve Disc	X19CrMoVNbN11-1 No ASTM Equivalent
Control Valve Seats	A336:F22, Class 3
Combined Reheat Valve Body	Carbon Steel
Combined Reheat Valve Disc	Carbon Steel
High Temp Valve Stems	X19CrMoVNbN11-1 No ASTM Equivalent
Lead Steam Piping	EN10028:P295GH No ASTM Equivalent
Hot Reheat Piping	Carbon Steel
Cold Reheat Piping	Stainless Steel
HIP Rotor	22NiCrMoV12-7 No ASTM Equivalent
HP Diaphragm/Blade Carriers	A182:F6b / A216Gr.WCC
HP Blades	A565:Gr.616
HP Shell	GX6CrNiMo12-1 No ASTM Equivalent
LP Rotor	23CrNiMo 7-4 No ASTM Equivalent
LP Diaphragm/Blade Carriers	A240type405 / A516Gr.70
LP Blades	A565Gr.616/Last 2 Blades A565:XM32
LP Casings	A516Gr.70
LP Outer Casing	A516Gr.60

Table 10.2-3—HP Rotor

Chemical Composition of Cast – Weight %				
Element		**Symbol**	**Minimum**	**Maximum**
Carbon		C	0.20	0.25
Silicon		Si	0.10	0.40
Manganese		Mn	0.40	0.80
Phosphorous		P	-	0.012
Sulfur		S	-	0.012
Nickel		Ni	2.80	3.20
Chromium		Cr	1.50	2.00
Molybdenum		Mo	0.40	0.60
Vanadium		V	-	0.11
Copper		Cu	-	0.12
Phosphorous + Tin		P + Sn	-	0.018
Arsenic		As	-	0.018
Antimony		Sb	-	0.003
Aluminum		Al	-	0.015
Mechanical Property Requirements at 23°C ± 5°C at Rim and Subsurface Test Locations				
Heat Treatment Stage		**After Post-Weld Heat Treatment**		
Property	**Unit**	**Orientation**	**Minimum**	**Maximum**
Tensile Strength	N/mm^2	Long. / Transv	660	-
0.2% Proof Strength	N/mm^2	Long. / Transv	550	650
Elongation on 5.65 √So	%	Long. / Transv	15 / 14	-
Reduction of Area	%	Long. / Transv	50	-
Notch Impact Property Requirements at Rim and Subsurface Test Locations				
Heat Treatment Stage		**Delivery Condition and After Post-Weld Heat Treatment**		
Property	**Unit**	**Orientation**	**Minimum**	**Maximum**
Notch Impact Strength at Minimum Operating Temperature	J	Transv.	81	-
FATT (50%)	°C	Long / Transv	-	-30

Table 10.2-4—IP Discs and Shaft End

Chemical Composition of Cast – Weight %			
Element	**Symbol**	**Minimum**	**Maximum**
Carbon	C	0.20	0.25
Silicon	Si	0.10	0.40
Manganese	Mn	0.40	0.80
Phosphorous	P	-	0.012
Sulfur	S	-	0.012
Nickel	Ni	2.80	3.20
Chromium	Cr	1.50	2.00
Molybdenum	Mo	0.40	0.60
Vanadium	V	-	0.11
Copper	Cu	-	0.12
Phosphorous + Tin	P + Sn	-	0.018
Arsenic	As	-	0.018
Antimony	Sb	-	0.003
Aluminum	Al	-	0.015

Mechanical Property Requirements at 23°C ± 5°C at Rim and Subsurface Test Locations				
Heat Treatment Stage		**After Post-Weld Heat Treatment**		
Property	**Unit**	**Orientation**	**Minimum**	**Maximum**
Tensile Strength	N/mm^2	Long. / Transv	740	880
0.2% Proof Strength	N/mm^2	Long. / Transv	635	-
Elongation on 5.65 √So	%	Long. / Transv	15 / 14	-
Reduction of Area	%	Long. / Transv	50	-
Notch Impact Property Requirements at Rim and Subsurface Test Locations				
Heat Treatment Stage		**Delivery Condition and After Post-Weld Heat Treatment**		
Property	**Unit**	**Orientation**	**Minimum**	**Maximum**
Notch Impact Strength at Minimum Operating Temperature	J	Transv.	81	-
FATT (50%)	°C	Long / Transv	-	-30

Table 10.2-5—LP Rotors

Material designation		23CrNiMo7-4		
Material type		Low alloy steel		
Applicable product form(s)		Forgings		
Chemical Composition of Cast – Weight %				
Element		Symbol	Minimum	Maximum
Carbon		C	0.20	0.26
Silicon		Si	-	0.30
Manganese		Mn	0.50	0.80
Phosphorous		P	-	0.010
Sulfur		S	-	0.015
Nickel		Ni	0.90	1.20
Chromium		Cr	1.70	2.00
Molybdenum		Mo	0.60	0.80
Vanadium		V	-	0.050
Phosphorous + Tin		P + Sn	-	0.020
Mechanical Property Requirements at 23°C ± 5°C at Rim and Subsurface Test Locations				
Heat Treatment Stage		Delivery Condition and After Post-Weld Heat Treatment		
Property	Unit	Orientation	Minimum	Maximum
Tensile Strength	N/mm^2	Long. / Transv	740	880
0.2% Proof Strength	N/mm^2	Long. / Transv	635	-
Elongation on 5.65 √So	%	Long. / Transv	17 / 15	-
Reduction of Area	%	Long. / Transv	50	-
Notch Impact Property Requirements				
Heat Treatment Stage		Delivery Condition and After Post-Weld Heat Treatment		
Property	Unit	Orientation	Minimum	Maximum
Notch Impact Strength at Minimum Operating Temperature	J	Transv.	81	-
FATT (50%)	°C	Long / Transv	-	-18

Next File