Westinghouse Technology Systems Manual

Section 19.0

Plant Operations

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19.0 PLANT OPERATIONS

Learning Objectives:

1. Given a list of plant evolutions similar to the following, arrange them in the order that they are performed during plant startup, shutdown, or power operations.

    a. Reactor coolant system (RCS) filling and venting;
    b. Establishing a pressurizer steam bubble;
    c. Starting reactor coolant pumps;
    d. Placing all engineered safety features (ESF) systems in an operable condition;
    e. Establishing the no-load T_{avg};
    f. Taking the reactor critical;
    g. Placing main feedwater in service;
    h. Synchronizing and loading the turbine-generator;
    i. Placing the rod control system in automatic, placing the steam generator level control system in automatic, and shifting the steam dump control system to the T_{avg} mode; and
    j. Escalating the turbine-generator load to the desired value.

19.1 Introduction

The purposes of this chapter are as follows:

1. To review control, instrumentation, and plant systems, and

2. To describe plant operations and system alignments during plant shutdowns, plant startups, and power operations.

Basic procedures for starting up, and operating at power, a pressurized water reactor plant are described in this chapter. This discussion is general in nature and is designed to review the systems discussed in the previous chapters of this manual and describe how they function during plant operations. An abbreviated plant startup procedure is provided in Appendix 19-1 and is used in conjunction with the material contained in this chapter.

19.2 Plant Heatup

19.2.1 Initial Conditions

For the purposes of this discussion, it is assumed that the reactor coolant system has been filled and vented, the reactor coolant pumps (RCPs) are secured, and the plant is aligned in a solid-water condition as shown in Figure 19-1. Solid plant operation is one method of pressure control during a shutdown.

With this pressure control scheme, the pressurizer and the RCS are completely filled with water. The pressurizer power-operated relief valves (PORVs), their associated block valves, and the pressurizer spray valves are shut. The pressure in the RCS is controlled between 320 and 400 psig by maintaining a flow balance between the coolant removed from the RCS and the coolant being returned. Coolant removal is accomplished by letdown, primarily from the residual heat removal system (RHR), and to a lesser extent from the chemical and volume control system (CVCS) letdown line. Coolant is returned to the primary system via the CVCS by one of the centrifugal charging pumps.

If the charging and the letdown flows are equal, RCS pressure remains constant. Any imbalance between charging and letdown causes the pressure in the RCS to increase or decrease. As an example, increasing charging flow and maintaining the letdown flow constant increase the mass of coolant in the RCS. Since water is virtually incompressible, a mass increase causes a pressure increase.

While the plant is in this configuration, HCV-128 (the letdown isolation valve from the RHR system) is fully open. The control room operator manipulates CVCS backpressure regulating valve PCV-131 in either automatic or manual to vary the rate of letdown from the RCS. Additional letdown flow from the CVCS is available through letdown orifices 8149A, B, and C. Since the pressure in the RCS is low at this time, letdown flow via this piping is extremely low.

RCS overpressure protection is provided by the CVCS letdown line relief valve located between the letdown orifice isolation valves and the containment letdown isolation valve (CV 8152), by the RHR pump suction and discharge relief valves, and by the pressurizer PORVs.

The pressurizer PORV low temperature overpressure mitigation switches must be in the UNBLOCK position for the PORVs to actuate at low pressures. The PORVs, if actuated, provide cold overpressure protection by discharging water from the pressurizer to the pressurizer relief tank (PRT). They open, if the pressure in the RCS exceeds the cold overpressure protection setpoint.

The nuclear steam supply system (NSSS) is in MODE 5, cold shutdown: T_{avg} < 200°F, K_{eff} < 0.99, and N/A for the core power level. In addition, the following conditions exist: the RCS pressure is being maintained between 320 and 400 psig, the boron concentration is sufficient to yield a shutdown margin of at least 1% ΔK/K, the pressurizer is solid, and reactor coolant pumps are secured.

Decay heat is removed from the core by the residual heat removal system with letdown established for RCS cleanup. The steam generators are in “wet layup” (filled to the 100% level with water), and all secondary systems are secured with the exception of one circulating water pump. The main turbine and both feedwater pump turbines are on their respective turning gears. All pre-startup checklists have been completed.

19.2.2 Operations

As required by the plant's Technical Specifications, the reactor coolant must be at its no-load operating temperature prior to criticality. The reactor coolant is heated by decay heat from the reactor core and reactor coolant pump heat.
With the plant in cold shutdown, the pressure in the RCS must be at least 320 psig to support running the reactor coolant pumps. A pressure of 320 psig provides two functions: first, it ensures a net positive suction head for the RCPs and second, it ensures that the minimum differential pressure required for lifting the number one pump seals is met. In addition, the pressure in the RCS must be maintained below 450 psig while the residual heat removal system is aligned to the reactor coolant system. This ensures that the low pressure piping of the RHR system is not over pressurized and prevents the lifting of the RHR pump discharge relief valves. Finally, seal injection flow from the chemical and volume control system is required to cool and lubricate the lower radial bearings and the seal packages of the RCPs.

Prior to starting the reactor coolant pumps, a steam bubble is established in the pressurizer. This ensures that a surge volume is available in the pressurizer for water expansion caused by the heatup of the coolant.

Steam bubble formation in the pressurizer is accomplished by heating the water volume of the pressurizer with the pressurizer heaters. Concurrently, charging and letdown flows are adjusted to maintain the pressure within the RCS between 320 and 400 psig.

When the temperature in the pressurizer reaches 428°F to 448°F (saturation temperature for an RCS pressure between 320 psig and 400 psig), charging flow is reduced to form the steam bubble. As the steam bubble forms, RCS letdown is increased, and the charging flow is maintained constant. The difference between these flow rates causes the level in the pressurizer to decrease, and operators lower the level to 25 percent. With a steam bubble established in the pressurizer, RCS pressure is controlled is by pressurizer heater and spray valve operation.

Nitrogen Bubble Pressure Control

RCS pressure control through use of a nitrogen cover gas can be used as an alternate method of controlling pressure. This control scheme may be used when the shutdown requires access to the RCS. In this mode of pressure control, as shown in Figure 19-2, the pressurizer is filled to 90 percent, as indicated by the cold-calibrated level instrument, and vented to the PRT via open PORVs.

A Tygon hose is temporarily installed between the pressurizer vent line (upstream of the PORVs) and the vent on the PRT to supply nitrogen to the pressurizer. The nitrogen pressure regulator for the PRT is adjusted so that six psig of nitrogen overpressure is applied to the PRT. This form of pressure control provides a stable RCS pressure without constant operator action, while still allowing some expansion and contraction of the coolant.

During nitrogen bubble pressure control, RHR flow is maintained for decay heat removal, and letdown and charging are maintained for purification of the reactor coolant. Nitrogen is used as a cover gas to minimize corrosion and to prevent explosive mixtures of hydrogen and oxygen within the RCS piping or components.

RCS overpressure protection is provided by the letdown line relief valve (if aligned), the RHR pump suction and discharge relief valves, and the rupture discs installed on the PRT. Since the RCS and the pressurizer are not completely filled with coolant, the chances of an overpressure event are unlikely. The transformation of the pressurizer void from nitrogen to steam is accomplished at the start of the plant heatup.

Prior to drawing a steam bubble, charging and letdown must be in service. Letdown is via the RHR-to-CVCS cross-connect valve HCV-128. A letdown flow of 75 gallons per minute is established through coordinated operation of HCV-128 (fully open) PCV-131 (throttled). When pressurizer level is < 80 percent, a charging pump is started to maintain pressurizer level constant during bubble formation.

All groups of pressurizer heaters are energized to raise the pressurizer water temperature to saturation. Steam formation begins when the pressurizer water temperature is at saturation, approximately 230°F at 6 psig. With the pressurizer at saturated conditions, further heating causes the temperature and pressure in the pressurizer to increase. As pressure increases, steam and nitrogen are displaced to the PRT.

Indications of steam formation are provided by the pressurizer vapor space and pressurizer PORV tailpipe temperature instruments. Initially, these instruments indicate the containment ambient temperature. With steam formation, their indications approach the saturation temperature of 230°F. Positive indication of a steam bubble is determined by the use of the auxiliary spray valve from the CVCS. If a steam bubble exists, closing the PORVs and initiating auxiliary spray flow into the pressurizer cause a rapid pressure decrease in the pressurizer. When this phenomenon is observed, the PORVs are placed in automatic, and the connection between the PRT and the pressurizer is isolated, and the Tygon tubing is removed. As pressure increases toward 320 psig, letdown flow is increased to accommodate the expansion of the reactor coolant and to lower the level in the pressurizer.

Once a bubble is drawn in the pressurizer and the pressure in the RCS has reached 320 psig, the reactor coolant pumps are started. The RCPs are started one at a time until all four pumps are running. After all reactor coolant pumps are operating, the residual heat removal pumps are stopped, since they are no longer needed to remove decay heat or to provide forced flow through the core as required by the plant’s Technical Specifications.

With all four RCPs operating and the RHR system secured, the reactor coolant begins to heat up at a rate of approximately 50°F per hour. The residual heat removal system alignment is maintained in its initial configuration to provide an adequate letdown capacity for the removal of the excess coolant volume produced by expansion due to heatup. As a result of the heatup and the draining of the pressurizer, approximately one-third of the reactor coolant system volume (30,000 gallons) is diverted to the holdup tanks through the chemical and volume control system.

Prior to exceeding 200°F (entering MODE 4), all surveillance requirements for entering this MODE must be satisfactorily completed (see Checklist No.1). The plant's Technical Specifications define MODE 4, hot shutdown, as: 350°F > T_{avg} < 200°F, K_{eff} < 0.99, and N/A for the core power level.

As the reactor coolant temperature approaches 200°F, steam generator draining is commenced through the normal blowdown system. If the oxygen concentration in the reactor coolant is high, hydrazine is added through the chemical and volume control system for oxygen scavenging (the oxygen concentration must be within specification before the coolant temperature exceeds 250°F).

When the oxygen concentration is within specification, a hydrogen overpressure is applied to the volume control tank. This is accomplished by first securing the nitrogen regulator, opening the vent from the volume control tank to the waste gas header, and raising the volume control tank level to force the nitrogen to the waste gas system. After the volume control tank level has risen to approximately 95%, the hydrogen regulator is placed in service, and the last of the nitrogen is purged to the waste gas system. The volume control tank level is allowed to return to normal with the hydrogen regulator maintaining an overpressure of approximately 15 to 20 psig.

An inspection of containment is conducted for debris that could cause blockage of the containment sumps or produce fire hazards as the systems and their components heat up. Finally, before the plant enters MODE 4, the containment spray system is aligned for operation. At approximately 220°F RCS temperature, steam formation begins in the steam generators. The nitrogen supply to the steam generators, having been applied to prevent or minimize corrosion inside the steam generators, is now isolated.

Secondary Plant Heatup

Warming of the steam lines and the main turbine is performed simultaneously with the RCS heatup; however, before steam can be supplied to the main turbine, the turbine lubricating oil and cooling water systems must be placed in service. Motor-driven lubricating oil pumps provide the necessary lubrication for rolling the main turbine. To ensure the even heating of the turbine rotor, the turbine must be on the turning gear prior to warming.

The condensate and circulating water systems are started at this time. The condensate and feedwater systems are aligned to provide cleanup of the secondary water by circulating condensate through one condensate polishing demineralizer. The condensate flows through the in-service polisher and the low pressure heaters to the main feedwater pump suctions. The feedwater pumps are aligned for operation, and the feed pump turbines are rotating on their respective turning gears. Condensate flows through the idle feedwater pumps and the high pressure heaters and then back to the condenser through the feedwater pump recirculation valve.

Warming of the steam lines is initiated by opening the main steam isolation valves (MSIVs). thereby admitting steam to the individual steam lines up to the main turbine stop valves. The steam lines are thus heated as the coolant is heated. Condensate that forms in the steam lines is drained to the condenser via steam line drain traps and drain trap bypasses. Simultaneous warming of the steam lines and the main turbine is accomplished by clearing all turbine generator trip signals and initiating turbine shell warming. The turbine electrohydraulic control (EHC), gland sealing steam, and condenser air removal systems must be placed in service to provide steam valve control and a condenser vacuum. Steam blanketing of the moisture separator reheaters (MSRs) is also initiated to warm and deaerate the MSR first- and second-stage reheater tube bundles. MSR blanketing steam is supplied by the auxiliary steam system.

Before the reactor coolant temperature reaches 350°F, the operators must satisfactorily complete the surveillance requirements for entering MODE 3, hot standby (see Checklist No. 1). MODE 3 is defined by the plant's Technical Specifications as: T_{avg} > 350°F, K_{eff} < 0.99, and N/A for the core power level.

The residual heat removal system is now isolated from the reactor coolant system and aligned for at power operation (emergency core cooling system lineup). At this time, all reactor coolant letdown is through the normal letdown orifices of the chemical and volume control system. After the residual heat removal system is isolated from the reactor coolant system, pressure is allowed to increase as the temperature in the pressurizer increases.

RCS Heatup and Pressurization

As the plant heatup continues, the pressurizer level continues to increase due to coolant expansion. Once placed in automatic, the pressurizer level control system automatically compensates by reducing the charging flow. During this evolution, the seal injection flow control valve, HCV-182, may require adjustment by the control room operator to maintain the proper reactor coolant pump seal injection flows as the charging flow varies.

As reactor coolant pressure increases, letdown flow also increases. The letdown backpressure regulating valve (PCV-131) is adjusted until the normal letdown pressure (350 psig) is achieved, and the orifice isolation valves are closed as necessary to maintain letdown flow below the allowed maximum of 120 gpm. When reactor coolant system pressure reaches 1925 psig, the cold leg accumulator isolation valves are opened, and all emergency core cooling system equipment is checked for proper alignment.

Pressure and temperature relationships must be constantly observed during a combined plant heatup to prevent an inadvertent reactor trip or safety injection actuation signal. Although the reactor is shut down, a reactor trip signal would cause the shutdown rods, possibly already withdrawn, to trip into the core. A safety injection actuation signal would cause the insertion of the shutdown rods and the activation of the design bases accident (DBA) sequencers. A safety injection actuation can occur with sloppy RCS pressure control. Once the pressurizer pressure is raised above 1915 psig (P-11 setpoint), the block signal of the low pressurizer pressure safety injection actuation is automatically removed. After that, any evolution that would cause RCS pressure to decrease below 1807 psig initiates a low pressure safety injection actuation.

A safety injection actuation and main steam isolation can occur if the high steam line flow setpoint is exceeded with steam pressures below 600 psig or the RCS T_{avg} below 553°F. High steam flow could result from an increase in steam flow through the steam dump valves or from an increase in the turbine warming rate. Also, overfeeding a single steam generator with cold feedwater can cause its pressure to decrease, thereby initiating a high steam line ΔP safety injection actuation.

The primary plant heatup is terminated by automatic actuation of the steam dumps (in steam pressure control) when the pressure inside the steam header pressure reaches 1092 psig. The RCS temperature remains constant at 557°F, the steam dumps removing any excess energy that would tend to drive the RCS temperature higher.

Turbine warming is secured after a specified warming time has been completed. Upon completion of heatup and pressurization, the reactor coolant is at the normal no-load temperature and pressure values, and the plant is ready for a reactor startup. The turbine and steam lines are warmed, with preparations completed for secondary startup. The pressurizer heaters and sprays are placed in automatic control when the pressure reaches the normal operating value of 2235 psig.

A reactor coolant leak rate test is performed when the reactor coolant temperature is greater than 400°F and the pressure is equal to 2235 psig. This test is required at this time only if the reactor coolant system has been opened for refueling or maintenance.

Prior to reactor startup, the plant conditions are as follows:

- The RCS is at normal operating temperature and pressure (557°F, and 2235 psig),
- The reactor is shut down (subcritical),
- A condenser vacuum has been drawn,
- The steam dump control system is operating in the steam pressure mode,
- The main turbine and feedwater pump turbines are rotating on their turning gears, and
- All electrical power is supplied from off-site.

19.3 Reactor Startup to Minimum Load

A reactor startup is performed at the no-load temperature of 557°F. The Technical Specifications require a minimum temperature, 551°F, for criticality. If the coolant average temperature drops below this value, the operator either restores the temperature within a short period of time or makes the reactor subcritical.

Prior to the withdrawal of the control rods to cause core criticality, an estimated critical condition (ECC) is calculated. The ECC calculation is a reactivity balance comparing the previous critical condition and reactivity changes following the last shutdown to the desired conditions for the next startup. Since the previous and present reactivity conditions are known, it is relatively easy to calculate the required conditions for the next criticality. The reactivity variables for which the operator has direct control are boron concentration and control rod position. The ECC is normally computed using a desired critical rod position. The boron concentration is then adjusted so that the reactor will be critical at the desired rod position.

Prior to entering MODE 2, startup, and MODE 1, power operation, all surveillance requirements for entering these modes must be satisfactorily completed (see Checklist No. 2). MODE 2 is defined by the plant's Technical Specifications as: $K_{eff} \geq .99$ and core power level ≤ 5%. MODE 1 is defined as: $K_{eff} \geq 0.99$ and core power level > 5%.

Control rods are withdrawn to establish criticality. It is difficult to identify exactly when criticality is achieved during a startup; however, it is readily apparent when supercritical conditions are reached. Supercriticality is indicated by a constant positive startup rate and steadily increasing source range count rate with no control rod withdrawal. Criticality is declared when these conditions are observed. After criticality is achieved, the control rods are positioned to increase nuclear power to 10^{-8} amps in the intermediate range. When power exceeds the source range block permissive (P-6) setpoint, the source range trip is manually blocked and the source range high voltage supply is de-energized. Power is stabilized at 10^{-8} amps to record actual critical conditions. The data recorded consists of the control rod positions, boron concentration, and RCS loop average temperatures.

After recording the critical data, the control rods are positioned to increase power to the point of adding heat, approximately one percent power as indicated on the power range instruments, and then to stabilize power at about two percent. As nuclear power increases above the point of adding heat, the fuel and moderator temperatures increase. These temperature increases add negative reactivity because of the negative fuel and moderator temperature coefficients.

As the moderator temperature increases, the coolant expands into the pressurizer, causing the level and pressure to increase. Also, the steam generator temperatures and pressures begin to increase. Since the steam dumps are in the steam pressure mode of control, the steam dump valves modulate open, maintaining the steam header pressure at 1092 psig. 1092 psig is the saturation pressure for 557°F, which is the no-load T_{avg}. With the steam dumps in steam pressure mode, the RCS T_{avg} does not follow the programmed T_{avg}; it increases to produce the primary-to-secondary ΔT needed to support a steam flow of about two percent of the full-load value.

As the steam dumps modulate open, increasing the steam flow to the main condenser, feedwater flows to the steam generators must be increased. Since the motor-driven (nonsafety-grade) auxiliary feedwater pump can supply only about two percent of rated feed flow, care is exercised to ensure that the power level does not exceed two percent.

With the power level at some point between 1 x 10^{-8} amps and two percent, the anticipated reactivity changes for power escalation, caused by the increase in power defect and by the change in xenon concentration, are determined, and the required boron concentration change is started. The rate of power increase could be limited by improper control rod position if the power defect and xenon concentration change are not predicted correctly.

The power level is maintained at two percent while a main feedwater pump is started and aligned to supply the steam generators through the main feed regulating bypass valves. The main feedwater bypass valves are then manually manipulated to control steam generator levels. The main feed pump speed is controlled in manual to maintain 50 - 150 psid between the feed and steam pressures, enough to ensure adequate feed flow to the steam generators through the bypass valves. With a main feedwater pump feeding the steam generators and the auxiliary feedwater system realigned to its normal at-power standby lineup, turbine startup may proceed.

To minimize primary plant transients, the turbine is rolled with reactor power between 10 and 15 percent. Control rods are withdrawn to raise core power and the RCS temperature. The steam generator temperatures and pressures would tend to increase with the RCS temperature; however, the steam dumps modulate open to maintain a constant steam pressure constant and to create the steam demand which changes the ΔT across the core.

With nuclear power at 15 percent, the main turbine is rolled off the turning gear and accelerated to 1800 rpm. As steam flow to the turbine increases, the steam dumps modulate in the closed direction to maintain the 1092-psig steam header pressure. With the turbine running at 1800 rpm, the turbine auxiliary systems are aligned for normal operation, and the turbine protection system is tested to verify proper operation. Also at this time, the MSR steam control is placed in automatic, thereby removing the auxiliary steam supply from MSR steam blanketing and initiating operation of the normal first- and second-stage MSR steam supplies. Generator synchronization is performed after satisfactory turbine protection system testing.

When the main generator voltage, frequency, and phases are matched with those of the grid, the generator output breakers are closed, and the generator picks up a minimum load of approximately 60 MWe. When the generator output breakers close, the turbine EHC system automatically shifts from speed control to load control, and operators can now increase the generator’s electrical output to the grid.

19.4 Power Operations

The turbine loading rate is determined by the most limiting of the following: the turbine loading limit curve, fuel pre-conditioning requirements, or the load dispatcher’s request. Once the loading rate is determined, the turbine load is increased to 180 MWe, about 15 percent turbine load. Increasing the turbine load to 180 MWe results in a shift of steam flow from the steam dumps to the turbine with little or no change in nuclear power. When the steam dump valves are fully closed, they are placed in the T_{avg} mode of operation.

Rod control is placed in automatic when the turbine load satisfies the C-5 interlock (15 percent turbine load) and T_{avg} is within 1°F of T_{ref}. Since the main feedwater bypass regulating valves are rated for 20 - 25 percent of full-load feedwater flow, the main feedwater regulating valves are placed in service prior to the load increasing above 20 percent. Main feed pump speed control can be placed in automatic when the main feed regulating valves are controlling the steam generator levels.

To prevent axial xenon oscillations and to maintain peaking factors within license limits, the operator must insure that the indicated axial flux difference (AFD) is maintained within the limits illustrated in Figure 19-3. Some nuclear units may operate with AFD maintained within a required target band which is more restrictive than the limits shown in this figure. Even with the liberal limits of Figure 19-3, the plant is likely to operate with AFD administratively maintained within a much more restrictive AFD target band. Such restrictions mandate the following operational conventions:

1. The control rods are nearly fully withdrawn during all phases of power operations (except for short-term transients). The increase in power defect associated with a power escalation, is thus overcome with boron dilution.

2. The dilution of the coolant boron concentration is a slow process. Therefore, power changes at sustained rates of greater than 1% - 2%/minute are not possible if the AFD is to be maintained within the band.

During the power escalation from 20 percent to 100 percent power, additional secondary pumps are placed into service. These include condensate pumps, circulating water pumps, service water pumps, the second feedwater pump, and heater drain tank pumps. Condensate demineralizers are also sequentially placed in service as power increases.

The turbine load is increased by selecting the desired loading rate and pressing the load increase pushbutton to increase the load setpoint to the desired value. The main turbine control valves modulate to positions which should produce the generator electrical output selected with the load-set controller. A turbine first-stage pressure feedback signal may adjust the control valve positioning signal to ensure that the desired load is actually attained.

The single-loop loss of flow permissive (P-8) enables the single-loop loss of flow reactor trip when reactor power exceeds 39%.

At approximately 50% load, a calorimetric calculation (heat balance) is performed on the secondary system, and an adjustment to the power range nuclear instruments is performed if necessary. Further calorimetric calculations are performed at 90% and 100% power. These additional calculations are performed to ensure that the power range nuclear instruments are properly calibrated.

At all times when the reactor is critical, the control banks must be maintained above their respective insertion limits. All shutdown banks and control banks A and B must be fully withdrawn, while control banks C and D must be withdrawn to positions that are greater than the limits specified in Figure 19-4. Maintaining the rod banks above their respective insertion limits ensures that sufficient negative reactivity is available to achieve and maintain the required shutdown margin in the event of a reactor trip.

19.5 Plant Shutdown

A plant shutdown is accomplished by essentially reversing the steps described for completing a plant startup.

APPENDIX 19-1
Plant Startup from Cold Shutdown

I. INITIAL CONDITIONS

1. Cold Shutdown - MODE 5:

   - $K_{eff} < 0.99$
   - 0% power
   - $T_{avg} < 200°F$

2. Reactor Coolant System: solid.
3. RCS Temperature: 150 - 160°F.

> **Note:**
> *Temperature may be less than 150°F depending upon the decay heat load of the core.*

4. RCS Pressure: 320 - 400 psig.
5. Steam Generators: filled to wet layup (100% wide-range level indication).
6. Secondary Systems: shutdown, main turbine and feedwater pump turbines on their turning gears.
7. Pre-Startup Checklists: completed.

II. INSTRUCTIONS

A. Heatup from COLD SHUTDOWN to HOT SHUTDOWN (MODE 5 to MODE 4)

1. Permission received from Operations Supervisor for startup.
2. Begin establishing steam generator water levels to 33 ± 5% narrow-range indication.
3. Verify or establish RCP seal injection flow.

> **CAUTION:**
> *Do not exceed a heatup rate of 100°F/hr in the pressurizer or 100°F/hr in the RCS. Do not exceed 320°F ΔT between pressurizer and spray temperature. Use auxiliary spray for pressurizer volume and coolant mixing.*

4. Energize pressurizer heaters and begin pressurizer heatup.
5. Establish a pressurizer steam bubble by;

   a. Increasing pressurizer temperature using pressurizer heaters.
   b. Adjust charging and letdown flow to maintain pressurizer pressure at approximately 320-400 psig while reducing pressurizer level.
   c. As pressurizer temperature approaches 428°F (saturation temperature for 320 psig), reduce pressurizer level toward 25%.

6. Start the reactor coolant pumps. After running the pumps for five minutes, sample the RCS for chemistry specifications. Partially open pressurizer spray valves for coolant mixing.
7. Maintain the RCS temperature < 160°F by adjusting flow through the RHR heat exchangers.

NOTE:
The 160°F limit is based on cold water addition accident. This limits the ΔT between seal injection water accumulating in the intermediate leg and the remainder of the RCS.

8. Stop RHR pumps.
9. Allow RCS temperature to increase to 200°F.
10. When RCS temperature reaches 200°F, ascertain that primary system water chemistry is within specifications.
11. When pressurizer level is at the no-load operating level (25%), place the pressurizer level control system in automatic.
12. Verify shutdown rods are withdrawn and that sufficient SHUTDOWN MARGIN is available.
13. Ensure applicable pre-startup Technical Specification requirements are met. (See Checklist No. 1.)
14. At 200°F RCS temperature, establish a hydrogen blanket in the volume control tank.
15. Open main steam isolation valves and warm main steam lines.
16. Continue pressurizer heatup to maintain desired pressure. Use low pressure letdown control valve to maintain letdown flow. Once a steam bubble is established in the pressurizer, RCS pressure will be controlled by heater and spray operation.
17. Condensate cleanup is in progress.
18. When condensate chemistry is within specifications, align the condensate and feedwater systems to the normal at-power configuration.
19. Verify condenser vacuum.
20. Warm the main turbine.

CAUTION:
Prior to reaching 350°F in the RCS, perform or verify the following:

- *Verify the control rod drive mechanism cooling fans are operating.*
- *Terminate residual heat removal letdown to the CVCS.*

B. Heatup from HOT SHUTDOWN to HOT STANDBY (MODE 4 to MODE 3)

1. Ensure applicable pre-startup Technical Specification requirements are met. (See Checklist No. 1.)
2. Complete the ECCS Master Checklist (SI, RHR, etc. are aligned).
3. Maintain RCS pressure within the operating band of the Pressure-Temperature Limitations Curve.

> **NOTE:**
> *As the RCS pressure increases, maintain letdown flow at a maximum of 120 gpm by increasing the setting of the backpressure regulator (PCV-131) until pressure reaches 350 psig and then by closing the letdown orifice isolation valves as necessary.*

4. Prior to the RCS reaching 1000 psig, open each cold leg accumulator isolation valve and then de-energize each valve's motor operator.
5. When RCS pressure exceeds 1915 psig, verify the block of the pressurizer low pressure safety injection actuation automatically resets.
6. When RCS temperature reaches 553°F, verify the block of the high steam line flow safety injection actuation automatically resets.
7. Maintain RCS temperature with the steam dump control system in the steam pressure mode.
8. Establish HOT STANDBY conditions of 557°F T_{avg}.

C. Heatup from HOT STANDBY to POWER OPERATIONS (MODE 3 to MODE 1)

> **NOTE:**
> *See Checklist No. 2.*

1. Obtain administrative permission to take the reactor critical.
2. Notify system dispatcher of unit startup and approximate time when the generator will be tied to the grid.
3. Notify onsite personnel of the reactor startup over the public address system.
4. Perform reactor trip breaker check (if not performed during the previous seven days).
5. Calculate the estimated critical boron concentration for the desired critical control rod withdrawal position.
6. If necessary, conduct a boron concentration change to achieve the estimated critical boron concentration. Equalize the boron concentrations in the reactor coolant loops and the pressurizer by turning on the pressurizer backup heaters.

NOTE:
Nuclear instrumentation shall be monitored very closely in anticipation of an unplanned rate of reactivity change.

NOTE:
Block the alarm for source range high flux level at shutdown at both source range drawers.

7. Verify all shutdown banks are fully withdrawn within 15 minutes of withdrawing control banks.
8. If the shutdown banks are inserted, complete a shutdown margin calculation (involving the shutdown banks at the fully withdrawn position) to preclude an inadvertent MODE change during rod withdrawal. Withdraw the shutdown banks to the fully withdrawn position.
9. Verify proper operation of all reactor coolant pumps.
10. Withdraw the control bank rods in manual to take the reactor critical.
11. If the control bank height at criticality is below the rod insertion limit for 0% power:

    a. Reinsert all control bank rods to the bottom of the core.
    b. Recalculate the estimated critical boron concentration.
    c. Borate to the newly calculated concentration.
    d. Withdraw the control bank rods in manual to take the reactor critical

12. Withdraw rods to increase reactor power. Block the source range high flux trip at P-6 (10^{-10} amps on the intermediate range). Take critical data at $1x10^{-8}$ amps (typically).
13. Withdraw rods to bring reactor power to approximately 2% on the power range indicators and select the highest indicating power range channel to be recorded on the NR-45 recorder.
14. Check that the steam dump pressure controller is set for 1092 psig and operating in automatic.
15. If one is not already running, start a main feedwater pump at 2% power. Maintain steam generator levels at 33 ± 5% narrow-range level indication during secondary plant startup by throttling the feedwater bypass regulating valves.

CAUTION:
The secondary plant operator should coordinate changes in steam generator steaming rates removal and in feedwater addition rates with the reactor operator while rod control is in manual.

16. Verify the turbine has been on the turning gear for at least one hour.
17. Increase reactor power by manual withdrawal of the control banks until the steam dumps are bypassing steam flow equivalent to 10 - 15% nuclear power.

18. When reactor power increases above 10%, verify the "Nuclear At-Power" Permissive P-10 light illuminates and the "At-Power" Permissive P-7 light extinguishes.

NOTE:
The "at-power" reactor trips are now enabled.

19. Manually block the intermediate range high flux reactor trip and the power range high flux, low setpoint reactor trip after P-10 has been reached.
20. Verify that the main and unit auxiliary transformer cooling systems are aligned for automatic operation.
21. Accelerate the main turbine to 1800 rpm, and then synchronize the generator and connect it to the grid.
22. Increase generator load at the desired rate while maintaining T_{avg} with manual rod control.

CAUTION:
Maintain programmed steam generator level during the following step.

23. At approximately 15% power, transfer feedwater flow control from the bypass valves to the main feedwater regulating valves.
24. When turbine power has increased above ~180 MWe (15% - the C-5 interlock setpoint), transfer the rod control system to automatic.
25. After rod control is placed in automatic, check that steam pressure is less than the pressure control setpoint (1092 psig) and that all steam dump valves are closed, then transfer the steam dump control system to the T_{avg} control mode.
26. Transfer steam generator feedwater regulating control valves and feed pump speed control to automatic when power exceeds 15%.
27. Place additional secondary equipment in service as necessary to support further load increases.
28. At 50% power, place the remainder of secondary pumps in service.
29. Perform secondary calorimetric (heat balance) calibrations for nuclear instrumentation adjustment as required

Checklist Number 1

> **NOTE:**
> *This listing is typical of the TECHNICAL SPECIFICATION limiting conditions for operation and TECHNICAL REQUIREMENTS for changing MODES during a plant heatup. This is not a comprehensive list.*

REACTIVITY CONTROL (Section 1):

- Shutdown Margin
- Charging Pumps
- Boration Flow Paths
- Borated Water Sources

INSTRUMENTATION (Section 3):

- Reactor Trip System Instrumentation
- Engineered Safety Features Actuation System Instrumentation

REACTOR COOLANT SYSTEM (Section 4):

- RCS Loops
- Pressurizer Safety Valves
- RCS Leakage, Chemistry, Activity
- Steam Generator Tube Integrity
- Pressurizer
- Pressurizer PORVs
- RCS Pressure/Temperature Limits

EMERGENCY CORE COOLING SYSTEMS (Section 5):

- ECCS Trains
- Accumulators
- Refueling Water Storage Tank

CONTAINMENT SYSTEMS (Section 6):

- Containment Leakage, Structural Integrity
- Internal Pressure
- Containment Spray and Cooling Systems
- Containment Isolation Valves
- Air Locks
- Air Temperature
- Spray Additive System

PLANT SYSTEMS (Section 7):

- Main Steam Safety Valves
- Component Cooling Water System
- Condensate Storage Tank
- Auxiliary Feedwater System
- Service Water System
- Main Steam Isolation Valves

ELECTRICAL POWER SYSTEMS (Section 8):

- AC Sources
- Distribution Systems
- DC Sources

Checklist Number 2

> **NOTE:**
> *This listing is typical of the TECHNICAL SPECIFICATION limiting conditions for operation and TECHNICAL REQUIREMENTS for changing MODES during reactor startup and power operations. This is not a comprehensive list.*

REACTIVITY CONTROL (Section 1):

Moderator Temperature Coefficient
Rod Group Alignment Limits
Shutdown and Control Banks - Rod Insertion Limits
Rod Position Indication

POWER DISTRIBUTION LIMITS (Section 2):

Axial Flux Difference
Heat Flux Hot Channel Factor ($F_Q(Z)$)
Nuclear Enthalpy Rise Hot Channel Factor
Quadrant Power Tilt Ratio

INSTRUMENTATION (Section 3):

Reactor Trip System Instrumentation
Engineered Safety Features Actuation System Instrumentation
Movable Incore Detectors

REACTOR COOLANT SYSTEM (Section 4):

DNB Parameters
Minimum Temperature for Criticality
RCS Loops

CONTAINMENT SYSTEMS (Section 6):

Hydrogen Mixing System

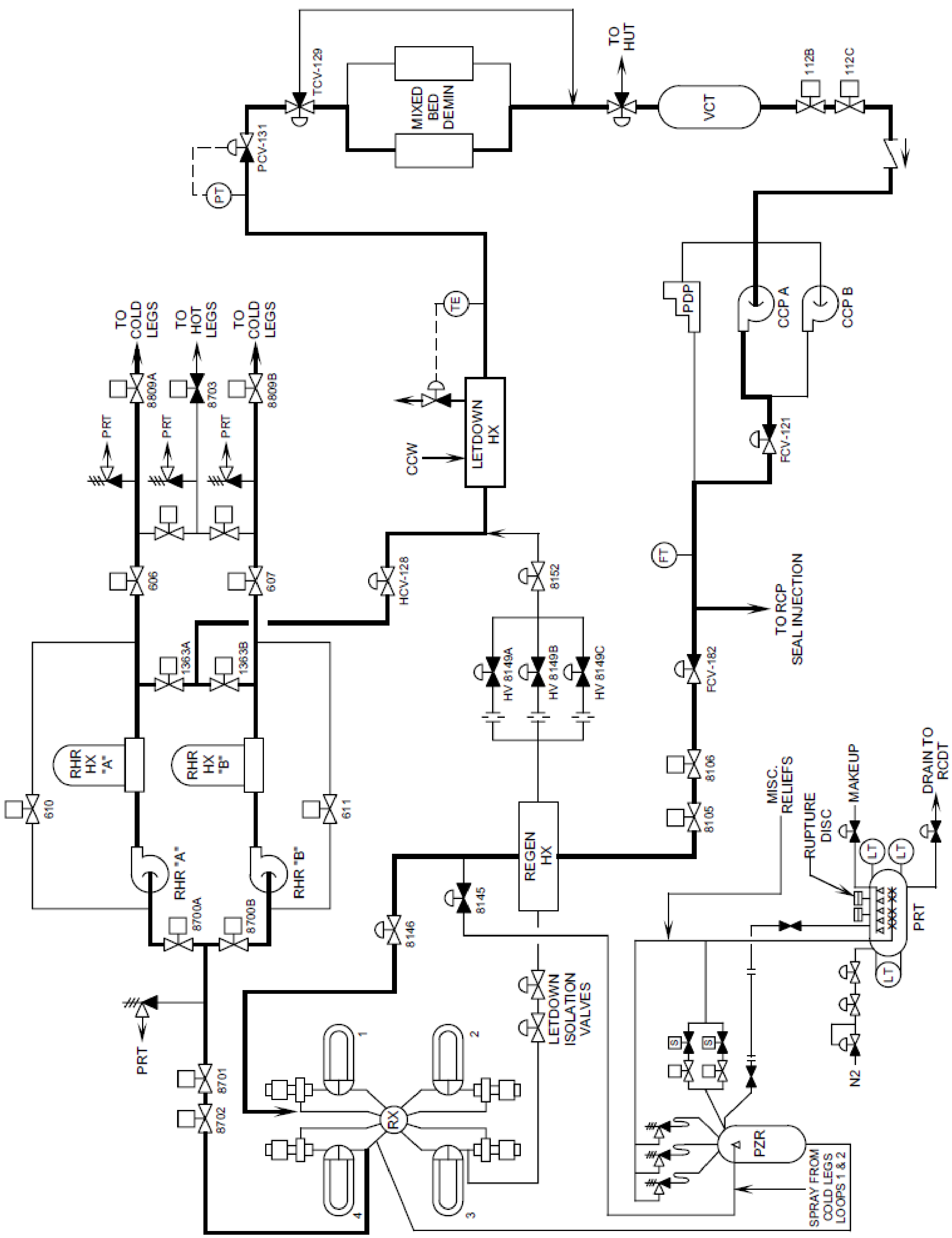

Figure 19-1 Solid Plant Pressure Control

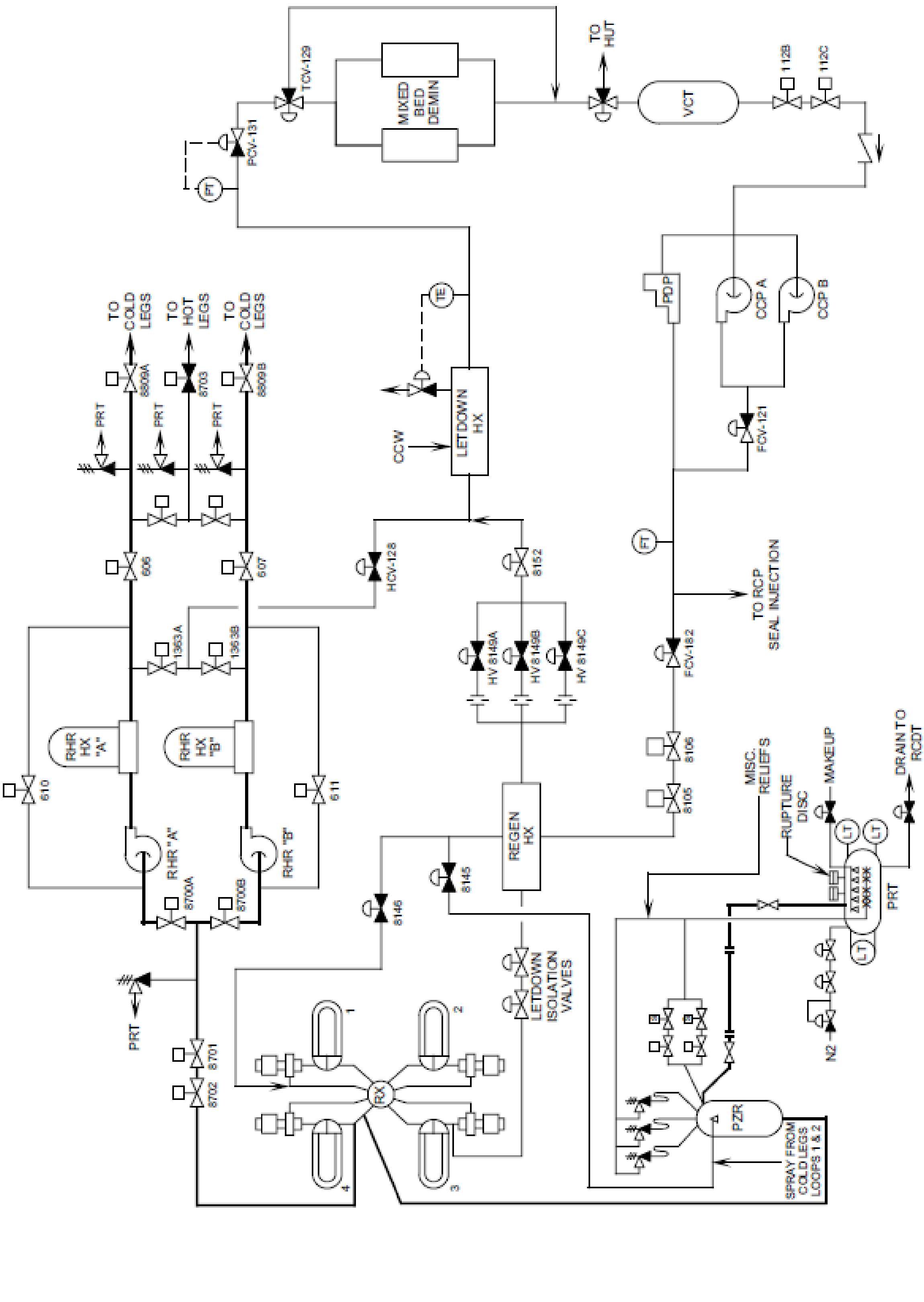

Figure 19-2 Nitrogen Bubble Pressure Control

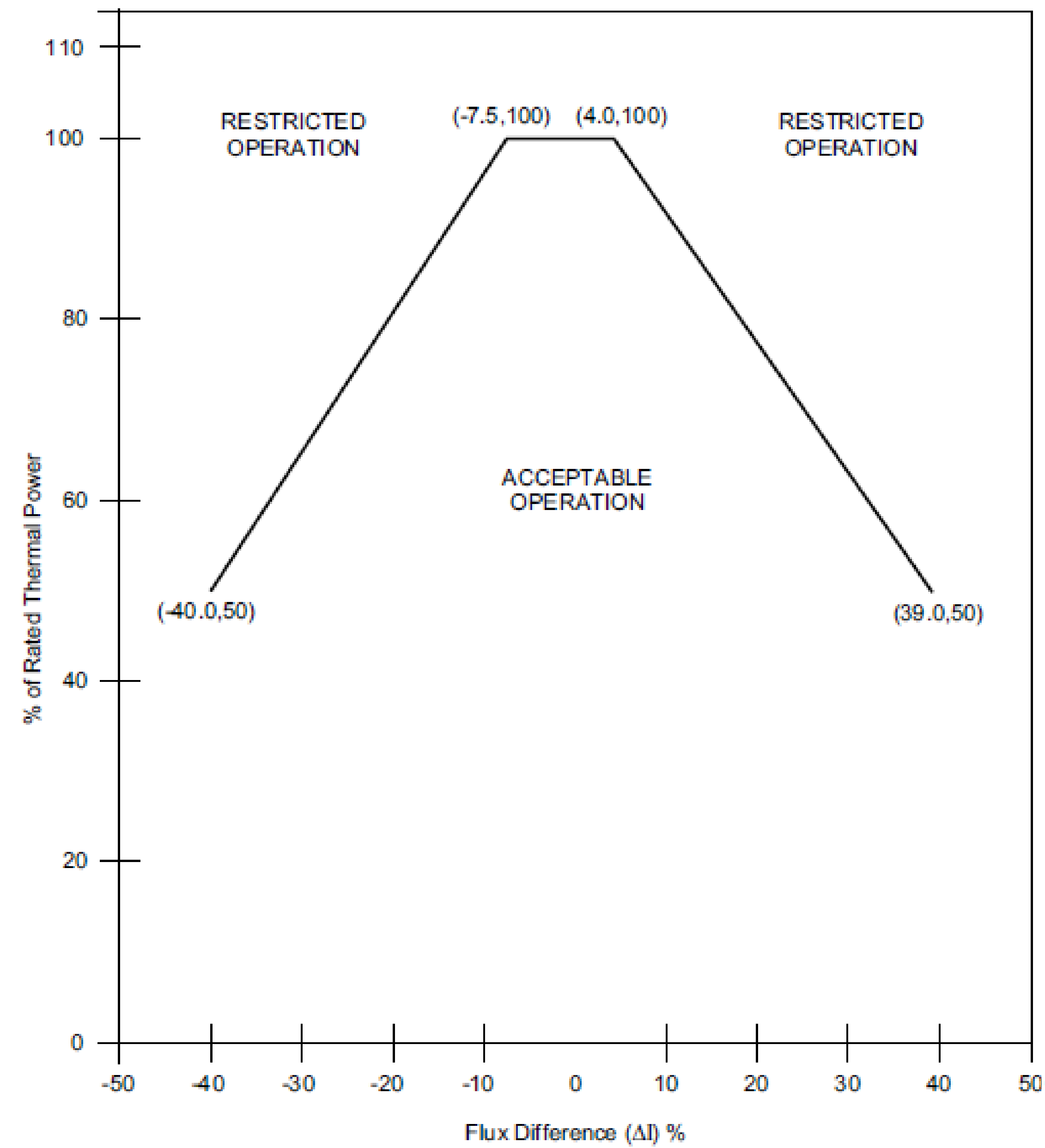

Figure 19-3 Axial Flux Difference Limits

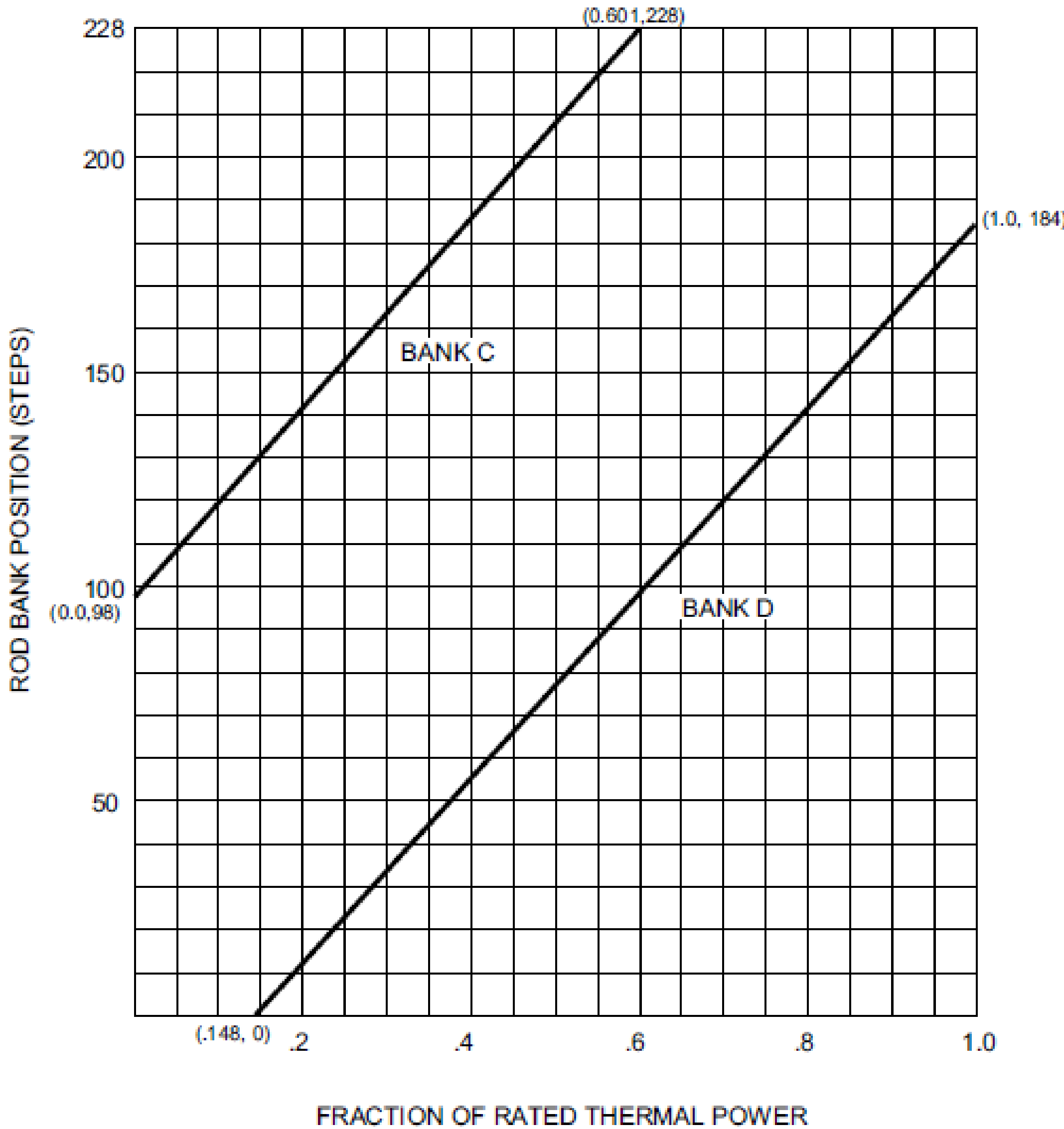

Figure 19-4 Rod Insertion Limits vs. Thermal Power