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13 POWER DISTRIBUTION LIMITS

Learning Objectives:

1. State the purpose of imposing power distribution limits.
2. State the limiting conditions for operation (LCOs) in the technical specifications related to power distribution.

13.1 Introduction

The limiting conditions for operation (LCOs) in technical specifications are:

1. Linear heat rate (LHR),
2. Total planar radial peaking factor (F_{xy}^{T}),
3. Total integrated radial peaking factor (F_{r}^{T})
4. Axial shape index (ASI) limit,
5. Azimuthal power tilt T_q, and
6. Departure from nucleate boiling ratio (DNBR) limits.

These specifications limit the core power distribution to the initial values assumed in accident analysis.

Operation within the limits imposed by these LCOs limit the potential fuel cladding failures that could breach the primary fission product barrier and release fission products in the event of a loss of coolant accident (LOCA), loss of forced RCS flow, ejected CEA, or other events requiring termination by the reactor protection system (RPS). These LCOs limit the amount of damage to the fuel cladding during an accident by assuring the plant is operating within acceptable conditions at the onset of an event.

Methods of controlling power distribution include:

1. Use of full length CEAs to alter axial power distribution,
2. Decreasing CEA insertion by boration, thereby improving power distribution and
3. Correcting off optimum conditions which cause margin degradations (CEA misalignment).

The core power distribution is controlled so that, in conjunction with other core operating parameters (CEA insertion and alignment limits), the power distribution does not result in violation of the limiting condition for operation. LCOs and limiting safety system settings (LSSS) are based on safety analysis so that specified acceptable fuel design limits (SAFDLs) are not exceeded as a result of anticipated operational occurrences (AOOs). There are two (2) CE SAFDLs (DNB and LHR). Both SAFDLs are maintained by RPS trips; however, the RPS setpoints assume that power distribution limits are within their safety analysis bounds. If a power distribution limit exceeds its allowable technical specification value, the RPS setpoint may not provide protection.

In addition, power distribution limits ensure that acceptable consequences are not exceeded during postulated accidents. The power distribution limits must be maintained within analyzed bounds to ensure that the LOCA acceptance criteria of

10CFR50.46 are satisfied. Generally speaking, these limits are maintained administratively. For example, no RPS trips are installed to ensure 2200°F cladding temperature is not exceeded during a cold leg break.

Power distribution is the product of multiple parameters where various combinations may produce acceptable power distributions. Operation within the design limits of power distribution is accomplished by generating operating limits on peak LHR and DNBR.

The power distribution at any point in the core must be limited to maintain the fuel design criteria. This is accomplished by maintaining the power distribution and coolant conditions so that the peak LHR and DNBR are within operating limits supported by the safety analysis, with due regard for the correlations between measured quantities, the power distribution, and uncertainties in the determination of power distribution.

Fuel cladding failure during a LOCA is limited by restricting the maximum LHR so that the peak cladding temperature does not exceed 2200°F. High cladding temperatures are assumed to cause severe cladding failure by oxidation due to a zircaloy-water reaction.

DNB occurs when the local heat flux addition from the fuel rods to the reactor coolant causes nucleate boiling to be replaced by a steam film along regions of the cladding. This results in a large difference between the cladding surface temperatures and the coolant saturation temperature. Inside the steam film, high cladding temperatures are reached, and a zircaloy-water reaction may take place. The chemical reaction may cause failure by oxidation of the cladding, allowing an uncontrolled release of radioactive fission products to the coolant. Proximity to the DNB condition is expressed by the DNBR. DNBR is defined as the ratio of the cladding surface heat flux required to cause DNB to the actual surface heat flux. The minimum DNBR value during both normal operation and AOOs is limited to the value given by the CE-1 correlation corrected by such factors as fuel rod bow and grid spacer location.

The CE-1 correlation relates system pressure, mass flow rate, heat flux, and inlet enthalpy to the heat flux required to cause DNB. As with any mathematical correlation, some error in predicting DNB occurs. By use of an experimental model a statistical comparison was obtained between the actual point of DNB and the predicted point of DNB.

The standard method of stating the statistical evaluation of DNBR is:

This DNB SAFDL assures with at least a 95% probability at a 95% confidence interval that DNB will not occur.

For comparison, during normal steady state operation at 100 percent rated power, the DNB ratio is approximately equal to two.

Since DNBR is related to boiling, a look at some factors which affect boiling and how they can change DNBR are considered below:

Coolant Temperature - A high coolant temperature will decrease DNBR closer to the limit. This is because a high temperature is closer to saturation temperature and therefore closer to a DNB condition. A limit of 548°F is placed on cold leg temperature.

RCS Pressure - Decreasing RCS pressure will also decrease DNBR closer to the limit. Lower pressure means closer to saturation pressure, and therefore closer to a DNB condition. Steady state RCS pressure should be maintained above 2200 psia.

Core Flow - Lower flow through the core will increase cold leg temperature (Tc) for the same power level. This means coolant temperature is closer to saturation temperature and therefore DNBR decreases. RCS flow rate shall be greater than or equal to340,000 gpm.

Power Level - Higher than expected local power density results in higher coolant temperature, also a higher heat flux at the surface of the fuel rod. This means closer to DNB, therefore, DNBR decreases.

All these factors can have an effect to decrease DNBR. The choice of several reactor protection setpoints are dependent on maintaining DNBR during normal operation and during AOOs.

13.2 Power Distribution Limits

Although the operator’s responsibility is to insure that DNBR, fuel temperature, cladding temperature, and peak power density limits are not exceeded, the operator has no instrumentation directly measuring these parameters. Control room indications such as loop coolant temperatures and power only give average or total effects. Local variations in fuel rod power and coolant temperatures are not detected by normal operational instrumentation. In order to provide the operator with local power information, an incore instrumentation system is used. The incore instrumentation consists of rhodium detectors which are directed through the center guide tube of selected fuel assemblies. The rhodium detectors are used to measure local power levels at selected elevations through the fuel assembly.

These power levels are then used to verify that the maximum local heat flux in the core and the maximum enthalpy rise in the core are not sufficient to cause departure from nucleate boiling conditions, fuel pellet melting, or fuel rod oxidation.

The data obtained directly from the incore instrumentation is the magnitude of the actual nuclear power density at the selected locations. This data is compiled by the plant computer to yield power distribution data.

13.2.1 Linear Heat Rate

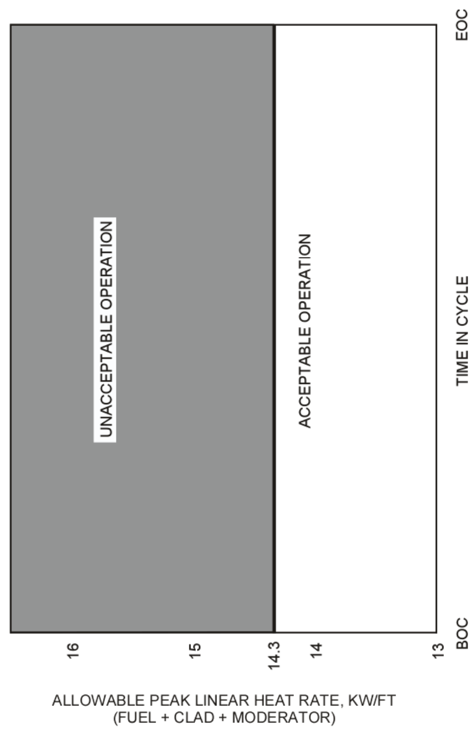

Figure 13-1 Allowable Peak Linear Heat Rate vs. Time in Cycle

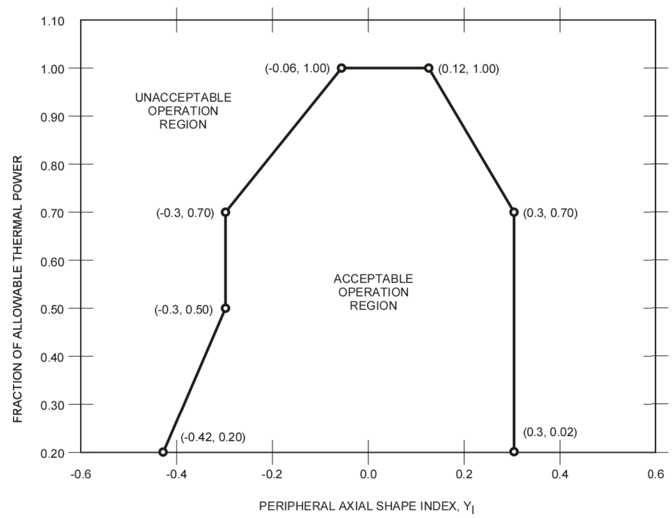

Figure 13-2 Linear Heat Rate Axial Flux Offset Control Limits

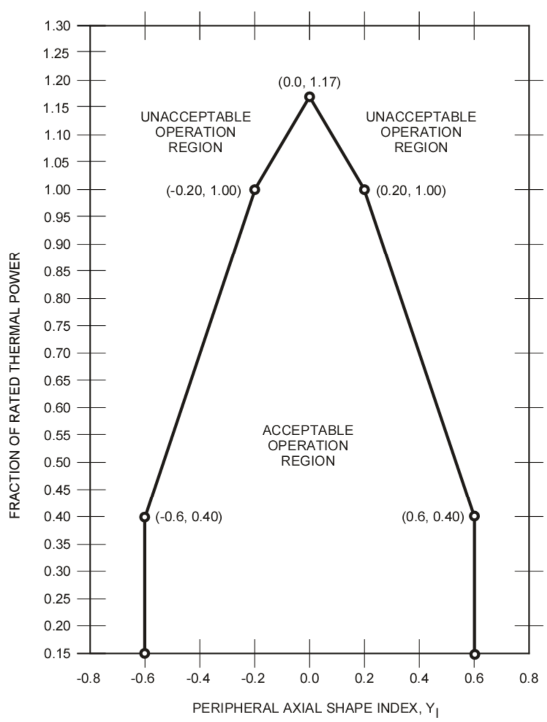

Figure 13-3 Axial Power Distribution - High Trip Setpoint
Peripheral Axial Shape Index vs. Fraction of Rated Thermal Power

The limitation on LHR ensures that in the event of a LOCA, the peak temperature of the fuel cladding will not exceed 2200°F. Three figures are used in the core operating limits report (COLR) to ensure compliance with linear heat rate requirements. The first figure (figure 13-1) requires that the linear heat rate be less than or equal to a specific value in kW/ft. The second figure of interest is a plot of thermal power versus ASI (figure 13-2). Since the action statement for the LCO contains an OR statement, both figures must be satisfied. If figure 13-2 is compared with the ASI/power limits of figure 13-3, the limits of figure 13-2 are more restrictive. Figure 13-3 is the limit curve for the LPD RPS trip which ensures that the SAFDLs are not exceeded. The LOCA heat rate limits are more restrictive than the SAFDLs and these limits are administratively maintained.

13.2.2 Total Planar Radial Peaking Factor

The planar radial peaking factor (F_{xy}) is defined as the maximum ratio of the peak to average power density of the individual fuel rods in any of the unrodded horizontal planes, excluding tilt. When tilt is included the term F_{xy}^{T} is used. The limit F_{xy}^{T} ensures that the assumptions used in the analysis for establishing the LHR limit and local power density (LPD) LSSS remain valid during operations at various allowed CEA insertion limits. The bases of technical specifications define F_{xy}^{T} as $F_{xy}(1+T_q)$ where T_q is the azimuthal tilt. In summary ,the planar radial peaking factor limits help to ensure that a fuel cladding temperature of 2200°F is not exceeding during a LOCA and the SAFDLs for DNB and kW/ft are not exceeded.

13.2.3 Total Integrated Radial Peaking Factor

The unrodded integrated radial peaking factor F_r is the ratio of the peak pin power to the average pin power in an unrodded core. Limitations on F_r ensure that the assumptions used in the analysis in establishing the DNB margin LCO, and the thermal margin low pressure (TMLP) LSSS setpoint remain valid during operation at various allowable CEA group insertion limits. Adjusted for tilt F_r becomes F_r^{T}

$(F_r^{T} = F_r(1+T_q))$

13.2.4 Azimuthal Power Tilt

Azimuthal power tilt T_q is the power asymmetry between azimuthally symmetric core locations. Limits are placed on T_q to ensure that the assumptions used in the analysis for establishing the LHR limit and the LPD LSSS remain valid during operations at various allowed CEA insertion limits. In addition, the assumptions used in the analysis in establishing the DNB margin LCO, and the TMLP LSSS setpoint also remain valid during operation at various allowable CEA group insertion limits.

13.2.5 DNB Parameters

Limits are placed on cold leg temperature, pressurizer pressure, RCS flow and ASI to assure that each of the parameters are maintained within the normal steady state envelope of operation assumed in the transient and accident analysis. The limits are consistent with the safety analyses assumptions and have been analytically demonstrated adequate to maintain a minimum DNB SAFDL throughout each analyzed transient.

In addition to the DNB criterion, there are two (2) other criteria which set the limits in technical specifications (figure 13-2). The second criterion is to ensure that the existing core power distribution at full power is less severe than the power distribution factored into the small break LOCA analysis. This results in a limitation of the allowed negative ASI value at full power. The third criterion is to maintain limitations on peak LHR at low

powers (figure 13-2) to assure the LHR criteria for this condition because the LHR LCO is set to maintain only the LOCA kW/ft requirements at high power levels. At reduced power levels, the kW/ft requirements of certain AOOs (such as CEA withdrawal) tend to become more limiting than that for LOCA.

13.3 Monitoring of Power Distribution Limits

The values of the power distribution limits are usually determined by the plant computer and supplied to the operator upon demand. However, the inspector/regulator can look at several readily available indications to ensure that the power distribution limits are being satisfied.

The CEA position indication systems will provide information concerning CEA alignment and position. If all CEAs are aligned to within the technical specification limits and the regulating CEAs are positioned in accordance with the power dependent insertion limits, the radial and axial core flux shapes should fall within the analyzed bounds of safety analysis. In addition, total power should be less than or equal to the licensed power limit. If total power satisfies this requirement, plant power is less than the safety analysis assumed power. Finally, T_q may be determined from the power range nuclear instrumentation.

13.4 Xenon Redistribution

During normal operation, the core xenon distribution is proportional to the radial and axial flux shapes. If changes occur in either of these flux shapes, then xenon will redistribute. The xenon redistribution will, in turn, cause changes in flux shape which change core power distribution factors. Examples of events that will cause flux shape changes are:

1. A dropped CEA,
2. A misaligned CEA,
3. A turbine run back with the reactor regulating system in automatic and
4. Power maneuvering with the CEAs.

13.5 Limiting Transients/Accidents

In the preceding paragraphs, statements have been made about ensuring that the values assumed in transient and accident analysis are not exceeded. The limiting transient and accidents, along with the appropriate limits, are listed below:

1. Loss of forced reactor coolant flow - there must be at least a 95% probability at a 95% confidence level that the hot fuel rod in the core does not experience DNB,
2. During a double ended rupture of a cold leg, the peak cladding temperature must not exceed the 10CFR50.46 limit of 2200°F and
3. During an ejected CEA accident, the fission energy input to the fuel must not exceed 280 cal/gm.

13.6 Summary

Core power distribution technical specifications ensure that the initial conditions assumed in the safety analysis for anticipated operational occurrences and accidents

are maintained.   Power distribution specifications include limits on linear heat rate, planar radial peaking factor, integrated radial peaking factor, azimuthal tilt, cold leg temperature, pressurizer pressure, RCS flow, axial shape index, and thermal power.

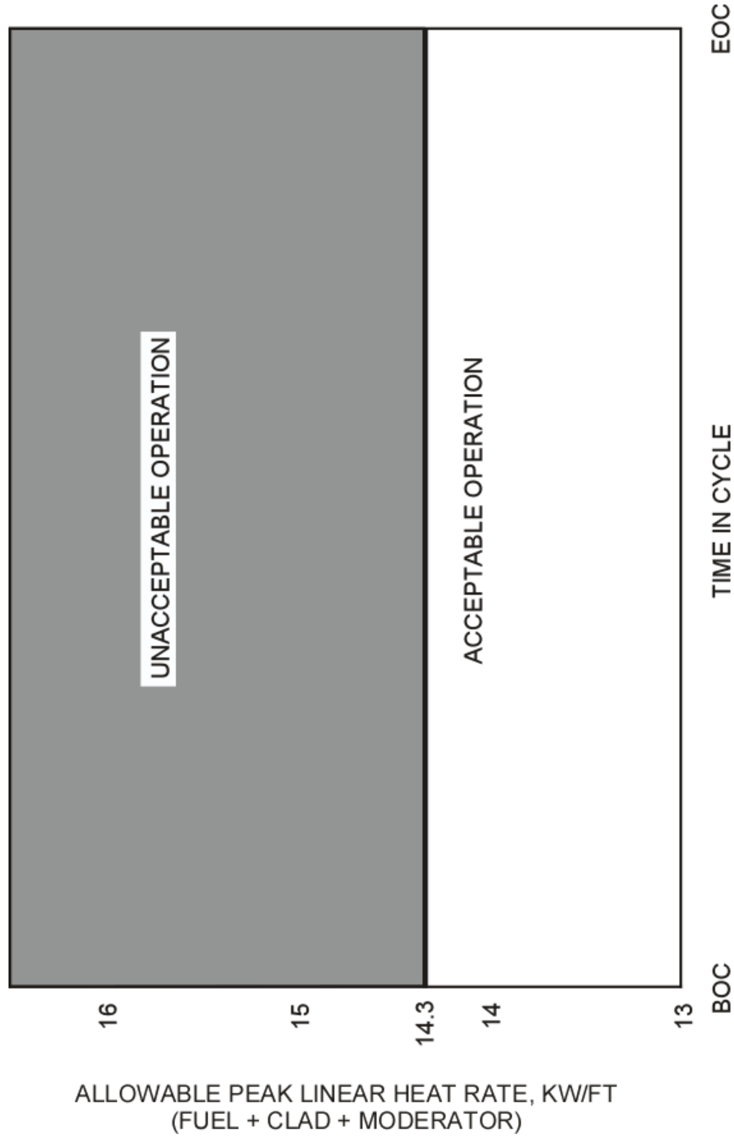

Figure 13-1 Allowable Peak Linear Heat Rate vs. Time in Cycle

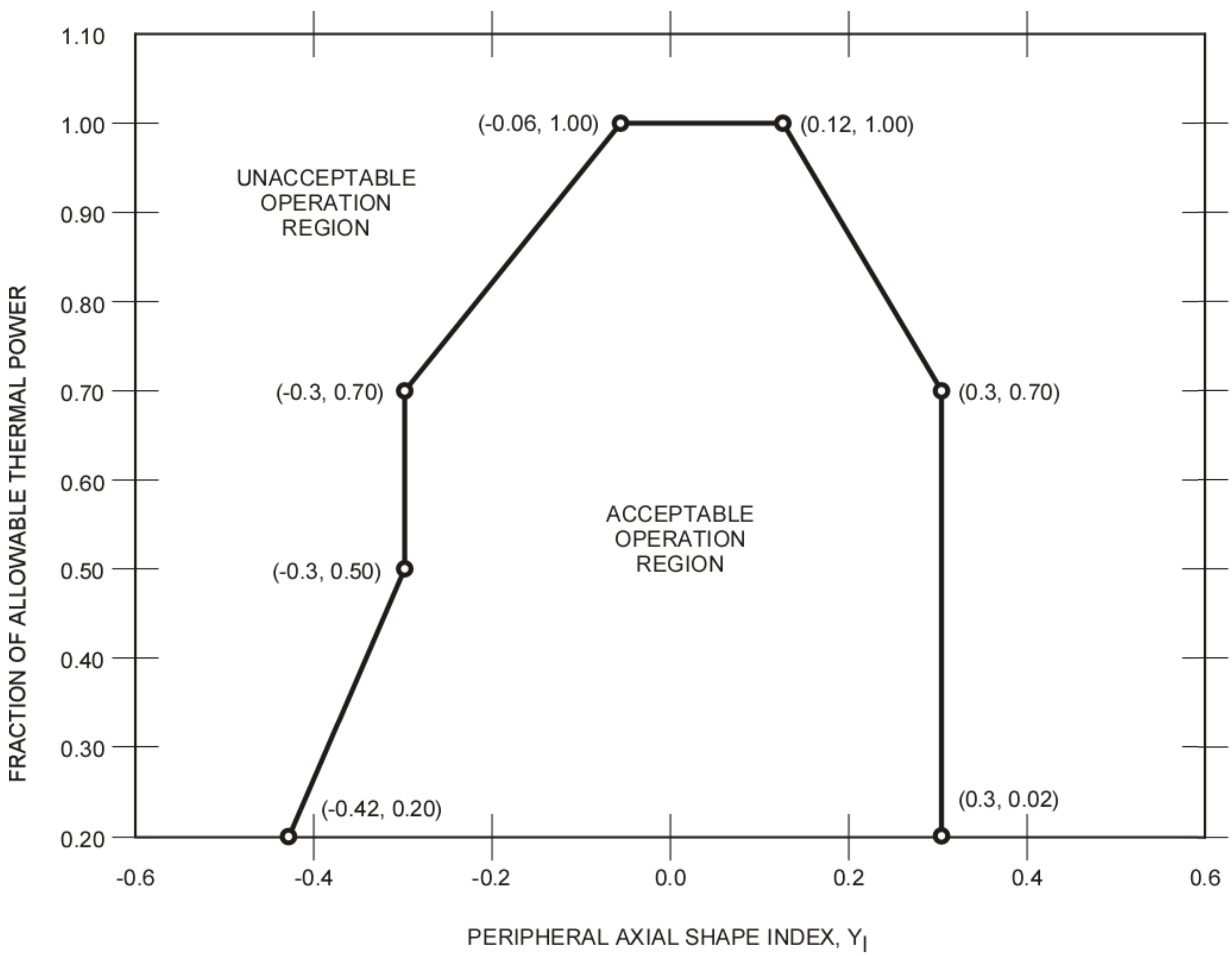

Figure 13-2 Linear Heat Rate Axial Flux Offset Control Limits

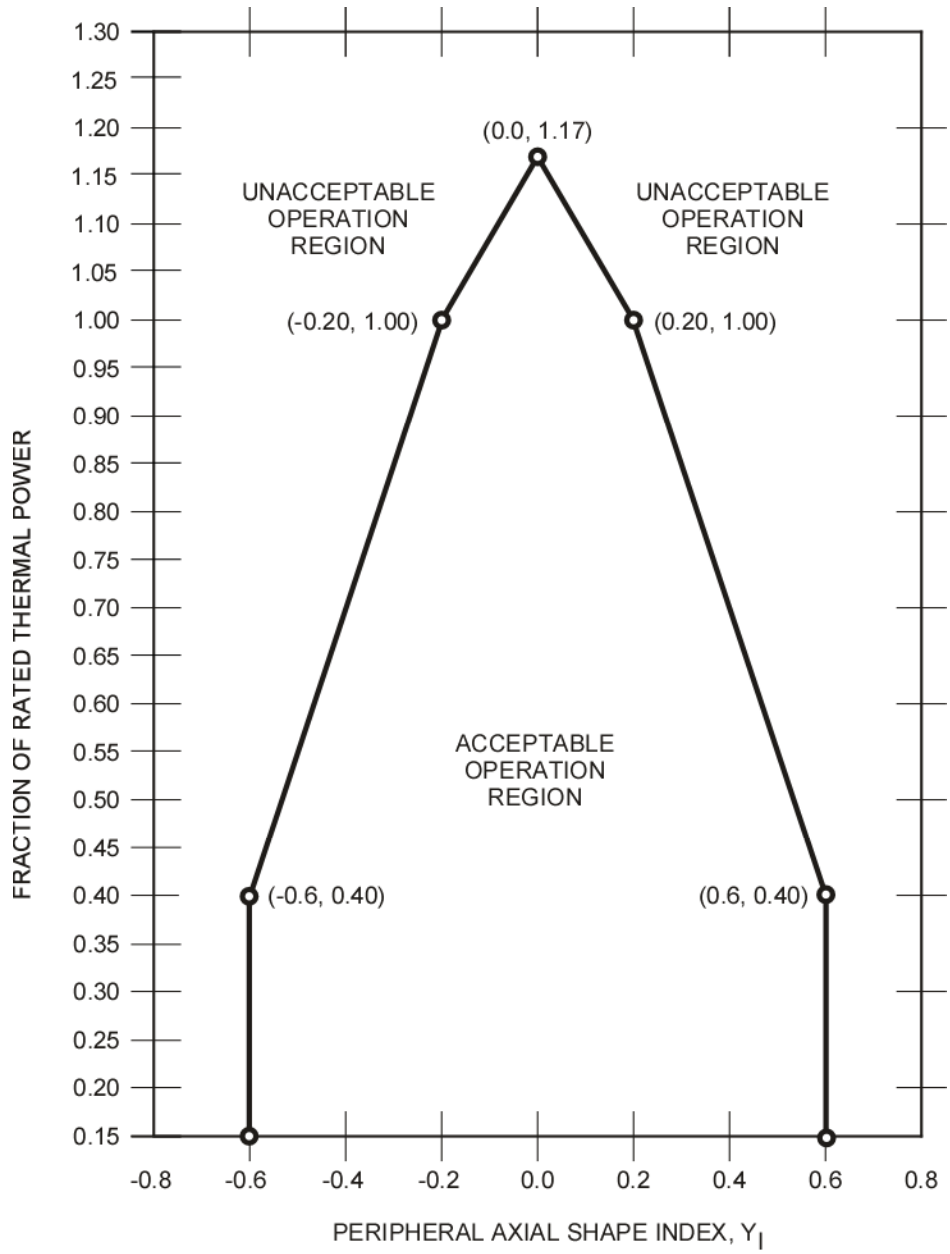

Figure 13-3 Axial Power Distribution – High Trip Setpoint Peripheral Axial Shape Index vs. Fraction of Rated Thermal Power