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PBF PR-1 TEST EXPERIMENT SAFETY ANALYSIS

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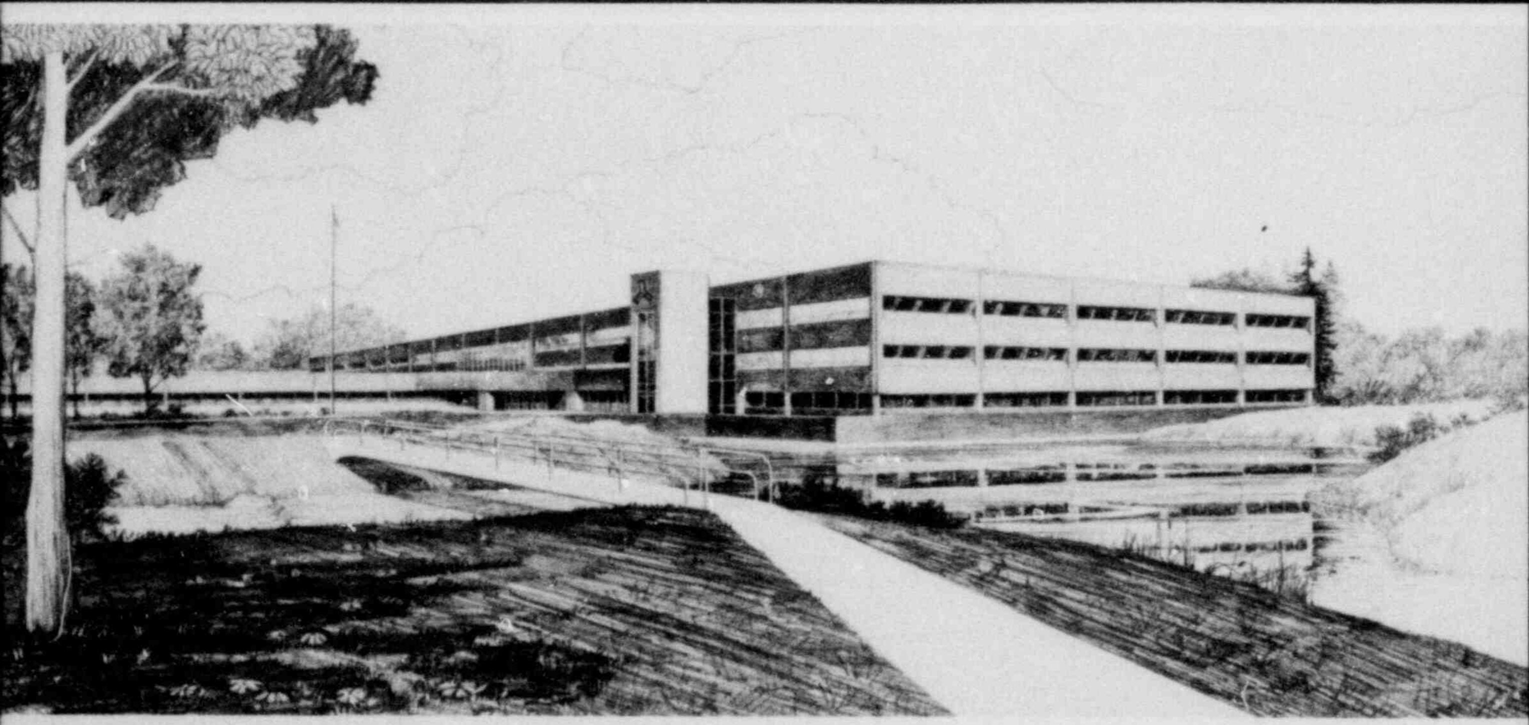
Idaho Operations Office • Idaho National Engineering Laboratory



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INTERIM REPORT

CONTENTS

1. Scope

This document defines the operating envelope and contains the safety analysis for PBF Test PR-1 described in the Experiment Operating Specification (EOS).

2. Basic Operating Control Documents

PBF Technical Specifications, CI-1238, Rev. 29.

Power Cooling Mismatch Series, Test PR-1, Experiment Operating Specification, EG&G-TFBP-5027 Rev. 1, January 1980, D. T. Sparks, R. W. Garner.

Test PR-1 Experiment Safety Analysis, EG&G-TFBP-5080, January 1980, S. R. Gossmann.

Experiment Operating Procedure, EOP-056.

Reactor Operations Manual.

PBF Standard Practices Manual.

3. Experiment Description and Operation

3.1 Introduction

Test PR-1 (PCM-RIA-1) will be performed in the Power Burst Facility (PBF) with four, BWR-type test fuel rods. Test PR-1 will involve; steady state operation to provide power calibration information, a series of power cooling mismatch (PCM) DNB cycles induced by reduction in coolant flow rate and a series of Reactivity Insertion (RIA) power excursions. In addition, steady state and power oscillation gap conductance data will be obtained to extend the data base for evaluating the effects of fuel pellet density, initial gap gas composition on gap conductance.

Specific objectives of Test PR-1 are to; (1) evaluate coolant flow and test rod power conditions at the onset of DNB for fresh fuel rods, (2) evaluate thermal-hydraulic conditions and temperatures at which return to nucleate boiling (RNB) is achieved, (3) evaluate test conditions leading to the onset of DNB and rewet for rods with collapsed cladding, (4) evaluate the potential for two-phase flow instabilities, and (5) evaluate the fuel pellet temperature distribution during low-energy RIA power excursions and provide additional data on collapsed, embrittled fuel and failure limits.

3.2 Experiment Design

Test PR-1 will be conducted with four separately shrouded fuel rods. The fuel rods, individual flow shrouds, and fuel rod instrumentation are supported by the test train in the PBF In-Pile Tube (IPT). The design characteristics of the test components are summarized in this section of the ESA.

3.2.1 Test Fuel and Flow Shrouds. The UO_2 (10% U-235 enrichment) test fuel rods nominal design parameters are detailed in

Table 1 of the EOS. The cladding material is zircaloy-2. One of the rods contains 61.35 g U-235, another contains 63.35g, and the other two contain 64.68 g U-235 each (Reference 1). The total U-235 content for the PR-1 test rods is therefore 254.06 g. The rod orientation and rod instrumentation are shown in Figure 1 of the EOS.

Each of the rods is contained in a circular zircaloy flow shroud with 19.3 mm inside diameter.

3.2.2 Test Train. The PR-1 test train positions and supports the four test fuel rods. The test train is of the 4X hardware design used in previous PBF tests. Major test train components are the IPT flow tube, the hanger rod, and the upper particle screen.

The coolant flow at the bottom of the test train is divided between the inside and outside of the rod flow shrouds by an orifice plate located at the bottom of the test train. All of the flow in and around the flow shrouds is channeled through the particle screen located at the top of the test train.

Detailed description of the test train is given in Reference 2.

3.2.3 Planned Experiment and Plant Instrumentation. Each test rod will be instrumented to measure the cladding surface temperature, fuel pellet centerline and off-center temperature, rod internal pressure, and cladding elongation. In addition, Rod 524-4 will be instrumented with cladding internal thermocouples for evaluating the perturbation effects of cladding external thermocouples and provide information on rewetting from film boiling conditions.

In addition to the instrumentation located directly in or on a test rod, instrumentation to determine test rod power, coolant conditions, coolant pressure drop, and local neutron flux are located on the shroud and test assembly.

The above instrumentation along with the plant instrumentation to be used for the test are described in Section 2 of the EOS.

3.3 Experiment Operation and Faults Identification.

This section of the ESA describes the various parts of the PR-1 test and identifies faulted conditions for further discussion in Section 5 of this ESA. The descriptions contained in this section of the ESA are almost identical to those in Section 3 of the EOS except that the ESA contains additional discussion for each part concerning the possible faults for each part.

Test PR-1 will consist of seven parts: (1) steady state operation over a range of PBF core power levels during which the test rod power densities will be determined and a calibration between test rod power density and SPND current will be obtained, (2) a preconditioning period that will provide information on the effects of fuel cracking on gap conductance values, (3) a power oscillation period during which the power will be oscillated about several nominal power levels, (4) a period during which the fuel rods will be "aged" and the conditions at the onset of DNB for fresh fuel rods will be evaluated, (5) a repeat transient operation period during which the return to nucleate boiling (RNB) conditions will be evaluated, (6) a period of transient operation to evaluate conditions at the onset of DNB and rewet on rods with collapsed cladding, and (7) a period of operation involving a series of step transients with increasing energy depositions to evaluate the fuel temperature distribution in low-energy RIA's and provide additional data on collapsed, embrittled rod failure limits. Specific details of each period of operation are discussed below. A schematic representation of the test sequence is shown in Figure 2 of the EOS for the power calibration and preconditioning portions, in Figure 3 of the EOS for the power oscillation portion of the the test, and in Figure 4 of the EOS for the transient operation including parts (4), (5), and (6). The RIA portion of the test, Part 7, will be initiated from low power at coolant conditions of 6.45 MPa system pressure, 538 K inlet temperature and 0.107 l/s coolant flow through each shroud. Energy insertions of 98, 163 and 240 cal/gram are proposed for the RIA testing. It is possible that following the repeated DNB transients of parts (4), (5), and (6), some of the rods may have failed. If two or more of the rods are determined to have failed, part (7) will not be run. It is estimated that the total test time will be approximately 90 hours, including RIA transients.

3.3.1 Power Calibration - Part 1. The objective of the power calibration portion (Part 1) of the test will be to relate the fuel rod power generation of each of the four rods to the PBF core power and the self powered neutron detectors (SPND's). The test rod power generation will be determined for each rod by thermal hydraulic energy balance under single phase (subcooled) coolant conditions.

During the power calibration, data will be obtained from which steady state gap conductance values can be determined. The power calibration will include test rod power densities that are the same as will be used during the power oscillation period so that a direct evaluation of the effect of pellet cracking, provided by the preconditioning period, can be determined. The planned coolant conditions were chosen by thermal hydraulic calculations to provide a high cladding surface heat transfer rate in the region where temperature measurements are to be made. During the first segment of the power calibration, coolant conditions will be 6.45 MPa system pressure, 538 K inlet temperature, and a volumetric flowrate 0.107 l/s through each flow shroud. During the second segment of the power calibration, the coolant pressure and temperature will be 7.17 MPa and 540 K, respectively, with the coolant flow between 0.20 and 0.52 l/s.

Based on the values obtained during previous gap conductance test with BWR design rods, the anticipated power calibration constant for the 10% enriched BWR-design test is 4.2 kW/m per MW of core power (EOS). The anticipated PBF operation and experiment coolant flow requirements for the power calibration portion of the test are summarized in Table 2 of the EOS. Power calibration data will be obtained for approximately 10 minutes at each of the reactor power levels ranging from approximately 3.1 MW to approximately 12.5 MW. The primary measurements required for calculation of the fuel rod peak power are: the coolant flow rate, the coolant temperature rise through the flow channel, the axial neutron flux profile, and the coolant inlet conditions (temperature and pressure). The time-integrated axial power profile will be determined by scanning the cobalt flux wires. The data from the SPNDs will be analyzed to determine the time-dependent axial power profile.

During this part of the test it is possible that test rod failure could occur as a result of overpower operation or low test rod flow or a combination of the two. Failure of the test rods under such conditions during this part of the test would have no more severe consequences than the rod failure expected in parts 4, 5 and 6 of the test (the DNB tests). The possible failure modes and protective requirements imposed by this ESA are discussed in Section 3.3.6 of the ESA.

The estimated figure of merit (FOM) for this test is 4.2 kW/m/MW. A measured FOM will be obtained using the measured test rod power and known reactor power. As a safeguard against continuing the test with insufficient knowledge about test characteristics beyond this point, this ESA imposes a 20% limit on the maximum discrepancy between the pre-test estimate and measured value of the FOM (Operating Envelope, Section 4, Item D).

3.3.2 Preconditioning Period - Part 2. Following the power calibration, the test fuel will be "conditioned" for approximately six hours. The conditioning period (Part 2) will induce fuel cracking to simulate the physical condition of the fuel after it has operated in a power reactor for a period of time. As shown in Figure 2 of the EOS, steady state power levels are planned to occur seven times during the preconditioning period. At each steady state power level, data will be obtained to estimate fuel cracking effects upon gap conductance as a function of conditioning time. Coolant conditions during the preconditioning period will be the same as were used during the power calibration period for the respective power levels. Specific durations at each steady state power level will be determined during operation by the TFBP Project Engineer.

The possible faults during this part of the test are the same as in part 6 of the test.

3.3.3 Power Oscillation - Part 3. Following the preconditioning period, the reactor will be operated at the required power levels (based on the power calibration) to provide nominal test rod peak power densities of 13, 26, 39, and 52 kW/m. At each power level the reactor will be operated at steady state for approximately 10 to 15 minutes to assure equilibrium conditions prior to the oscillations, and to obtain steady state gap conductance data.

Following the brief steady state operation at each power level, the core power will be sinusoidally oscillated. Table 3 of the EOS, provides a schedule of the planned oscillation conditions to be investigated during the power oscillation portion of the test. Analysis of data obtained on-line during Test PR-1 may indicate a need to change the specific oscillation conditions. For example, several intermediate power levels may be run to study the effect of gap closure on cladding temperature wave shapes. At each oscillation condition, the reactor will be oscillated for approximately 40 cycles to obtain sufficient data to reduce statistical uncertainties.

Coolant conditions during the oscillation portion of the test will be; inlet temperature of 477.61 K, inlet flow rate of 0.517 l/s, and an inlet pressure of 7.17 MPa.

Following the first series of power oscillations at 52 kW/m test rod power (approximately 17.5 hours on Figure 3 of the EOS), the test rod power will be reduced according to the following procedure; following a 15 minute hold at constant power and coolant conditions, the test rod power will be linearly reduced by 20% at a rate of 0.5% (of initial power) per second. This procedure will be repeated until the 13 kW/m level to initiate the repeat oscillation period is attained (6 transients). Following the repeat oscillations at 52 kW/m test rod power (approximately 23.5 hours on Figure 3 of the EOS), the test rod power will be reduced as previously described except that the ramp rate will be accomplished within 5 seconds.

In addition to the possible rod failure due to overpower and low flow, a power transient is possible during this part of the test. Reactor power will be oscillated using the transient rod control system. Failure of this control system could result in rapid transient rod withdrawal from the reactor core. It is shown in the faults and consequence section of this ESA (Section 5) that transient rod runaway during this part of the test will not result in exceeding reactor or IPT limits.

3.3.4 <u>Aging and DNB Onset Evaluation - Part 4</u>. Part 4 of the PR-1 test operation includes fuel rod aging and determination of the thermal-hydraulic conditions at the onset of film boiling. Aging of the fuel rods is a procedure used to prevent premature DNB by removing entrapped gases from the surface of the fuel rods. The procedure will be to operate the fuel rods in nucleate boiling for approximately one hour prior to DNB testing.

To evaluate the conditions for onset of DNB, the reactor will be operated at the power level required to provide a test rod peak power of approximately 47 kW/m. DNB will be induced by reducing coolant flow until an indication of film boiling is observed. At the first indication of DNB, the rod power will be rapidly decreased and the flowrate increased to return to nucleate boiling or subcooled conditions. This procedure will be followed for loop pressures of 7, 13, and 15.5 MPa. Following this sequence of three tests, the procedure will be repeated for system pressures of 13 MPa and 15.5 MPa to evaluate repeatability. Coolant temperature and flow conditions will be consistent with those required to provide the minimum inlet subcooling at each pressure condition, as constrained by loop operational limits. Approximate values for the coolant inlet temperature for the various system pressures are; 544 K (7 MPa), 590 K (13 MPa) and 608 K (15.5 MPa). The inlet temperatures specified assume an increase in IPT inlet temperature capability due to the variable speed pump modifications. If the modifications are not completed or inlet temperature capability not increased, temperatures as high as practicable within loop operating constraints will be attained.

The possible consequences of rod failure during this part of the test are discussed in Section 3.3.6.

3.3.5 Return to Nucleate Boiling (Rewet) Evaluation - Part 5. To help evaluate the conditions and temperature at which rewet from film boiling occurs, four DNB transients are planned; two at 13 MPa and two at 15.5 MPa system pressures. Film boiling will be initiated by reducing flow at constant power (47 kW/m) and rewet induced by a rapid flow increase. The test rod power and coolant inlet temperature will be held constant during each transient. The inlet temperature will be the same as in Part 4 for the respective pressures.

3.3.6 DNB, Rewet and Potential for Instabilities - Part 6. The repeated transients of parts 4 and 5 are expected to result in the zircaloy cladding collapsing onto the fuel pellet stack (waisting) and subsequently altering; (a) the conditions at the onset of film boiling, (b) the rewet behavior of the rods, and (c) the thermal response characteristics of the test fuel rods. To evaluate these changes, four additional transients are planned at the same pressures as Step 5. Film boiling will be induced by a flow reduction at constant power (47 kW/m) until all four rods have attained film boiling conditions. The fuel rods will be allowed to stabilize at a high temperature condition (approximately 15 to 30 seconds) and the flowrate will be increased to rewet the rods.

Following the four DNB transients (two transients plus repeats at the 13 MPa and 15.5 MPa pressure conditions), two to five additional transients will be performed to provide information on the potential for two-phase instabilities. The specific conditions (system pressure, test rod power and inlet subcooling) will be determined during the test. The relative conditions for Parts -4, -5 and -6 of Test PR-1 are illustrated in Figure 4 of the EOS.

During parts 4, 5 and 6 of the test, the test fuel rods will be operated under film boiling conditions. The film boiling operation, depending on the cladding surface temperatures and time spent in film boiling will tend to oxidize and embrittle the cladding. Cladding failure could occur during the film boiling operation or upon rewet. Neither fuel melting nor cladding melting is expected under the planned operating conditions of power and flow (Reference 3). Under overpower and excessively low flow conditions, however, rod melting could occur. A molten fuel-coolant interaction can be postulated to result in a coolant pressure pulse that would threaten the IPT pressure limits. Also, it can be postulated that hot or molten fuel could contact the IPT walls exceeding the IPT temperature limit. The failed fuel could also be washed out of the IPT and threaten the loop limits on U-235 inventory. In order to minimize the severity of the above postulated faults, this ESA imposes limits on reactor power and on low flow, and specifies minimum instrumentation requirements. It is shown in Section 5 of this ESA that none of the above postulated faults result in exceeding IPT or loop limits.

3.3.7 RIA Tests - Part 7. Assuming no more than two of the test rods have failed during the DNB cycles of Parts-4, -5, and -6 described above, a series of increasingly severe RIA's will be performed, with a maximum planned energy deposition of 240 cal/gram. Since an objective of the RIA tests is to obtain fuel temperature distribution information, the tests will not be performed if sufficient fuel instrumentation are not operational.

If the RIA [illegible] e performed, it is intended that the first test will be a [illegible] cal/gram test, the second 163 and the last 240 cal/gram. Coolant conditions of 6.45 MPa system pressure, 538 K inlet temperature, and 0.107 l/s shroud coolant flow rate are required prior to each RIA.

During this part of the test, it can be postulated that reactor limits on energy release could be exceeded if too much positive reactivity were inserted by the transient rods or if test fuel failure during the power burst produced a positive reactivity effect that would add to the transient rod reactivity and thereby exceed the reactor limit on energy release. An oversized power burst could result in exceeding IPT and loop limits if large coolant pressure pulses should occur, if molten fuel should contact the IPT, or if failed fuel washed out into the loop.

Protection against these faults is provided by limiting the amount of transient rod reactivity available for burst initiation. This ESA specifies control rod limit switch settings in the Operating Envelope (Section 4, Item E and F). In Section 5 of this ESA, it is shown that the above faults will not result in exceeding reactor or IPT limits.

4. Operating Envelope

All operations will be in accordance with the Technical Specifications requirements. Specific Operating Envelope requirements are as follows:

A. The reactor power scram setpoints for all steady state operations are:

PPS Scram Setpoint - 28 MW (nominal)
AEPL-1, 2, 3 First Shutdown Setpoint - 20 MW
AEPL-1, 2, 3 Second Shutdown Setpoint - 20 MW, with 0.0 sec delay

B. For burst operation (RIA portion of the test) the time-level scram (Item 2, Table 7.5-1 in Technical Specifications) shall be set at: Position 3 for the first burst, Position 7 for the second burst, Position 11 for the third burst.

C. A flow intercalibration is required prior to reactor operation at high power. The loop low flow shutdown (of the reactor) shall be that which corresponds to a single test rod shroud flow of 0.04 l/s. The IPT low ΔP alarm (dPR-10-3) shall be that which corresponds to a single test rod shroud flow of 0.04 l/s. If the IPT Low ΔP instrument alarms, the reactor shall be manually scrammed immediately.

D. A power calibration is required as part of the PR-1 test. The test data obtained from the power calibration procedure will be used to calculate test rod power and figure of merit (FOM). If the measured FOM for any rod differs from the expected FOM (4.2 kW/m/MW) by more than 20%, the test will be interrupted in order to assess the implication and consequences of continuing with such a discrepancy. The experiment test data, experiment instrumentation performance and reactor test data will be reviewed by PBF System Engineering to determine if the approved safety analysis would be invalidated. If the review and evaluation reveals hazards not originally considered in the ESA, the ESA will be revised accordingly and resubmitted for review and approval.

E. The Control Rod PPS Scram Limit Switches shall be positioned at 25.7 $\pm$ 0.1 in.

F. The Control Rod Operate Limit Switch positions will be determined after the low power critical control rod position and the FOM have been measured. Using these measured values the Control Rod Operate Limit Switches shall be positioned to limit control rod withdrawal to 0.16 $ above that required for the largest planned RIA burst. These switches shall be positioned to provide this limit prior to the start of the RIA portion of the PR-1 test.

G. If the measured IPT pressure during the RIA transients indicate an IPT source pressure pulse exceeding 23.45 MPa as a result of any of the power bursts, the need for a dimensional inspection of the IPT will be evaluated and reviewed with PRAC and ID before proceeding with further burst testing.

H. Minimum instrumentation requirements for this test are selected from the planned instrumentation complement in the EOS, Table IV.

The minimum requirements are as follows:

Instrumentation	Time Required to be Operable
The 69 MPa pressure Transducer (SYS PRES 70 OUT TT)	Through the RIA portion of the test
4 test rod shroud turbine flow meters	Until intercalibrated with loop flow (FRC-10-1C)
1 test rod coolant temperature rise ΔTC on rod with an operable turbine flow meter	Through power calibration

In addition, the 4 test rod shroud turbine flow meter outputs shall be displayed for monitoring by the experimental power reactor operator. If all 4 flow meters indicate no shroud flow, the reactor shall be manually scrammed immediately.

5. Faults and Consequences

The analysis presented in Reference 4 includes all reactor and loop faults considered in the Technical Specifications. The experiment dependent faults are discussed below.

5.1 Secondary Criticality

The limit on U-235 accumulation in the loop and attached systems is 400 g. The cumulative variable log shows 127 g U-235 in the loop prior to test PR-1. Reference 1 shows that the four PR-1 fuel rods contain a total of 254 g U-235. Assuming a 100% failure, dispersal and washout of the four PR-1 test fuel rods, the maximum U-235 loop inventory would then be 127 + 254 = 381 g. This test, thus, does not contain enough U-235 to make secondary criticality in the loop a credible accident.

5.2 Reactor and Test Fuel Fission Product Inventory

In estimating the reactor core and test fuel fission product inventory, the power histories in the EOS for the various parts of the test have been used. In Reference 1, the integrated reactor power for the entire test is shown to be 306 MWh. With 20% allowance for overpower operation, the result is 367 MWh for the reactor. This number is much less than the 28 MW for 48 hours or 1344 MWh allowed in the Technical Specifications.

Using the estimated peak FOM = 4.2 kW/m/MW, the test fuel integrated power for the four rods is 4 x 4.2 x 367 = 6169 kWh/m. With the fuel length of 0.9144 m, the result for the fuel rods is 5641 kWh = 5.641 MWh. The Technical Specifications allow 2 MW for 48 hours or 96 MWh.

The fission product inventory or equivalent MWh for the reactor core and for the test fuel rods has been shown above to be much less than the Technical Specifications limits.

5.3 IPT Overheating

It was postulated in Section 3.3 that hot fuel particles from failed fuel rods during steady state operation (parts 1 through 6) could produce local IPT overheating by contact with the IPT wall. The fault leading to fuel rod failure and release of hot fuel particles was operation under severe power-coolant-mismatch conditions. Such conditions existed during test PCM-1 where massive rod failure and some fuel melting occurred. The zircaloy test flow shroud and IPT flow tube did not melt through and no IPT damage occurred. In addition to these experimental results, the analysis of Reference 5 shows that it is extremely unlikely for hot fuel to melt through the shroud and flow tube and contact the IPT provided some flow is maintained through the IPT. In order to ensure some IPT flow at all times the Operating Envelope requires an automatic low loop flow scram. The IPT ΔP pressure sensor low ΔP alarm is used for a second reactor scram system under low flow conditions. When the low IPT ΔP alarm is activated, the operator is required to manually scram the reactor immediately. The setpoint for both of these systems is equivalent to 0.04 l/s through each shroud (In Reference 3 it is estimated that CHF will occur at about 0.08 l/s through each shroud). In addition, the Operating Envelope requires display and monitoring by the operator of the four shroud flow meters. As long as any of these flow meters indicate flow, flow through the IPT is assured. When none of them indicate flow the operator is required to immediately scram the reactor.

Three independent reactor power shutdown channels (the AEPL System) are required and set to reduce the severity of the power-coolant-mismatch conditions.

During the steady state portion of the test (Parts 1 through 6) it is considered extremely unlikely that overheating of the IPT by contact with hot fuel will occur.

This conclusion is based on the following considerations:

1. The experimental results of PCM-1 discussed above indicate that overheating of the IPT during severe PCM experiments is unlikely.

2. The analysis of Reference 5 shows that contact of hot fuel with the IPT is extremely unlikely provided some IPT flow is maintained.

3. Simultaneous failure of the three independent low flow shutdowns required (1 automatic, 2 manual) is unlikely.

4. Failure of the AEPL system to shutdown the reactor for excessive overpower operation is extremely unlikely.

During the RIA portion of the test (part 7) an oversized power burst could produce massive fuel rod failure and release molten fuel. Test RIA-ST-4 was such a test. The transient burst energy deposition in the RIA-ST-4 test rod was almost twice that expected for PR-1 even under faulted conditions for PR-1 (burst initiated from control rod operate limit switch position). In test RIA-ST-4, the molten fuel did not penetrate the flow shroud and hot fuel did not contact the IPT wall. On the basis of the RIA-ST-4 test results and the limits imposed in the ESA on burst reactivity by the control rod limit switch setting requirements, it is considered extremely unlikely that IPT overheating would result during the RIA part of the PR-1 test.

5.4 High Pressure in the IPT - Loop Coolant System

The RIA portion of test PR-1 will be performed with both thermal swell accumulators (TSA's) in service. In the two TSA configuration, the system has full design capability as detailed in Reference 6 with regard to pressure boundary integrity. The analysis in this section of the ESA is concerned with the safety of the IPT. In particular, it is demonstrated that neither the Technical Specifications source pressure pulse limit of 51.72 MPa nor the more restrictive 23.45 MPa limit of Reference 7 will be exceeded.

The maximum planned burst energy deposition in the PR-1 rods is about 240 cal/g for each rod. This is about the same energy depostion used in Test RIA-1-1 (Reference 8). The four RIA-1-1 rods were also individually shrouded. Failure of the RIA 1-1 rods did not produce a pressure pulse. The PR-1 rods having been subjected to film boiling operation will have embrittled cladding and probably failed cladding. With the PR-1 cladding in this condition, the rods are expected to fail at lower energy depositions than 240 cal/g. For this reason, pressure pulses for the PR-1 RIA tests are not expected.

One possibility exists for pressure pulse generation. If the cladding should crack, let the rods become waterlogged and then the cracks seal themselves, the RIA transient energy would be deposited in a waterlogged rod. Reference 13 shows that water logged rods (with good cladding) can produce pressure pulses in the coolant of about 14 MPa. In order to evaluate the maximum pressure pulses acting on the IPT, the accoustical analysis of Reference 1 modeled the PR-1 test including the four rods and shrouds, the hanger rod region above the shrouds, the outlet particle screen, the top of the IPT as a closed plane surface, and the bottom of the shrouds where the flow orifice is located. Applying a 14 MPa pulse of 1 msec duration at either the bottom or the center of each of the shroud coolant regions to simulate the failure of the waterlogged rods, the analysis results show that the test train geometry greatly attenuates the pulse amplitude. The coolant regions outside of the shrouds experience pressure pulses not exceeding 3.45 MPa. Even with a pressure pulse at the center of the shroud of 41.4 MPa, the coolant regions outside of the shroud do not experience pressure pulses exceeding 14 MPa.

This analysis shows that the 23.45 MPa source region (shroud region) pressure pulse IPT limit will not be exceeded and that even if the source region limit is exceeded, the IPT itself will not be subjected to pressure pulses exceeding 14 MPa.

5.5 IPT or Subpile Room Piping Failure due to High Reaction Force

This fault applies to the IPT and accoustic filter supports and is also applied indirectly to the subpile room piping. Since the lower IPT support and reactor coolant piping penetrate the reactor vessel bottom head, the consequences of a high reaction force in the IPT would not necessarily be limited to the IPT system.

The IPT design is based on conservative cases with regard to reflection and reinforcement of the source pressure pulse. Since the design pulse is not exceeded, the design reaction forces will not be exceeded. This fault is extremely unlikely.

5.6 Effects of Experiment Feedback Reactivity

A postulated fault during the RIA portion of PR-1 concerns the reactivity effect of test fuel failure and dispersal adding to the transient rod initiating reactivity and thereby producing a larger burst than intended. It is shown in Reference 9, that the reactivity effect of fuel failure and dispersal is negligible provided the dispersed fuel is contained in the small volume of the flow shrouds. The most violent RIA test performed in PBF was RIA-ST-4 with an energy deposition in excess of 500 cal/g and a resulting pressure pulse inside the shroud in excess of 34.5 MPa. The flow shroud in that test held together and retained the dispersed fuel. The PR-1 maximum power burst will be in the order of 240 cal/g and it is considered extremely unlikely that the flow shrouds would fail and not retain the failed fuel. In conclusion, it is considered extremely unlikely that a positive feedback reactivity effect due to fuel failure would significantly increase the strength of the power burst such that the reactor burst limit would be exceeded.

The following discussion scopes the available margin on reactor burst energy release. From the GAP-CON 2-3 test data, it is estimated that the low power critical control rod position will be about 18 inches. The control rod PPS limit switches are set to scram the reactor if the rods are withdrawn past 25.7 inches. If the burst is initiated inadvertently from the 25.7 inch position a reactivity of 2.94 $ would be inserted. From Reference 10, the corresponding reactor stable period would be 1.79 msec. The reactor transient energy release would be about 1000 MJ (Reference 11). Thus in the worst case, a margin of 1350 - 1000 = 350 MJ is available between this faulted condition and the reactor limit on transient energy release. The FOM for this test is about 1.27 cal/g/MJ (Reference 1). The maximum planned burst for PR-1 is about 240 cal/g. With the 0.16 $ allowance on burst reactivity in the operating envelope (control rod operate limit switch settings) the planned burst could be as large as 327 cal/g for the test rods or 257 MJ reactor energy release. This analysis shows that even if the maximum burst is inadvertently initiated from the control rod operate limit switch position an ample margin exists between the burst energy release and the reactor energy release limit.

5.7 Transient Rod Runaway During Power Oscillation

In Section 3.3.3 it was postulated that during the power oscillation part of the test, transient rod runaway could produce a power transient. The analysis of Reference 12 was performed to evaluate the severity of the resulting power excursion. The transient rods were assumed to produce a reactivity ramp of 4.20 $/sec and the PPS scram was set at 29.4 MW (28 MW nominal). The analysis shows that transient rod ejection from lower nominal (steady state) power levels results in larger transient energy releases but the initial reactor fuel energy is smaller. The net result is that the larger total energy releases (transient plus initial) occur for the highest initial power level. Such transients are shown in Reference 12 to not result in exceeding reactor limits even when the initial power level is taken at the maximum value of 29.4 MW. The power oscillation portion of the test will be performed with a nominal power of 12.5 MW and peaking during each cycle to 15 MW. The AEPL shutdown setpoints are set at 20 MW. It is thus shown that this part of the test will not result in exceeding reactor limits in the event of transient rod runaway.

6. Conclusions

The PR-1 test meets the acceptance criteria in Reference 4 which defines test operation accident consequences acceptable to EG&G Idaho, Inc. management for faults categorized by likelihood of occurrence.

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