SAFETY EVALUATION REPORT
PUBLIC SERVICE COMPANY OF COLORADO
FORT ST. VRAIN NUCLEAR GENERATING STATION
DOCKET NO. 50-267

CORE REGION CONSTRAINT DEVICES

1.0 Background

Temperature flucutations have been observed in the Fort St. Vrain core on a number of occasions. The fluctuations manifest themselves as periodic variations in core region outlet temperatures with accompanying variations in steam temperature and changes in signal level on flux detectors. The fluctuations are core wide but with phase relationships from region to region such that average power and average temperatures remain relatively constant. Since the onset of fluctuations is a function of core pressure drop and pressure drop can be maintained at a sufficiently low value that fluctuations do not occur below the currently authorized level of 70% of full power, NRC has allowed continued routine power operations. To permit acquisition of diagnostic data, limited operations in a fluctuating mode has also been permitted, subject to surveillance and test limits specified in special test procedure, RT-500, which has been approved by NRC.

While the precise cause of the fluctuations is not fully understood, it appears from extensive analysis of data that it is related to hydraulically induced lateral motion of refueling regions coupled with thermal expansion/contraction of core and/or core support members. Each of the 37 refueling regions consists of seven columns of elements positioned at the bottom by dowels and tied together at the top by "keyed plenum elements". The main stream of coolant passes into each of the regions via an adjustable orifice, and a smaller bypass flow passes through gaps between the regions. Since the regions are not structurally tied to each other at the top, it is possible, at a sufficiently high core pressure drop, for sufficient pressure differences to develop across a region to induce lateral motion, thus triggering fluctuating

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behavior.

Since all available evidence suggested that such lateral motion was associated with fluctuating behavior of the core, PSCo by letter dated March 23, 1979, requested authorization to install region constraint devices (RCDs) into the core. These RCDs are designed to link together the 37 refueling reflector columns at the top plane of the core. In effect these ties control motion of refueling regions at the top plane, thus ensuring that bypass gaps remain approximately uniform in width. Thus stabilized, lateral motion is restrained, preventing large changes in gap size by random motion of regions or groups of regions within the freedom of motion possible for the unrestrained structure.

Eighty four RCDs are involved. These devices consist of triangular carbon steel segments with an inconel pin at each corner. Each assembly weighs about 200 pounds. These pins are inserted into the handling holes of the keyed plenum elements at the edges of adjacent refueling regions, thus mechanically interlocking them. They are held in place by their weight. The pins are sufficiently long to ensure that they remain engaged in the handling holes through all predicted differences in fuel column height between adjacent regions.

These devices have now been installed, and it is anticipated that the plant will be brought on line in early December, 1979. Our evaluation of the RCDs is summarized below.

2.0 Plant Operations with Region Constraint Devices

2.1 Nuclear Design

The RCDs will not affect reactivity of the core, since they are installed at the top plane of the core on the metallic keyed plenum elements. These elements are at a plane above the upper graphite reflector blocks, and the perturbation on reflected neutrons of the added RCDs is totally negligible. We concur in PSC's assessment that in the unlikely event an RCD pin should break and fall through reflector handling holes into the first row fuel block the power depression in that block would be less than 1%. This is well within the tolerances considered in the design and would have no discernible effect on core performance.

Because the RCDs are located at the outer periphery of the refueling regions, they cannot interfere with control rod operation, even if they are postulated to be displaced. The control rods are fully protected by their location at the orifice assembly in the center of each region.

2.2 Thermal Hydraulic Design and Fuel Performance

The staff has reviewed the RCD design and analysis detailed in PSCo's letter of March 23, 1979 to determine if thermal-hydraulic parameters of the existing Fort St. Vrain core will be perturbed such that existing safety analyses might be rendered invalid or incomplete. We found that the potential effects on core flow distribution and core pressure drop are insignificant and that there are insufficient buoyancy forces to levitate the RCDs under reverse flow conditions.

Even though not expected, the consequences of a loose RCD were analyzed (in response to a staff question). It was determined that a loose RCD could cause only a partial blockage of one of the four inlet parts of an orifice valve. That could cause a small reduction in the total region flow rate, but the safety consequences of a partial flow blockage of this nature are inconsequential when compared to the full orifice valve closure incident discussed in FSAR Section 3.6.5.1.

We conclude that there is reasonable assurance that the RCDs will have no adverse effect on the thermal-hydraulic behavior of the Fort St. Vrain reactor core, therefore, the existing safety analyses are not invalidated by thermal-hydraulic considerations.

Because the installation of the Region Constraint Devices is expected to result in a small decrease (1.2% maximum) in total gap flow, the effect (if any) on fuel temperatures should be beneficial. Consequently, because fuel temperatures during normal operation are anticipated to be about the same or slightly lower after RCD installation, fission product release should also be no different than before. Accordingly, we agree with PSC that the design fission products inventories presented in Section 3.7 of the FSAR should continue to serve as appropriate input (i.e., pre-accident circulating activity) source terms for accident analyses.

2.3 Structural Evaluation

2.3.1 Normal Operation

For normal operating conditions, the core structural evaluation focussed primarily on the margin of safety for the components with the highest stresses; viz., the upper plenum block keys, RCS bolts, and RCD pins. The normal operating loads include loads due to pressure gradients across regions and loads required to move regions to unfavored positions. ("Favored position" refers to the slight leaning of columns that occurs due to the stackup of normal tolerances and to irradiation shrinkage of graphite).

The maximum normal operating loads occur at the boundary of the core because both the pressure gradients and cumulative cross-core gaps can be at maximum there. The RCDs transfer the pressure gradient and irradiation shrinkage loads from the refueling regions to the hex reflector columns where the loads then pass through the hex reflector block keys into the permanent side, reflector blocks. According to PSCo's RCD safety analysis report, the maximum normal operating load for hex reflector block keys and RCDs at the core boundary is 1167 lbs. The failure mode for the reflector block keys is shearing of the threads of the screws which attach the key to the block. Since the maximum normal operating load (of 1167 lbs.) corresponds to a reported maximum shear stress in the threads of 2290 psi, and since the shear yield stress at 760^{o}F for the plenum element threads is 16,000 psi, we conclude that there is sufficient safety margin to provide reasonable assurance that the reflector block keys will not fail during normal operation.

With regard to the bending stresses in the RCD pins and loads in the RCD bolts, the reported analyses showed that irradiation shrinkage can produce RCD pin bending stresses as high as 36,700 psi. But since the yield stress of the Inconel 718 RCD pins is 134,000 psi at 760^{o}F, we conclude that there is reasonable assurance that the pins will not fail due to bending loads. Similarly, since the maximum tensile stress of 6,500 psi in the RCD bolts compares to a yield stress of 80,200 psi (at 760^{o}F), there is reasonable assurance that the RCD bolts will not fail during normal operation.

2.3.2 Abnormal Conditions

To determine the structural integrity of the core under abnormal conditions a seismic analysis of the core was performed, and the seismic loads were combined with the normal operating loads. A 0.05g Operating Basis Earthquake (OBE) and 0.10g Design Basis Earthquake (DBE) were examined.

The addition of the RCDs alters the seismic load path through the top plenum elements such that some of the loaa is transferred by the RCDs through the hex reflector block keys to the core boundary. As a result, the loads in the hex reflector block keys are increased and additional loads are produced in the RCDs. The load paths through the top plenum elements were established experimentally using a 1/10 scale two-dimensional plastic model. The model indicated that when the core is accelerated in a horizontal direction, the RCDs restrict horizontal translation and cause the fuel regions to pivot about the RCD pins. This pivoting closes the gaps between the fuel regions and causes the loads between the regions to be carried by compressive forces between the blocks to the boundary.

The maximum RCD seismic load computed to be 3,270 lbs. for the DBE; when combined with the normal oprating load, the total RCD load was 4,437 lbs. Likewise, the corresponding maximum combined loads for the reflector blocks keys was 4,847 lbs. When translated into stresses, the results indicated that the reflector block screw thread and RCD bolt stresses were well below yield (9,510/16,100 and 24,900/80,200, respectively). For the DBE, the RCD stresses in the outer filters were predicted to reach yield (134,000 psi). However, since the pin will not fail until all the fibers in a cross section reach yield (i.e., until the hinge moment is exceeded, and since the maximum safe shutdown earthquake pin moment was analyzed to be 11,200 in -lb. compared to a hinge moment of 19,500 in-lb., this indicated that there is a safety margin of 39% before pins would fail.

2.3.3 Dowell Shear and Fuel Element Impact Forces

The above discussion centered solely on the loads and stresses analyzed for the RCDs, themselves, and the reflector block keys to which the RCDs transmit loads directly. To determine how the addition of the RCDs would affect the graphite core components, we asked staff consultants in the Reactor and Advanced Heat Transfer Technology Group of the Los Alamos Scientific Laboratory to analyze the dowel shear forces and fuel element impact forces during a seismic event. The results of that analysis are presented in a letter report (Joel G. Bennett (LASL) to Michael Tokar (NRC), April 24, 1979). The LASL study indicated that the addition of the RCDs would be expected to decrease the maximum dowel shear forces for all cases except very low or very high frequencies (neither of which is considered credible for large measure structures of the FSV type). Thus, it was concluded that the addition of the RCDs should serve to make the Fort St.

Vrain core a more seismically safe structure.

3.0 Plant Operations and Testing

3.1 Cycle 2 Data

The Fort St. Vrain Reactor was shut down for refueling during the spring of 1979. Through examination of selected core components, it was confirmed that there had been no damage to core components owing to motion that is believed to occur when the reactor had operated in a fluctuating mode.

During the fall of 1979, further fluctuation tests were done. While detailed study of the test data is continuing, the staff and their consultants from Oak Ridge National Laboratory have had an opportunity to review the raw data. We also discussed the data with PSCo at a meeting at the site on November 19 and 20, 1979. In general, we have concluded that fluctuations which occurred during cycle 2 are similar to those in Cycle 1. Periods and amplitudes are similar, although fluctuations during Cycle 2 appeared to be more regular and core wide. The pressure drop threshold for onset of fluctuations also appears to be slightly lower. There is nothing in the data that would contradict the theory upon which the Region Constraint Devices were based as a corrective measure.

3.2 Operations with Core Restraint Devices

By letter dated December 4, 1979 PSCo described their plans for resumption of operations with the RCDs installed in the core. PSCo will perform tests to determine whether the RCDs have any effect on orifice calibration, power and flow distributions and core outlet temperature profiles. The data system for fluctuation tests will be calibrated and verified to be operable. Tests to determine whether the RCDs prevent the tendency for fluctuations will be deferred until the winter peak power demand has passed. The reactor will be brought to power with core pressure drop maintained at a value sufficiently low that fluctuations would not be expected, based on data acquired prior to installation of RCDs and be operated in a steady mode. During rise to power and such steady operations, control room instrumentation will be monitored for indications of fluctuations. Should they occur inadvertently, corrective measures will be taken to stop them; i.e., power reduction.

When tests are resumed to verify the effects of the RCDs, the test limits of RT-500 will be utilized. This procedure has been reviewed and found acceptable by the staff. The test sequence will be modified, however, in anticipation of the beneficial effects of the RCDs. Orifice adjustments will be made to establish a configuration at which fluctuations were observed at the lowest power in previous tests and power will be increased in 3% increments to 70% power in an attempt to induce fluctuations. Should operations remain stable, orifices will be readjusted to a higher core pressure drop and this sequence will be repeated until it is verified that stable operation can be achieved at 70% power with a pressure drop of about 4.5 psi. Operations above 70% power will not be permitted until the staff has reviewed the data acquired from these tests. Since the operational and test plans outlined by PCSo are essentially identical to those previously approved for the unrestrained core, we conclude that operations, as proposed, with installed RCDs is acceptable.

4.0 Conclusions

Based on our review of the potential effects of the RCDs on the core, the proposed operating and test plans, and the test data from Cycles 1 and 2, we conclude that the Fort St. Vrain reactor can be safely operated with installed RCDs up to the presently authorized level of 70% of full power.

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