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10.2 THERMAL MARGIN LOW PRESSURE AND LOCAL POWER DENSITY TRIPS

Learning Objectives:

1. State the purposes of the thermal margin low pressure (TMLP) and local power density (LPD) trips.
2. List the inputs to the TMLP and LPD trips.
3. State the plant conditions used to determine when these trips are in effect.

10.2.1 Introduction

The TMLP trip and the LPD trip function ensure that the specified acceptable fuel design limits of departure from nucleate boiling and linear power density are not exceeded during anticipated operational occurrences. The TMLP and LPD trips also help to ensure cladding integrity during upset conditions such as a complete loss of reactor coolant system (RCS) flow. In addition, a TMLP trip will be generated if asymmetric steam generator conditions exist.

The TMLP trip receives inputs from:

1. RCS hot leg temperature,
2. RCS cold leg temperature,
3. Linear power range safety channel,
4. Pressurizer pressure,
5. Axial shape index (ASI),
6. RCS flow dependent selector switch (FDSS), and
7. Steam generator pressures.

The TMLP calculator combines all of these inputs, with the exception of pressurizer pressure, and calculates an allowable operating pressure (setpoint). If the actual pressure in the reactor coolant system is less than or equal to the allowable operating pressure, a trip signal is generated.

The LPD trip receives inputs from both of the neutron detectors of the linear power safety channel and compares the reactor's actual ASI (internal tilt) with an allowable ASI generated by the LPD trip unit. If actual ASI exceeds allowable ASI, a trip signal is generated.

10.2.2 TMLP Calculator

The purpose of the TMLP trip is to prevent reactor operations with the departure from nucleate boiling ratio less than its design value. In addition this calculator will generate a reactor trip signal if asymmetric steam generator conditions exist.

An asymmetric steam generator is a condition of more heat removal from one steam generator than from the opposite steam generator. This condition is indicated by a differential pressure between steam generators that is in excess of a preselected value.

10.2.2.1 ΔT/ΔT Power Calculations

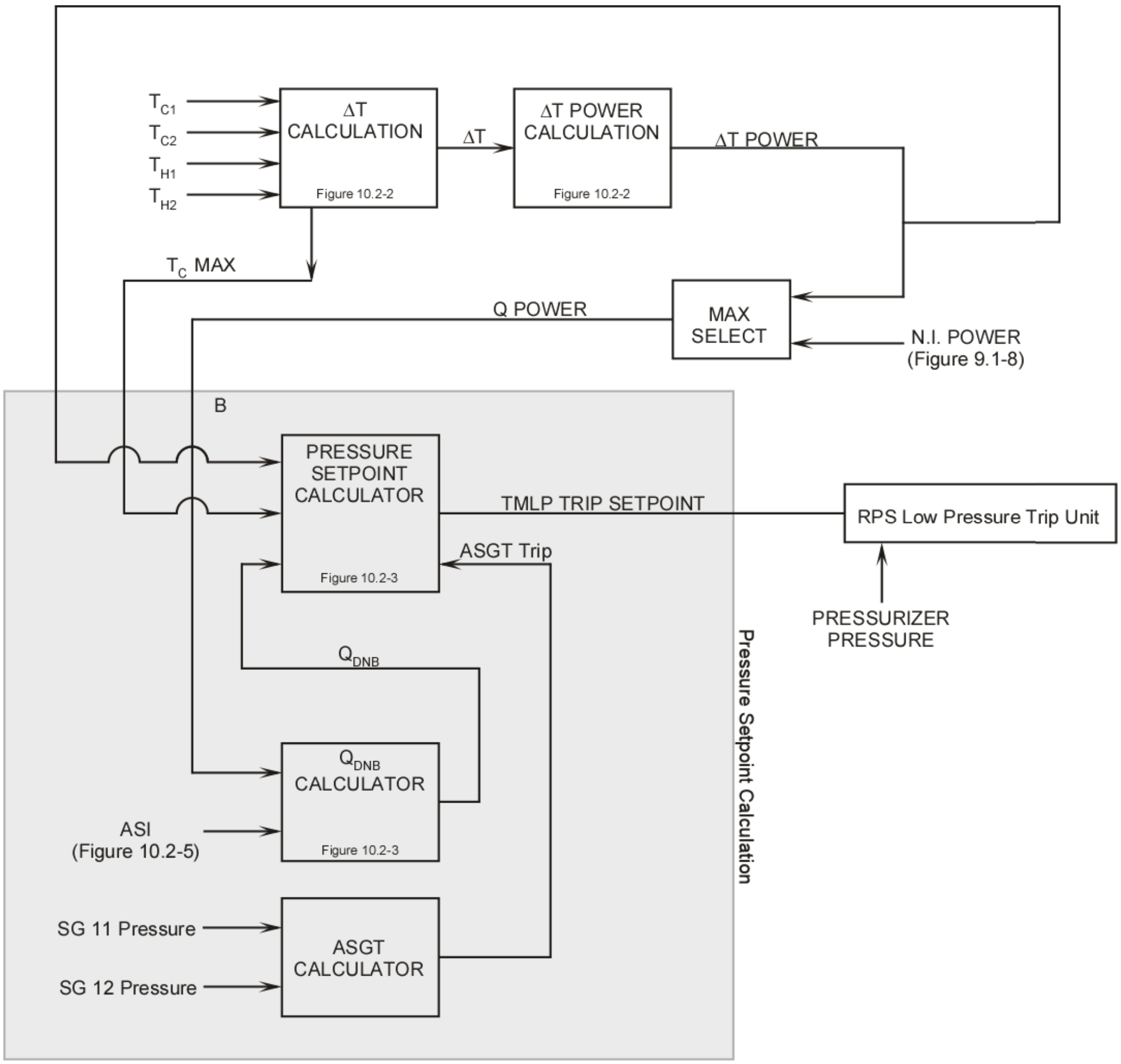
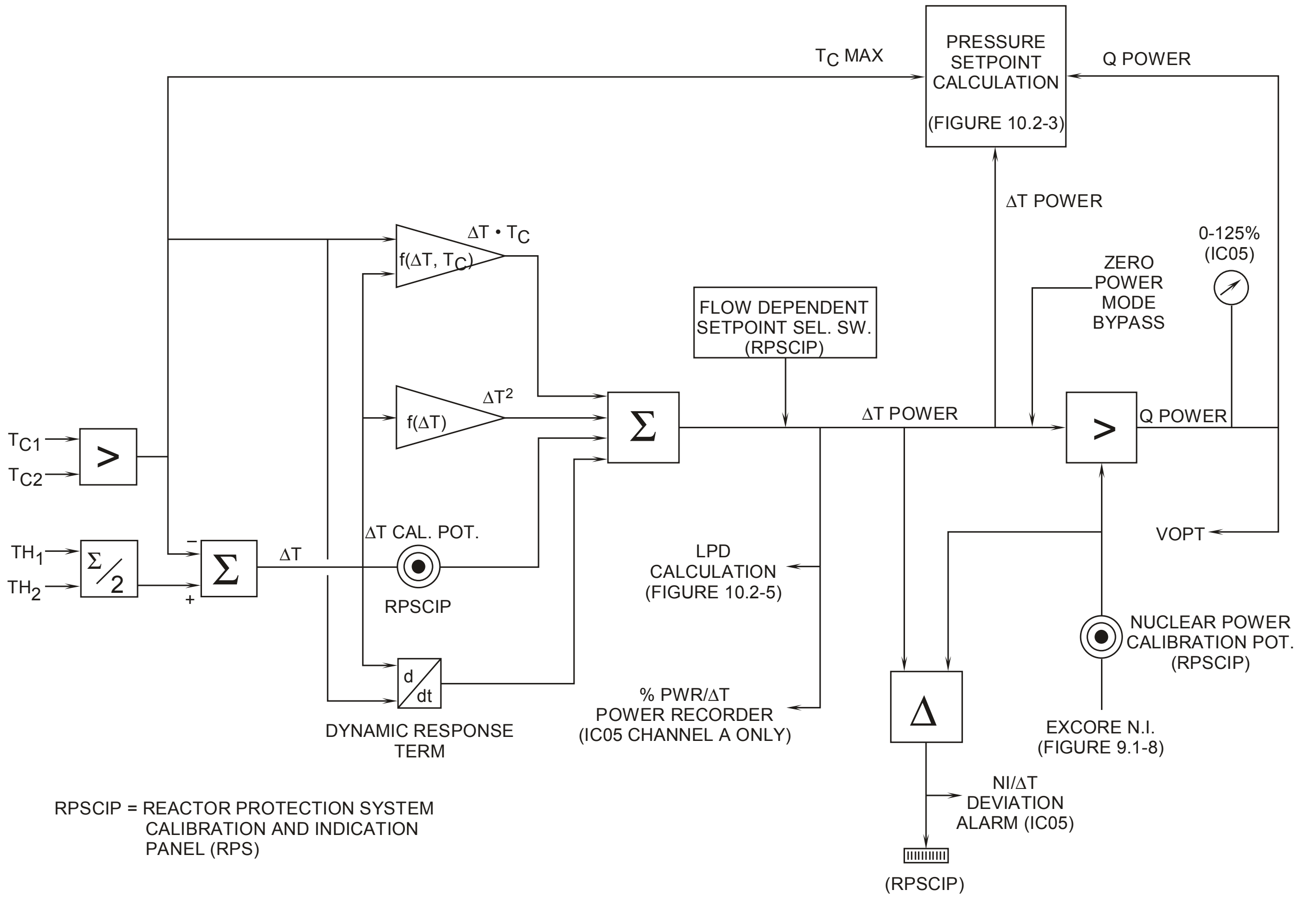


Figure 10.2-1 ΔT/TMLP Calculation Block Diagram

Since one function of the TMLP trip is to prevent departure from nuclear boiling (DNB), and DNB varies with power, the TMLP calculation utilizes two power signals. One of the power signals comes from the excore nuclear instrumentation linear power safety channel. The other power signal comes from ΔT power which is calculated by the TMLP calculator. As shown in Figure 10.2-1, each of the four TMLP calculators receive an input from the excore linear power safety channel located in its respective reactor protection system (RPS) channel. The nuclear power input signal is sent to a high select unit (>) that selects the highest of nuclear power or ΔT power.



The ΔT power calculation shown on Figure 10.2-2 uses the following formula:

$$\dot{Q} = \dot{m}(T_h - T_c)$$

The temperatures used in the calculation are average T_h and the maximum T_c. The mass flow rate ($\dot{m}$) is a constant that is placed into the calculation. The mass flow rate constant is unity for four reactor coolant pump (RCP) operation and less than unity for other pump configurations.

In addition to the ΔT calculation, the calculator also generates terms proportional to the first and second powers of ΔT and to the product of ΔT and T_c. These three terms are used to account for coolant density, specific heat, and flow rate variations with power. To provide an indication during mild transients, such as ramp load changes, a dynamic response term (d/dt) is added to the ΔT.

The output of the ΔT calculation is sent to a high select unit (>), to the LPD calculator, to recorders in the main control room, and to the pressure setpoint calculation portion of the TMLP calculator. The high select unit selects the highest of ΔT or excore nuclear power. The selected power is called Q power and is sent to the pressure setpoint calculator and to the variable overpower trip (VOPT) circuitry. A difference amplifier (Δ) subtracts ΔT power from excore nuclear power and displays the result on a reactor protection system (RPS) meter. If the difference between nuclear power and ΔT power exceeds ± 5%, a control room annunciator will alarm.

When nuclear power is below 10^{-4}% (as sensed by the wide range logarithmic channels) and the zero power mode is selected, the ΔT power input to the high select is defeated. As a result, the high select unit output (Q power) is forced to select the power signal from the excore nuclear instrumentation. The purpose of this interlock is to block the ΔT power calculation when RCS temperatures are below the narrow range values (less than 515°F).

In addition to the input to the high select unit, ΔT power is also supplied to the calculation of LPD. The LPD calculation will also select the highest of ΔT power and excore nuclear power and use the selected signal in the LPD trip setpoint generation.

ΔT power from the RPS channel A calculation is supplied to two control room recorders. Each of these recorders plots ΔT power (RPS-channel A) and control channel power from one of the two redundant reactor regulating systems (RRS).

As described earlier, the output of the high select unit (Q power) is also supplied to the variable overpower trip. Meters located in the main control room display Q power.

10.2.2.2 Pressure Setpoint Calculator

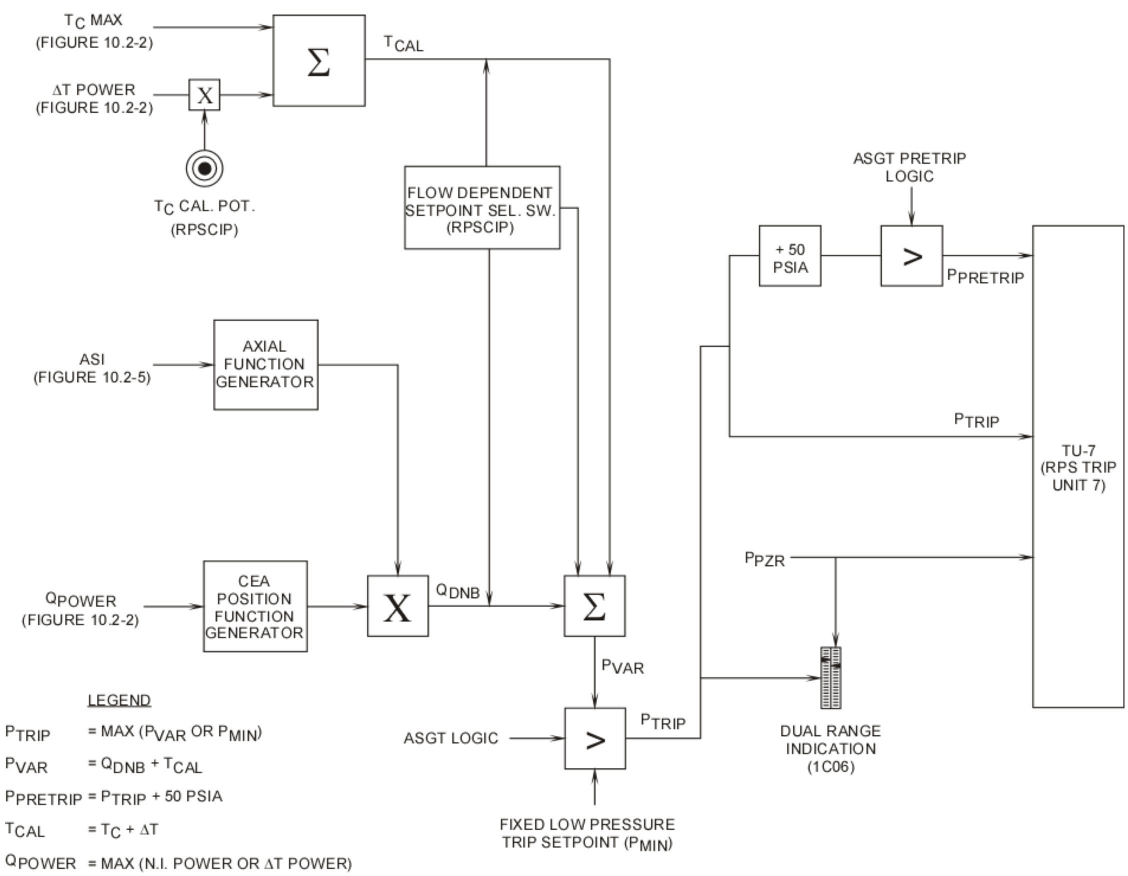


Figure 10.2-3 TMLP Pressure Setpoint Calculation

The pressure setpoint calculator (Figure 10.2-3) performs the following functions:

1. Generates a signal (Q_{DNB}) which is a function of core power (Q) modified by penalty factors based on worst case CEA position and calculated ASI. Q_{DNB} is also modified by the input from the Flow Dependent Setpoint Selector Switch (FDSS).

2. Generates a variable low pressure trip signal (P_{VAR}) based on inputs from Q_{DNB}, T_{CAL} and the FDSS.
3. Selects the highest of the following:
   - asymmetric steam generator input,
   - the low pressure trip signal (P_{VAR}), or
   - a fixed low pressure trip setpoint (P_{MIN}), and
4. Generates a pressure pre-trip ($P_{PRETRIP}$) at 50 psia above the pressure trip signal and the pressure trip signal (P_{TRIP}).

The pressure setpoint calculator expresses core thermal limits in terms of inlet temperature, axial shape index, core power (multiplied by control element assembly position corrections), and coolant flow. Note that DNB is a function of all of these factors. The combination of these signals generates a three-dimensional power signal. The output of the pressure setpoint calculator is a conservative pressure limit.

Q_{DNB} is generated as a function of core power (Q), control element assembly (CEA) position and ASI. In the generation of this function, the maximum CEA deviation permitted for continuous operation is assumed. In addition, the required CEA sequencing is also assumed. Finally, the CEAs are assumed to be at the transient insertion limit.

The ASI function is essentially a set of limiting axial power distributions at 100% power as determined from axial shape analysis. The axial shape analysis determines the axial shapes that result in a minimum DNBR (All other DNB factors are held constant). The axial shape analysis includes CEA Power Dependent Insertion Limits (PDILs) and an overpower margin. Q_{DNB} is modified by a flow constant, determined by the position of the FDSS.

The second input into the low pressure trip setpoint calculation is T_{CAL}. Due to temperature differences that can occur in less than full RCS flow conditions, the cold leg RTD may not produce an accurate indication of the hot channel inlet temperature. T_{CAL}, which is a function of ΔT power, compensates the highest T_c for possible temperature differences. In addition, a flow dependent constant determined by the position of the FDSS is applied to the ΔT power input to $T_{CAL.}$

The final input to the low pressure trip setpoint calculation is a flow dependent constant determined by the position of the FDSS. Since plant technical specifications prohibit power operation with less than four reactor coolant pumps, most units have modified the flow dependent setpoint selector to only supply the four pump signal. After all the inputs are combined, a low pressure trip setpoint (P_{VAR}) is generated.

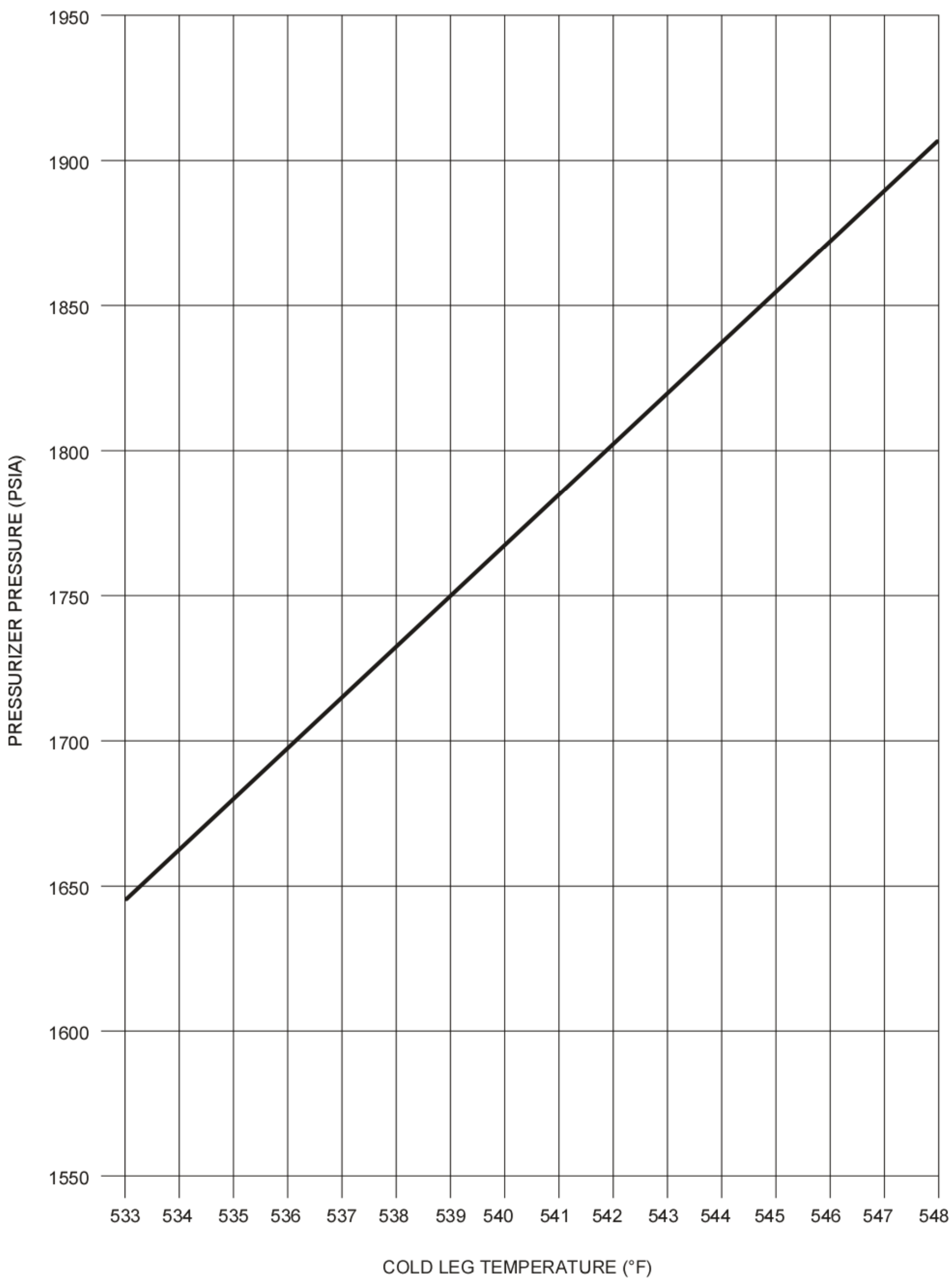


Figure 10.2-4 Pressure Setpoint Versus Temperature

A plot of P_{VAR} as a function of T_{CAL} is shown in Figure 10.2-4. Once the setpoint value has been calculated, it is sent to a setpoint high select unit.

10.2.2.3 Trip Setpoint Selection

As shown on Figure 10.2-3, the setpoint high select unit, which provides P_{TRIP} has the following inputs:

1. $P_{VAR,}$
2. A fixed low pressure setpoint, P_{MIN}, of 1875 psia, and
3. Asymmetric steam generator trip (ASGT) logic circuit.

The fixed setpoint of 1875 psia ensures that the reactor will be tripped prior to pressure dropping below 1875 psia. In effect, this limits the calculation requirements of the TMLP circuitry by ensuring a reactor shutdown at or below this pressure, even though P_{VAR} might calculate a setpoint below 1875 psia.

The ASGT input functions to preclude core radial flux imbalances caused by reduced heat transfer from the RCS to a steam generator whose main steam isolation valve (MSIV) is inadvertently closed. Closing of a MSIV would produce isothermal conditions in one loop. Since less than perfect mixing occurs at the core inlet, one-half of the core would see hot water from the loop associated with the closed MSIV, and the other one-half of the core would see cold water. The negative moderator temperature coefficient may cause unacceptable power peaking in the one-half of the core that is supplied with cold water.

The ASGT calculator receives pressure inputs from each steam generator and calculates a steam generator ΔP. If a ΔP of 135 psid exists, a 2500 psia setpoint will be sent to the trip setpoint high select unit in the TMLP pressure setpoint calculator. This setpoint should be higher than the variable (P_{VAR}) or fixed (P_{MIN}) setpoints and will be selected by the high select unit. The selection of the 2500 psia setpoint by two of the four TMLP calculators will result in a reactor trip. ΔPs of less than 135 psid result in a zero input into the trip setpoint high select unit and have no effect on the TMLP trip calculation.

Regardless of the trip value selected, the output of the high select unit is sent to the TMLP pre-trip and trip circuitry.

10.2.2.4 TMLP Pre-Trip Functions

The pre-trip bistable monitors pressurizer pressure and the output of the setpoint high select unit via a 50 psia bias that is added to the high select unit's output. For example, if the output of the select unit is 2100 psia, the pre-trip bistable would de-energize when actual pressurizer pressure drops to 2150 psia. When the pre-trip bistable de-energizes, a control element withdrawal prohibit (CWP) signal is generated and pre-trip alarms and indication lights are energized. The CWP prevents additional energy from being added to the RCS, and the pre-trip alarms and indication lights alert the plant operators of the possibility of a TMLP trip. Pre-trip functions are disabled in the zero power mode bypass mode of operation. Pre-trip functions are operable above 10^{-4}% power as sensed by the wide range logarithmic power channels.

10.2.2.5 Trip Signal Generation

The output of the setpoint high select unit is sent to the trip bistable where it is compared with actual pressurizer pressure. If pressurizer pressure equals the setpoint, a trip signal is generated. Trip functions may be disabled by zero power mode bypass key operation but will be automatically reinstated above 10^{-4}% power as sensed by the wide range logarithmic power channels. The TMLP trip is interlocked when testing the linear power range safety channel. If any power range channel test switch is moved from the operate position, a TMLP trip will be generated in that channel.

10.2.2.6 TMLP Indications

Each TMLP calculator supplies a meter located in the main control room. Each TMLP setpoint meter is next to a pressurizer pressure meter for that particular channel. If both values are equal, a reactor trip signal should be generated.

10.2.3 Local Power Density Trip

The purpose of the LPD trip is to prevent cladding damage caused by high linear heat rates (kW/ft.). High linear heat rates can occur during axial xenon oscillations or improper operation of the CEAs. Linear heat rate is not a readily measurable parameter, but it is calculated in the LPD trip unit using inputs of total power, ASI and the planar radial peaking factor (Fxy).

Power and ASI are direct inputs into the trip calculator, while Fxy is a conservatively fixed input (amplifier gain adjustments) that results from plant safety analysis.

10.2.3.1 LPD Total Power Input

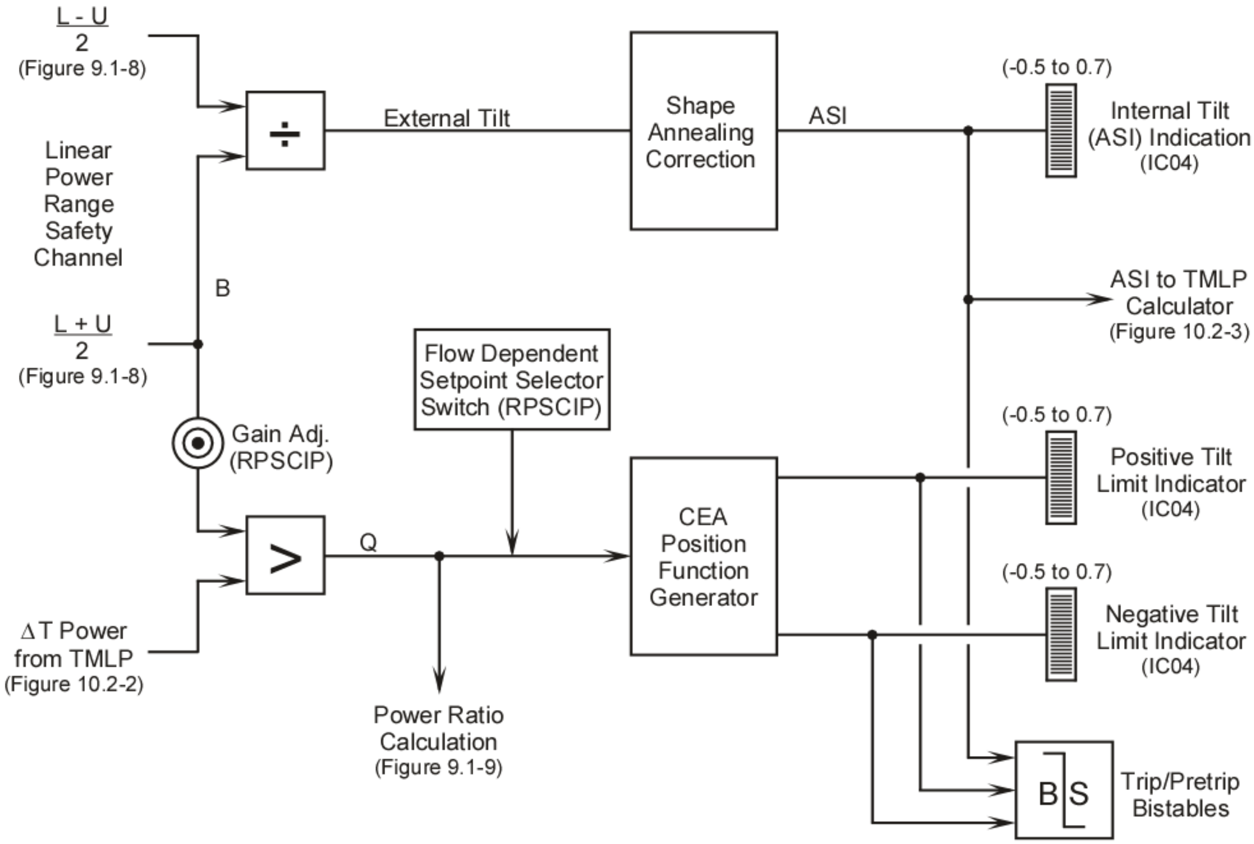


Figure 10.2-5 Local Power Density Trip Block Diagram

Like the TMLP trip unit, the LPD trip unit (Figure 10.2-5) also uses two power input signals. One based on ΔT power, and the other signal is based on the excore linear power range safety channel. ΔT power is supplied to the LPD trip unit from the TMLP calculation. The linear power range safety channel supplies two inputs to the LPD trip unit. One of the two signals is the average of the upper and lower detector ((L + U)/2) outputs, and the second signal is the difference between the outputs of the lower and upper detectors divided by 2 to normalize the signal to 100% ((L - U)/2). The average of the upper and lower detector signals (total nuclear power) is sent to a high select unit that selects the highest of ΔT power or neutron power. In addition to the input to the high select unit, the average power is sent to a ratio unit for the calculation of ASI. The ratio unit also receives an input from the difference of the lower and upper detectors.

10.2.3.2 Ratio Unit and Shape Annealing

The ratio unit divides the average of the difference in the lower and upper detector outputs ((L - U)/2) by the average of the upper and lower detector outputs $\frac{L+U}{2}$ to obtain an axial shape index factor called external tilt. This signal is equal to $\frac{L-U}{L+U}$, and is proportional to ASI. Since the upper neutron detector can sense neutrons that

originated in the lower half of the core, and the lower detector can sense neutrons that originated in the upper half of the core, a shape annealing correction must be applied to external tilt so that it is truly an ASI signal.

The shape annealing correction factors are derived during testing by comparing incore neutron detector ASI with excore ASI. Various ASIs are generated by inducing axial xenon oscillations. A linear least-squared fit of the data points is performed to yield the shape annealing correction factors. The external tilt is then modified by the shape annealing correction factors to yield internal tilt or ASI.

10.2.3.3 ASI Limit Generation

Nuclear power and ΔT power are supplied to a high select unit where the highest of the two powers is selected for the power signal (Q) in the LPD calculation. Q power is modified by a flow constant determined by the FDSS. The modified Q power signal is supplied to a function generator where it is modified by CEA position. The CEA modification is the same as the modification performed in the TMLP calculator. The modified Q power is sent to the calculation of positive and negative tilt limits.

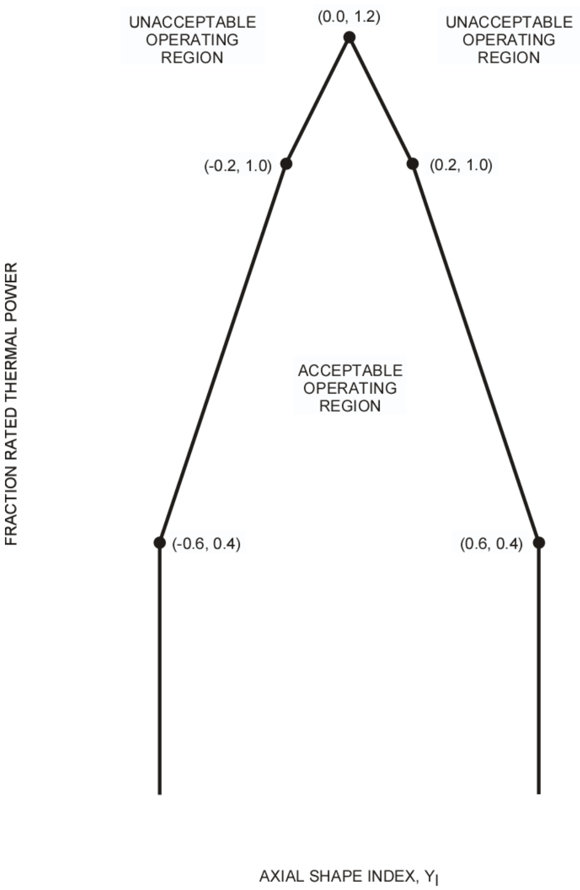


Figure 10.2-6 Axial Shape Index Boundary

Positive and negative trip limits, as well as their associated pre-trip limits, are calculated as a function of Q. The tilt limit envelope or tent (Figure 10.2-6) represents conservative values of ASI and prevents linear heat rate limits from being exceeded. The tilt trip limits and tilt pre-trip limits are supplied to the trip and pre-trip bistables where they are compared with the actual value of internal tilt. As with all RPS trips, if the actual value exceeds the limit, pre-trip and trip signals will be generated.

10.2.3.4 LPD Indications

In addition to the typical pre-trip and trip alarms, the LPD calculation also supplies three main control room meters. One meter displays internal tilt, while the positive and negative trip limits are displayed on the other two meters. If internal tilt is between the limits, LPD trips will not occur.

Q power from each of the four LPD calculations is supplied, via the power ratio calculator, for the generation of Pre-Power Dependent Insertion Limit (PPDIL) and Power Dependent Insertion Limit (PDIL) alarms. The highest of the four Q power signals is selected. An allowable CEA position is calculated that is a function of the highest Q power, and compared to actual CEA position. If the CEAs exceed the allowable CEA position, alarms will be generated to alert the operator. It should be

noted that the PPDIL and PDIL limits differ by a constant, and comparisons with both limits are made.

10.2.3.5 LPD/Power Range Interlocks

The LPD trip, like the TMLP trip, is interlocked with the nuclear instrumentation test switches. If any test switch in moved from the operate position, an LPD trip will be generated. Also, the LPD trip is automatically bypassed when nuclear power, as sensed by the linear power range safety channels, is less than or equal to 15%. The bypass is automatically removed when power is increased above 15%.

10.2.4 Summary

The TMLP and LPD trips ensure that DNBR and linear heat rate limits are not exceeded. In addition, the TMLP trip provides protection for asymmetric steam generator conditions. The TMLP trip receives inputs from hot and cold leg temperatures, linear power range safety channels, pressurizer pressure, the flow dependent setpoint selector, and steam generator pressures. The TMLP trip is bypassed when the zero mode bypass is in effect. The trip is automatically reinstated when power exceeds 10^{-4}%. The LPD trip receives inputs of nuclear power from the linear power range safety channel and ΔT power from the TMLP circuitry. The LPD circuitry provides input to a high select unit that selects the highest of nuclear power or ΔT power. The average power is sent to a ratio unit for the calculation of ASI limits, pre-trip values and trip values. The ASI values are displayed in the main control room.

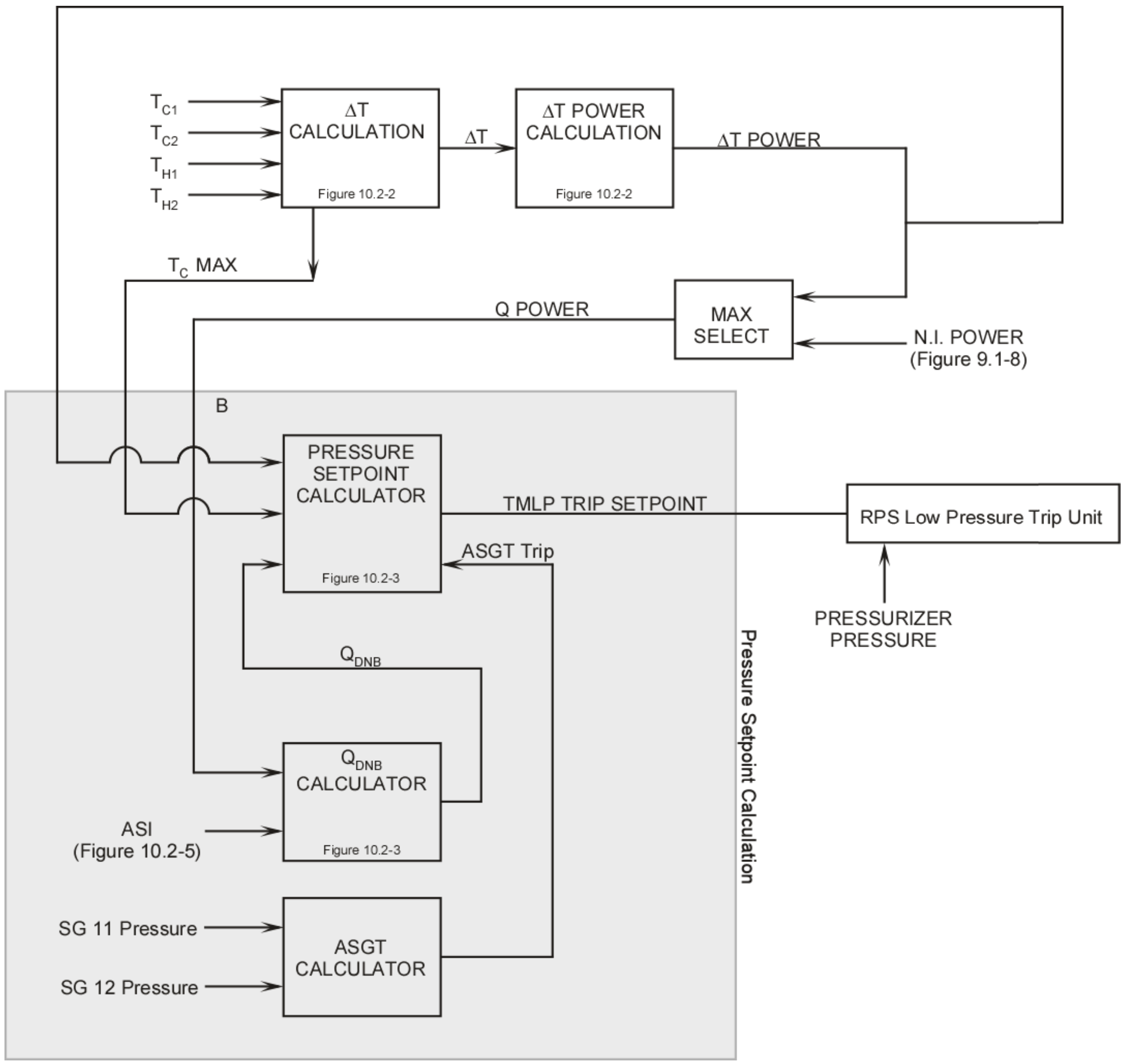


Figure 12.2-1 ΔT/TMLP Calculation Block Diagram

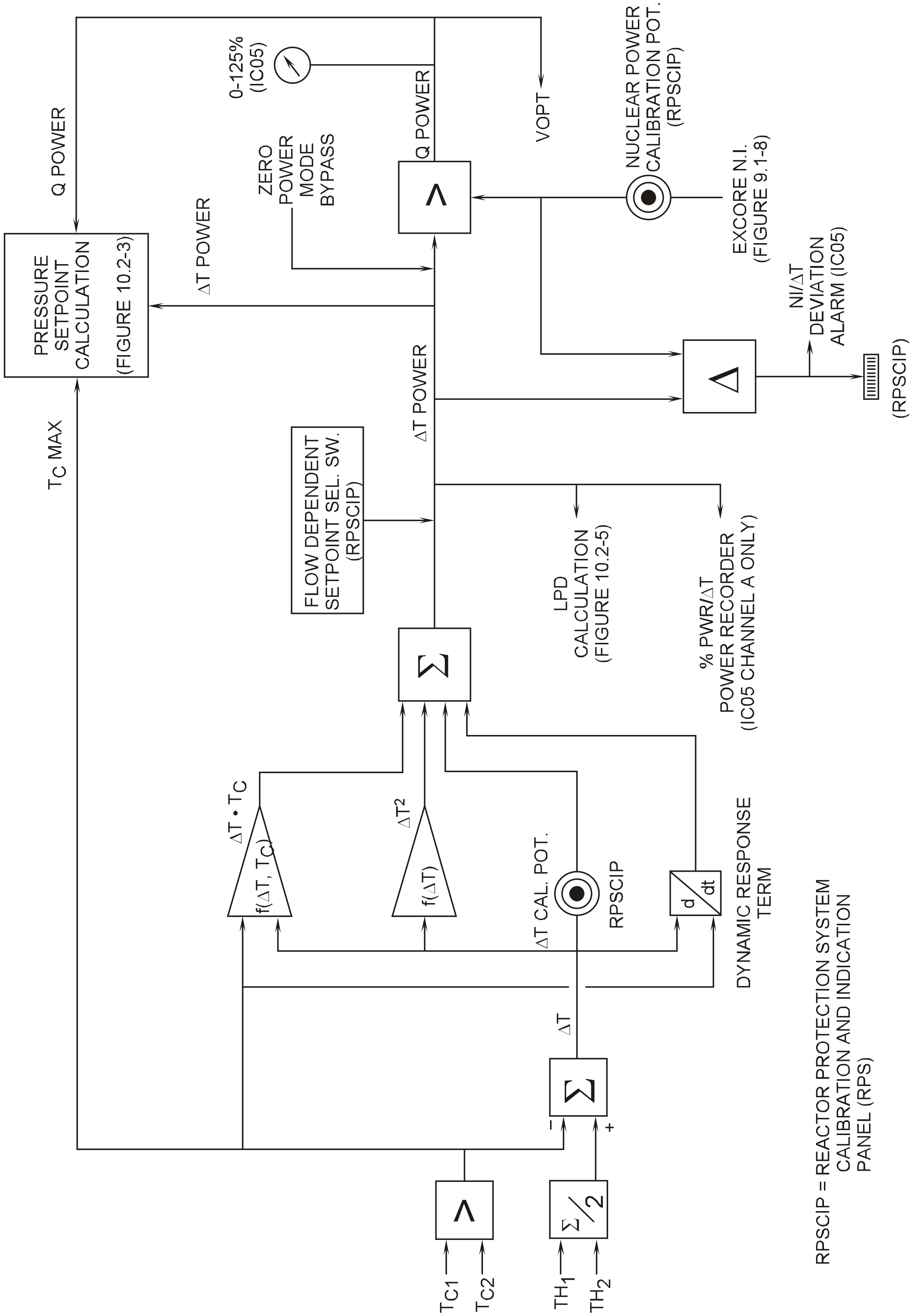


Figure 10.2-2 TMLP ΔT Power Calculation

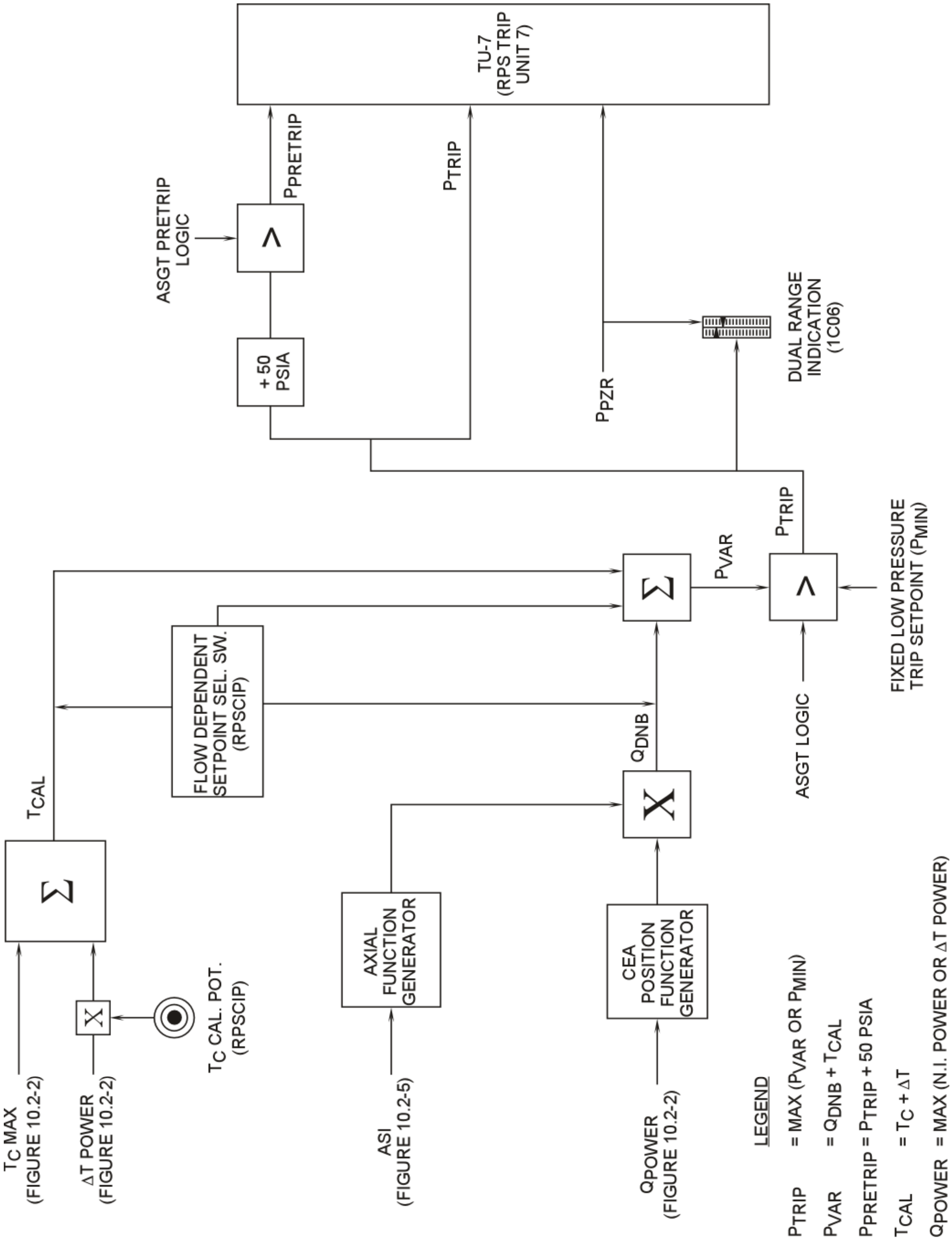


Figure 10.2-3 TMLP Pressure Setpoint Calculation

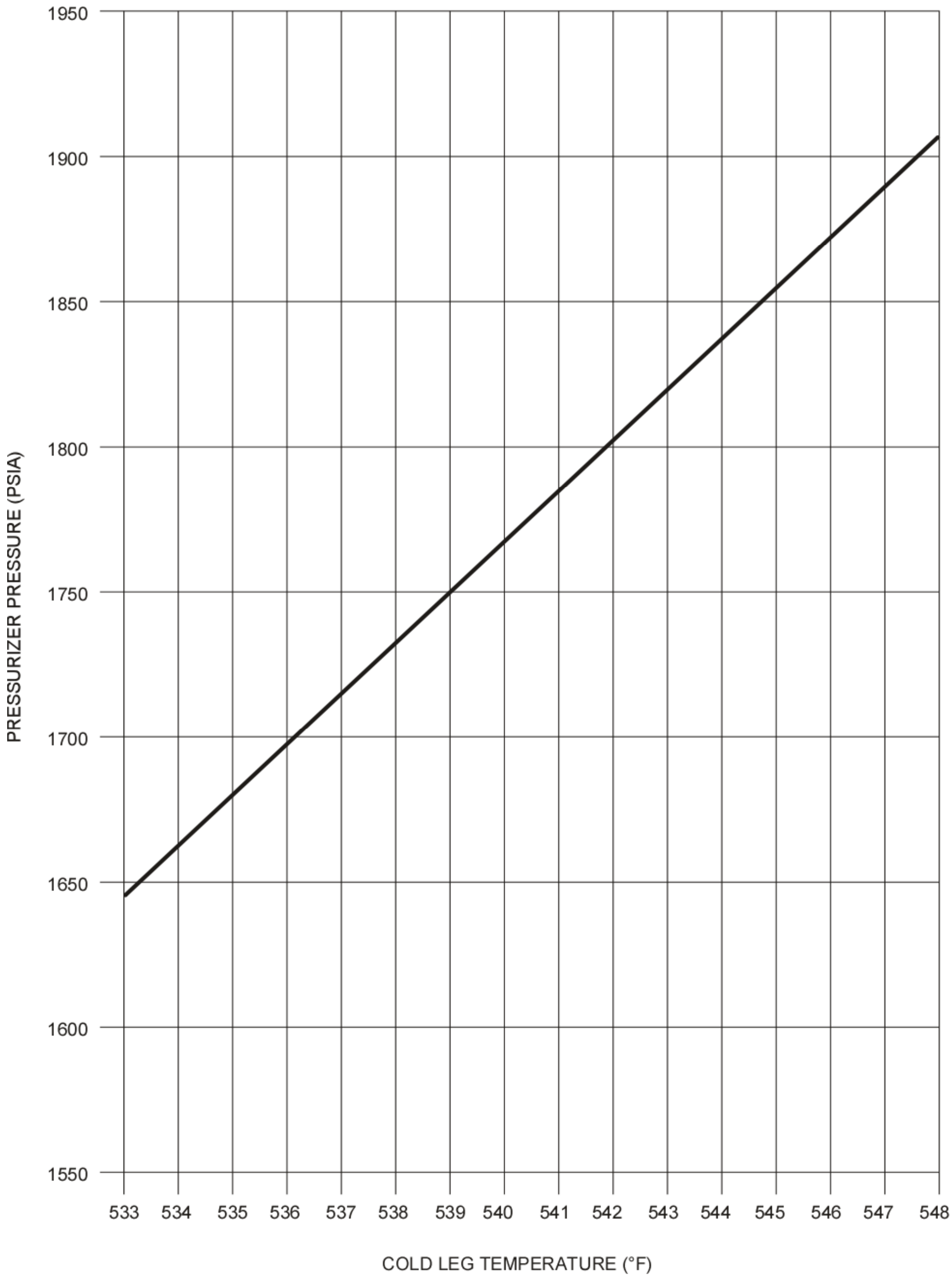


Figure 10.2-4 Pressure Setpoint vs. Temperature

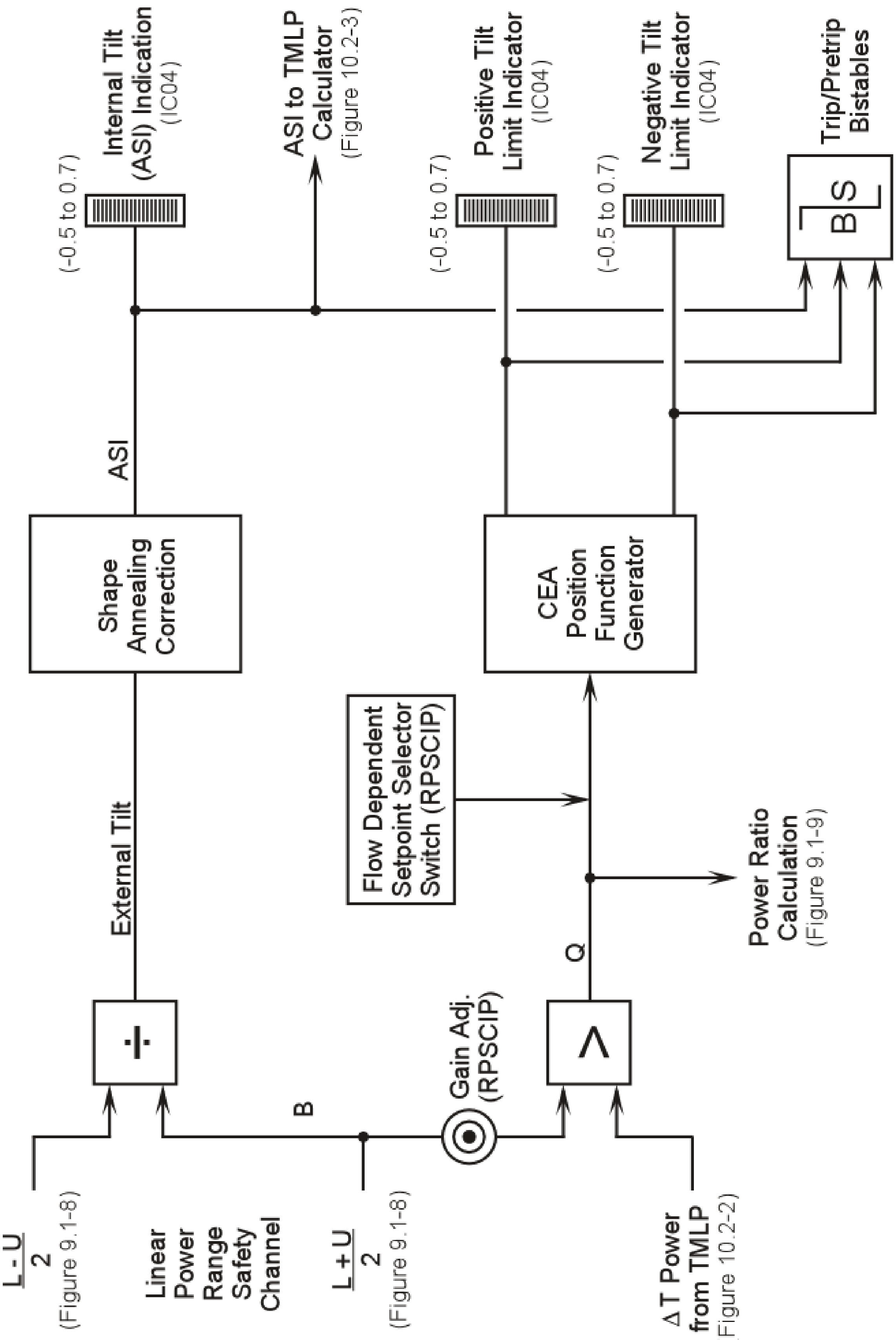


Figure 10.2-5 Local Power Density Trip Block Diagram

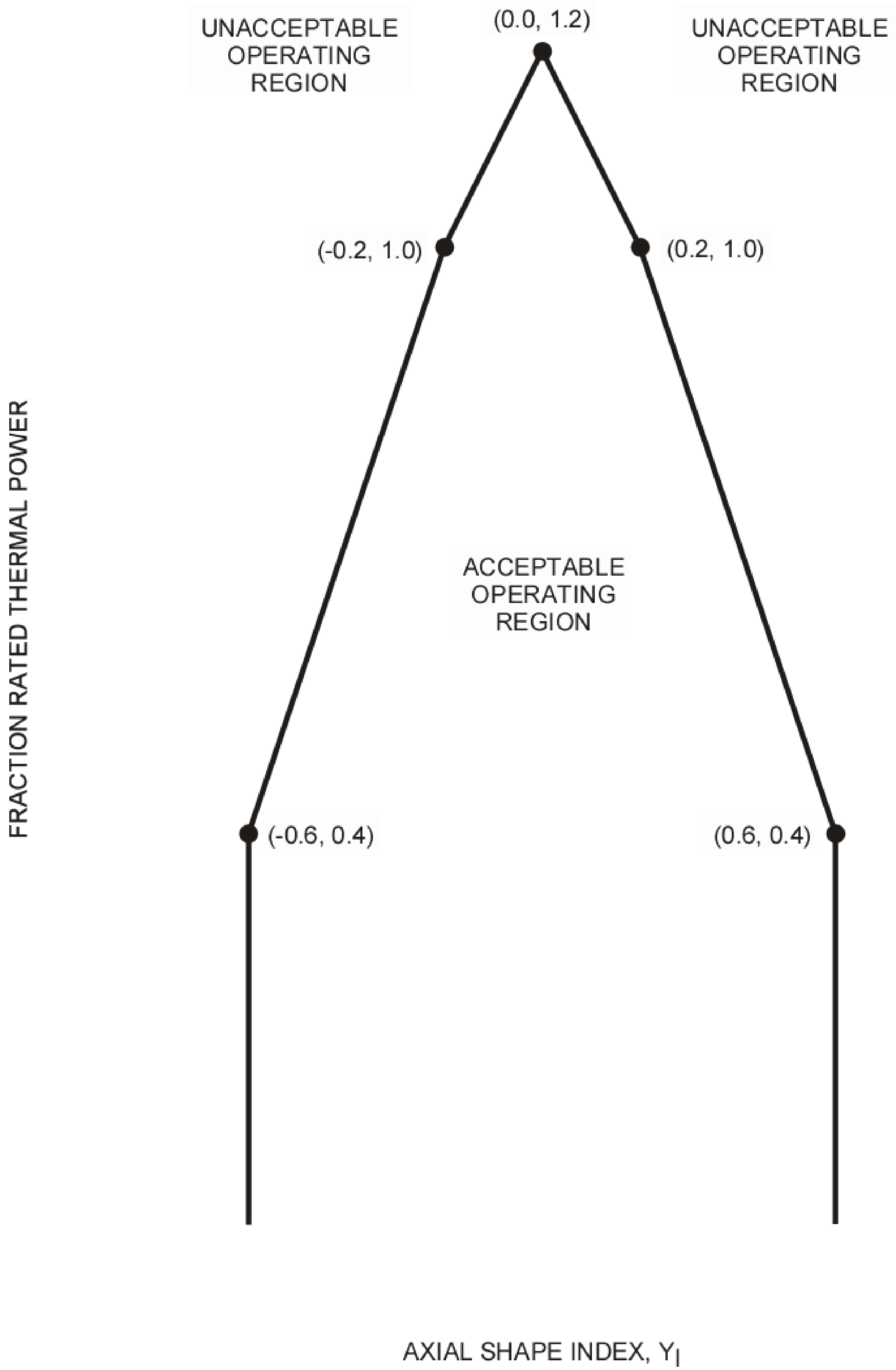


Figure 10.2-6 Axial Shape Index Boundary