EGG-TFBP-TR-5028

October 1979

PBF TC-1 TEST
EXPERIMENT SAFETY ANALYSIS

S. R. GOSSMANN

U.S. Department of Energy
Idaho Operations Office • Idaho National Engineering Laboratory

This is an informal report intended for use as a preliminary or working document

NRC Research and Technical
Assistance Report

Prepared for the
U. S. Nuclear Regulatory Commission
Under DOE Contract No. DE-AC07-76ID01570
FIN No. A6041

EG&G Idaho

8007290 174

EGG-TFBP-TR-5028
October 1979

PBF TC-1 TEST

EXPERIMENT SAFETY ANALYSIS

S. R. GOSSMANN

Review:

S R Gossmann 10/11/79
PBF Systems Engineering

C O Noucatte / SRG by [illegible] 10/11/79
PBF Facility Division

W G Lussie ~~10/11/79~~ 10/18/79
Power Reactor Advisory Committee

Approval:

10/11/79
TFBP Technical Support Division

CONTENTS

1. SCOPE 1

2. BASIC OPERATING CONTROL DOCUMENTS 1

3. EXPERIMENT DESCRIPTION AND OPERATION. 1

   3.1 Introduction 1

   3.2 Experiment Design. 3

      3.2.1 Test Fuel and Flow Shrouds. 4

      3.2.2 Test Train. 5

      3.2.3 LOCA Blowdown System. 6

      3.2.4 Planned Experiment and Plant Instrumentation. . . . 6

   3.3 Experiment Operation and Faults Identification 6

      3.3.1 Planned Pre-Blowdown Operating Conditions 7

      3.3.2 Power Calibration and Preconditioning Phases. . . . 8

      3.3.3 Blowdown and Quench Phases. 10

4. OPERATING ENVELOPE. 12

5. FAULTS AND CONSEQUENCES 15

   5.1 Reactor and Loop Faults, Excluding the Experiment. 15

      5.1.1. Site Boundary Dose 16

   5.2 Technical Specifications Requirements for the ESA. 17

   5.3 Analyses 17

      5.3.1 Quench Failure. 17

      5.3.2 Shutdown Margin 22

      5.3.3 Secondary Criticality 22

      5.3.4 LOC/MOD Cycle Use Factor. 24

CONTENTS (Cont'd)

5.3.5 Experiment Fission Product Inventory. 24
5.3.6 IPT Pressure and Reaction Force 24
5.3.7 Transient Rod Accident Simultaneous with Blowdown . 26
6. CONCLUSIONS 26
REFERENCES. 27

TABLES

I. Test TC-1 Henry Nozzle Throat Diameters and Locations. 29
II. PBF Technical Specifications Requirements for ESA. 30

FIGURES

1. Reactor Power Variation with Time During the Transient. 31

1. SCOPE

This document defines the operating envelope and contains the safety analysis for PBF Test TC-1 described in the Experiment Operating Specification (EOS), EGG-TFBP-5013.

2. BASIC OPERATING CONTROL DOCUMENTS

PBF Technical Specifications, CI-1238, Rev. 28.

Loss-of-Coolant Accident Test Series, TC-1, Experiment Operating Specification, EGG-TFBP-5013, September 1979, T. R. Yackle.

Test TC-1, Experiment Safety Analysis, EGG-TFBP-5028.

Experiment Operating Procedure, EOP-054.

Reactor Operations Manual.

PBF Standard Practices Manual.

3. EXPERIMENT DESCRIPTION AND OPERATION

3.1 Introduction

Test TC-1 is one in a series of Loss of Coolant Accident (LOCA) tests to be performed in the Power Burst Facility (PBF). The effects of externally mounted cladding thermocouples on the fuel rod thermal behavior during LOCA blowdown and reflood cycles will be investigated in the test. Potential thermocouple effects include: (a) delayed DNB, (b) momentary cladding rewets following DNB, (c) premature cladding rewet during a blowdown two-phase slug period, and (d) early cladding rewet during reflood. The two-phase slug period will be controlled by momentarily opening the hot leg valve. The slug will consist of lower plenum liquid that is sent through the flow shrouds and will be designed to quench the fuel rods at a rate that is similar to the slug experienced early in the LOFT L2-2 and L2-3 tests.

To investigate the effects of cladding thermocouples, the TC-1 test will consist of four LOFT-type fuel rods that were fabricated at Battelle and will be tested in the LOCA test train hardware. Each fuel rod will be instrumented with three internal fuel thermocouples located near the midplane of the fuel stack. The leads of some of these internal thermocouples will be installed in slots on the outside of the fuel pellets and the thermocouple tip will be resistance welded to the inside cladding surface. The remainder of the thermocouples will be placed approximately one mm into the fuel pellet within pellet holes. Two of the fuel rods will be instrumented with four external cladding thermocouples and will include LOFT-type thermocouple extensions to near the bottom of the rod. In this manner, a comparison will be made between the thermocouple response of rods with and without external thermocouples.

The test program will consist of two to four blowdowns that are similar to the LLR tests. Goal cladding temperatures for each blowdown will be between 900-1000 K with a two-phase slug sent through each flow shroud during blowdown. The initial test rod power will be about 39 KW/m and the PBF servo-controlled transient rods will be used to maintain a low power level throughout blowdown. Following blowdown, the reactor power will be maintained at about 2 MW for about 2 minutes as cladding temperatures increase to about 900-1000 K and reflood is initiated. There will be a maximum of four blowdowns depending upon available funds and schedule. Thermocouple effects will be investigated in the first test during blowdown and reflood with a nominal "LOFT-type" slug during blowdown and a nominal LOFT reflood rate. The test will be repeated up to three times to statistically verify the conclusions if meaningful thermocouple effects are identified during the first blowdown. If expected conditions are not established or thermocouple effects are not identified after the first blowdown (primarily during the two-phase slug), it will be recommended that the test conditions be modified rather than repeating a potentially meaningless test. Results will be compared with out-of-pile tests and should provide insight for future tests.

The test will be performed in five separate phases; loop heatup, preconditioning operation, blowdown, reflood, and quench. The tests will be sequenced as follows. The primary coolant loop conditions will be increased to the desired pressure and temperature. The test rods will be power cycled in the preconditioning phase and then operated at steady state for approximately 1-1/2 hours to build up the desired fission product inventory. The blowdown will follow, with a rapid depressurization of the PBF test train and LOCA system. The blowdown will use the same valve sequencing and initial reactor power as in LLR-5 except for the slug period when the hot leg is briefly opened and the cold leg closed. The depressurization, coolant density, and FCM will be the same as LLR-5. The test will be terminated with a reactor scram, reflood and quench followed by long-term cooling provided by the quench system.

3.2 Experiment Design

Test TC-1 will be conducted with four separately shrouded PWR type 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. Except for some minor differences, the Test TC-1 experiment design is the same as that of Test LLR.

3.2.1 Test Fuel and Flow Shrouds. The four TC-1 fuel rods (UO2, 9.9% U-235 enrichment) were fabricated by Battelle. (Reference 1.) The geometry of the active length of the fuel rods is identical with the LOFT fuel. LOFT cladding was utilized to fabricate the fuel rods. The fuel rod design characteristics are listed in Table I of the EOS. The LLR test rods had a U-235 enrichment of 9.5%.

Differences in the TC-1 fuel rod assembly compared with LLR (Reference 2) are: Battelle uses longer end caps, shorter bottom insulator, shorter fuel column length, no annular fuel and approximately the upper half of the fuel column has three equally spaced slots at 120° that are approximately 0.66 mm deep and 0.66 mm wide to accomodate internal thermocouples. The Battelle design uses shorter cladding, an internal zircaloy transfer piece that permits the internal thermocouple leads to transfer from near the cladding surface into the plenum spring annulus. The stainless steel upper rod adapter is longer. The overall result of these fuel rod differences relative to an LLR rod is:

(1) the rod internal void volume with slotted fuel pellets is greater than in an LLR rod, and

(2) the elevation of the top of the fuel active column is lower by 45.72 mm than in an LLR.

Each fuel rod will be encased within a fluted flow shroud as shown in Figure 1 of the EOS. The flow shrouds are Zircaloy-4 with an initial outside diameter of 25.4 mm, a wall thickness of 1.24 mm, and a flow area the same as the LOC-11, LOC-3 and LOC-5 shrouds.

Other than the U-235 enrichment and the flow shroud flow area differences between the TC-1 and LLR rods and shroud, the other design differences have no identified, possible safety consequences. The effect of the greater TC-1 rods U-235 enrichment in discussed in Section 5.3.2 of the ESA and shown to not present a much greater safety problem than in test LLR. The fluted flow shrouds used for TC-1 have a larger flow area than the circular flow shrouds used in LLR; however, it is shown in Reference 3 that the low flow set points for protection against CHF during the power calibration and preconditioning phases of TC-1 are adequate to provide the necessary protection if the set points are scaled up by the area ratio.

3.2.2 <u>Test Train</u>. The TC-1 test train positions and supports the four test fuel rods. Major test train components are the fuel rod support plates, IPT flow shroud (flow tube), two particle screens and the catch basket, several filler pieces, and the zircaloy hanger rod tube which also serves as the reflood line.

The IPT flow tube section in the central core region is made from zircaloy. The flux shaper used in the LLR test train has been removed for test TC-1. The effect of no flux shaper has been considered in the quench system failure analysis of Section 5.3.1 of the ESA. The results show no adverse effects due to the absence of the flux shaper.

All of the coolant passing the fuel rods is channeled through particle screens located in the lower and upper plenums of the test train. The maximum size of the screen openings for both screens is 0.889 mm (Reference 4.) The screen openings are smaller than the instrumented spool flow homogenizer screen openings (1.905 mm) as required in Technical Specifications 3.7 LCFO F (Item 1 of Table II in this ESA).

Detailed description of the test train is given in Reference 4.

3.2.3 LOCA Blowdown System. For Test TC-1, the PBF LOCA Blowdown system will be set up and operated to produce a cold-leg break by opening both cold-leg blowdown valves.

During the blowdown the IPT will depressurize through the Henry nozzles. Table I gives the proposed Henry nozzle dimensions as well as the Technical Specifications requirement for the Henry nozzle dimensions. The proposed values therefore meet the Technical Specifications requirement. This test will use the same Henry nozzles as used in Test LLR.

Detailed description of the LOCA Blowdown System is given in Reference 5.

3.2.4 Planned Experiment and Plant Instrumentation. The planned experiment instrumentation of the TC-1 test consists of devices to measure fuel surface and cladding surface temperature, axial length change, and coolant pressure, temperature, density and flowrate. The measurement and instrumentation descriptions are in Section 2.4 of the EOS.

Tables IX, X, XI, and XII of the EOS contain the plant instrumentation measurements that will be used in the analysis of test results.

3.3 Experiment Operation and Faults Identification

Section 3.1 of this ESA has briefly summarized the TC-1 test operation from beginning to end. Section 3 of the EOS contains the details of the experiment operating procedures for the various phases of the test. As stated in the EOS, the first part of test TC-1 (TC-1A) will be setup prior to blowdown with the steady state operating conditions used for test LLR-5 (Reference 6). If those operating conditions do not result in the desired test results, the conditions will be adjusted before TC-1B is performed. According to the TC-1 Test Project Engineer, it is likely that a successful test will result using the LLR-5 test conditions. However, it is possibly that conditions closer to those used for test LLR-4 will be necessary. The LLR Test ESA (Reference 7) showed that the LLR-4 conditions were more severe, relative to safety considerations, than the LLR-5 conditions. Because of the similarities between tests TC-1 and LLR, the safety analyses in this ESA will use the LLR-4 test results as an upper bound for enveloping the operation of test TC-1. This section of the ESA will discuss those portions of the operating procedure that have safety implications. Faulted conditions will be identified for further discussion in Section 5 of this ESA.

3.3.1 Planned Pre-Blowdown Operating Conditions. The preblowdown steady state operating conditions as specified in the EOS are:

A. Operation Based on LLR-5 test results:

a)	Reactor Power	14.5 MW
b)	Test Rod Power (FOM=2.72 kw/m/MW)	39.4 kW/m
c)	Flow per shroud	0.8 ℓ/sec
d)	Inlet Temperature	600 K
e)	Inlet Pressure	15.5 MPa
f)	IPT Inlet Flow	12.27 ℓ/sec

B. Operation Based on LLR-4 test results:

a)	Reactor Power	20.8 MW
b)	Test Rod Power (FOM=2.72 kw/m/MW)	56.6 kW/m
c)	Flow per shroud	0.8 ℓ/sec
d)	Inlet Temperature	600 K
e)	Inlet Pressure	15.6 MPa
f)	IPT Inlet Flow	12.3 ℓ/sec

Note that items d) and f) satisfy the Technical Specifications 3.7 LCFO E requirements for IPT inlet temperature and IPT inlet flow.

3.3.2 <u>Power Calibration and Preconditioning Phases</u>. Tables IV and V of the EOS show the approximate, planned, operating sequence for the power calibration and preconditioning phases of the test. As shown in the tables, the planned test rod power will be about 39.4 kW/m (about 14.5 MW reactor power). According to the procedure in the EOS, prior to the initial power escalation for each part of the test (TC-1A, B, C and D), the test inlet temperature, pressure and flow will have been brought to the desired preblowdown values and the loop and test train flow meters will have been intercalibrated. In Section 3.2 of the EOS, it is pointed out that it may be necessary to operate the reactor at some low power level (less than 3MW) during the heatup phase (before the power calibration phase) in order to bring the test inlet temperature to the 600K required for the test. In this event, the flow intercalibrations would then be performed after instead of before the initial power escalation. This change in procedure does not introduce safety problems for which there is no protection and thus is considered satisfactory for the following reasons. The EOS in Section 3.9 requires a reactor scram from two thermocouple circuits if the cladding temperatures measured during the power calibration and preconditioning phases exceed 700K. In addition, this ESA requires verification that there is flow through each shroud before the power escalation. (See Operating Envelope Section 4, Item K.) The purpose of this requirement is to provide a safeguard against starting the power escalation with a check valve (located at the top of each shroud) accidentally closed.

The Operating Envelope requires specific combination of instruments to be operable during the power calibration phase. The figure of merit (FOM) for this test is 2.72 kW/m/MW (axial peak) estimated from the LLR test. The maximum planned test rod power is 39.4 kW/m (14.5 MW reator power) based on LLR-5 conditions and

56.6 kW/m (20.8 MW reactor power) based on LLR-4 conditions. 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 estimated and measured FOM (Operating Envelope, Item J).

During this portion of the test, the transient rods will be at an indicated position of 40 in. (inserted 4 in. into the core, EOS Section 3.4). Transient rod system failure could eject the transient rods from the core producing a reactivity insertion of about +0.5$ and a relatively small power excursion. This fault is scoped by the analysis in Section 5.3.6 of the Faults and Consequences section of this ESA.

During this portion of the test, it is planned to operate with constant flow and to raise and lower power level as shown in Tables IV and V of the EOS. Test fuel melting or failure can be postulated as a result of unplanned flow reductions or operation at too high a power level or both. Such test fuel failures could result in damage to the IPT due to overpressure or overheating of the IPT walls and possible secondary criticality problems in some loop components if test fuel should wash-out into the loop and collect in those loop components. These faults are considered in the Faults and Consequences section of this ESA where safety margins are evaluated and protective system setpoints (low flow and power level) are determined. The Operating Envelope specifies the systems and setpoints to provide the necessary protection.

At approximately 15 minutes before blowdown the transient rod power level controller will be activated in preparation for the desired power control during the blowdown. During these 15 minutes, the power will be held at about 14.5 MW by the control system. The transient rods will remain approximately at the 40 inch position during this part of the test unless a control system failure causes them to move [illegible] out of the core rapidly. A second postulated control system failure would result in increasing power level to the first AEPL shutdown level (17.4 MW) without causing scram. These faults are analyzed in Section 5.3.6 in the Faults and Consequences section of this ESA. The Operating Envelope specifies the power level setpoints for protection against these faults.

3.3.3 Blowdown and Quench Phases. This phase of the TC-1 test starts at about 5 sec. before the blowdown with activation of the Start Sequence Button. The Programmable Function Generator (PFG) used to provide the power demand signal to the transient rod power level control is turned on at this time by the REDCOR. The power demand program is shown in Figure 1. As shown in the figure, the blowdown starts at about time zero. As shown, power will be held steady at the initial value (14.5 MW) until 1.5 sec. after blowdown. The power demand is then reduced down to about 2.0 MW in about 0.1 second and held at that value until about 20 sec.

In the control system input circuits, the PFG is followed by a power trim knob which allows the operator to vary power manually up or down relative to the 2.0 MW level output from the PFG. At about 20 sec. into the blowdown, the operator may make power level adjustments (most likely increasing power) in order to achieve the test rod cladding conditions specified by the TFBP Project Engineer. For the TC-1 test, the PFG will be set up to generate a -10 V signal corresponding to a power level demand of about 14.5 MW. This is the maximum PFG output available under normal operation of the device. The power trim knob will be initially set at a value of 1.0. The power multiplication range for this knob is 0.1 to 2.5 times the PFG output. Thus after the PFG output has decreased to about 2.0 MW, the operator could manually increase power to about 5.0 MW or reduce it to 0.2 MW. Between 20 and 100 sec after blowdown, reactor power could thus vary between 0.2 and 5.0 MW.

Another power control system failure is possible during this phase of the test. It is considered possible for the REDCOR signal to fail to start the PFG program. If this should happen, the PFG output would remain at the initial -10 V (14.5 MW) and the power level controls would hold that power level until the reactor is scrammed. Once the blowdown has started (about time zero in Figure 1), analysis in Reference 3, has shown that the test rod cladding would not reach melting temperatures in less than 4 sec if the reactor is not scrammed. To prevent possible IPT overpressure or overheating and possible secondary criticality in the blowdown tank, three independent shutdown channels (the AEPL System) will be required for this test. These shutdown channels will incorporate variable setpoints with a change in setpoint controlled by independent timers. For this test, the initial setpoints on all three channels will be 17.4 MW. One channel will change setpoint at about 9 sec from the blowdown sequence initiation. The setpoint would be reduced from 17.4 MW to 5.5 MW at about 4 sec after blowdown. The other two channel setpoint changes would be initiated by the isolation valve logic and the setpoint change from 17.4 MW to 5.5 MW would also occur at about 4 sec after blowdown. Thus, if the PFG should fail - the output does not decrease as programmed or if it should increase, the reactor will be scrammed at about 4 sec. after blowdown. This fault is further considered in this ESA (Section 5.3.1) under Faults and Consequences.

The other postulated control system failure during this phase of the test is transient rod ejection producing a power excursion during the blowdown. This is also considered in the Faults and Consequences section of this ESA (Section 5.3.1).

At about 100 sec into the blowdown, a preprogrammed reactor scram and reflood initiation should occur. Failure of the scram, reflood and subsequent quench could result in IPT problems due to overheating or overpressure in the event of test rod melting or rod failure. Also failure of quench could result in IPT overheating due to reactor gamma-heating of the IPT wall. The Faults and Consequences Section 5.3.1 considers these problems. The programmed reactor scram will be backed up by two independent delayed scrams. One is initiated by the isolation valve logic and the other by a low flow channel in the initial condition spool piece. Both of these scrams would occur at about 0.2 sec after the programmed scram occurs. Protection against the quench system failure will be provided by loop coolant injection at about 350 sec after blowdown. Loop coolant injection is initiated by a timer signal unless latched out by a signal set at 20 gpm cooling flow.

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 pre-blowdown operation are:

PPS Scram Setpoint - 28 MW (nominal)
AEPL-1, 2, 3 First Shutdown Setpoint - 17.4 MW

B. AEPL-1, 2, 3 Second Shutdown Setpoints:

AEPL-1, -2 - 5.5 MW with 4 sec. delay referenced to isolation valve logic

AEPL-3 - 5.5 MW with 9 sec. delay referenced to Start Sequence Button operation (5 sec. before blowdown).

C. A flow intercalibration is required prior to reactor operation above 3 MW. The loop low flow shutdown (of the reactor) setpoints on FRC-10-1 and FR-11-29-2R shall be that which corresponds to a single test rod flow of 0.6 ℓ/sec. The time delay on FR-11-29-2R shall be 99.9 sec. These setpoints shall be set prior to nuclear operation.

D. The programmed (REDCOR) reactor shutdown shall be at 104.7 sec. (time zero is at operation of Sequence Start Button).

E. The KS-11-32-1 (valves position scram) time delay setting shall be at 99.9 sec (time zero is at isolation valve closure).

F. The Programmable Function Generator (PFG) program shall be such that at the steady state power preceding the blowdown, the PFG output shall be -10 V. The manual trim power-control knob setting prior to blowdown shall be 1.0.

G. The timer for loop coolant injection (backup quench) shall be set at 350 sec (FS-11-14-3).

H. The initial demineralized water cooling flow setpoint (FIC-11-14-2) shall be set for 3.2 ℓ/sec.

I. The quench tank (11-M-3) pressure shall be set at a minimum of 0.9 MPa (PI-11-21-2). The quench tank low level valve close setpoint (LS-11-22-1 and LS-11-10-2) shall be set at 20% below initial level (LI-11-10-3) (Item 10, Table II).

J. A power calibration is required as part of the TC-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 differs from the expected FOM by more than 20%, the test will be interrupted in order to assess the implications and consequences of continuing with such a discrepancy. The experiment test data, experiment instrumentation performance and reactor test data will be reviewed by PBF Systems 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. Reactor operation shall not exceed ~~155~~ 217 MWh for the complete test series (TC1-A through TC1-~~D~~E).

K. Minimum instrumentation requirements for this test are selected from the planned instrumentation complement in the EOS, Section 2.4. The minimum requirements are as follows:

Instrumentation	Time Required to be Operable
1 test train pressure transducer out of the 4 required in the EOS	To blowdown initiation
*1 shroud turbine flow meter on each shroud (2 per shroud in EOS)	Prior to nuclear operation
1 shroud turbine flow meter	Until intercalibrated with inlet spool turbine meter, if operable, loop flow meter FRC-10-1 and LOCA flow meter FR-11-29-2C.
1 coolant temperature rise TC on rod with an operable turbine flow meter.	Through power calibration.

---

* One turbine flow meter on each shroud must be indicating shroud flow prior to nuclear operation to protect against accidental closure of the check valves. If no flow through a shroud is indicated, nuclear operations will be delayed until it can be verified that the required shroud flow is available.

L. Reactor power level shall be 100 KW or greater when activating the transient rod power level controller. The transient rods shall be set up for low speed operation.

M. Continued operaion with failed rods is permitted for all portions of test TC-1. Operation with failed rods will not result in IPT overheating. This conclusion is based on the analysis of Reference 15. The model used in Appendix B of Reference 15 is applicable to 4 individually shrouded rods. During test PCM-1, extensive rod failure occurred during high power operation (about 78 kW/m). The test train inlet and outlet particle screens where fuel particles collected did not fail (Reference 16) as a result of continued high power operation with failed fuel in the screens. The catch basket is farther removed from the high flux region than the particle screen. Melt through of the catch basket due to subsequent high power operation with failed fuel in the catch basket is less likely than for the particle screens. In the event of upper test train screen failure the other loop components are protected by the loop strainer.

5. FAULTS AND CONSEQUENCES

The faults and consequences for the TC-1 test are treated in the following categories; (1) reactor and loop faults which are neither experiment nor LOCA Blowdown System dependent, (2) items required by the Technical Specifications to be included in the ESA.

5.1 Reactor and Loop Faults, Excluding the Experiment

The analysis presented in Reference 8 includes all reactor and loop faults considered in the Technical Specifications, except part 3.7. Acceptable consequences are shown for faults which are not experiment dependent and not affected by the LOCA Blowdown System.

5.1.1 Site Boundary Dose. The site boundary thyroid dose, assuming no evacuation, is calculated in Reference 9 for a postulated reactor flow blockage (62 rod meltdown) occurring at the end of the TC-1 test. In Reference 10, flow blockage is shown to be the controlling design basis accident for site boundary dose. The postulated accident is the same as that in the FSAR except that actual operating history to date plus that projected for the TC-1 test is used. In performing this analysis, the following conservative assumptions were made in Reference 9:

(a) 25 days shutdown between the end of LOC-5 and TC-1*

(b) LOC-5 was performed according to the planned power history with 20% margin on MWh.

(c) TC-1 is performed according to the planned power history with 20% margin on MWh.

The results of the calculation are listed below:

Flow Blockage Accident	Dose, Rem
FSAR design basis	8.68
With no filtration and 100%/day building leak rate; operation as described above	0.33

---

* Reference 9 assumed 25 days shutdown; however 23 days shutdown is more consistent with the present test schedule. The margin between the calculated dose and the dose limit is large enough to permit the 23 day shutdown without further analysis.

The flow blockage accident is classed unlikely and the allowable dose (from ERDAM-0524) is 1.5 Rem, thyroid.

5.2 Technical Specifications Requirements For The ESA

The items required by the Technical Specifications to be included in the ESA are shown in Table II of this ESA.

5.3 Analyses

The following subsections of this section of the ESA provide the basis for the method of compliance to the Technical Specifications requirements of Table II. Where appropriate, the faults analyzed are categorized by likelihood of occurrence.

5.3.1 Quench Failure. This subsection considers the possibility of IPT damage due to overheating by contact with molten UO2 or reactor γ-heating and the possibility of damage due to pressure pulses generated by fuel failure as a consequence of quench failure during blowdown. The requirements of Items 2) and 3) of Table II are met by the analyses in References 11 and 3 and summarized in this section.

The analyses in Reference 3 conservatively estimate the test rod temperature following quench system failure for two postulated cases of power level control during the blowdown. The second case considers that at 5 sec prior to blowdown when the PFG program is started, control system failure raises power step-wise from 14.5 MW to 21.0 MW and holds at that value for 4 sec after blowdown when the reactor is scrammed by the AEPL Shutdown system. At 115 sec after blowdown, reflood and later quench cooling does not occur as planned. The first case considers that at 4 seconds after the blowdown during the planned power reduction starting from LLR-4 operating conditions the operator or some control fault increases power up to the three AEPL setpoints of 5.5 MW. Reflood and later quench initiation fails to occur as planned at 115 sec after blowdown. It is shown in Reference 3 that the conditions in the first case analyzed result in the highest test rod temperatures before and after quench failure and thus that case is the most likely to result in IPT damage. In both of the cases, the cladding and fuel centerline temperatures do not reach the melting point due to the assumed absence of coolant over the period 4 to 500 seconds after blowdown.

The analysis of Reference 3, case 1 is summarized as follows:

(a) At 5 sec before blowdown the Programmable Function Generator is activated. The preblowdown initial test conditions are the maximum for this test - the LLR-4 conditions. Reactor power is assumed to be at 21 MW which is above the first AEPL setpoint. This power level is held for 4 sec after blowdown by the control system then stepped down. In LLR-4 (Reference 6) a programmed scram occurred at 3 sec after blowdown reducing power. For the TC-1 analysis it is assumed that the power is reduced from 21 MW to 5.5 MW at 4 sec after blowdown and held at that value until the programmed scram occurs at 115 sec after blowdown. The initial temperature for the analysis were obtained from Reference 6. Between 4 and 115 sec after blowdown, the analysis assumes complete absence of coolant for the test rods. Heat losses from the rods occur by radiation to the flow shrouds. The rod heat sources are fission heat from the sustained 5.5 MW reactor power, decay heat and heat from a cladding metal water reaction at the cladding surface. The shrouds are cooled by radiation to the flow tube which in turn radiates to the IPT. The IPT wall is assumed to be at a constant high temperature of 800 K. The analysis calculates the fuel centerline and cladding surface temperatures for 500 sec after blowdown assuming that reflood and quench cooling at 115 sec has failed. The LLR-4 initial conditions for this case (Reference 6) are 1850 K for fuel centerline, 1100 K for cladding surface and 575 K for shrouds and flow tube temperatures. After about 12 sec without coolant, the fuel centerline has increased to about 1968 K and the cladding surface temperature has increased to about 1690 K. From that point on both of those temperatures decrease slowly so that after 500 sec without coolant, the fuel centerline in 1439 K and the cladding surface temperature is about 1400 K. The shroud temperatures starting at 575 K reach a maximum of about 1317 K after about 160 sec without cooling then decrease slowly to 1276 K after 500 sec.

(b) The conservative assumption made in this analysis are as follows:

(1) The initial maximum power level for the test is overestimated (21 vs. 17.4 MW) and held for 9 sec (5 sec before to 4 sec after blowdown). From 4 to 115 sec after blowdown, reactor power is assumed to be held at the maximum possible value 5.5 MW (AEPL set point). Analysis performed at 14.5 MW initial power would have resulted in lower fuel and cladding temperatures.

(2) The decay heat assumed for the analysis is based on infinite time reactor operation at 21 MW. The test plan only requires steady state operation at power to build up 78% of the maximum decay heat in the rods. The decay heat sources assumed in the analysis are therefore overestimated.

(3) All coolant is assumed to have been expelled from the IPT at 4 sec after blowdown.

(4) A minimum value for the view factors for shroud-to flow tube radiation energy transfer is assumed. This would result in overestimating shroud temperatures and cladding surface temperature.

The above analysis has shown that more than 500 sec from blowdown without cooling water must elapse before cladding melting temperature would be approached. UO2 temperatures at that time would be about 1660 K below UO2 melting and the cladding about 700 K below melting. With the requirement for LCI at 350 sec after blowdown and without cladding or UO2 melting, the assumption that hot fuel does not contact the IPT wall and overheat the IPT is valid.

In Reference 7, the effect of transient rod runaway accompanied by the effect of blowdown reactivity was analyzed for the LOFT Lead Rod Test (LLR). The results for the LLR test showed that transient rod runaway from high power (29.4 MW, PPS Scram Setpoint) or from 1 MW did not deposit enough energy in the test rods to produce fuel melting or fuel failure. Those results apply to the TC-1 test with an additional level of conservatism. The maximum possible power level for TC-1 is 17.4 MW (AEPL setpoint). A power excursion starting from this lower power level would deposit less energy in the test rods than in the case analyzed in Reference 7. Reference 7 showed that LLR rods would not fail due to a power excursion due to transient rod runaway and blowdown reactivity effects. Since the conditions considered for the LLR tests are equal to or more severe than those possible for the TC-1 test, the LLR test ESA conclusion that fuel melting or fuel failure is not likely also applies to the TC-1 test.

The analysis of Reference 11 considers the case of the IPT walls overheating due to reactor gamma heating after blowdown. The analysis conservatively assumes the inner IPT wall to be adiabatic after blowdown. In applying the results of that analysis to TC-1 the following conservative assumptions will be made. The pre-blowdown power is assumed to be 21 MW (AEPL first Scram Setpoint in 17.4 MW). At 4 sec after blowdown the power will decrease step-wise to 5.5 MW (AEPL second scram Setpoints) and stay at that level until the programmed scram time of 115 sec. From 115 sec to 350 sec the decay power will be taken as 1.26 MW (6% of the initial power) and held constant until loop coolant injection occurs at 350 sec. The total integrated power after blowdown is thus 21x4 + 5.5x111 + 1.26x235 = 991 MW-sec. Figure 2 of Reference 11 then shows that for the initial steady state power of 21 MW prior to blowdown and a total of 991 MW-sec generated after blowdown, the 811K IPT wall temperature limit would not be exceeded. The same figure shows that about 1200 MW-sec for 30 MW initial operation would be required to raise the IPT temperature to the 811K limit, thus, a substantial safety margin is available.

LLR test results (Reference 6) and the analyses in this section show that the pressure would not exceed the pre-blowdown value of 15.5 MPa during the blowdown. These results indicate that the following two Technical Specification requirements are met:

(1) 3.7 SL B; LOCA Blowdown System pressure limit of 25.8 MPa is not exceeded (23.4 MPa plus 10% margin) (Item 2, Table II).

(2) 3.7 LCFO J; the 20 sec minimum blowdown time requirement is satisfied (Item 6, Table II).

All of the above analyses in this section for estimating the possibility of fuel rod melting and fuel failure show that fuel failure is not expected during blowdown. The transient rod failures assumed could be considered anticipated faults. Quench system failure is considered unlikely. Failure of the three independent scrams at 115 sec is considered extremely unlikely. Considering the conservatism in the analyses and the fault categories for the postulated failures, it is concluded that IPT damage due to overheating or large pressure pulses is extremely unlikely.

5.3.2 Shutdown Margin. Technical Specification part 3.7 LCFO G (Item 4, Table II of this ESA) requires that the reactor and experiment configuration be such that shutdown is possible with blowdown and one stuck control rod. The analyses cited in the Technical Specification Bases show that, for the existing reactor core configuration, voiding the IPT when it is water-filled has a greater reactivity worth than voiding the IPT when it contains fuel. The analyses show that for voiding the initially water-filled IPT with one stuck control rod the shutdown margin is about 1$.

It is required by Technical Specification 6.7 LCFO (4) that (without reference to voiding) the shutdown margin be at least 3$ and the reactor not be critical with one stuck control rod. Experiment results reported in Reference 12 show compliance for the existing reactor core configuration.

Operating experience with the LLR test (U235 enrichment of 9.5%) and test LOC-3 and LOC-5 with 12.5% U235 enrichment and with all three tests having approximately the same IPT coolant conditions has shown that the shutdown margin was satisfied. Test TC-1 with 9.9% U235 enrichment and coolant condition the same as for the LLR tests is scoped by the LLR, LOC-3 and LOC-5 coolant conditions and U235 enrichment and thus test TC-1 would also satisfy the shutdown margin requirements.

The TC-1 experiment does not involve alteration of the analyzed reactor core configuration; therefore, no experiment constraints on coupling effects are required.

5.3.3 Secondary Criticality. The limit on U235 accumulation for blowdown experiments is 500 g total in the experiment and blowdown tank (Item 5, Table II). For operation prior to blowdown the limit for dispersed fuel in the loop and attached systems is 400 g. This limit is imposed by section 9010 of the Safety Manual because the criticality evaluation for the PBF loop and attached system (excluding the LOCA modification) does not meet the current Safety Division Standards, Section 9030 of the Safety Manual. The 400 g limit regardless of Safety Manual limit, is considered safe, since the minimum conservatively calculated critical limit for any loop component is 600 g (Reference 13).

The cumulative log for U235 in the loop shows 127 g for all previous tests except LOC-5. During the LLR-3 Test one fuel rod failed apparently because of water logging. Approximately one-half of a fuel pellet was lost (0.5 g U235, Ref. 14). No fuel was lost during the LLR-SO, LLR-5, LLR-4, LLR-4A, LOC-3 and LOC-5 Tests. During the last LOCA test in PBF, test LOC-5, no rod failures are believed to have occurred and thus no fuel is believed to have been lost from the test rods. The preliminary test data for LOC-5 indicate that the internal rod pressure sensors maintained essentially normal pressure readings during the entire test and thus cladding integrity was not breached. Without cladding failure, fuel losses are not possible. During test TC-1, the maximum cladding surface temperatures planned would not exceed 1000 K. The EOS requires automatic intiation of the quench or reflood system during the blowdown if cladding temperatures exceed 1200 K. Because of the low temperatures rod failures are not expected during TC-1 unless the rods are defective and become water logged as in the one rod that failed during LLR-3.

It is shown in Reference 3, that the maximum U235 content for the TC-1 test is 210g. If all this U235 is assumed to be lost during the test and washed out into the loop, the loop U235 inventory would then be 337g which is within the most conservative loop limit of 400g. If the 210g went into the blowdown tank, the tank inventory would then be 210.5g (assuming the total 0.5g from the LLR-3 rod failure went into the blowdown tank). The only possiblity of exceeding the limit on U235 accumulation would then have to result from gross over enrichment of the TC-1 test rods. An enrichment error of over 19% on each of the 4 rods would be required in order to exceed the 400g loop limit. An error of that size is considered unlikely. It is also considered unlikely that total failure of all four rods would occur and that the test train particle screens would fail and allow total wash-out of the fuel to the loop. In conclusion it is considered extremely unlikely that the U235 accumulation limits on either the blowdown tank or the loop could be exceeded during any phase of test TC-1.

5.3.4 LOC/MOD Cycle Use Factor. In Reference 3 it is shown that through the TC-1 test, the maximum use factor for blowdown operation will be 0.84 and the maximum use factor for heatup and cooldown cycles will be 0.115. In arriving at these two values, the analysis in Reference 3 included four blowdowns and four heatup and cooldown cycles. The requirements of Item 6, Table II (A Technical Specifications requirement) are thus met.

5.3.5 Experiment Fission Product Inventory. The fission product inventory for the TC-1 test fuel has been estimated in Reference 3 using the power history given in Tables IV and V of the EOS for all four parts of the test (TC-1A through TC-1D). Neglecting the planned 11 hour shutdown between each part of the test, the total MWh for the four parts is 1.22 MWh. With a 20% allowance for uncertainty in the FOM and rod power, the integrated power is 1.47 MWh. The Technical Specifications limit (Item 7, Table II) for fission product inventory in terms of MWh for unirradiated rods is 2MW for 48 hours or 96 MWh. The experiment fission product inventory for TC-1 is then well within the Technical Specification limit.

5.3.6 IPT Pressure and Reaction Force. Item 8, Table II requires an evaluation of IPT pressure and reaction force.

This section considers the possibility of IPT and related systems damage due to large pressures and reaction forces as a result of fuel rod failure during the steady state operations preceding the blowdown.

The low flow setpoints on two instruments (paragraph 4.0 C) are selected to prevent high cladding temperature prior to blowdown. The analysis in Reference 3 shows that at about 600 K CHF starts at 0.43ℓ/s per rod. The low flow setpoints correspond to 0.6ℓ/s per rod. From the EOS the normal flow at power prior to blowdown is 0.8 ℓ/s rod. The referenced analysis was performed for a rod power of 63 kW/m which is 60% above the planned test power for the rods and 10% above the first AEPL shutdown setpoint. Based on the above, meltdown of fuel and cladding prior to blowdown is considered unlikely during the steady state operation.

During the TC-1 test the transient rods will be in service controlling reactor power before the blowdown. Failure of the transient rods power level controller could eject the transient rods from the core at the steady state power level of 14.5 MW.

In the LLR ESA (Reference 7, Section 4.3.6) the severity of the resulting power excursion was evaluated. It was concluded in the LLR ESA that the resulting test rod fuel temperatures would be too low for fuel melting and the energy deposition would be too low for rod failure in comparison to the RIA Scoping Tests results.

The application of these LLR analyses to TC-1 is valid because of the following reasons:

(a) Both tests have the same steady state operating condition, i.e., power levels, FUM, coolant conditions

(b) The transient rods are at the same initial position before the assumed runaway thus the resulting reactivity ramp and power excursion would be the same for both tests.

Considering the analysis results for steady state operation and for the power excursions due to transient rod runaway it is concluded that a pressure rise approaching the 23.4 MPa limit or a significant reaction force as a result of fuel failure is extremely unlikely.

5.3.7 Transient Rod Accident Simultaneous with Blowdown. Item 9 of Table II requires demonstration that the combined effect of transient rod runaway and voiding due to blowdown for the experiment is less severe than the combined effect of transient rod runaway and voiding due to TSA rupture disk failure. In particular, it is necessary to show that the voiding reactivity insertion rate in the active core region of the IPT for the blowdown experiment is smaller than the voiding reactivity insertion rate in the active core region for the TSA rupture disk failure. In Reference 7 (LLR ESA, Section 4.3.7) it was shown that the LLR blowdown reactivity effect satisfied the Technical Specification requirement. The initial TC-1 blowdown transient is expected to be the same as the initial LLR blowdown transient since the coolant conditions, test train design and Henry nozzles are the same. The maximum voiding reactivity insertion rate occurs at the start of the blowdown and not at some later time during the blowdown when some differences will occur due to the hot leg valve action to be used in the TC-1 test. The TC-1 blowdown voiding reactivity rate satisfies the Technical Specifications requirement.

6. CONCLUSIONS

The TC-1 Test meets the acceptance criteria in Reference 8 which defines test operation accident consequences acceptable to EG&G Idaho, Inc. management for faults categorized by likelihood of occurrence.

REFERENCES

1. F. E. Panesko, "Product Specification TC-1 Fuel Rods," TTPS 025, Rev. 1, Aug. 28, 1979.

2. PBF/LOFT Lead Rod Test Program Experiment Operating Specification, TFBP-TR-302, Rev. 1, Jan. 1979, D. J. Varacalle, Jr.

3. EDF-PBF-1404, Miscellaneous Analyses for TC-1 ESA, S. R. Gossmann, Oct. 4, 1979.

4. W. P. Polkinghorn, S. B. Letson, PBF/LOFT Lead Rod Test Experiment Configuration Specification, ES 50364 A, Dec. 7, 1978.

5. L. D. Kirol, PBF LOCA Blowdown Modification, System Design Description, ANC-70042 Rev. A (26 April 1977).

6. PBF/LOFT Lead Rod Program Tests LLR-3, -4, -5 Quick Look Report, TFBP-TR-315, D. J. Varacalle, Jr. and R. W. Garner, April 1979.

7. PBF LOFT Lead Rod Test Experiment Safety Analysis, TFBP-TR-305, S. R. Gossmann, E. V. Mobley, Dec. 1978 with DRR's: TFBP-191, March 29, 1979; TFBP-189, March 20, 1979; TFBP-177, Feburary 1, 1979; TFBP-170, Jan. 1, 1979.

8. Ltr. H. B. Barkley to R. E. Wood, HBB-134-76, PBF Technical Specifications, July 16, 1976.

9. Ltr. H. K. Peterson to S. R. Gossmann, HKP-71-79, NSB Thyroid Inhalation Dose for PBF Flow Blockage Accident following TC-1 Operation, Sept. 14, 1979.

10. EDF-PBF-1235, Radiological Safety Analysis for RIA 1-2, Nov. 15, 1978, E. V. Mobley.

11. EDF-PBF-1200, In-Pile Tube Gamma Heating with Blowdown, Sept. 21, 1978, R. J. Loyl.

12. CI-1262, July 1974, Nuclear Startup and Statics of PBF Reactor, paragraphs II.4, III.5 and III.6.

13. Ltr. E. E. Burdick to R. L. Benedetti, PBF Loop Minimum Critical Masses, EEB-100-78, Oct. 12, 1978.

14. Ltr. R. R. Hobbins to R. L. Benedetti, HOBB-18-79, Fuel Loss from LLR Rod 312-3, March 23, 1979.

15. TR 608 TA 47, PBF In-Pile Tube Integrity During Molten UO2 Release from a Single Fuel Rod, R. L. Chapman, N. E. Pace, March 14, 1975.

16. EDF-PBF-1045, PBF PCM-1 Test Train, May 15, 1978, R. L. Ooley.

TABLE I

TEST TC-1 HENRY NOZZLE THROAT DIAMETERS AND LOCATIONS

Nozzle Designation	Location	Throat Diameter (mm)
FE-11-1-1	Hot leg	14.22
FE-11-1-2	Hot leg	13.56
FE-LR-C-1*	Cold leg	12.47
FE-LR-C-2*	Cold leg	23.90

*FE-LR-C-1 replaces FE-11-1-3

*FE-LR-C-2 replaces FE-11-1-4

Technical Specification 3.7 LCFO F Requirements (Item 1, Table II)

FE-11-1-1,-2,-3,-4 shall not exceed 24.13 mm diameter.

FE-11-1-2 shall not be less than 12.70 mm diameter.

TABLE II

PBF TECHNICAL SPECIFICATIONS REQUIREMENTS FOR ESA

Applicable Specification	Subject	Method of Compliance*
1) 3.7 LCFO F	Nozzle and Screen sizes	Paragraph 3.2.2 for screens and paragraph 3.2.3 for nozzles
2) 3.7 SL-A,B	High temperature, pressure (during blowdown)	Analysis per paragraph 5.3.1
3) 3.7 LSSS A	Delay time, setpoints	Analysis per paragraph 5.3.1, Operating Envelope
4) 3.7 LCFO G, 6.7 LCFO (4)	Coupling and shutdown margin	Analysis per paragraph 5.3.2
5) 3.7 LCFO H	Secondary criticality (Blowdown Tank)	Analysis per paragraph 5.3.3
6) 3.7 LCFO J	Use factor (cyclic loads), minimum blowdown time	Analysis per paragraph 5.3.1, 5.3.4
7) 3.5 LCFO E	Fission product inventory (experiment)	Analysis per paragraph 5.3.5
8) 3.5 SL-B	IPT pressure and reaction force (preblowdown)	Analysis per paragraph 5.3.6
9) 3.7 LCFO I	Transient rod accident and IPT voiding	Analysis per paragraph 5.3.7
10) 3.7 LCFO C	Quench tank pressure and level	Analysis per Reference 3 and Operating Envelope, Item I

---

* Paragraphs in this ESA except Item 10.

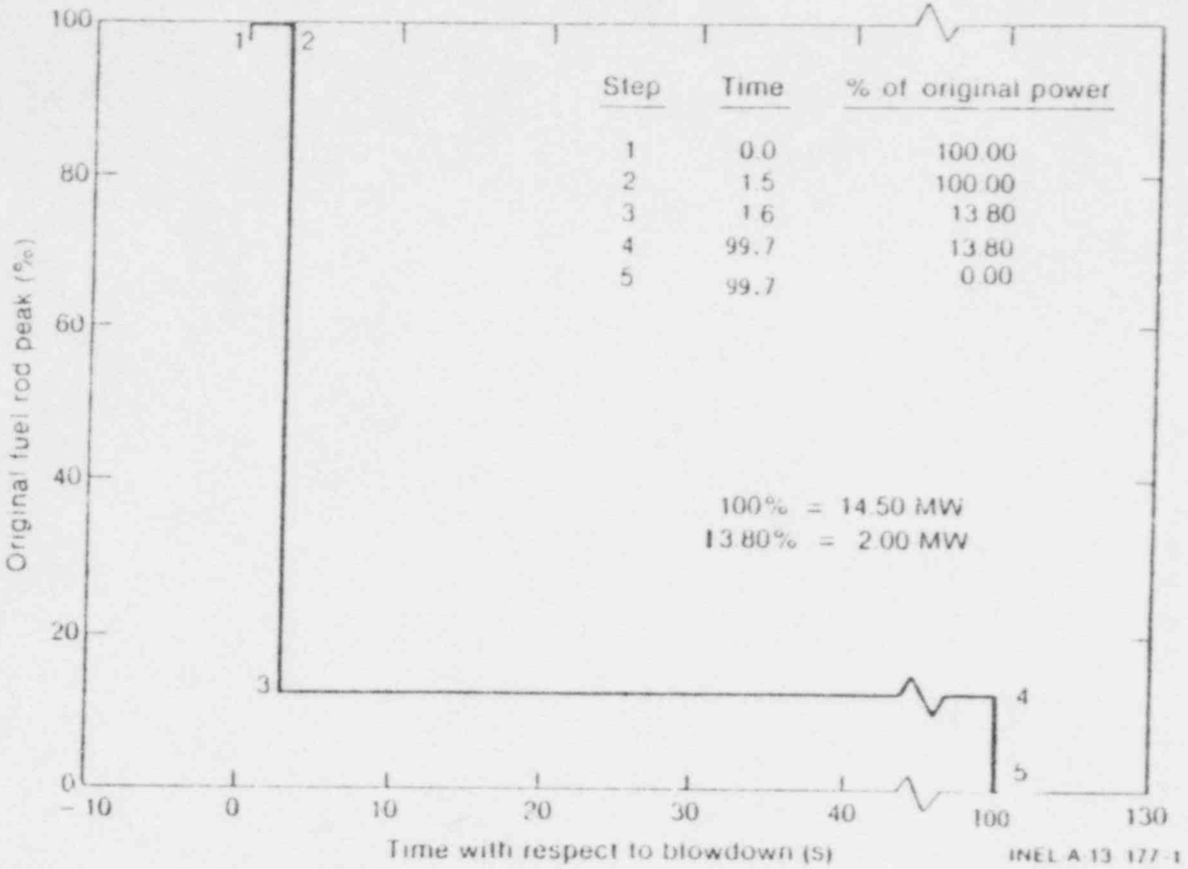

Fig. 1 Reactor power variation with time during the transient.