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Interim Report on ORNL Assistance in Evaluating a Licensing Request - Amendment of the Fort St. Vrain Reactor Tech Spec LCO 4.1.9

S. J. Ball

SUMMARY

The Fort St. Vrain reactor tech spec LCO 4.1.9 and its proposed amendments were reviewed. Because of both overly-conservative and non-conservative features of the current requirements, a new approach is suggested, along with a means of verifying its adequacy.

Objective

The objective of this task is to provide NRC Region IV with technical and analytical support in their evaluation of a request by Public Service Co. of Colorado (PSC) to amend the Fort St. Vrain (FSV) HTGR Technical Specification - Limiting Condition for Operation (LCO) 4.1.9. The intent of LCO 4.1.9 is to ensure that during low power and low flow operating conditions (0-15%) core region temperatures will be limited to acceptable maximum values. The major basis for the concern is that at low core flows (and hence low core pressure drops), the effects of higher buoyancy forces of the pressurized helium coolant in the cooler channels coupled with the higher flow resistances in the hotter channels may lead to flow stagnation and reversals in some channels. The uncertainties of the region heat removal processes under these circumstances make it desirable to ensure that region flow stagnation and reversals do not occur. The basis of the current LCO 4.1.9 is to specify a set of conservative operating limits for both startup and shutdown, hot and cold, and pressurized and not. NRC, PSC, and GA Technologies (GAT) have all identified problems with the consistency, accuracy, and conservatism of the current and interim technical specifications. It was concluded that an independent analysis should be done to provide a basis for the licensing action required to resolve questions about the operating limitations. Resolution of acceptable operating limits may result in changes to the FSV Technical Specifications in order to ensure conservative protective factors.

Background and Approach

The approach taken to help resolve the questions raised in determining acceptable operating limits makes use of an existing ORNL code (ORECA-FSV), which calculates the dynamic thermal hydraulic behavior of the FSV core, to explore the problems of flow stagnation and core overheating for a variety of representative and conservative startup and shutdown scenarios.

The FSV version of the ORNL ORECA code has been used extensively in code verification studies, and, in general, has shown good agreement with both FSV data and calculations by the GAT RECA code. In simulating typical startups, the ORECA calculation begins with a zero-power uniform-temperature core and follows user-input trajectories of total circulator flow, thermal power, primary system pressure, and core inlet temperature. Guidelines for typical startup scenarios were initially obtained from the FSV DC-5-2 (Issue C) manual both for startup from refueling conditions and for startup with full inventory. Subsequently, plant data logger records were obtained from PSC to get up-to-date information on startup and shutdown operating procedures, to check data consistency, and to determine how close the operating parameters approach the prescribed limits. For shutdowns, the power and flow rundown conditions are arbitrary user inputs. In both cases, orifice manipulation routines are executed to go from approximately equal-flow to equal temperature rise settings, or vice versa, at specified times. Other user inputs include the refueling region peaking factors and orifice positions and the various core and refueling region bypass flow fractions.

A watchdog routine was added to ORECA which detects violations of the existing LCO (both for LCO 4.1.9 Figs. 1 and 2 conditions), noting the beginning and ending times for the violations and, for the Fig. 2 case, the value of the maximum region temperature rise. An additional watchdog routine was added to look for violations of LCO 4.1.7, which governs adjustments of the core inlet orifice valves, as this turned out to be more effective in limiting core temperatures in some cases than did LCO 4.1.9.

The ORECA code includes a model of the dynamic response of the region outlet thermocouples, which have fairly long response times -- especially at the low flows associated with startup and shutdown. Calculations for LCO 4.1.9 of core thermal power and region temperature rises are made based on these simulated thermocouple measurements rather than "actual" region outlet temperatures, since the measurements are used by the operators to determine the coordinates on the two figures.

Example startup and shutdown runs were studies in some detail. Mag tapes with plant data logger outputs for the November 3, 1983 startup and the most recent (January 17, 1984) shutdown were adapted for use on ORNL computers, along with PSC's "HISTORY" program for reading, deciphering, printing, and plotting the data. PSC also supplied calculated region peaking factors (RPFs) at crucial points in the runs so that the ORECA code could be set up to simulate the runs.

The ORECA code was set up and run for the major "stopping points", and good agreement between the steady-state calculations and data were found. In each case the agreement was optimized by varying the assumed core bypass flow fraction, and the optimum bypasses were well within expected ranges.

The PSC HISTORY code was modified to do further investigations of possible problems with tech spec limitations. The LCO 4.1.9 and 4.1.7 watchdog routines added to ORECA were adapted to HISTORY and run with the startup and shutdown data. For LCO 4.1.9, flow "margins" (actual core flow/minimum allowable flow) are output when Fig. 1. (equal-flow orifice settings) is applicable, and region temperature rise "margins" (maximum allowable ΔT minus worst-case measured ΔT) are output when Fig. 2 (orifices anywhere) is applicable. For LCO 4.1.7, the worst-case margin (maximum allowable region outlet temperature minus the worst-case measured outlet temperature) is calculated both for the startup case (average core outlet <950°F) and for the conditions (>950°F) specified by Fig. 4.1.7-1. In the latter analysis, all region outlet temperature readings are taken at face value rather than using comparison regions for some, as is done in the most recent version of the tech spec.

Problems with the Current Tech Spec

There appear to be several basic problems and limitations with the restrictions and the bases for both the existing and temporarily-imposed LCOs. First of all, the idea of LCO 4.1.9 is to limit the maximum core temperature by ensuring that region flow stagnation will not occur. Since there is no direct way of measuring stagnation, the calculation needs to be fairly conservative and, for the sake of simplicity, cover a wide range of possible values for operating parameters such as RPFs and orifice positions, for example. Another simplification that increases the conservatism is making the LCO apply to both startup and shutdown conditions. These restrictions lead to numerous cases for which "normal" startup and shutdown operating paths would violate LCO 4.1.9 even though there would be absolutely no danger of overheating the fuel. It appears that the problem lies in the overly conservative approach that has been taken for specifying the range of allowable RPFs, intra-region maximum column power tilts, and region orifice positions for a given power level. In specifying the worst-case combinations of these parameters for determination of a minimum acceptable core coolant flow, one would typically come up with operating conditions that would either be almost impossible to arrive at, or at least would involve gross, and obvious, readily-detectable excessive region outlet temperatures.

While on one hand these conservatively-applied restrictions lead to unnecessarily severe operating limits, the other basic problem with the current specs is: assuring that stagnation will not occur doesn't assure that the core will not overheat. This is because predictable and stable region flow redistributions can occur in which high-RPF regions heat up and choke off much of their flow long before stagnation occurs. For example, in simulated cases using high RPF values (3.0), adherence to LCO 4.1.9 alone would have resulted in overheated fuel (>1600°C) even if equal flows were maintained, while total fuel failure temperatures (>2500°C) would be reached rather quickly if relatively low-resistance "equal-flow" orifice settings were assumed, allowing the regions' flows to redistribute such that the hotter regions had less flow. In some cases, proper consideration in the tech specs for limiting such excessive fuel temperatures are found in LCO 4.1.7, which limits all region temperature rises (ΔTs) to within 400°F (or less) of the arithmetic average outlet temperature. For average core outlet temperatures <950°F all ΔT's must be within 400°F of the average, and for average outlets >950°F, the more restrictive limits of LCO Fig. 4.1.7-1 apply.

An algorithm for detecting compliance to Fig. 4.1.7-1, which shows allowable mismatches between region outlet temperatures and the average core outlet, was applied to the FSV startup data. Some non-compliance times were detected for cases that were off-scale on the graph - i.e. where the curves were extrapolated to values of average core ΔT below 660°F. These were all cases where the measured region outlet temperatures were quite low (<1200°F), so there would not be any real problem with overheating. However, this does point out operating regions where there are apparently no applicable tech specs for limiting core temperatures.

Another basic problem with LCO 4.1.9 is due to the dependence of the sizes of the margins (or approaches to non-compliance) on the method of core flow calculation. Core flow is used directly as a margin parameter in LCO 4.1.9 Fig. 1, and figures into the power calculation for both Figs. 1 and 2. The data logger program generates several estimates of core flow that sometimes differ widely. The method of deriving flow used for the tech spec calculations should be clearly established, understood, and verified where possible. For example, in the FSV startup data, using the flow calculation from the reactivity status ("REACT") program (data logger list #188) the LCO 4.1.9 watchdog showed total non-compliance times after the actual startup of 0.2 hr (Fig. 1) and 6.2 hr (Fig. 2). However, if the HISTORY program "RX" flow calculation (data logger list #251) is used, the total time out of compliance was much less - 0.4 hr (Fig. 1) and 1.0 hr (Fig. 2). In none of these cases was the maximum core temperature near an unsafe limit nor were any regions close to a flow stagnation condition. Assuming the "RX" flow calculation to be correct, the periods of non-compliance were short enough such that no tech spec violations were detected.

There is also a much less significant problem for the very early (zero-power) stages of a startup. For example, in the FSV startup data, the LCO 4.1.9 watchdog detected periods of (Fig. 1) "violations" before the actual startup, when the reactor power was zero and the maximum core temperatures were <250°F. This indicates a need for clarification of the tech spec.

Suggested Alternative Strategies

An alternative LCO 4.1.9 which would better satisfy the intent of the tech spec (limit core temperatures) would have the region orifice positions set according to calculations of the RPFs (accounting for rod position), with verification of the success of the maneuvers made via measurement of region temperature rises. In cases where the total circulator flows are low, stipulations should be made about the absolute orifice settings such that significant flow redistributions due to heatup effects would be avoided. For such an LCO, a single upper-limit on power-to-flow ratio would probably be sufficient. As long as the temperatures did not get too far out of line, there could be reasonably long compliance times for correcting off-normal flows.

This general strategy was studied using the ORECA code in a variety of startup scenarios and operating conditions between 0 and 15% power. From these, the following general observations and conclusions could be made:

1) If there are some regions with very high RPFs (e.g. 2.0 - 3.0), there is no problem adjusting orifices to prevent excessive core temperatures for low powers (e.g. 1 - 5%), but as the power level increases, either a much higher flow-to-power ratio would be needed or the orifice positions would have to be dispersed widely. Typically, however, these very high RPFs are present only during control rod manipulations at very low power levels, so this should not be a practical operational problem. In any case, the control strategy should be to keep the orifice openings small, in general, which would reduce the tendency for gross flow redistributions and stagnation.

2) In the startup simulations, the tendency for flow redistribution was readily observable, and could be established from relatively simple tests. Once the extent of these redistributions are verified experimentally,

there should be no problem in specifying safe operating limits. Briefly, the tests would consist of establishing given low-power operating points (power, flow, and orifice configuration) and then making small changes (e.g., decreases) in flow. The higher-RPF region temperature rises would be expected to increase more than the average due to the region flow redistribution effects. As long as these redistributions are relatively small and predictable, there would be no danger of flow stagnation, and thus maximum core temperatures could be readily inferred from the measured region outlet temperatures.

3) The characteristics of this acceptable operating path could be established in one-time-only tests during a startup run, and could be applied to subsequent startups and shutdowns. The revised operating procedure would consist of a method for calculating desired orifice positions as a function of RPFs, and an allowable minimum flow-to-power ratio (which might have to be a function of power). The flow-to-power ratio requirements should account for the near-zero power case.