10.2 Turbine Generator

10.2.1 Design Bases

10.2.1.1 Safety Design Bases

The turbine generator (T-G) does not serve nor support any safety function and has no safety design basis. The turbine generator is, however, a potential source of high energy missiles that could damage safety-related equipment or structures. The turbine is designed to minimize the possibility of failure of a turbine blade or rotor. Turbine integrity is discussed in Subsection 10.2.3. The effects of potential high energy missiles are discussed in Chapter 3. In addition, the main steam turbine stop valves are analyzed to demonstrate structural integrity under safe shutdown earthquake (SSE) loading conditions.

10.2.1.2 Power Generation Design Bases

Power Generation Design Basis One—The T-G is intended for either base load or load following operation. The gross generator outputs at reference guaranteed reactor rating and valves-wide-open (VWO) operation are given on the heat balances shown on Figures 10.1-2 and 10.1-3, respectively.

Power Generation Design Basis Two—The T-G load change characteristics are compatible with the instrumentation and control system which coordinates T-G and reactor operation.

Power Generation Design Basis Three—The T-G is designed to accept a sudden loss of full load with sufficient margin to the overspeed trip.

Power Generation Design Basis Four—The T-G is designed to permit periodic under load testing of steam valves important to overspeed protection, emergency overspeed trip circuits, and several other trip circuits.

Power Generation Design Basis Five—The failure of any single component will not cause the rotor speed to exceed the Emergency Overspeed (EOS).

Power Generation Design Basis Six—Turbine control functions required for turbine protection possess sufficient redundancy such that failure of a single component input does not compromise the integrity of the turbine protection system.

Power Generation Design Basis Seven—The T-G auxiliary systems (stator cooling, lube oil cooling, etc.) are designed either with enough redundancy to support full power operation with a single failure or to provide a signal to the reactor power control system to automatically reduce power to within the capability of the remaining on-line capacity.

10.2.1.3 Functional Limitations Imposed by the Design or Operational Characteristics of the Reactor Coolant System

10.2.1.3.1 Turbine Stop Valve

During an event resulting in turbine stop valve fast closure, turbine inlet steam flow will not be reduced faster than that shown in Figure 10.2-1.

10.2.1.3.2 Turbine Control Valve

During any event resulting in turbine control valve fast closure, turbine inlet steam flow will not be reduced faster than that shown in Figure 10.2-2.

The turbine control valve steam flow shutoff rate, upon a step reduction to zero in pressure regulation flow demand (no resulting bypass steam flow demand), will be within the region shown in Figure 10.2-3. Any single control system failure or T-G event will not cause a faster steam flow reduction than that shown in Figure 10.2-3 without initiating an immediate reactor trip.

The turbine control valves are capable of full stroke opening and closing times not greater than 7 seconds for adequate pressure control performance.

10.2.1.3.3 Automatic Load Maneuvering Capability

Within the automatic load following region of the power/flow operating map (Figure 15.0-1), steam flow will automatically respond to a load demand step as follows:

(1) For positive load demand signal changes less than 10% Nuclear Boiler Rated (NBR), power change rates are limited only by the response rates of the reactor.

(2) For positive load demand signal changes greater than 10% NBR, the resulting first 10% NBR thermal power change may be at 1% NBR/s, with the balance of the power change taking place at rates up to 15% NBR/min (0.25% NBR/s). This is accomplished by permitting the load demand signal to initially step upwards 10%, followed by a 15% NBR/min ramp.

(3) For negative load demand signal changes, rates are not limited.

10.2.2 Description

10.2.2.1 General Description

The turbine-generator consists of an 188.5 rad/s (1800 rpm) turbine, moisture separator/reheaters, generator, exciter, controls, and associated subsystems.

The turbine consists of a double-flow, high-pressure unit, and three double flow low-pressure units in tandem. The high-pressure unit has extraction points for reheater reheating steam and high pressure feedwater heating. Moisture separation and reheating of the high-pressure turbine exhaust steam is performed by two combined moisture separator/reheaters (MSRs). An MSR is located on each side of the T-G centerline. The steam passes through the low-pressure turbines, each with four extraction points for the four low-pressure stages of feedwater heating, and exhausts into the main condenser. In addition to the moisture separators in the external MSRs, the turbine steam path has provisions for removing some additional moisture and routing it to extraction lines.

The generator is a direct driven, three-phase, 60 Hz, 188.5 rad/s (1800 rpm) synchronous generator with a water-cooled armature winding and hydrogen cooled rotor.

The turbine-generator uses a digital monitoring and control system which, in coordination with the turbine Steam Bypass and Pressure Control System, controls the turbine speed, load, and flow for startup and normal operations. The control system operates the turbine stop valves, control valves, and intermediate stop and intercept valves. T-G supervisory instrumentation is provided for operational analysis and malfunction diagnosis.

Automatic control functions are programmed to protect the Nuclear Steam Supply System through appropriate corrective actions (Section 7.7).

T-G accessories include the bearing lubrication oil system, electrohydraulic control (EHC) system, turbine hydraulic system, turning gear, hydrogen and CO_2 system, seal oil system, stator cooling water system, exhaust hood spray system, turbine gland sealing system, MSR reheater heating steam system, and turbine supervisory instrument (TSI) system.

The T-G unit and associated piping, valves, and instruments are located completely within the Turbine Building. The safety-related instruments located within the Turbine Building are the safety-related Reactor Protection System (RPS) sensors on the T-G unit used to detect fast closure of the turbine control valves and closure of the main stop valves and the Leak Detection and Isolation System (LDS) sensors used to detect high main condenser shell pressure, low main steam header pressure, and main steam line leakage. The safety-related instrumentation is fail safe, hence any local failure associated with the T-G unit will not adversely affect any safety-related equipment. Failure of T-G equipment cannot preclude safe shutdown of the reactor.

The Turbine Building contains the safety-related electrical switchgear and trip breakers for the condensate pumps for the mitigation of a postulated feedwater line break in accordance with Subsection 8.3.1.1.1.

10.2.2.2 Component Description

The MSRs, MSR drain tanks, stator water coolers, and stator water demineralizer are designed to ASME Code Section VIII requirements. The balance of the T-G is designed to Turbine Manufacturer’s Standards.

Main Stop and Control Valves—Four high-pressure main stop and control valves admit steam to the high-pressure (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.

The main stop valves are operated in an open-closed mode either by the emergency trip, fast acting valve for tripping, or by a small solenoid valve for testing. The disks are totally unbalanced and cannot open against full differential pressure. A bypass is provided to pressurize the below seat areas of the four valves. Springs are designed to close the main stop valve in approximately 0.20 seconds under the emergency conditions listed in Subsection 10.2.2.5.

Each stop valve contains a permanent steam strainer to prevent foreign matter from entering the control valves and turbine.

The control valves are designed to ensure tight shutoff. The valves are of sufficient size, relative to their cracking pressure, to require a partial balancing. 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 control valve is designed to close in approximately 0.20 seconds.

High-Pressure Turbine—The HP turbine receives steam through four steam leads, one from each control valve outlet. The steam is expanded axially across several stages of stationary and moving blades. Steam pressure immediately downstream of the first stage is used as a load reference signal for reactor control. Extraction steam from the turbine supplies the last stage of feedwater heating. HP turbine exhaust steam is collected in eight cold reheat pipes, four at each end of the turbine. Most of the exhaust steam is routed to the MSR inlet, but part of it is diverted and supplies the next to last stage of feedwater heating.

Moisture Separator Reheaters—Two horizontal cylindrical-shell, combined moisture separator/reheaters (MSRs) are installed in the steam path between the high and low pressure turbines. The MSRs serve to dry and reheat the HP turbine steam exhaust (crossaround steam), before it enters the low-pressure turbines. This improves cycle efficiency and reduces moisture-related erosion and corrosion in the low-pressure turbines. Crossaround steam is piped into the bottom of the MSR. Moisture is removed in chevron-type moisture separators, and is drained to the appropriate stage of feedwater heating. The steam next passes upward across the two reheater stages. Heating steam to the first reheater stage is supplied by extraction steam and heating steam to the second reheater stage is supplied with main steam. Reheated steam is routed to the intermediate stop and intercept valves, which are located just upstream of the low-pressure turbine inlet nozzles. Relief valves are provided on the MSR for overpressure protection.

The reheaters drain, via drain tanks, to the forward pumped heater drain system, which discharges to the reactor feedwater pump suction. Safety valves are provided on the MSR for overpressure protection.

Intermediate Stop and Intercept Valves—Hydraulically operated intermediate stop and intercept valves are provided in each hot reheat line just upstream of the Low Pressure (LP) inlet. Upon loss of load, the intercept valves first close then throttle steam to the LP turbine, as required to control speed. The intermediate stop valves close on a turbine trip. The intermediate stop and intercept valves are designed to rapidly close to control turbine overspeed.

Steam from the MSRs enters the LP turbine through these valves which are located as close to the LP turbine as possible to limit the amount of uncontrolled steam available for overspeeding the turbine. Upon loss of load, the intercept valve first closes then throttles steam to the LP turbine, as required to control speed and maintain synchronization. These valves are capable of opening against full system pressure and are designed to close in approximately 0.2 seconds.

Low-Pressure Turbines—Each LP turbine receives steam from two hot reheat lines. The steam expands axially across several stages of stationary and moving blades.

Extraction Non-return Valves—Upon loss of load, the steam contained downstream of the turbine extractions could flow back into the turbine, across the remaining turbine stages, and into the condenser. Associated condensate could flash to steam under this condition and contribute to the backflow of steam or could be entrained with the steam flow and damage the turbines. Non-return valves are employed in selected extraction lines to minimize the potential for overspeeding.

Generator—The generator is a direct-driven, three-phase, 60 Hz, 188.5 rad/s (1800 rpm), four-pole synchronous generator with water-cooled stator and hydrogen cooled rotor.

The rotor is manufactured from a forging and includes layers of field windings embedded in milled slots. The windings are held radially by slot wedges at the rotor outside diameter. The wedge material maintains its mechanical properties at elevated temperature. The magnetic field is generated by DC power which is fed to the windings through collector rings located outboard of the main generator bearings. The rotor body and shaft is machined from a solid steel forging. Detailed examinations include:

(1) material property checks on test specimens taken from the forging;

(2) photomicrographs for examination of microstructure;

(3) magnetic particle and ultrasonic examination;

(4) residual stress measurement at vendor factory test.

Bulk Hydrogen System—The bulk hydrogen and CO_2 system is illustrated on Figure 10.2-4. The hydrogen system is designed to provide the necessary flow and pressure at the main generator for purging carbon dioxide during startup and supply makeup hydrogen for generator leakage during normal operation.

The system consists of hydrogen supply piping with all the necessary valves, instrumentation, gas purity measuring equipment, hydrogen gas dryers, and bulk hydrogen storage unit.

Fires and explosions during filling and/or purging of the generator are prevented by inerting the generator with CO_2 so that a flammable mixture of hydrogen and oxygen cannot be produced. Unneeded hydrogen is vented outside through a flame arrestor.

The bulk hydrogen system utilizes the guidelines given in Reference 10.2-3 with respect to these portions of the guidelines involving hydrogen that do not deal specifically with the HWC system. Specifically, the bulk hydrogen system piping and components will be located to reduce risk from their failures. The bulk hydrogen storage is located outside but near the Turbine Building. The hydrogen lines are provided with a pressure reducing station that limits the maximum flow to less than 100 standard cubic meters per minute before entering the Turbine Building. Equipment and controls used to mitigate the consequences of a hydrogen fire/explosion will be designed to be accessible and remain functional during the postulated postaccident condition. The design features and/or administrative controls shall be provided to ensure that the hydrogen supply is isolated when normal building ventilation is lost.

The arrangement of buildings at the facility and location of building doors and the bulk hydrogen storage cylinders will be designed to ensure that damage to buildings containing safety-related equipment due to combustion of hydrogen or an explosion is unlikely.

Additionally, the bulk hydrogen system piping in the Turbine Building is designed in accordance with the industry practice.

10.2.2.3 Normal Operation

During normal operation, the main stop valves, intermediate stop valves and intercept valves are wide open. Operation of the T-G is under the control of the Electro-Hydraulic Control (EHC) System. The EHC System is comprised of three basic subsystems: the speed control unit, the load control unit, and the flow control unit. The normal function of the EHC System is to generate the position signals for the four main stop valves, four main control valves, and six intermediate stop valves and intercept valves.

10.2.2.4 Turbine Overspeed Protection System

The normal speed control system (EHC) comprises a first line of defense against turbine overspeed. This system includes the main steam control valves, intermediate steam intercept valves, extraction system non-return valves, and fast-acting valve-closing functions within the EHC system. The normal speed control unit utilizes three speed signals. Loss of any two of these speed signals initiates a turbine trip via the Emergency Trip System. An increase in speed above setpoint tends to close the control and intercept valves in proportion to the speed increase. The EHC fully shuts off steam to the high pressure turbine (HP) at approximately 105% of the turbine rated speed by closing the turbine control valves, and the EHC fully shuts off steam to the low pressure turbines (LPs) at approximately 107% of the turbine rated speed by closing the intercept valves.

Rapid turbine accelerations resulting from a sudden loss of load at higher power levels normally initiate the fast-acting solenoids via the speed control system's Power-Load Unbalance (PLU) function, to rapidly close the control and intercept valves irrespective of the current turbine speed. The PLU function is the second line of defense against overspeed and is implemented in the EHC. The PLU uses the difference between turbine power and load indications, which are high pressure turbine exhaust steam pressure and generator current, respectively, to cause fast closure of the turbine control valves and intercept valves when the difference between power and load exceed approximately 40%, to limit overspeed in the event of a full load rejection. The normal speed control system, including the PLU function, is designed to limit peak overspeed resulting from a loss of full load, to at least 2% below the overspeed trip set point. Typically, this peak speed is in a range of 105-108% of rated speed, and the overspeed trip set point is typically close to 110% of rated speed. All turbine steam control and intercept valves are fully testable during normal operation. The fast closing feature, provided by action of the fast-acting solenoids, is testable during normal operation.

If the normal speed control and the PLU function should fail, the overspeed trip devices close the steam admission valves including the main and intermediate stop valves. This turbine overspeed protection system comprises the third line of defense against turbine overspeed. It is redundant, highly reliable and diverse in design and implementation from the normal speed control system and protection system. This overspeed protection system is designed to ensure that even with failure of the normal speed control system, the resulting turbine speed does not exceed 120% of rated speed. In addition, the components and circuits comprising the turbine overspeed protection system are testable when the turbine is in operation.

The overspeed trip system is electrical, redundant and diverse and consists of the primary and emergency overspeed trip functions. Reliability is achieved by using two sets of redundant speed sensing probes, which input to the independent and diverse primary and emergency trip modules in the control system. For additional reliability, two-out-of-three logic is employed in both the primary and emergency overspeed trip circuitry. Either trip module can de-energize one of the trip solenoids of the electro-hydraulic Emergency Trip Device (ETD). The ETD is composed of two independent trip solenoid valves, each with two normally energized solenoid operated pilot valves. The solenoid operated pilot valves de-energize in response to detection of an overspeed condition by the turbine speed control logic. De-energization of both solenoid operated pilot valves is necessary to cause the spool in their respective trip solenoid valve to reposition, which depressurizes the emergency trip fluid system, rapidly closing all steam inlet valves. Accordingly, the repositioning of only one of the two trip solenoid valves is necessary to trip the main turbine. A single component failure does not compromise trip protection, and does not result in a turbine trip. Each trip solenoid valve in the ETD is testable while the turbine is in operation.

The overspeed sensing devices are located in the turbine front bearing standard, and, therefore, are protected from the effects of missiles or pipe breakage. The hydraulic lines are fail-safe; that is, if one were to be broken, loss of hydraulic pressure would result in a turbine trip. The ETD is also fail-safe. Each trip solenoid transfers to the trip state on a loss of control power to both of its associated pilot valves, resulting in a turbine trip. These features provide inherent protection against failure of the overspeed protection system caused by low trajectory missiles or postulated piping failures.

Refer to Figure 10.2-5, Turbine Overspeed Trip System Functional Diagram. The primary overspeed trip function is redundant and utilizes three passive speed magnetic pickups that are separate from the active speed sensors used for normal speed control emergency trip function. Each speed signal is compared to a speed setpoint of approximately 110% of rated speed, and produces trip signals arranged in two-out-of-three logic, to de-energize the solenoid operated pilot valves of one of the two trip solenoid valves of the electro-hydraulic ETD. Both solenoid operated pilot valves must be de-energized to trip the associated trip solenoid valve. The ETD has two redundant trip solenoid valves. Tripping of either redundant trip solenoid valve will drain the emergency trip fluid, resulting in a turbine trip.

The emergency overspeed trip function is also redundant and uses three speed sensors that are separate from those used by the primary overspeed trip function. The speed setpoint for this trip function is approximately 111% of rated speed. The trip signals are arranged in two-out-of-three logic to de-energize the solenoid operated pilot valves of one of the two trip solenoid valves in the ETD to cause a turbine trip.

The control signals from the two turbine-generator overspeed trip systems are isolated from, and independent of, each other. The trip logic functions for the primary trip function are performed using hardware logic devices, and the emergency trip functions are performed in software/firmware to eliminate common cause failures from rendering the trip functions inoperable. The two overspeed trip systems are installed in separate cabinets, each with its own redundant uninterruptible power sources.

Each turbine extraction line is reviewed for potential energy and contribution to overspeed. The number and type of extraction non-return valves required for each extraction line are specified based on the enthalpy and mass of steam and water in the extraction line and feedwater heater. Higher energy lines are provided with power-assisted closed non-return valves, controlled by air relay dump valves, which in turn, are activated by the emergency trip fluid system. The air relay dump valves, actuated on a turbine trip, dump air from the extraction non-return valve actuators to provide rapid closing. The closing time of the extraction non-return valves is sufficient to minimize steam contribution to the turbine overspeed event.

The following component diversities are employed to guard against excessive overspeed:

(1) Main stop valves/control valves

(2) Intermediate stop valves/intercept valves

(3) Normal speed control/primary overspeed control/emergency overspeed control

(4) Fast acting solenoid valves/emergency trip fluid system (emergency trip device)

(5) Speed control signals/primary overspeed trip/emergency overspeed trip

The main stop valves and control valves provide full redundancy and diversity in that these valves are in series and have independent control signals and operating mechanisms. Closure of all four stop valves or all four control valves effectively shuts off all main steam flow to the HP turbine. The intermediate stop and intercept valves are also fully redundant and diverse in that they are in series and have independent control signals and operating mechanisms. Closure of either valve or both valves in each of the six sets of intermediate stop and intercept valves effectively shuts off steam flow to the three LP turbines. This arrangement is such that failure of a single valve to close does not result in a maximum speed in excess of design limits.

10.2.2.5 Turbine Protection System

In addition to the overspeed trip signals discussed, the ETS closes the main stop and control valves and the intermediate stop and intercept valves to shut down the turbine on the following signals:

(1) Emergency trip pushbutton in control room

(2) Moisture separator high level

(3) Low condenser vacuum

(4) Low lube oil pressure

(5) LP turbine exhaust hood high temperature

(6) High reactor water level

(7) Thrust bearing wear

(8) Not used

(9) Emergency trip at front standard

(10) Loss of stator coolant

(11) Low hydraulic fluid pressure

(12) Selected generator trip

(13) Loss of EHC electrical power

(14) Excessive turbine shaft vibration

(15) Loss of two speed signals - either Normal Speed Control or Emergency Overspeed Trip

All of the above trip signals except generator trips, loss of power, and vibration and manual trips use two-out-of-three coincident trip logic.

When the ETS is activated, it overrides all operating signals and trips the main stop and control valves, and intermediate stop and intercept valves.

10.2.2.6 Turbine-Generator Supervisory Instruments

Although the turbine is not readily accessible during operation, the turbine supervisory instrumentation is sufficient to detect any potential malfunction. The turbine supervisory instrumentation includes monitoring of the following:

(1) Vibration and eccentricity

(2) Thrust bearing wear

(3) Exhaust hood temperature and spray pressure

(4) Oil system pressures, levels, and temperatures

(5) Bearing metal and oil drain temperatures

(6) Shell temperature

(7) Valve positions

(8) Shell and rotor differential expansion

(9) Shaft speed, electrical load, and control valve inlet pressure indication

(10) Hydrogen temperature, pressure, and purity

(11) Stator coolant temperature and conductivity

(12) Stator-winding temperature

(13) Collector air temperatures

(14) Turbine gland sealing pressure

(15) Gland steam condenser vacuum

(16) Steam chest pressure

(17) Seal oil pressure

10.2.2.7 Testing

The primary and emergency overspeed trip circuits and devices can be tested remotely at shut down, rated speed, and under load, by means of controls in the Main Control Room. Operation of the overspeed protection devices under controlled speed conditions is checked at startup and after each refueling or major maintenance outage. In some cases, operation of the overspeed protection devices can be tested just prior to shutdown, thus negating the need to test overspeed protection devices during subsequent startup, if no maintenance is performed affecting the overspeed trip circuits and devices.

During refueling, or maintenance shutdowns, coinciding with the inservice inspection schedule required by Section XI of the ASME Code for reactor components, at intervals defined in Subsection 10.2.3.6, at least one main steam stop valve, one turbine control valve, one intermediate stop valve, and one intercept valve are dismantled to conduct visual and surface examinations of valve seats, disks and stems. If unacceptable flaws or excessive corrosion is found in a valve, all other valves of that type are dismantled and inspected. Valve bushings are inspected and cleaned, and bore diameters checked for proper clearance.

Main stop valves and turbine control valves, intercept valves and intermediate stop valves are exercised quarterly (or as required by the missile probability analysis) by closing each valve and observing the remote valve position indicator for fully CLOSED position status. This test also verifies operation of the fast close function of each main steam stop, turbine control, intercept and intermediate stop valve during the last few percent of valve stem travel.

Access to required areas outside of the turbine shielding is provided on the turbine floor under operating conditions.

Provisions for testing each of the following devices while the unit is operating are included:

(1) Main stop and control valves

(2) Turbine bypass valves

(3) Low pressure turbine intermediate stop and intercept valves

(4) Emergency trip devices

(5) Turbine extraction nonreturn valves

(6) Not Used

(7) Not Used

(8) Not Used

(9) Lubricating oil pumps

(10) Control fluid pumps

10.2.3 Turbine Integrity

10.2.3.1 Materials Selection

Turbine rotors and parts are made from vacuum melted or vacuum degassed Ni-Cr-Mo-V alloy steel by processes which 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 turbine materials have the lowest fracture appearance transition temperatures (FATT) and highest Charpy V-notch energies obtainable, on a consistent basis, from water quenched Ni-Cr-Mo-V material at the sizes and strength levels used.

Low-pressure turbine wheel (disc) forgings are made from vacuum treated Ni-Cr-Mo-V alloy steel forgings. The fracture appearance transition temperature (50% FATT), as obtained from Charpy tests performed in accordance with ASTM A-370, will be no higher than 0ºF for low-pressure turbine wheel (disc) forgings. The Cv energy at the minimum operating temperature will be at least 60 ft-lbs for a low-pressure turbine wheel (disc) forging. A minimum of three Cv specimens will be tested in accordance with specification ASTM A-370 to determine this energy level. The determination of FATT is used in lieu of nil-ductility transition temperature methods.

Large integral rotors are also made from vacuum treated Ni-Cr-Mo-V alloy steel forgings. Their larger size limits the achievable properties. The fracture appearance transition temperature (50% FATT), as obtained from Charpy tests performed in accordance with ASTM A-370, will be no higher than +40ºF for large integral forgings. The Cv energy at the minimum operating temperature will be at least 45 ft-lbs for a large integral rotor forging. A minimum of three Cv specimens will be tested in accordance with specification ASTM A-370 to determine this energy level.

Current turbine designs utilize rotors produced from large integral forgings. Future turbine designs may include fabricated rotors produced from multiple wrought components. Acceptable material properties will be consistent with component size and fabrication method.

10.2.3.2 Fracture Toughness

Suitable material toughness is obtained through the use of selected materials as described in Subsection 10.2.3.1, to produce a balance of adequate material strength and toughness to ensure safety while simultaneously providing high reliability, availability, efficiency, etc. during operation.

Stress calculations include components due to centrifugal loads, interference fit, and thermal gradients where applicable. The ratio of material fracture toughness, K_{IC} (as derived from material tests on each major part or rotor), to the maximum tangential stress intensity at speeds from normal to design overspeed is at least 2 at minimum operating temperature. The fracture toughness (KIC) value is determined using a value of deep-seated FATT based on the measured FATT values from trepan specimens, and a correlation factor obtained from historical integral rotor test data. The COL applicant will provide the test data and the calculated toughness curve to the NRC staff for review. (See Subsection 10.2.5.1 for COL license information.)

Sufficient warmup time is specified in the turbine operating instruction to assure that (1) toughness will be adequate to prevent brittle fracture during startup, and (2) the above ratio of fracture toughness to stress intensity is maintained during all phases of anticipated turbine operation.

10.2.3.3 High Temperature Properties

The operating temperatures of both the high-pressure and the low-pressure rotors are below the stress rupture range. Therefore, creep-rupture is not a failure mechanism.

Basic stress and creep-rupture data are obtained in standard laboratory tests at appropriate temperatures with equipment and procedures consistent with ASTM recommendations in Reference 10.2-2, Subsection 10.2.6.

10.2.3.4 Turbine Design

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

(1) Turbine shaft bearings are designed to retain their structural integrity under normal operating loads and anticipated transients, including those leading to turbine trips.

(2) The multitude of natural critical frequencies of the turbine shaft assemblies existing between zero speed and 20% overspeed are controlled in the design and operation so as to cause no distress to the unit during operation.

(3) The turbine rotor average tangential stress (excluding stresses in the blade/wheel region) at design overspeed resulting from centrifugal forces, interference fit (as applicable), and thermal gradients does not exceed 0.75 of the minimum specified yield strength of the material.

(4) The design overspeed of the turbine is at least 5% above the highest anticipated speed resulting from a loss of load. The basis for the assumed design overspeed will be submitted to the NRC staff for review. (See Subsection 10.2.5.2 for COL license information.)

10.2.3.5 Preservice Inspection

The preservice procedures and acceptance criteria are as follows:

(1) Forgings are rough machined with minimum stock allowance prior to heat treatment.

(2) Each finished machined rotor is subjected to surface visual examinations, using established acceptance criteria. These criteria are more restrictive than those specified for Class 1 components in the ASME Boiler and Pressure Vessel Code, Sections III and V, and include the requirement that subsurface sonic indications are either removed or evaluated to ensure that they will not grow to a size which will compromise the integrity of the unit during its service life. Forgings undergo 100% volumetric (ultrasonic) examination subject to established inspection methods and acceptance criteria that are equivalent or more restrictive than those specified for Class I components in ASME Code Sections III and V. Subsurface sonic indications are not accepted if found to compromise the integrity of the unit during its service life. Rotor forgings may be bored to remove defects, obtain material for testing and to conduct boresonic inspection.

(3) Finished machined rotors are also subjected to surface and visual examination. Specific portions, including any bores, keyways, or drilled holes, are subject to magnetic particle test. Surface indications are evaluated and removed if found to compromise the integrity of the unit during its service life. All flaw indications in keyways and drilled holes are removed.

(4) Each fully bladed turbine rotor assembly is factory spin tested at 20% overspeed.

Additional preservice inspections include air leakage tests performed to determine that the hydrogen cooling system is tight before hydrogen is introduced into the generator casing. The hydrogen purity is tested in the generator after hydrogen has been introduced. The generator windings and all motors are megger tested. Vibration tests are performed on all motor-driven equipment. Hydrostatic tests are performed on all coolers. Required piping is pressure tested for leaks.

10.2.3.6 Inservice Inspection

The inservice inspection program for the turbine assembly includes complete inspection of all normally inaccessible parts, such as couplings, coupling bolts, turbine shafts, turbine blades and turbine rotors. During plant shutdown (coinciding with the inservice inspection schedule for ASME Section III components, as required by the ASME Boiler and Pressure Vessel Code, Section XI), turbine inspection is performed in sections during the refueling outages so that a total inspection has been completed at least once within the time period recommended by the manufacturer.

The recommended maintenance and inspection program plan for the turbine assembly, valves and controls ensures that the annual turbine generator missile probabilities are maintained at or below the acceptable level (see Subsection 10.2.1).

This inspection consists of visual, surface and volumetric examinations as indicated below:

(1) Visual, magnetic particle, and ultrasonic examination of all accessible surfaces of rotors.

(2) Visual, magnetic particle, or liquid penetrant examination of turbine blades.

(3) Visual and magnetic particle examination of couplings and coupling bolts.

The inservice inspection of valves important to overspeed protection includes the following:

(1) All main stop valves, control valves, extraction nonreturn valves, intermediate stop and intercept valves are tested under load. Test controls installed in the main control room permit full stroking of the stop valves, control valves, intermediate stop and intercept valves. Valve position indication is provided in the main control room. Some load reduction may be necessary before testing main stop and control valves, intermediate stop and intercept valves. Extraction nonreturn valves are tested by equalizing air pressure across the air cylinder. Movement of the valve arm is observed by the main control room valve position indication.

(2) Main stop valves, control valves, extraction nonreturn valves, intermediate stop and intercept valves are tested by the COL applicant as required by the turbine missile probability analysis, by closing each valve and observing by the main control room valve position indication that the valves move smoothly to a fully closed position. Closure of each main stop valve, control valve, intermediate stop and intercept valve during test is verified by observation of the main control room valve position indication. This test also verifies the fast closure function during the last portion of the valve travel.

    Tightness tests of the main stop and control valves are performed at least once per maintenance cycle by checking the coastdown characteristics of the turbine from no load with each set of four valves closed alternately, or using warm-up steam as an indicator with the valves closed.

(3) All main stop valves, main control valves, intermediate stop and intercept valves are disassembled and visually inspected once during the first three refueling or extended maintenance shutdowns. Subsequent inspections are scheduled as required by the turbine missile probability analysis. The inspections will be conducted for:

(a) Wear of linkages and stem packings.

(b) Erosion of valve seats and stems.

(c) Deposits on stems and other valve parts which could interfere with valve operation.

(d) Distortions, misalignment or cracks.

Inspection of all valves of one functional type (i.e., stop, control, intercept) are conducted for any detrimental, unusual condition (as defined by the turbine valve inservice inspection program) if one is discovered during the inspection of any single valve.

10.2.4 Evaluation

The turbine-generator is not nuclear safety-related and is not needed to effect or support a safe shutdown of the reactor.

The turbine is designed, constructed, and inspected to minimize the possibility of any major component failure.

The turbine has a redundant, testable overspeed trip system to minimize the possibility of a turbine overspeed event.

Unrestrained stored energy in the extraction steam system has been reduced to an acceptable minimum by the addition of nonreturn valves in selected extraction lines.

The T-G equipment shielding requirements and the methods of access control for all areas of the Turbine Building ensure that the dose criteria specified in 10CFR20 for operating personnel are not exceeded.

All areas in proximity to T-G equipment are zoned according to expected occupancy times and radiation levels anticipated under normal operating conditions.

Specification of the various radiation zones in accordance with expected occupancy is listed in Chapter 12.

If deemed necessary during unusual occurrences, the occupancy times for certain areas will be reduced by administrative controls enacted by health physics personnel.

The design basis operating concentrations of N-16 in the turbine cycle are indicated in Section 12.2.

The connection between the low-pressure turbine exhaust hood and the condenser is made by means of a stainless steel expansion joint.

Since there is no nuclear safety-related mechanical equipment in the turbine area and since the condenser is at subatmospheric pressure during all modes of turbine operation, failure of the joint will have no adverse effects on nuclear safety related equipment.

The T-G trip logic and control schemes will respectively use coincident logic and redundant controllers and input signals to assure that the plant availability goals are achieved and spurious trips are avoided.

10.2.5 COL License Information

10.2.5.1 Low Pressure Turbine Disk Fracture Toughness

The COL applicant will provide turbine material property data and assure sufficient turbine warmup time as required by Subsection 10.2.3.2.

10.2.5.2 Turbine Design Overspeed

The COL applicant will provide the basis for the turbine overspeed as required by Subsection 10.2.3.4(4).

10.2.5.3 Turbine Inservice Test and Inspection

The COL applicant will provide the turbine inservice test and inspection requirements as noted in Subsection 10.2.3.6.

10.2.6 References

10.2-1 Not Used.

10.2-2 ASTM Section III, Vol 03.01, E139-83 “Standard Practice for Conducting Creep, Creep Rupture and Stress Rupture Tests for Metallic Materials.”

10.2-3 Electric Power Research Institute, “Guidelines for Permanent BWR Hydrogen Water Chemistry Installations – 1987,” EPRI NP-5283-SR-A, September 1987.

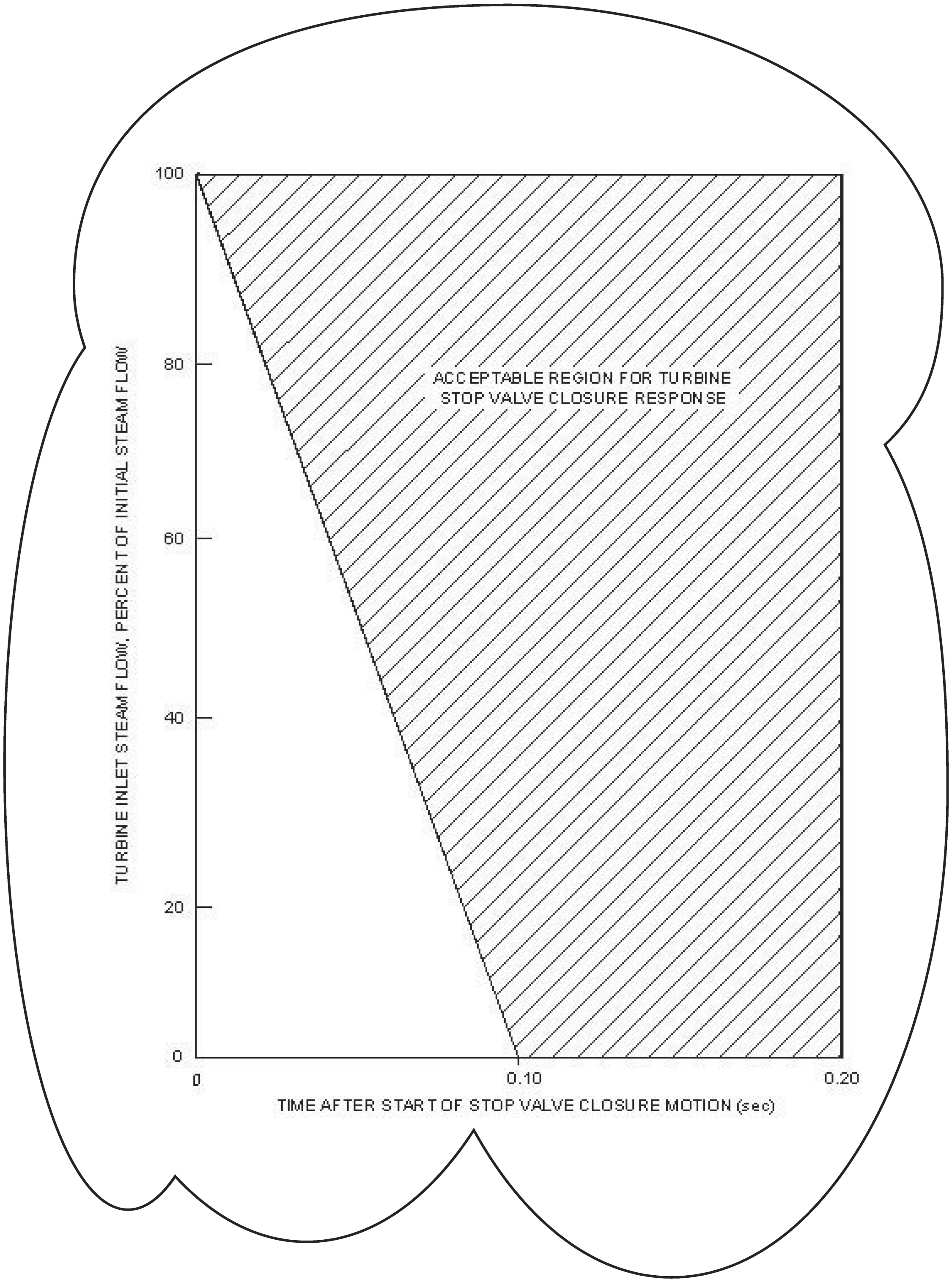

Figure 10.2-1 Turbine Stop Valve Closure Characteristic

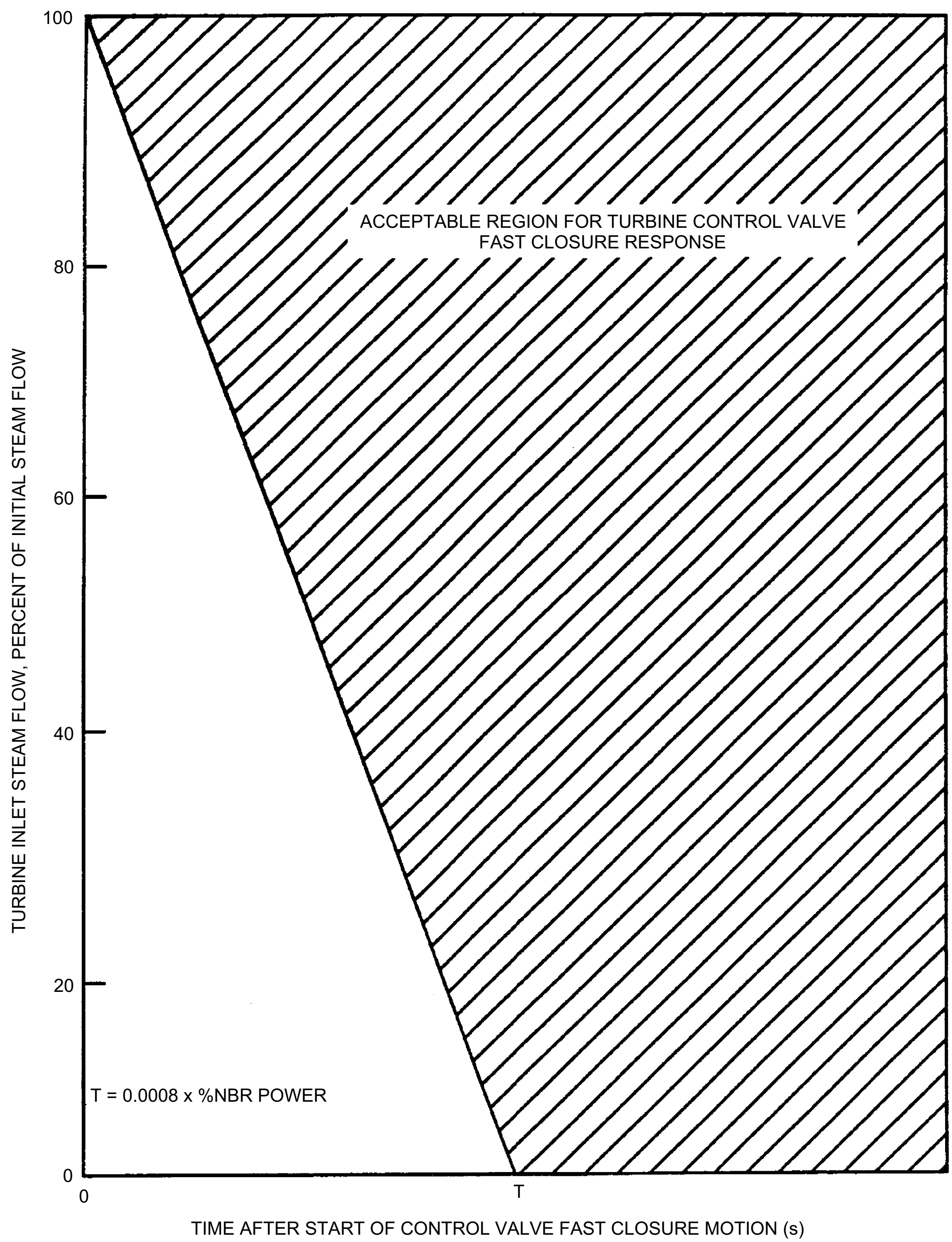

Figure 10.2-2 Turbine Control Valve Fast Closure Characteristic

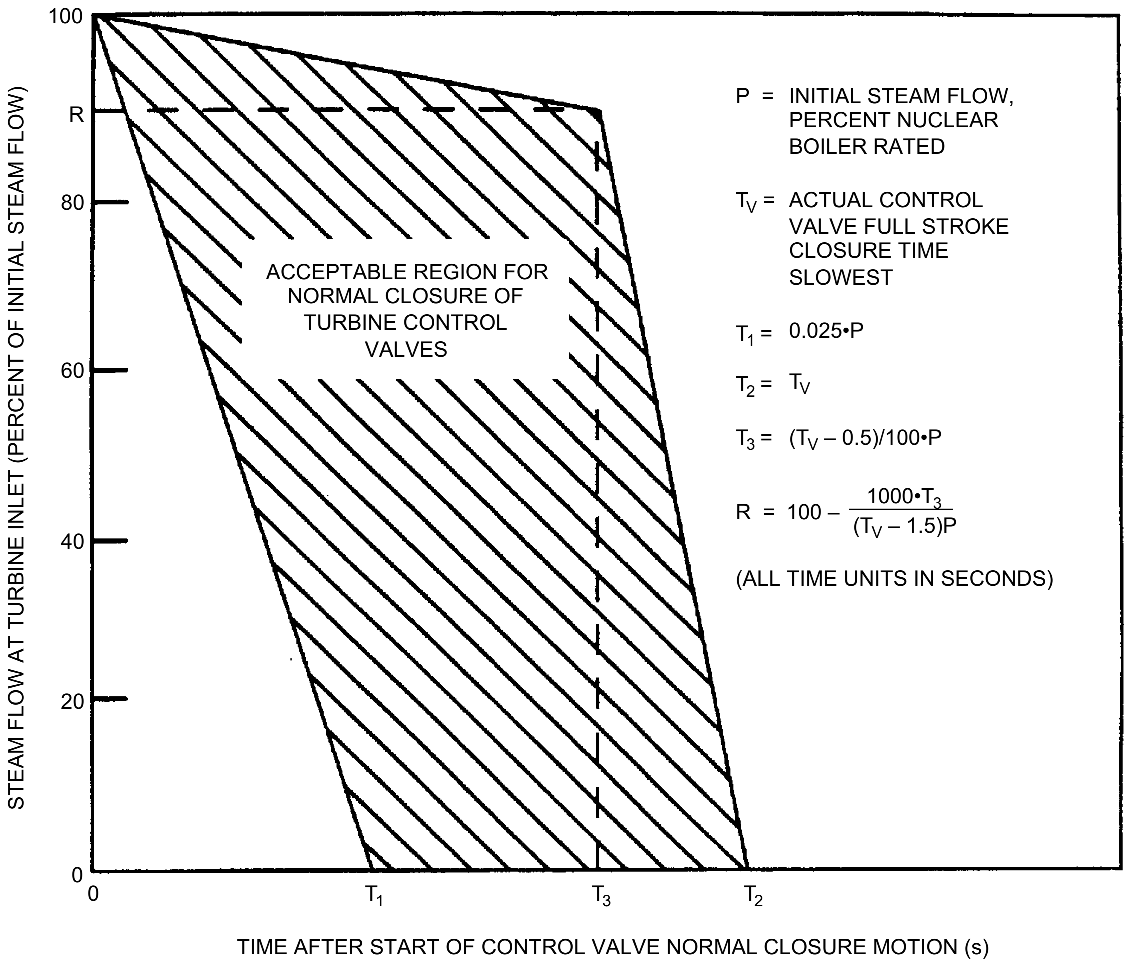

Figure 10.2-3 Acceptable Range for Control Valve Normal Closure Motion

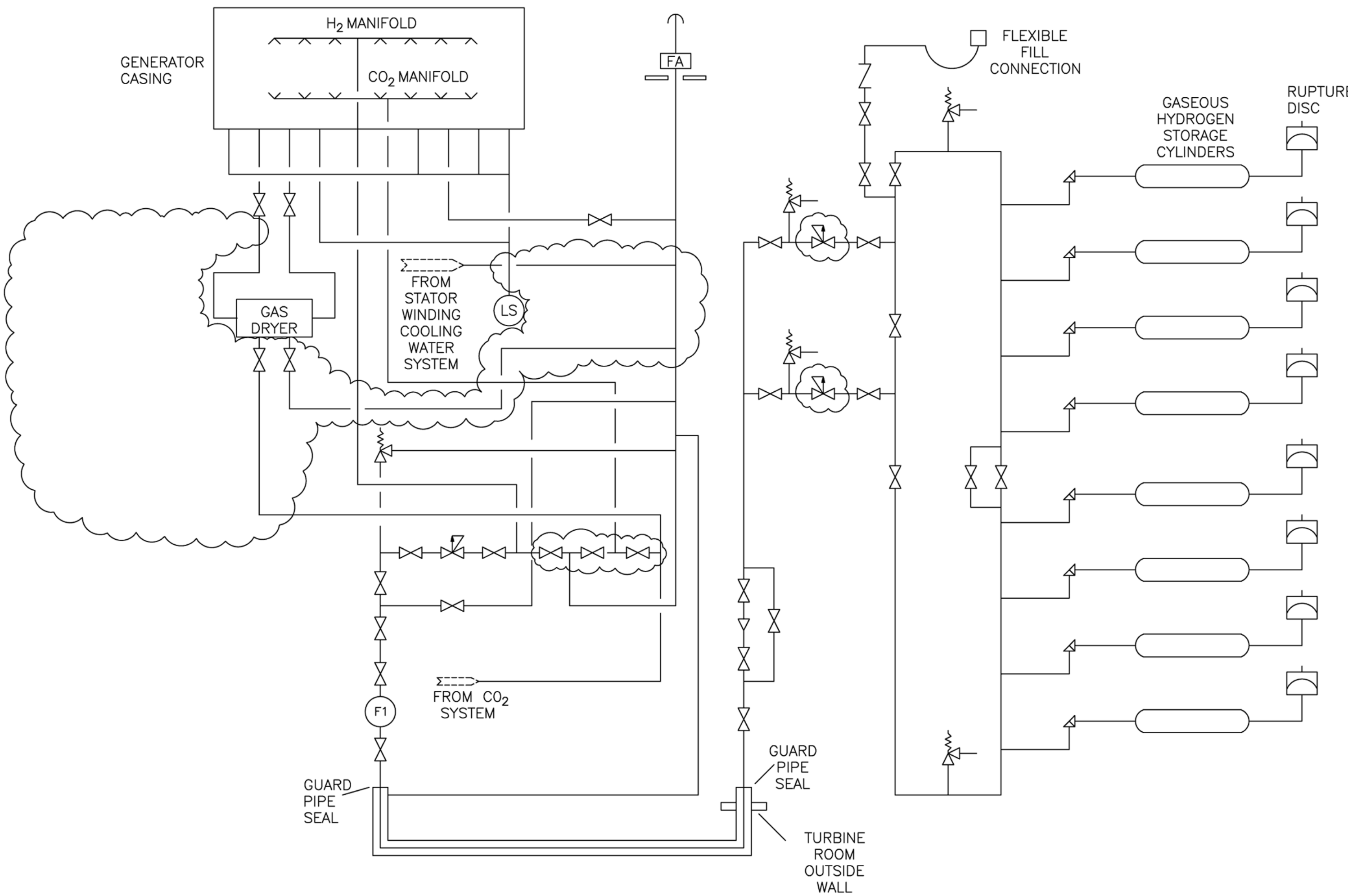

Figure 10.2-4 Generator Hydrogen and CO_2 System

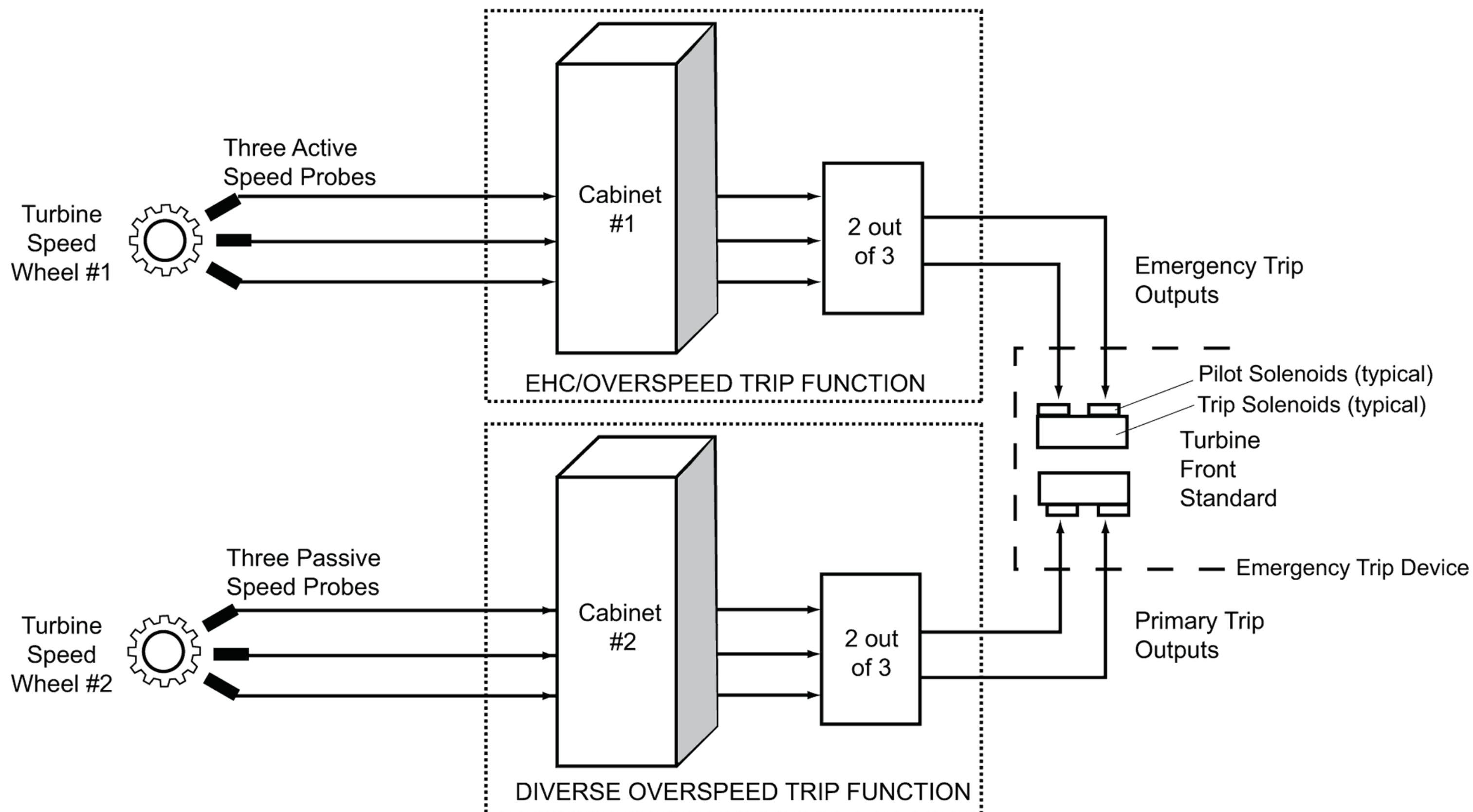

Figure 10.2-5 Turbine Overspeed Trip System Functional Diagram