3.1 Reactor Core - Safety Limit

3.1.1 Applicability

Applies to the limiting combinations of core thermal power and core helium flow rate.

3.1.2 Objective

To maintain the integrity of the fuel particle coatings.

3.1.3 Specification SL 3.1 - Reactor Core Safety Limit

The combination of the reactor core power-to-flow ratio and the total integrated operating time at the power-to-flow ratio during the lifetime of any segment shall not exceed the following limits.

3.1.3.1 Power-to-Flow Ratio Between 1.17 and 2.5

The combination of the reactor core power-to-flow ratio and the total integrated operating time at this power-to-flow ratio during the lifetime of any segment shall not exceed the limit given in Figure 3.1-1. This safety limit is exceeded when the combination of operating parameters (power, flow, and time) lies above or to the right of the line given in Figure 3.1-1.

For the purpose of obtaining the total effective integrated operating time for Figure 3.1-1, only transients resulting in a power-to-flow ratio above the curve of Figure 3.1-2, at the appropriate core power level shall be used.

For power-to-flow ratios between 1.17 and 2.5, the operator shall immediately reduce power to lower the power-to-flow ratio to less than 1.17. If this corrective action is not successful within two minutes, an immediate shutdown shall be initiated.

3.1.3.2 Power-to-Flow Ratio Greater than 2.5 and Less Than or Equal to 15

The time interval (t) from the start of the transient in power-to-flow ratio above Figure 3.1-2 to the time at which the power-to-flow ratio goes below a value of 2.5 shall be reduced by 100 seconds and the remaining time shall be limited to a total allowable time of 2 minutes. The allowable time for power-to-flow ratios less than 2.5 at times larger than (t) are given in 3.1.3.1.

3.1.3.3 Power-to-Flow Ratio Greater than 15

The time interval (t) from the start of the transient in power-to-flow ratio above Figure 3.1-2 to the time at which the power-to-flow ratio goes below a value of 2.5 shall be reduced by 60 seconds and the remaining time shall be limited to a total allowable time of 2 minutes. The allowable time for power-to-flow ratios less than 2.5 at times larger than (t) are given in 3.1.3.1.

3.1.3.4 Power-to-Flow Ratio Less Than 1.17

For power-to-flow ratios exceeding values of Figure 3.1-2 but less than 1.17, an operating time limit of 100 hours shall be used. If the combination of power-to-flow ratio and percentage of design core thermal power exceeds the curve of Figure 3.1-2, the operator will take action to bring the combination of power-to-flow and percentage of design core thermal power under the curve of Figure 3.1-2. If this cannot be accomplished in four hours, an orderly shutdown shall be initiated.

3.1.4 Basis for Specification SL 3.1

In order to assure integrity of the fuel particles as a fission product barrier, it is necessary to prevent the failure of significant quantities of fuel particle coatings. Failure of fuel particle coatings can result from the migration of the fuel kernels through their coatings. The dependence of the rate of migration of the particle kernel upon temperature and temperature difference across the particle kernel using 95% confidence levels on the experimental data was used. During power operation, there is a temperature gradient across each fuel rod, the higher temperature being at the center of the fuel rod and the lower temperature at the outer edge of the fuel. In an overtemperature condition, fuel kernels can move through their coatings in this temperature gradient, in the direction of the higher temperature.

The Core Safety Limit has been constructed to assure that a fuel kernel migrating at the highest rate in the core will penetrate a distance less than the combined thickness of the buffer coating plus the inner isotropic coating on the particle.

The quantity of failed particle coatings in the core at all times is determinable by measurement of gaseous fission product activity in the primary loop.

In Figure 3.1-1, the quantity P is the fraction of design core thermal power, i.e., core thermal power (MW) divided by 842. The quantity F is the fraction of design core coolant flows at the circulators, i.e., the total coolant flow at the circulators in (lb/hr) divided by 3.5×10^6 lb/hr.

The limiting combinations of core thermal power and core coolant flow rate are established using a series of short time conservative assumptions. All hot channel factors discussed in Section 3.6 and all power peaking factors discussed in Section 3.5.4 of the FSAR were applied in determining this limiting curve. The range of region radial power peaking factors (average power density in any refueling region, $\overline{P}_{reg}$, divided by average power density in the core, $\overline{P}_{core}$) was assumed to be less than or equal to 1.83 and greater than or equal to 0.4. The maximum intra-region power peaking factor (average power density in a fuel column, $\overline{P}_{col}$, divided by the average power density in a fuel region, $\overline{P}_{reg}$) used was 1.46 ± 0.2 for regions with control rods inserted and 1.34 ± 0.2 for all unrodded regions. A conservative estimate of the most unfavorable axial power distribution was also used. That is, the ratio of power density in the bottom layer of fuel elements of a core region, $P_{lower\ layer}$, to the average power density of the region, P_{reg}, is less than or equal to 0.90 ± 0.09 for regions with control rods fully inserted or withdrawn, and 1.23 ± 0.12 for regions with control rods inserted more than two feet. The measured region coolant outlet temperature for the nine regions with their orifice valves most fully closed and all regions with control rods inserted more than two feet, was assumed to be not more than 50°F greater than the core average outlet temperature. The measured region coolant outlet temperature for the remaining core regions was assumed to be not more than

200°F greater than the core average outlet temperature. During normal full power operation, a condition with any measured region outlet temperature more than 50°F above average should not persist for longer than a few hours. A measurement uncertainty for the core region outlet temperature of ± 50°F was assumed. A 5% uncertainty in flow measurement and a 5% uncertainty in reactor thermal power measurement was assumed in establishing the limit.

For the total fuel lifetime in the core, based on calculations incorporating plant parameters and uncertainties appropriate for longer times, migration of the fuel particle kernel through its coating would be less than 20 microns for the fuel with the most damaging temperature history and with the core operated constantly at any of the power-to-flow ratios and power combinations shown on the curve of Figure 3.1-2. Out of a total inner coating thickness of 70 microns, only 50 microns have been used for the determination of fuel particle failure in setting the limit curve in Figure 3.1-1.

As can been seen from Figure 3.1-1, sufficient time (at least nine minutes) is available for the operator to take corrective action to prevent the core safety limit from being exceeded for power-to-flow ratios less than or equal to 2.0. In order to reach a power-to-flow ratio of this magnitude through an increase in core power, significant equipment malfunction, or failure, and/or one or more significant deviations from operating procedures would have to occur.

However, high core power-to-flow ratios can also be obtained as a result of a reduction or loss of primary coolant circulation. The core negative coefficient of reactivity provides an intrinsic means to reduce the core power and the power-to-flow ratio, and the plant control system will usually initiate scram sequences in such cases. Nevertheless, for brief periods of time prior to or during the scram, high power-to-flow ratios can exist. Due to the slow thermal response of the core as a result of its high heat capacity, these power-to-flow ratios can exist for short periods of time without significantly increasing fuel temperatures and fuel kernel migration distances.

The behavior of the core during numerous transients has been discussed in the FSAR. The slow thermal response of the core is evident from the analysis results shown in Chapter 14 and Appendix D. For example, the Loss of Forced Circulation (LOFC) accident analysis presented in FSAR Appendix D shows that the maximum core temperature rises at a rate of only 6°F/minute for the first two hours following transient initiation. During that time, however, the primary flow rate is zero, while due to fission product decay heat the effective core power is as high as 3%. Thus, the power-to-flow ratio is far above the highest value shown in Figure 3.1-1.

Under transient conditions, either abnormal rapid power increases or sudden flow decreases, the allowable time in Figure 3.1-1 and 3.1-2, which was derived from steady state calculations, is not a meaningful indicator of kernel migration and fuel integrity. Accordingly, a delay period is appropriate for transients entailing either a sudden decrease in primary coolant flow with a consequent decrease in reactor power or an abnormal rapid power increase.

This delay period represents the time required for the fuel to heat up from normal operating temperatures to the steady state temperatures at higher power-to-flow ratios represented by the Core Safety Limit Curve. Therefore, this delay period can be allowed without compromising the integrity of the fuel. As a result of many transient analyses, the delay period has been conservatively set at 100 seconds for transients resulting in a power-to-flow ratio above 2.5 but less than or equal to 15 and 60 seconds if the power-to-flow ratio is greater than 15.

The allowable time, after the delay time, for all transients which lead to a power-to-flow ratio in excess of 2.5 is set at 2 minutes which is also the allowable time for a power-to-flow ratio of 2.5 given by Figure 3.1-1.

The limitation of allowable operating time to a value of 100 hours for all operations with a power-to-flow ratio above the curve of Figure 3.1-2 and below a value of 1.17 provides a conservative limit since this is the allowable time for a power-to-flow ratio of 1.17 given by Figure 3.1-1. Limiting the continuous operating time in this range of power-to-flow ratios to a value of 4 hours is additionally conservative. The 4 hours continuous operating time limit must be included as a fraction of the 100 hours allowable time.

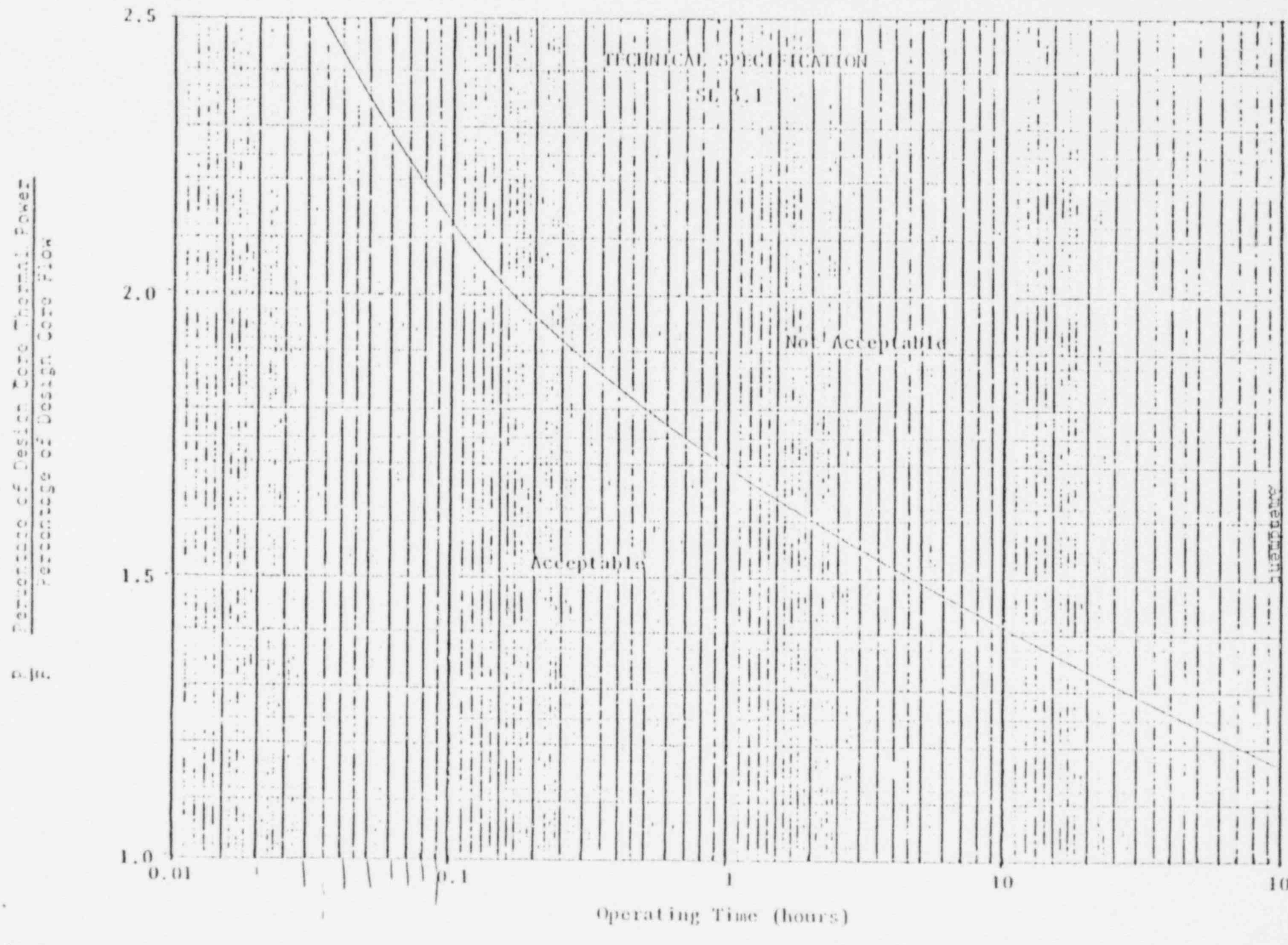

Fig. 3.1-1 Core safety limit (Jan. 1979)

TECHNICAL SPECIFICATION

SL 3.1

Fig. 3.1-2 Percentage of Design Core Thermal Power, P (%)