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RIA SCOPING TEST

EXPERIMENT SPECIFICATION DOCUMENT

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1. INTRODUCTION AND SUMMARY

The experiment requirements and objectives for the reactivity initiated accident (RIA) tests to be conducted in the Power Burst Facility (PBF) are described in the RIA Experiment Requirements Document (ERD)[1]. The primary objectives of the RIA research are to determine fuel failure thresholds, modes and consequences as functions of enthalpy insertion, irradiation history, and fuel design. Coolant conditions of pressure, temperature, and flow rate that are typical of hot-startup conditions in commercial BWRs will be used in the Series 1 tests.

The first RIA test outlined in the ERD, RIA 1-1, is to be performed using four test fuel rods (two unirradiated and two irradiated) in the four rod hardware. The test fuel rods are to be exposed to a power transient in PBF which deposits an energy of about 300 cal/g at 90% of the fuel radius (i.e., near the fuel surface). This will be the first RIA experiment ever performed at hot-startup conditions and three potential problems have been identified since the ERD was written. These problem areas, described in detail in the next section of this document, are: identification of the fuel failure threshold energy deposition for hot-startup conditions, evaluation of calorimetry techniques for RIA transient tests, and determination of possible pressure pulses that can result from fuel failure in a water filled system. Also, recent TREAT test results have indicated that it may be difficult to obtain usable information from some of the instruments planned for use on the Series 1 tests. To resolve the questions raised by the TREAT tests it will be necessary to expose selected instruments to a power burst and monitor their response under adiabatic, constant pressure conditions. Consideration of these potential problems made it clear that an RIA Scoping Test, the subject of this Experiment Specification Document, must be performed to resolve these potential problems prior to performance of test RIA 1-1.

The RIA Scoping Test should be comprised of five single rod experiments. The first rod will be subjected to a series of transient power bursts of ever increasing energy release to determine the energy deposition failure threshold. The second rod will be subjected to an energy deposition about 50 cal/g less than the energy deposition required for failure during the first test. The third rod will be tested at the failure threshold energy deposition. A calorimetric power calibration will be performed on the second and third rods for comparison purposes. Rods four and five will be subjected to very high energy depositions (475 and 600 cal/g average energy insertion, respectively) to evaluate pressure pulse generation due to fuel fragmentation at hot-startup conditions. Calorimetric power calibrations will be performed on rods four and five. In the event of unexpectedly large pressure pulse generation for rods four and five it may be necessary to perform additional high energy deposition tests to determine the energy deposition required for fuel dispersal and subsequent pressure pulse generation.

The PBF-TFBF single rod test train or its equivalent will be used for the scoping tests. Instrumentation for measurement of pressure pulse generation and test rod power will be necessary for the test. To evaluate the effects of radiation on the performance of the fuel rod instrumentation planned for the RIA Series 1 tests, two pressure sensors and an LVDT should be placed in a nearly adiabatic, constant pressure environment within the test train and monitored during the bursts. No test rod instrumentation will be required.

Results of the Lead Rod Test Series will be used to make preliminary estimates of the transient burst period required.

2. RIA SCOPING TEST RATIONALE

The three potential problem areas identified since the ERD was written for RIA testing that lead to the RIA Scoping Test are: hot-startup threshold energy deposition, applicability of calorimetry, and pressure containment capability.

2.1 Hot-Startup Threshold Energy Deposition

RIA tests conducted in the SPERT, TREAT, and NSRR facilities indicate that when light water reactor fuel rods are subjected to peak energy depositions in the range from 270 to 300 cal/g (near the fuel surface), failure due to brittle rupture of the cladding occurs with cladding melting, oxidation and embrittlement. These tests were conducted at atmospheric pressure, ambient temperature, with no coolant flow, and using unirradiated test fuel rods. The RIA test series in PBF was planned to extend current knowledge of RIA fuel behavior to more typical reactor conditions.

Analytical studies have shown the coolant behavior to be important. Coolant flow past the fuel rods, if maintained during the transient, is calculated to result in lower cladding temperatures with higher test rod energies required to cause fuel rod failure (for fresh fuel rods). This effect results from the better energy transfer from the fuel rod with forced coolant flow. However, recent NSRR data on single test fuel rods contained in shrouds indicate that heat transfer can significantly affect thermal-hydraulic behavior and result in failure at energies less than 270 cal/g. Thus, the failure threshold may be larger than previously measured due to the effects of flow, or smaller due to the effects of flow shrouds. In addition the fuel failure threshold for irradiated rods may be somewhat lower also. The limited data preclude quantification; however, irradiated rods have failed at energy densities as low as 150 cal/g (average energy deposition). For these reasons it is advisable to perform scoping tests to determine the BWR hot-startup threshold energy deposition prior to Test RIA 1-1.

2.2 Applicability of Calorimetry

Because part of the test fuel rods to be used in the RIA tests will be preirradiated and because preconditioning of the test fuel rods is planned prior to the power bursts, fission product analysis methods for determining energy deposition are precluded. Therefore, calorimetry must be relied upon for the determination of test rod energy deposition. Calorimetric energy determination will be performed during steady-state operation.

Several problems exist in relating energy deposition during transients to steady-state calorimetric measurements:

1. The coolant density and void fraction within each test train flow shroud will be significantly different for steady-state operation than for a rapid RIA burst.

2. The ratio of test rod power to core power may be different for transient and steady-state operation because of the lack of delayed neutron and delayed gamma radiation during transient burst operation.

3. The time response of the self-powered neutron detectors (SPNDs) to be located in the IPT for time-dependent power measurements[a] may not be adequate for the fast rise time power bursts.

4. Uncertainty exists in correlating the very low signals from the core burst detectors during calorimetric measurements at low powers to the very high output during burst operation.

5. The axial power profile is expected to be different for steady-state and transient power conditions.

6. The neutron energy spectrum is different at the edge of the core where the core chambers are located than it is in the test space where the experiment is located.

The RIA Scoping Test is required to provide confidence in the calorimetric tecnhiques for determining energy deposition. Both fission product analysis and calorimetric measurements will be performed for comparison purposes.

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[a] These SPNDs must be calibrated either calorimetrically or from fission product analysis.

2.3 Pressure Containment Capability

During an RIA, fuel rod failure can result in fuel fragmentation, molten fuel and/or molten cladding interaction with the coolant and rapid pressure pulse generation. The capability of the IPT to contain pressures generated by an RIA is of paramount importance.

The Power Burst Facility In-Pile Tube System Design Basis Report states that the design basis peak source pressure was 51.7 MPa (7500 psia). This value resulted from an engineering judgment based upon the review of peak pressures observed in a variety of integral core destructive tests and Capsule Driver Core Tests.

However, all of the tests reviewed had initial ambient temperature and pressure conditions with a free surface boundary near the pressure source region. Differences between the tests reviewed and the configuration and initial conditions applicable to RIA tests in the PBF IPT were not considered in the Design Basis Report.

An analysis by ITI, Inc., performed under contract with EG&G, considers the effects of an RIA in PBF and reaches conclusions that have serious implications, if the analysis is valid[2]. The worst RIA case analyzed by ITI was a 25 rod cluster of BWR-6 type rods with an average energy deposition of 1090 J/g (260 cal/g). For this case the peak pressure was calculated to be 262 MPa (38000 psi). A pressure of 200 MPa (30000 psi) was calculated at 0.5 msec after failure. Application of a dynamic factor (calculated to be 1.6 to 2.0) results in an in-pile tube stress well beyond yield point.

Even with a single rod RIA test at 1090 J/g (260 cal/g) energy deposition, a source pressure of ~48 MPa (7000 psi) was calculated. When a dynamic factor is applied to this pressure, the IPT stress would exceed the 2% yield design limit imposed by Section III of the ASME Boiler and Pressure Vessel Code.

The results of the RIA Scoping Test will be used to evaluate the validity of these calculations.

3. RIA SCOPING TEST REQUIREMENTS

3.1 Fuel Rod Specifications

Table I lists the five fuel rods to be used in the RIA Scoping Test, the expected power calibration operation, the desired energy deposition, and the expected reactor period. The test requirements associated with each rod are as follows:

Rod One

The purpose of testing this rod is to determine the fuel failure threshold energy deposition for fresh fuel in a simulated power reactor environment. Since time, cost and material constraints preclude the use of a large number of rods to produce a statistically based quantity, a single fuel rod will be subjected to a number of power transients of increasing severity. The energy deposition in the rod will be increased in units of 25 cal/g starting from 150 cal/g until failure occurs. This number can then aid in determining if correlations for fuel failure from SPERT and NSRR data can be applied to rods operating at hot-startup conditions.

A calorimetric power calibration will be performed to gain experience and aid in evaluating the reliability of using this technique for determining test rod energy deposition in an RIA test.

Pressure pulses generated by fuel failure in this phase should be relatively low and representative of those generated by brittle rupture of the clad, and clad melting.

Rod Two

A fresh fuel rod will be subjected to a power transient resulting in an energy deposition slightly less than the fuel failure value determined using Rod 1.

Rod Three

A fresh fuel rod will be subjected to the power transient which resulted in failure of Rod one. Since Rods two and three are unirradiated with no preconditioning or power calibration operation, posttest fission product analysis will be used to evaluate the energy deposition, and comparisons can be made with the calorimetric results from Rod one.

Rod Four

A very large energy deposition (475 cal/g) in the fuel should result in a fuel failure mode characterized by cladding rupture and fuel fragmentation. This energy deposition should produce pressure generation information characteristic of this type of fuel failure.

Severe fuel fragmentation should result, and a good experimental evaluation of pressure pulses generated in the IPT during an RIA event should be possible.

Calorimetric power measurement calibration methods are necessary here since destruction of the fuel rod will probably preclude posttest fission product analysis.

Rod Five

A fresh fuel rod will be subjected to a power transient resulting in an energy deposition of 600 cal/g in the fuel rod. This test should result in more severe fuel failure consequences than for rod four, although the failure mode will probably be the same.

A calorimetric power calibration is also required for rod five because failure may preclude posttest fission product analysis.

The five fuel rods for the RIA Scoping Test are designated as 800-1, 800-2, 800-3, 800-4, and 800-5, respectively. The nominal design characteristics of these rods are given in Table II. The required pretest fuel rod characterization measurements are listed in Table III. The fuel pellets for Rods 800-1, 800-2, and 800-3 will be ground down to fit in available PWR 17x17 cladding and the pellets in Rods 800-2 and 800-3 should be highly characterized according to Table III.

3.2 Flow Shroud Specifications

A separate flow shroud for each rod should be fabricated from Zr-4 material and have a nominal inner diameter of 16.30 mm and an outer diameter of 22.6 mm. The as-built dimensions of the shroud should be measured at each end. Centering screws should not be installed in the flow shroud. Fuel particle catch screens should be installed at the inlet and outlet of the flow shrouds for Rods 4 and 5. The screens should have a mesh spacing of about 0.05 mm.

A flux wire (0.51% cobalt for rods 1, 4, and 5, and 100% cobalt for rods 2 and 3) enclosed in a small Zr tube should be attached to the outer wall of each flow shroud. The as-built axial and angular location of the flux wire holders and consequent position of the flux wires should be measured for each shroud. The flux wire should extend over the active fuel length of the rod. The required azimuthal orientation of the wire is listed in Table IV. A new flux wire will be required for each rod.

3.3 Test Assembly Specification

The PBF-TFBP single rod test train assembly (drawing No. 406259) or its equivalent is acceptable for the RIA Scoping Test.

4. INSTRUMENTATION SPECIFICATIONS

The instrumentation in this test is directed towards pressure pulse measurement, calorimetric measurement of the test rod power, and evaluation of the fuel rod instrumentation to e used in the Series 1 RIA tests. No instrumentation is required for the Scoping Test fuel rods. Table III summarizes the pressure pulse and rod power measurement requirements for the RIA Scoping Test.

Four experiments have recently been performed in the TREAT reactor to determine the response of various instruments to a radiation burst[3]. Both Kaman and strain bridge pressure sensors were tested. A strain bridge pressure sensor with DC excitation was also tested. The results of these tests indicated that:

1. A Kaman pressure sensor located in the core region probably will not work. (The sensitivity of the Kaman sensors was much too high, so the TREAT results are not conclusive.)

2. A strain bridge pressure sensor located in the core region will definitely not work.

3. A strain bridge pressure sensor located above the core and excited with DC current will probably work.

Based on these results, it is not clear whether the Kaman pressure sensors planned for use on the Series 1 rods will measure rod internal pressure during and shortly after a burst. Therefore, one Kaman and one DC excited strain post type sensor should be installed on the Scoping Test hardware at the expected axial location of use in the Series 1 tests. These sensors should be pressure and temperature isolated (i.e., see a constant pressure, adiabatic environment) and monitored during the various Scoping Test bursts. It would also be desirable to include one LVDT which is also isolated from the environment and monitored during the bursts.

5. REACTOR OPERATION

The estimated range of reactor transient periods required for the RIA Scoping Test will be determined from Lead Rod Test Series data. Precise specifications will be supplied in the Experiment Operating Specification (EOS) document.

A calorimetric power calibration will be required for rods 1, 4, and 5 of the test. Rod 1 will be subjected to a series of reactor transients starting at 150 cal/g and proceeding in 25 cal/g increments until rod failure. The Rod 1 transients will be preceded by 8 hours of steady-state operation at a test rod power of 50 kW/m (15 kW/ft) for fission product inventory buildup. External detection of fission products will indicate fuel rod failure. Each of the remaining rods will be subjected to only one power burst as specified in Table I. Rods 2 and 3 should be subjected to an absolute minimum of steady-state operation prior to the burst.

A fresh 100% cobalt wire should be inserted in the core region just prior to each power burst conducted in the five phases of the test. Steady-state reactor operation after the core flux wire is installed should be kept to a minimum. The reactor power level used to determine control rod position for criticality should be less than 1 kW. The transient power burst should be conducted at BWR hot-startup conditions, (7.24 MPa, 552 K, and 490 $kg/s.m^2$ mass flux or 86 cm^3/s flow through the flow shroud).

TABLE I

RIA SCOPING EXPERIMENT TESTING PHASES

Phase	Fuel Rod	Calorimetric Power Calibration Performed	Estimated Average Energy Deposition/MW·s (cal/g per MW·s)	Energy Deposition Radially Averaged At Axial Flux Peak (cal/g)	Reactor Transient Period Required (ms)	Required Reactor Transient Total Energy Release (MW·s)
1	800-1	Yes	0.76	150, 175, 200, 225, 250, 275 (Several Transients Until Rod Fails)	[a]	198 - 362
2	800-2	No	0.76	(Fuel Failure-50 cal/g)	[a]	Adjust
3	800-3	No	0.76	Fuel Failure	[a]	Adjust
4	800-4	Yes	1.69	475	[a]	281
5	800-5	Yes	1.69	600	[a]	355

[a] Reactor transient period needed to produce required total core energy release will be determined from Lead Rod Test Series data.

TABLE II

RIA SCOPING TEST FUEL ROD DESIGN CHARACTERISTICS

Characteristic	Rods 800-1, 2, 3[1]	Rods 800-4, 5[2]
Fuel		
Material	UO_2	UO_2
Pellet OD	8.23 mm ± 0.0127 mm	9.3 mm
Pellet length	15.2 mm	15.49 mm
Pellet Enrichment	5.8%	20%
Density	92% TD	93%
Fuel Stack Length	0.914 m	0.914 m
End Configuration	dished	flat
Burnup	0	0
Cladding		
Material	Zr-4	Zr-4
Tube OD	9.70 mm	10.73 mm
Tube Wall Thickness	0.64 mm	0.61 mm
Yield Strength		570 MPa
Ultimate Strength		700 MPa
Fuel Rod		
Overall Length	1.0 m	1.0 m
Filler Gas	Helium	Helium
Initial Gas Pressure	0.103 MPa	3.79 MPa

(1) Fuel pellets are 5.8% enriched manufactured by Batelle. Original diameter was 8.59 mm and were ground down to to be compatible with the cladding dimensions. Cladding material is PWR (17 x 17).

(2) These are Power Cooling Mismatch (PCM) test fuel rods.

TABLE III

FUEL ROD CHARACTERIZATION REQUIREMENTS

Measurement	Measurements Frequency	Measurements Made on These Fuel Rods	Comments
Pellet Diameter	100%	800-2,800-3	Measure at pellet midplane
Pellet Length	100%	800-2,800-3	At dish shoulder
Pellet Weight	100%	800-2,800-3	Dry pellets prior to weighing
Pellet Geometric Density	100%	800-2,800-3	
Pellet Immersion Density	10%	800-2,800-3	
Fuel Stack Length	Each Rod	800-1,800-2,800-3, 800-4,800-5	Use radiographic technique or equivalent
Cladding Inside Diameter	Continuous	800-2,800-3	Measurements at 0^o and 90^o orientation
Cladding Outside Diameter	Continuous	800-1,800-2,800-3, 800-4, 800-5	Measurement at 0^o and 90^o orientation, corresponding to ID measurements
Fuel Rod Overall Length	Each Rod	800-1,800-2,800-3, 800-4,800-5	
Leak Check	Each Rod	800-1,800-2,800-3, 800-4,800-5	
Photographs	Each Rod	800-1,800-2,800-3, 800-4,800-5	Photographs at 0^o, 90^o, 180^o, and 270^o orientation
Void Volume	Each Rod	800-2,800-3	
Rod Internal Pressure	Each Rod	800-2,800-3	

TABLE IV

MEASUREMENT REQUIREMENTS FOR THE RIA SCOPING TEST

Measurement	Instrument	Instrument Location	Desired Instrument Range	Desired Instrument Accuracy (% Full Scale)	Desired Response Time (s)	Comments
Coolant Pressure	Pressure Transducer	Near Outlet of IPT Flow Tube	0-69 MPa	± 5 %	3×10^{-5}	Transient pressure response measurement
Coolant Pressure	Pressure Transducer	Near Outlet of IPT Flow Tube	0-17 MPa	± 5 %	3×10^{-5}	Normal system pressure measurement. Should be calibrated @ 550 K.
Coolant Flow	Turbine Flow Meter	Inlet of flow shroud	63-568 cm^3/sec	± 2 %	N/A	
Coolant Inlet Temperature	Thermocouple	Inlet of Flow Shroud	300-600 K	± 1.5%	N/A	
Coolant Differential Temperature	Thermocouple Pair	Inlet and Outlet of Flow Shroud	0-20 K	± 1%	N/A	
Relative Neutron Flux	Cobalt SPND's	1 Vertical Column with 1 detector at 9 inches, 1 at 18 inches and 1 at 27 inches from bottom of fuel rod	6×10^{16} $n/cm^2/sec$	± 3%	.002	
Neutron Flux (IPT)	0.5% Cobalt wire rods 1, 4 and 5 100% Cobalt wire for rods 2 and 3	Outer Surface of Flow Shroud (Reactor North Orientation)	1.7×10^{18} nvt.			A new wire will be needed for each phase of the test.
Neutron Flux (Core)	100% Cobalt Wire		1.7×10^{18} nvt			A new wire will be needed for each power burst

REFERENCES

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3. R. C. Doerner, et al, Data Report for the IRT-10 Test, ANL/RAS-76-18, (May 1976).