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PBF LOC-5B TEST
EXPERIMENT SAFETY ANALYSIS

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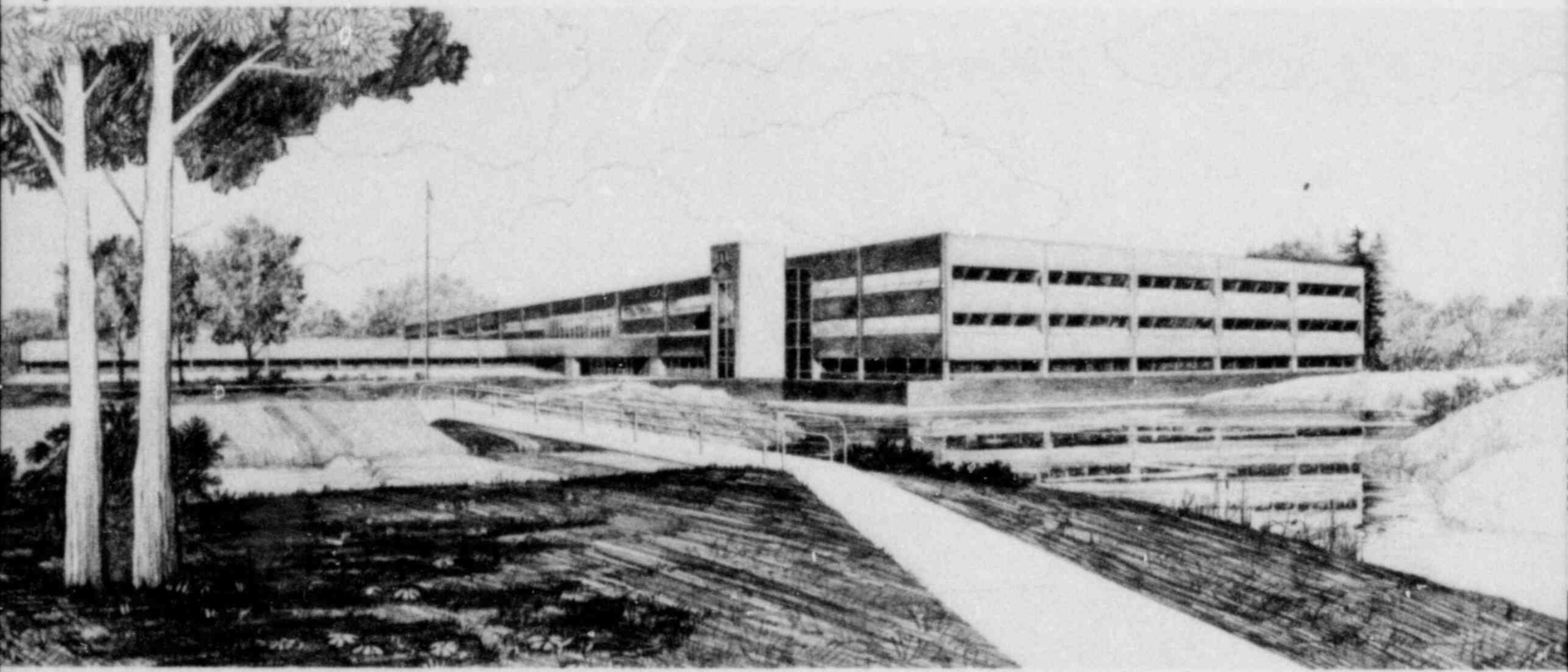

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CONTENTS

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. 3

3.2.2 Test Train. 4

3.2.3 LOCA Blowdown System. 5

3.2.4 Planned Experiment and Plant Instrumentation. . . . 5

3.3 Experiment Operation and Faults Identification 5

3.3.1 Planned Pre-Blowdown Operating Conditions 6

3.3.2 Power Calibration and Preconditioning Phases. . . . 6

3.3.3 Blowdown and Quench Phases. 8

4. OPERATING ENVELOPE. 11

5. FAULTS AND CONSEQUENCES 14

5.1 Reactor and Loop Faults, Excluding the Experiment. 14

5.1.1. Site Boundary Dose 14

5.2 Technical Specifications Requirements for the ESA. 15

5.3 Analyses 16

5.3.1 Quench Failure. 16

5.3.2 Shutdown Margin 21

5.3.3 Secondary Criticality 22

5.3.4 LOC/MOD Cycle Use Factor. 23

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

5.3.8 Test Operation with Test Rod Cladding Geometry Changes. 27

6. CONCLUSIONS 29

REFERENCES. 30

TABLES

I. Test LOC-5B Henry Nozzle Throat Diameters and Locations. . . . 33

II. PBF Technical Specifications Requirements f[illegible] 34

FIGURES

1. Operating Sequence for LOC-5B 35

2. Reactor Power Variation with Time During the Transient. 36

1. SCOPE

This document defines the operating envelope and contains the safety analysis for PBF Test LOC-5B described in the Experiment Operating Specification (EOS).

2. BASIC OPERATING CONTROL DOCUMENTS

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

Loss-of-Coolant Accident Test Series, Test LOC-5, Experiment Operating Specification, TFBP-TR-309, Rev. 1, August 1979, T. R. Yackle; DRR-TFBP-209, Aug. 22, 1979; DRR-TFBP-222, October 31, 1979, DRR-TFBP-211, September 4, 1979. DRR-TFBP-224, Nov. 16, 1979

Test LOC-5B, Experiment Safety Analysis, EGG-TFBP-5043, November 1979.

Experiment Operating Procedure, EOP-055.

Reactor Operations Manual.

PBF Standard Practices Manual.

3. EXPERIMENT DESCRIPTION AND OPERATION

3.1 Introduction

Test LOC-5B is one in a series of Loss of Coolant Accident (LOCA) tests to be performed in the Power Burst Facility (PBF). The behavior of four PWR fuel rods during the postulated conditions for a double-ended cold-leg break LOCA, with peak cladding temperatures stabilizing in the β - phase transition range, will be investigated during Test LOC-5B. Cladding ballooning with relatively large strain to failure is expected on all four rods. The cladding failure expected would produce small axial cracks in the cladding with some release of fission products. The generation of cladding fragments or UO2 fragments during blowdown is not expected.

The test will be performed in four separate phases: loop heatup, preconditioning operation, blowdown, reflood and quench. The primary coolant loop condition will be increased up 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 the test conditions similar to those expected in a PWR during a double-ended cold-leg break. During the blowdown, the test rods will continue to be heated by controlling reactor power (at about 1.62 MW) using the transient rod (TR) power level controller. The test will be terminated at about 50 seconds after blowdown with a reactor scram, reflood and quench cooling.

Test LOC-5B and Test LOC-5 are almost identical in design and in the planned test performance. The differences between the two tests are relatively minor and are summarized as follows:

1) Three of the four LOC-5B test fuel rods are the same rods used in LOC-5. These three rods have therefore experienced one nuclear blowdown. The fourth LOC-5B rod is a new one replacing the LOC-5 rod which experienced a small cladding crack during the LOC-5 test with zero or negligible loss of

UO2 (Reference 23). The new LOC-5B test rod is not as completely instrumented as the other three rods (Reference 1 and the EOS); however, the rod and flow shroud contain adequate instrumentation for measurement of rod power and figure of merit (FOM).

2) During the blowdown, the reflood flow rate for LOC-5B will be greater than used during LOC-5.

Because of the similarities between the LOC-5 and LOC5B test, the majority of the LOC-5 ESA (Reference 22)discussions and conclusions apply completely to the LOC-5B ESA. The differences between the two tests requiring additional analysis for LOC-5B are considered in the appropriate sections of this ESA. This ESA includes an additional section relative to the LOC-5 ESA. This additional section (5.3.8) considers the potential problem of using the three rods from LOC-5 which have already experienced one blowdown.

3.2 Experiment Design

Test LOC-5B 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). Except for some very minor differences, the Test LOC-5B experiment design is the same as that of Test LOC-5.

3.2.1 Test Fuel and Flow Shrouds. The UO2 (12.5% U-235 enrichment) test fuel rods consist of two rods that were previously irradiated to about 16,000 MWD/t in the Saxton reactor and two unirradiated rods of Saxton design. The cladding material is zircaloy-4. The fuel rod designation and burnup are given in Table I of the EOS. The as-fabricated nominal design characteristics of the fuel rods are given in Table II of the EOS.

The unirradiated rods are contained in fluted stainless steel flow shrouds, whereas the irradiated rods are contained in fluted zircaloy flow shrouds. The flow shroud characteristics are given in Table III of the EOS.

A plan view of the fuel rod orientation, flow shrouds and instrumentation within the IPT is shown in Figure 1 of the EOS.

3.2.2 Test Train. The LOC-5B 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), the flux shaper, two particle screens and the catch basket, several filler pieces, and the zircaloy hanger rod tube.

The IPT flow tube section in the central core region is made from zircaloy. The flux shaper is located within the central section of the flow tube to flatten the axial power profile over a 310 mm section in the central core region.

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 1). 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).

Detailed description of the test train is given in Reference 1.

3.2.3 <u>LOCA Blowdown System</u>. For Test LOC-5B, 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 Henry nozzle dimensions as well as the Technical Specifications requirement for the Henry nozzle dimensions. The values therefore meet the Technical Specifications requirement. This test will use the same Henry nozzles as used in Test LOC-5.

Detailed description of the LOCA Blowdown System is given in Reference 3.

3.2.4 <u>Planned Experiment and Plant Instrumentation</u>. The planned experiment instrumentation of the LOC-5B test consists of devices to measure fuel rod surface and centerline temperature, plenum pressure and temperature, axial length change, and coolant pressure, temperature, density and flowrate. The measurement and instrumentation descriptions are detailed in Sections 2.4 and Tables X, XI, and XII of the EOS.

Table VI of the EOS contains 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 LOC-5B 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. 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 pre-blowdown steady state operating conditions as specified in the EOS are:

a)	Reactor Power	25.5 MW
b)	Test Rod Power (FOM=2.1 kw/m/MW)	53.5 kW/m
c)	Flow per shroud	1.0 ℓ/sec
d)	Inlet Temperature	590 K
e)	Inlet Pressure	15.51 MPa
f)	IPT Inlet Flow	13.94 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 Power Calibration and Preconditioning Phases. Figure 1 shows the approximate , planned, operating sequence for the power calibration and preconditioning phases of the test as described in the EOS. As shown in the figure, the maximum test rod power will be about 53.5 kW/m (about 25.5 MW reactor power).

In Figure 1, at time 8 h, the test inlet temperature and pressure have been brought to the desired preblowdown values. At that same time, the loop and test train flow meters will be intercalibrated. Each shroud has two turbine flow meters - one at the top and one at the bottom of the shroud. After the flow calibration, the shroud flow will be set at the pre-blowdown value. Each shroud has a check valve at the top. As a safeguard against starting the power escalation shown in Figure 1 with a check valve accidentally closed, this ESA requires verification that there is flow through each shroud before the power escalation (see Operating Envelope Section 4, Item K). The Operating Envelope also requires specific combination of instruments for the test rod power measurement to be operable during the power calibration phase.

In Figure 1, the power calibration and fuel preconditioning covers the time interval starting at 9 h to about 16.5 h. During this time period the highest test rod power planned is 53.5 kW/m. The estimated figure of merit (FOM) for this test is about 2.1 kW/m/MW (axial peak, Page 24 of Reference 20). With this FOM, the highest reactor power planned is about 25.5 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 an 11% 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 Figure 1. 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 25.5 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 in or out of the core rapidly. A second postulated control system failure would result in increasing power level to the first AEPL (Reference 4) shutdown level (28 MW) or to the maximum PPS Scram level 29.4 MW (28 MW nominal) 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 <u>Blowdown and Quench Phases</u>. This phase of the LOC-5B 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 2. As shown in the figure, the blowdown starts at about time zero. As shown, power will be held steady at the initial value (25.5 MW) until 2.5 sec. after blowdown. The power demand is then reduced down to about 6.5 MW in about 0.3 sec., then in a series of ramps further reduced to about 1.73 MW at 12 sec. after blowdown, and finally reduced to 1.62 MW at about 20 sec. The sequence for this phase is available in more detail in Table VIII of the EOS.

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 1.62 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 LOC-5B test, the PFG will be set up to generate a -10 V signal corresponding to a power level demand of about 25.5 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 1.62 MW, the operator could manually increase power to about 4.05 MW or reduce it to 0.16 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 (25.5 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 2), analysis in Reference 21, Section A has shown that the test rod cladding would not reach melting temperatures in less than 5 sec if the reactor is

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* The LOC-5B EOS does not require this operator adjustment of power; however, in the safety analysis this procedure was assumed and shown to be safe. Should it be necessary to raise or lower power, the procedure has thus been covered by the ESA.

not scrammed. To prevent possible IPT overpressure or overheating and possible secondary criticality in the blowdown tank, three independent shutdown channels will be required for this test. The details for these channels are provided in Reference 4. 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 28 MW. One channel will change setpoint at about 10 sec from the blowdown sequence initiation. The setpoint would be reduced from 28 MW to 5.5 MW at about 5 sec after blowdown. The other two channel setpoint changes would be initiated by the isolation valve logic and the setpoint change from 28 MW to 5.5 MW would also occur at about 5 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 5 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 50 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 γ-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 - 28 MW

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

AEPL-1, -2 - 5.5 MW with 5 sec. delay referenced to isolation valve logic

AEPL-3 - 5.5 MW with 10 sec. delay referenced to Start Sequence Button operation.

C. A flow intercalibration is required prior to reactor operation above 3MW. 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 0.63 ℓ/sec. The time delay on FR-11-29-2R shall be 50.2 sec. These set points shall be set prior to nuclear operation.

D. The programmed (REDCOR) reactor shutdown shall be at 55 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 50.2 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 0.966 MPa (PI-11-21-2). The quench tank low level valve close setpoint (LS-11-22-1 and LS-11-10-4) shall be set at 30% below initial level (LI-11-10-3) (Item 10, Table II).

J. A power calibration is required as part of the LOC-5B 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 (2.1 kw/m/MW) by more than 11%, 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 235 MWh.

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 high power rod 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 high power rod coolant temperature rise ΔTC on rod with an operable turbine flow meter.	Through power calibration.

In addition, 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.

5. FAULTS AND CONSEQUENCES

The faults and consequences for the LOC-5B 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 6 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 7 for a postulated reactor flow blockage (62 rod meltdown) occurring at the end of the LOC-5B test. In Reference 8, 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 LOC-5B test is used. In performing this analysis, the following conservative assumptions were made in Reference 7:

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

(b) The assumed LOC-5B power history is a constant 33.6 MW for 7 hours with a total integrated power of 235 MWh. By comparison, the planned power history (Figure 1) only has 125 MWh integrated power.

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	1.45

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. Most of the LOC-5 analyses in Reference 21 apply to LOC-5B

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 9 and 21 and summarized in this section.

The analyses in Reference 21, Section B conservatively estimate the test rod temperature following quench system failure for three postulated cases of power level control during the blowdown. The third case considers that, up to the time for reflood initiation (50 sec), the power level control has been in accordance to plan (Figure 2) without the operator adjustment of power. 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 25.5 MW to 29.4 MW and holds at that value for 5 sec after blowdown when the reactor is scrammed by the AEPL Shutdown system. At 50 sec after blowdown, reflood and later quench cooling does not occur as planned. The first case considers that at 5 seconds after the blowdown during the planned power reduction 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 50 sec after blowdown. It is shown in Reference 21, Section B that the conditions in the second 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. The temperatures calculated for case 1 after quench failure are only slightly lower than for case 2. During the first few seconds, however, the temperatures for case 2 are much higher than for case 1. In all of the three cases, the cladding and fuel centerline temperatures do not reach the melting point due to the assumed absence of coolant over the period 5 to 500 seconds after blowdown.

The analysis of Reference 21, Section B, case 2 is summarized as follows:

(a) A power level control system fault occurs at 5 sec before blowdown with activation of the Programmable Function Generator. The power level is assumed to increase above the 28 MW setpoint of the three AEPL channels to the maximum PPS setpoint level (29.4 MW) without causing a scram. The reactor power is assumed to remain at 29.4 MW until 5 sec after blowdown when the AEPL setpoint drops to 5.5 MW and scrams the reactor. From that time on (5 sec after blowdown) the analysis assumes complete absence of coolant for the test rods. Heat losses from the rods occur by radiation from the rods to the flow shrouds. The rod heat sources are decay heat and the energy from a postulated cladding metal water reaction. The shrouds are cooled by radiation to the flux shaper which in turn radiates to the flow tube. The flow tube radiates to the IPT wall which 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 has failed.

The initial conditions for this case are 2690 K for fuel centerline temperature, 1910 K for cladding surface temperature and 575 K for shroud, flux shaper and flow tube temperatures at 5 sec after blowdown. At about 1.5 sec later, the cladding surface temperature increases to a maximum of 2043 K. From that level the cladding surface temperature decreases slowly to about 1540 K in about 180 sec then increases slowly to about 1590 K after about 500 sec from blowdown. The fuel centerline temperature never exceeds the initial 2690 K and at 500 sec from blowdown it has a value of about 1640 K. This analysis shows that more than 500 sec after blowdown would have to elapse without any cooling water for the test before fuel and cladding temperature would approach the melting points. The Operating Envelope (4.0, item G) conservatively specifies the Loop Coolant Injection, LCI (or back-up quench) delay time of 350 sec after blowdown. With loop coolant injection occurring at this time and with the conservative assumptions made in determining the time for LCI, test rod cladding melting is considered unlikely and UO2 melting is even less likely.

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

(1) Power level is assumed to increase from 25.5 MW to 29.4 MW which in turn postulates failure of the AEPL system shutdown at 28 MW. Analysis performed at the 28 MW power level would have resulted in lower fuel and cladding temperatures.

(2) The test fuel is heated by constant decay heat from 5 to 500 sec after blowdown at a value which overestimates the decay heat level for that period of time.

(3) The cladding surface is heated directly by a constant metal-water reaction heat source for the whole time interval and the strength of the heat source is overestimated.

(4) All coolant is assumed to have been expelled from the IPT at 5 sec after blowdown.

(5) A minimum value for the view factors for shroud-to-flux shaper 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 1500 K below UO2 melting and the cladding about 500 K below melting. With the requirement for LCI at 350 sec after blowdown and without cladding or UO2 melting, there is no way for hot fuel to get to the IPT wall and overheat the IPT.

In Reference 18, 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 LOC-5B test with an additional level of conservatism. First, the LOC-5B FOM is smaller than the LLR FOM (2.1 vs 2.71 kW/m/MW). Because of the smaller LOC-5 FOM, the same power excursion resulting from transient rod runaway would deposit less energy in the LOC-5B test rods than in the LLR rods. Secondly, the voiding reactivity rate for LOC-5B (0.34$/sec from Reference 5, Section F) is smaller than the LLR rate (0.48$/sec from Reference 18). This smaller voiding rate combined with the transient rod reactivity would result in a less severe power excursion for LOC-5B than for LLR and consequently further decrease the energy deposition in the LOC-5B rods relative to the LLR rods. The initial fuel temperature for the LOC-5B rods is about 2330 K (Reference 21, Section A) and for the LLR rods about 2325 K (Reference 18, page 23). Thus, LOC-5B relative to LLR has about the same rod temperatures, and smaller energy depositions for the postulated transient rod runaway accident combined with IPT voiding. The conclusion thus follows that fuel melting or fuel failure in the LOC-5B test is not likely.

The analysis of Reference 9 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 LOC-5B additional conservative assumptions will be made. The pre-blowdown power is assumed to be 30 MW (approximate PPS Scram Setpoint). At time of blowdown the power will decrease step-wise to 5.5 MW (AEPL-1, AEPL-2 and AEPL-3 Shutdown Setpoints) and stay at that level until the programmed scram time of 50 sec. From 50 sec to 350 sec the decay power will be taken as 1.8 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 5.5x50 + 1.8x300 = 815 MW-sec. Figure 2 of Reference 9 then shows that for the initial steady state power of 30 MW prior to blowdown and a total of 815 MW-sec generated after blowdown, the 1000°F IPT wall temperature limit would not be exceeded. The same figure shows that about 1200 MW-sec for 30 MW operation would be required to raise the IPT temperature to the 1000°F limit, thus, a substantial safety margin is available.

Previous blowdown test results and the analyses in this section show that the pressure does not exceed the pre-blowdown value of 15.51 MPa during the blowdown when holding power constant during blowdown. These results indicate that the following two Technical Specification requirements are met:

(1) 3.7 SL B; LOCA Blowdown System pressure limit of 25.79 MPa is not exceeded (23.45 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 failures show that rod failures severe enough to threaten the IPT are 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 50 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 10 show compliance for the existing reactor core configuration.

The analysis of Reference 15 for a 16 rod cluster with U235 enrichments of 20 to 93% shows that such a large reactivity experiment would meet the Technical Specification shutdown margin requirements. The LOC-5B test with 4 rods of 12.5% U235 enrichment falls within the envelope established by Reference 15 for blowdown experiments thus also satisfying the shutdown margin requirements.

The LOC-5B 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 cumulative log for U235 in the loop shows 127 g for all previous tests. 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). No fuel was lost during the LLR-SO, LLR-5, LLR-4, LLR-4A, LOC-3, LOC-5 and TC-1 Tests.

It is shown in Reference 21, that the maximum U235 content for the LOC-5B test is 224g. 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 351g which is within the most conservative loop limit of 400g. If the 224g went into the blowdown tank, the tank inventory would then be 224.5g (assuming the total 0.5g from the LLR-3 rod failure went into the blowdown tank). The only possibility of exceeding the limit on U235 accumulation would then have to result from gross overenrichment of the LOC-5B test rods. An enrichment error of about 22% on each of the 4 rods would be required in order to exceed the 400g loop limit. An error of the 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 LOC-5B.

5.3.4 LOC/MOD Cycle Use Factor. In Reference 24, it is shown that through the LOC-5B test, the maximum use factor for blowdown operation will be 0.88 and the maximum use factor for heatup and cooldown cycles will be 0.12. In arriving at these two values, the analysis in Reference 24 included one blowdown and one heatup and cooldown cycle. 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 LOC-5B test fuel can be estimated from the power history described in Section 5.1.1 of this ESA. The integrated test rod power is 1.97 MWh. The Technical Specifications limit (Item 7, Table II) for fission product inventory in terms of MWh operation for unirradiated fuel is 2 MW for 48 hours or 96 MWh. Thus assuming all four rods had no burnup prior to LOC-5B, the Technical Specifications requirement is met.

In the LOC-5B test, two of the rods will have a cumulative burnup of about 30,960 MWd/t which corresponds to 379 MWh neglecting decay since irradiation. The Technical Specifications would allow fission product inventory equivalent to 2 MW for 558 days or 2 MW for 13392 hours or 26784 MWh followed by 42 days decay time. Both the MWh hours and decay time previous to the OC-5B test meet the requirements on fission product inventory for the pre-irradiated rods.

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 calculation in Reference 5*, Section D shows that at 590 K CHF starts at 0.492 ℓ/s per rod. The low flow setpoints correspond to 0.63 ℓ/s per rod. From the EOS the normal flow at power prior to blowdown is 1.00 ℓ/s/rod. The referenced analysis was performed for a rod power of 67 kW/m which is 25% above the planned test power for the high power rods and 14% 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 LOC-5B 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 25.5 MW. 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. The analysis was performed using the PBF RELAP4 code (configuration control No. H00004IB).

From an initial power level of 18 MW, the total core energy release was about 12.3 MJ. From an initial power level of 29.4 MW, the total core energy release was about 6.5 MJ. The initial power level for LOC-5B is 25.5 MW. For conservatism in the following analysis for LOC-5B it is assumed that this accident would result in a core energy release of 12.3 MJ. The initial hot spot centerline fuel temperature is about 2330 K and the corresponding enthalpy is 165 cal/g. The LOC-5B FOM is 2.1 kW/m/MW which is equivalent to

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* This is a LOC-3 reference which applied to test LOC-5. It also applies to test LOC-5B.

0.89 cal/g/MJ for the LOC-5B rods. The total core energy release of 12.3 MJ would result in an energy deposition of 10.9 cal/g in each test rod. The total rod enthalpy would thus be increased to 176 cal/g and the temperature to 2393 K. This fuel temperature is too low for fuel melting and the energy deposition is too low for rod failure in comparison to the RIA Scoping Tests, RIA 1-1 and RIA 1-2 test results (Reference 13).

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 23.45 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. The figure on page 6 of Reference 12 shows the density reduction with time during the rupture disk failure. During the first one-half second of the transient due to rupture disk failure, the density decreases from 719 kg/m^3 to 541 kg/m^3 or equivalently at a rate of voiding of 24.8%/0.5 sec = 49.6%/sec. From Reference 5, Section F, the equivalent voiding rate for the LOC-5B blowdown is shown to be 10.5%/0.5 sec = 21.0%/sec which is less than that obtained for the rupture disk failure.

From Reference 12, the voiding reactivity insertion rate for the rupture disk failure is 1.04$/sec (0.496x2.1). In that analysis the maximum IPT voiding worth was taken as 2.1$.

For the LOC-5B test, the maximum voiding worth is 1.63$ (Reference 5, Section F). The LOC-5B blowdown voiding reactivity rate is therefore 0.34$/sec (0.21x1.63) which satisfies the Technical Specification requirements.

5.3.8 Test Operation with Test Rod Cladding Geometry Changes*.

The possibility exists of initiating a blowdown with excessively hot or molten fuel if the test rods clad geometry has significantly changed from the prior blowdown and the condition is not detected.

The analyses of Section 5.3.1 and 5.3.6 do not scope this condition. The postulated fault is that such a rod failure could result in local overheating of the IPT (Item 2, Table II). This is considered unlikely because of the small amount of excessively hot fuel involved and the presence of two more massive barriers between the fuel and the IPT (the flow shrouds and the flow tube).

Pressure within the IPT boundary is extremely low because of the blowdown event with the open system to the blowdown tank. Therefore, the simultaneous occurrence of high pressure and high IPT wall temperatures result in an extremely unlikely probability of a breach in the IPT wall (pressure boundary). In addition, the 811K limit of the IPT temperature is only a threshold for evaluation and does not imply breach or failure. In the extremely unlikely event of IPT damage, excessive repair or replacement of the IPT would be a

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* The discussion in this section applies only to the three original LOC-5 rods which have experienced one blowdown. From evaluation of the LOC-5 test data, it is concluded in Reference 27 that these three rods did not experience cladding ballooning to any significant extent.

programmatic impact of two to six months with the attendant delay costs. A more probable consequence is that local repair would be required which would be accomplished within the above scope.

Lacking formal analysis of this postulated fault, TFBP management, through administrative controls, will insure adequate review of the LOC-5 test results before the LOC-5B blowdown to minimize the probability of blowdown initiation with a rod in damaged condition. The potential consequences and probability of occurrence of this postulated fault are recognized and the risk is accepted by TFBP management.

Operation with failed rods during preconditioning will not result in IPT over heating. This conclusion is based on the analysis of Reference 25. The model used in Appendix B of Reference 25 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 26) 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 the 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.

6. CONCLUSIONS

The LOC-5B Test meets the acceptance criteria in Reference 6 which defines test operation accident consequences acceptable to EG&G Idaho, Inc. management for faults categorized by likelihood of occurrence.

REFERENCES

1. PBF LOC-5 Experiment Configuration Specification, ES-50425A, March 3, 1979, DRR-TFBP-221.

2. Reference deleted.

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

4. Adjustable Experiment Power Level Shutdown on PPS1, PPS2 and Ch. 3, FCF 795.

5. EDF-PBF-1305, Miscellaneous Analyses for LOC-3 ESA, February 6, 1979, S. C. Resch.

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

7. Ltr. S. R. Adams to S. R. Gossmann, SRA-35-79, NSB Thyroid Inhalation Dose (For PBF Flow Blockage Accident) Following LOC-5B Operation, November 8, 1979.

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

9. EDF-PBF-1200, In-Pile Tube Gamma Heating With Blowdown, September 21, 1978, R. J. Loyd.

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

11. Reference Deleted.

12. EDF-PBF-1207, TSA MOD/LOCA SYSTEM/GAPCON Test Accident Calculations, October 4, 1978, E. V. Mobley.

13. RIA Scoping Tests Quick Look Report, TFBP-TR-289, September 1978; RIA 1-1 Quick Look Report, TFBP-TR-300, October 1978; RIA 1-2 Quick Look Report, TFBP-TR-303, December 1978.

14. Reference Deleted.

15. TREE-NUREG-1024, Computed Reactivity Requirement and Control Rod Worth for 30MW, 2-Day Operation of PBF With a Large Reactivity Experiment, D. W. Nigg, A. J. Scott, September 1976.

16. Reference Deleted.

17. Reference Deleted.

18. TFBP-TR-305, PBF LOFT Lead Rod Test ESA, December 1978, S. R. Gossmann.

19. Reference deleted.

20. TFBP-TR-328, PBF-LOCA Test Series Test LOC-3 Quick Look Report, T. R. Yackle et al, July 1979.

21. EDF-PBF-1385 Miscellaneous Analyses for LOC-5 ESA, S. R. Gossman, August 17, 1979.

22. TFBP-TR-322, PBF LOC-5 Test Experiment Safety Analysis, S. R. Gossmann, Aug. 1979 with DRR-210 (Aug. 29, 1979).

23. Notegram; D. E. Owen to S. R. Gossmann, Oct. 31, 1979. Subject: LOC-5 Failed Rod Examination.

24. EDF-PBF-1415, Miscellaneous Analyses for LOC-5B ESA, Oct. 24, 1979, S. R. Gossmann.

25. 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.

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

27. Letter M. E. Waterman to T. K. Samuels, MEW-15-79, Extent of Cladding Ballooning of the LOC-5A Fuel Rods 605-5, 605-6 and 605-8, November 7, 1979.

TABLE I

TEST LOC-5B HENRY NOZZLE THROAT DIAMETERS AND LOCATIONS

Valve Designation Associated With Nozzle	Location	Throat Diameter (mm)
GB-LM-11-1	Hot leg	14.22 --(Not Used)
GB-LM-11-2	Hot leg	13.56 --(Not Used)
GB-LM-11-3	Cold leg	14.22
GB-LM-11-4	Cold leg	13.56

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

Nozzles associated with valves GB-LM-11-1, 2, 3, and 4 shall not exceed 25.27 mm. diameter.

Nozzles associated with valve GB-LM-11-1 or 2, associated with PS-11-5-1 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 24, and Operating Envelope, Item I

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* Paragraphs in this ESA except Item 10.

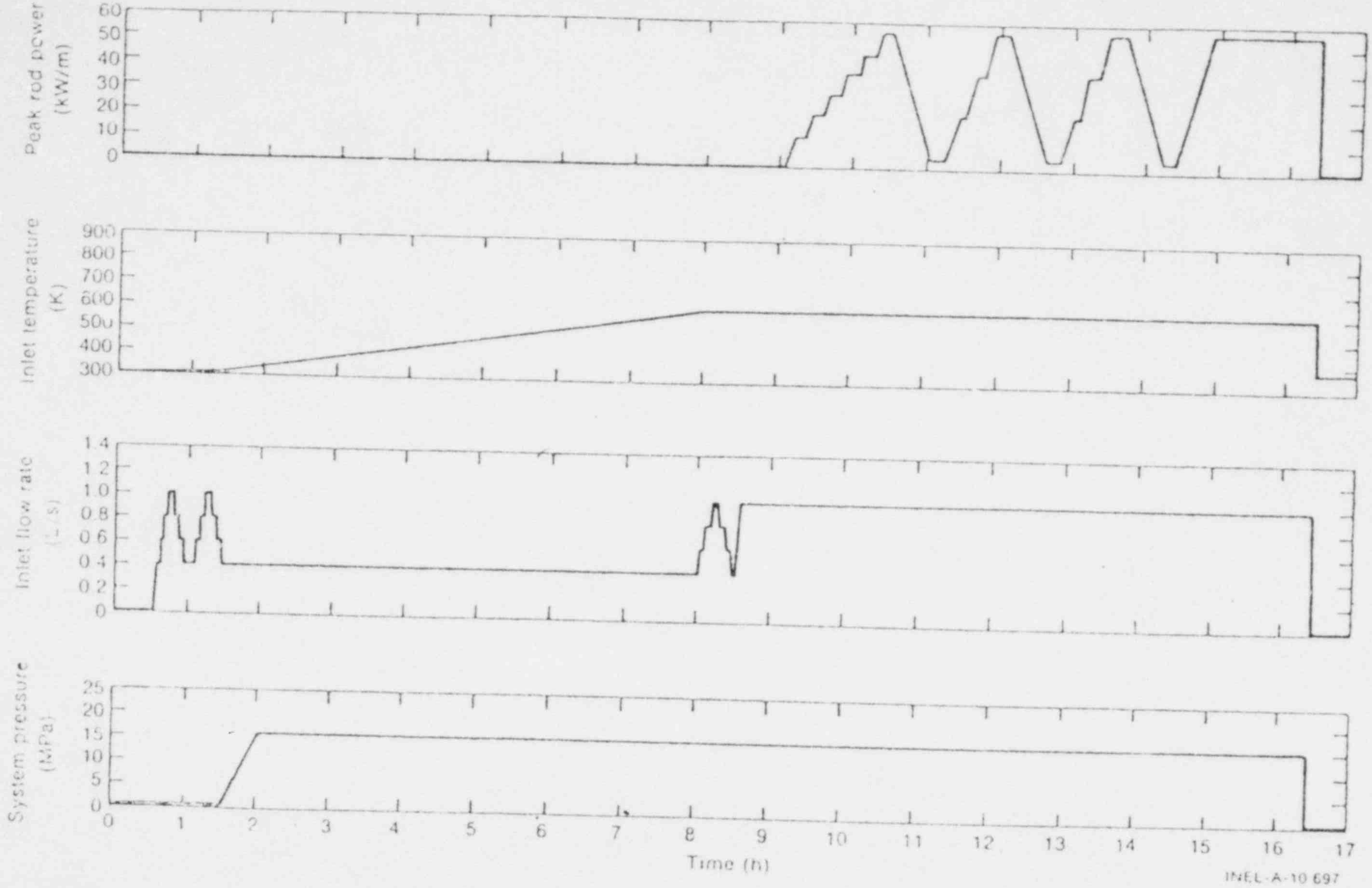
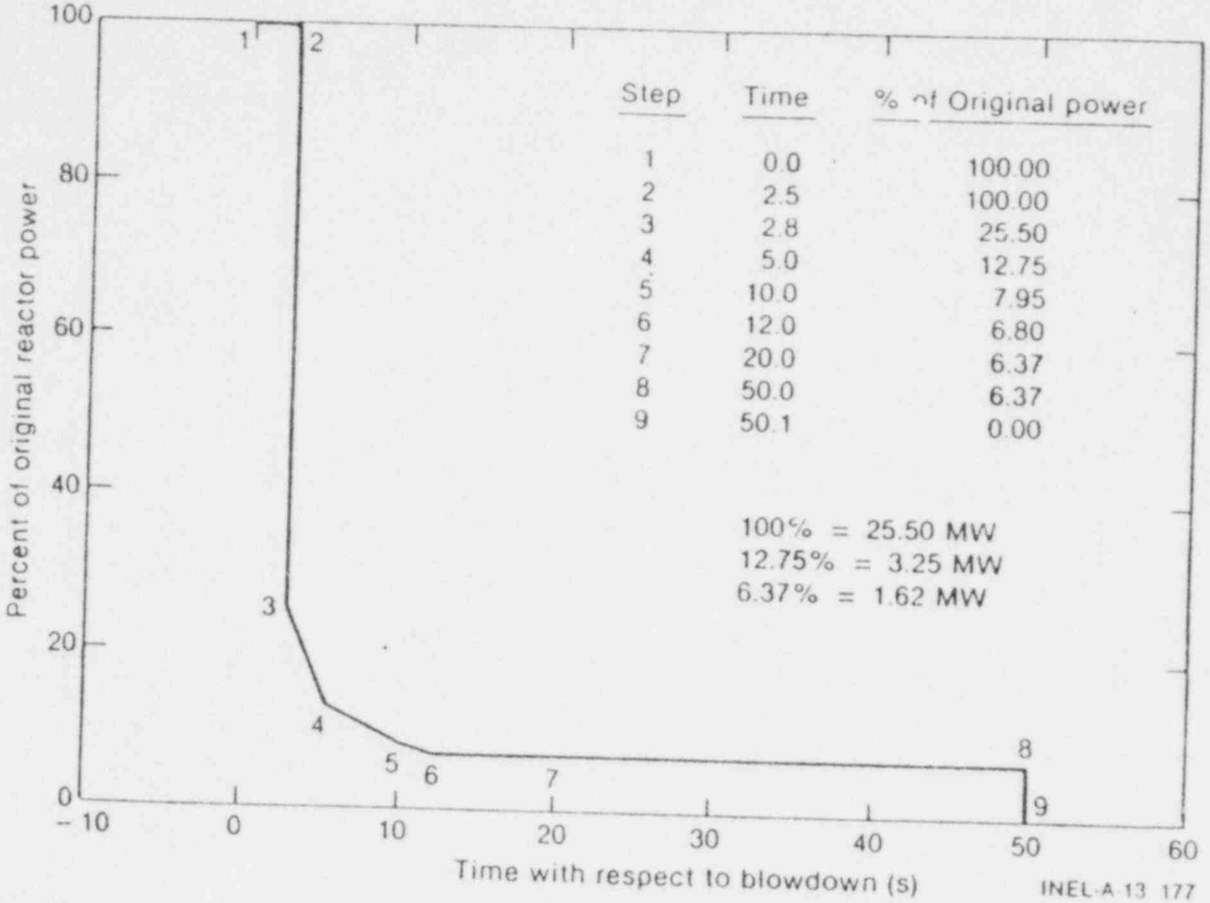


Fig. 1 Operating sequence for LOC-5B



Step	Time	% of Original power
1	0.0	100.00
2	2.5	100.00
3	2.8	25.50
4	5.0	12.75
5	10.0	7.95
6	12.0	6.80
7	20.0	6.37
8	50.0	6.37
9	50.1	0.00

100% = 25.50 MW
12.75% = 3.25 MW
6.37% = 1.62 MW

INEL-A-13 177

Fig. 2 Reactor power variation with time during the transient.