RIA 1-2
EXPERIMENT SPECIFICATION DOCUMENT

Prepared by: Z. R. Martinson A. M. Eaton
Z. R. Martinson, A. M. Eaton

Approved: R. K. McCardell
R. K. McCardell, Supervisor

P. E. MacDonald
P. E. MacDonald, Manager
Experiment Specification & Analysis "A" Branch

J. G. Crocker
J. G. Crocker, Manager
Thermal Fuels Behavior Division

Accepted: R. W. Marshall, Jr.
R. W. Marshall, Jr., Manager
PBF Design and Fabrication Division

EXPORT REVIEW COMPLETED
NO LICENSE REQUIRED
11/29/77
EC 650149

RIA 1-2
EXPERIMENT SPECIFICATION DOCUMENT

Prepared by: Z. R. Martinson A. M. Eaton
Z. R. Martinson, A. M. Eaton

Approved: R. K. McCardell
R. K. McCardell, Supervisor

P. E. MacDonald
P. E. MacDonald, Manager
Experiment Specification & Analysis "A" Branch

J. G. Crocker
J. G. Crocker, Manager
Thermal Fuels Behavior Division

Accepted: R. W. Marshall, Jr.
R. W. Marshall, Jr., Manager
PBF Design and Fabrication Division

1. INTRODUCTION

The purpose of the Reactivity Initiated Accident (RIA) test series to be conducted in the Power Burst Facility is the verification of analytical models capable of predicting light water reactor fuel performance during hypothetical control rod drop (or ejection) accidents^[1]. An important independent variable during an RIA is the magnitude of energy insertion in the fuel. Calculations indicate that peak fuel energy densities ranging from 4.2 to 18.8×10^5 J/Kg (100 to 450 cal/g) might occur in a light water reactor, depending on the design and operating conditions at the time of the accident^[2].

The specific objectives of the RIA research are to determine failure thresholds, modes and consequences as a function of enthalpy insertion, irradiation history and fuel design. The most severe RIA postulated is the BWR control rod drop accident, therefore the Series 1 tests are to be conducted under BWR hot-startup conditions. The second test in Series 1, RIA 1-2, will be comprised of four individual rods, each surrounded by a separate flow shroud. All of the rods will be pre-irradiated to about 5200 MWD/MTM. The main objectives of the test are to: (1) obtain irradiated fuel rod response for energy depositions of about 350 cal/g at 90% of the fuel radius at the axial flux peak and (2) evaluate the effect of fuel rod internal pressure during a RIA.

The test sequence will begin with steady-state power operation for pre-test conditioning of the fuel rods. During the steady-state operation calorimetric data will be obtained to provide a final basis for specifying the core transient behavior that will result in the desired test rod energy deposition. After the steady-state operation is completed, the reactor will be shutdown for flux wire replacement before running the RIA power transient.

In the following section, the current status of RIA irradiated fuel behavior knowledge, based primarily on the review of the NSRR and SPERT data and the fuel rod modeling studies presented in the Experiment

Requirements Document (ERD), is discussed. The intention of this section is to identify areas which need further resolution and to provide a basis for understanding the RIA Test Plan. Section 3 contains the hardware specifications including the test assembly and the test rods. Section 4 presents the measurement requirements needed to meet the objectives of the test. Section 5 briefly lists some of the reactor operation requirements associated with the RIA 1-2 test.

2. SUMMARY OF THE RIA EXPERIMENT REQUIREMENTS

Reactivity initiated accident experiments have been conducted in the SPERT, TREAT, and NSRR test facilities. These tests have been conducted using an atmospheric, room temperature capsule environment. The results from these programs are basically consistent and provide the primary basis for understanding and predicting the behavior of light water reactor fuel rods during a hypothetical RIA.

When light water reactor fuel rods are subjected to peak energy depositions ranging from 270 to 300 cal/g (near the fuel surface), failure due to brittle rupture of the cladding and cladding melting, oxidation and embrittlement has been observed. For these cases the data show that the peak cladding temperature can be well correlated with the energy deposition near the surface of the fuel pellet. The data also indicate that cladding failure does not occur if the pellet surface energy deposition is below 270 cal/g.

For pellet surface energy depositions (at 90% of the radius) greater than 350 cal/g, brittle fractures of the cladding and fuel fragmentation has been observed before melting occurs. These results suggest high internal pressures which may be due to fuel melting and vaporization and/or large fuel expansion forces (at large fuel energy densities). The fuel rod failure threshold for irradiated rods may be somewhat lower; the limited data preclude qualification, however irradiated rods have failed at energy densities as low as 150 cal/g (average energy insertion). Waterlogged fuel rods were found to fail at energy depositions ranging from 60-160 cal/g.

The current SPERT and HSRR data base is limited largely because the test coolant conditions are much different than those in a typical LWR. Additional data are required to extend current knowledge of RIA fuel behavior to more typical reactor conditions. Analytical studies have shown the coolant behavior to be important; since coolant flow past the rods, if maintained during the transient, will result in lower cladding temperatures and higher test rod energies to initiate fuel rod failure (for fresh rods). This is simply a result of better energy transfer from the fuel rod with forced coolant flow compared with the bulk pool film boiling typical of the capsule tests. Under these assumptions, less difference in test rod energy to initiate melting rupture vs. prompt fracture may be expected. Thus, additional data are needed to clearly establish both coolant and fuel rod behavior during an RIA at typical LWR reactor conditions.

The irradiated fuel rod response data from SPERT and TREAT are limited. Of primary importance in assessing LWR RIA consequences is the evaluation of irradiated fuel rod energy failure thresholds and the consequences of the failure of irradiated fuel rods. Other important parameters which have been studied and require additional experimental evaluation include the effects of fuel rod internal pressure and cluster size (large cluster vs. single rod tests).

The RIA Series 1 tests proposed in the ERD will extend understanding of RIA fuel behavior and provide model evaluation data for typical BWR hot-startup reactor conditions. The proposed tests are shown in Table 1. Tests RIA 1-1, RIA 1-2, RIA 1-3, and RIA 1-6 are primarily to bound the energy failure threshold for irradiated fuel rods. Parameters to be investigated in these tests also include fuel rod size, fuel rod internal pressure, and fuel rod burnup. Test RIA 1-4 will investigate the effects of test rod geometry. Additional tests involving more BWR rods

and/or waterlogged rods are presently being considered for inclusion as a result of discussions with GE and NRC.

3. EXPERIMENT CONFIGURATION SPECIFICATIONS

The specifications for the test hardware and fuel rods for RIA 1-2 are described in this section. The basic test configuration consists of four independently shrouded fuel rods which are installed in a support structure termed the test assembly. The specifications for the fuel rods, flow shrouds, and test assembly are listed below.

3.1 Fuel Rod Specifications

The fuel rods should consist of four MAPI^[a] rods previously irradiated to a burnup of about 5200 MWd/MTM in the Saxton Reactor. A fifth irradiated MAPI rod (802-5) should serve as a backup for the irradiated rods. The designation and burnup, of the fuel rods are given in Table II. The as-fabricated nominal design characteristics of these fuel rods are given in Table III. The pre-test fuel rod characterization measurements required are listed in Table IV. Rods 802-3 and 802-5 should not be opened prior to testing and only external characterization measurements are required for these rods.

The as-received internal pressure and gas composition of irradiated Rod 802-1 should be measured. After Rod 802-1 is instrumented, the internal back-fill gas pressure should be adjusted to the as-received measured pressure. The backfill gas composition should be 77.7% helium and 22.3% argon. This gas mixture simulates the thermal conductivity of fill gases, including fission gases, in the Saxton MAPI fuel rods. Rods 802-2 and 802-4 should be backfilled with the same mixture of helium and argon. The exact backfill pressure for Rods 802-2 and 802-4 will be specified in the EOS^[b].

[a] These are rods fabricated by the Mitsubishi Atomic Power Company and irradiated in the Saxton Reactor by the Westinghouse Electric Co.

[b] The backfill pressure for Rods 802-2 and 802-4 will correspond to the calculated End-of-Life internal pressure for BWR/6 fuel rods.

The fill tube previously used to backfill the PCM and IE test rods should be eliminated and the rods should be laser sealed after backfilling.

3.2 Flow Shroud Specifications

The four flow shrouds 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 each shroud should be measured at each end. Centering screws should not be installed in the flow shrouds. The shrouds should be designed so that undue force is not required to install the flow shrouds over the LVDT housing.

A (0.51% cobalt - 99.49% aluminum) flux wire, enclosed in a small Zr tube should be attached to the outer wall of each flow shroud. After the power calibration and pretest conditioning phases have been completed, the flux wires and Zr tubes should be removed and four 100% cobalt wires (similarly enclosed in Zr tubing) should be installed in their place. Attention should be given to making this flux wire exchange possible in the PBF canal. The as-built axial and angular location of the flux wires holders and consequent position of the flux wires should be measured. The flux wires should extend over the active fuel length of the rods. The desired azimuthal orientations are listed in Table V.

3.3 Test Assembly Specifications

The hardware should be designed to symmetrically position the four fuel rods in the PBF reactor in-pile tube. The active length of the test fuel rods should coincide with the active fuel length of the PBF core. Each fuel rod should be fixed rigidly at the top in the test assembly with the rod free to expand axially downward against the fuel rod axial growth measurement transducer.

To achieve the objectives of the RIA Test Series it is essential that the neutronic characteristics of the test assemblies used in the RIA four-rod tests are nearly identical. If there are differences in the neutronic characteristics of the test assemblies used for RIA Tests 1-1, 1-2, 1-3, and 1-6, it may be impossible to compare the test results for the preirradiated rods. Therefore, it is important that the ratio of the energy produced by the test fuel rods to the PBF core energy release be similar for each of the RIA tests. Specifically, the RIA 1-2 hardware must be designed such that the calculated figure of merit is within 5% of that calculated for the 4XB hardware.

It is also very important that the fuel rod azimuthal power distribution be the same for each of the Series 1 RIA Tests, (so that we have the same **ratio** of average to peak power within the test rods). A solid stainless steel central hanger rod (22.3 mm OD) will be used in the 4XB hardware design. This stainless steel central hanger rod is calculated to result in a uniform radial power profile (within 1%) for the four RIA fuel rods. The RIA 1-2 hardware should also contain a central steel hanger rod or a similar device to flatten the radial flux profile.

The hardware should be designed such that the coolant pressure transducers are located at the same axial location as the pressure transducers on the 4XB hardware. The location of the coolant thermocouples (inlet, outlet, and differential) should correspond closely to the thermocouple locations of the 4XB hardware.

Two Zr-4 water-filled tubes (10.7 mm OD) should be used to mount the self-powered neutron detectors on the hardware. The radial and axial location of SPNDs should be the same as the SPNDs installed in the 4XB hardware.

A flow restrictor orifice plate should be located above each turbine flowmeter. The number and the diameter of holes drilled in each of the orifice plates should duplicate that of the 4XB hardware orifice plates.

The hardware should be designed such that no coolant leakage occurs between the experiment coolant inlet and the flow shroud outlet.

4. INSTRUMENTATION SPECIFICATIONS

The instrumentation for this test is designed to aid in determining fuel rod characteristics and failure mechanisms during an RIA transient. Table V lists the instrumentation requirements for the test train and flow shrouds. Table VI lists the instrumentation required for each fuel rod.

A gas tight seal should be placed in all the fuel rod internal thermocouple leads. The cable below the gas seal should be leak checked. A centerline thermocouple gas seal located inside the fuel rod upper end cap is being built and tested. If this work produces an acceptable gas seal, a seal located in the end cap should be used. If the end plug seal is not feasible, then a ceramic-to-metal gas seal should be located above the upper end cap.

The RIA 1-2 test rods should be fabricated in such a manner that it is assured that they will be leak tight. Therefore, it may not be desirable to use the present laser welder for installing the cladding surface thermocouples unless it is improved to the standards of the machine at Exxon.

5. REACTOR OPERATION

The reactor transient period required to perform the RIA 1-2 test will be determined from the PBF Lead Rod Test Series data and reactor physics calculations. Based on incomplete results from the Lead Rod Tests it is estimated that a reactor period less than 3.5 ms will be required. Precise specifications will be included in the Experiment Operating Specification (EOS) document. The test sequence should begin with about 24 hours of steady-state power operation to condition the fuel. The steady-state operation will be done for fuel rod peak powers

up to 53 kW/m, coolant mass fluxes up to $3400 \text{ kg/s}\cdot\text{m}^2$, coolant inlet temperature of 553 K and a coolant pressure of 7.24 MPa. During the steady-state conditioning period, calorimetric data will be obtained to provide a final basis for choosing the RIA transient. Following the conditioning period, the reactor should be shut down for replacement of the four flux wires. A 100% cobalt flux wire should also be installed in the core before the transient. After the flux wire exchange, the test rods should only be exposed to the minimum possible power operation before the power burst. Criticality determinations should be conducted at steady-state powers of less than 1 kW. Before conducting the actual transient power burst, a trial transient should be performed. The purpose of the trial transient is to check the test procedure and reactor system as completely as possible before conducting the actual power transient. The trial transient should be done in the same manner as the actual burst except the control rods would be withdrawn to a position less than that required to make the reactor critical. The actual transient power burst should then be conducted from BWR hot-startup conditions. (7.24 MPa, 552 K, and $86 \text{ kg/s}\cdot\text{m}^2$).

TABLE II

RIA 1-2 FUEL RODS

<u>PBF RIA TEST ROD NUMBER</u>	<u>ORIGINAL WESTINGHOUSE NUMBER</u>	<u>AVERAGE BURNUP (MWd/MTU)</u>
802-1	MAPI M-2	5220
802-2	MAPI M-13	5110
802-3	MAPI M-33	5320
802-4	MAPI M-24	5150
802-5	MAPI M-42	4600

TABLE III

RIA 1-2 FUEL ROD FUEL ROD DESIGN CHARACTERISTICS

<u>Characteristic</u>	<u>MAPI⁽¹⁾</u>
Fuel	
Material	UO ₂
Pellet OD	8.9 mm
Pellet Length	15.2 mm
Pellet Enrichment	5.7%
Density	94% TD
Fuel Stack Length	0.914 m
End Configuration	dished
Burnup	5200 MWD/MTU
Cladding	
Material	Zircaloy 4
Tube OD	9.99 mm
Tube Wall Thickness	9.572 mm minimum
Yield Strength	570 MPa
Ultimate Strength	700 MPa
Fuel Rod	
Overall Length	0.992 m
Filler gas	Helium
Initial Gas Pressure	0.103 MPa

(1) Data are preirradiation values.

TABLE IV
FUEL ROD CHARACTERIZATION REQUIREMENTS

	Measurement	Measurements Frequency	Measurements Made on These Fuel Rods	Comments
	Fuel Stack Length		802-1, 802-2, 802-3, 802-4, 802-5,	Use radiographic technique or equivalent
	Cladding Outside Diameter	Continuous	802-1, 802-2, 802-3, 802-4, 802-5	Measurement at 0° and 90° orientation
	Fuel Rod Overall Length	Each Rod	802-1, 802-2, 802-3, 802-4, 802-5	
	Neutron Radiograph	Each Rod	802-1, 802-2, 802-3, 802-4, 802-5	
	Leak Check	Each Rod	802-1, 802-2, 802-3, 802-4, 802-5	
21	Photographs	Each Rod	802-1, 802-2, 802-3, 802-4, 802-5	Photographs at 0°, 90°, 180°, and 270° orientation
	Void Volume	Each Rod	802-1, 802-2, 802-4	
	Rod Internal Pressure	Each Rod	802-1, 802-2, 802-4	

REFERENCES

1. United States Nuclear Regulatory Commission, Reactor Safety Research Program, A Description of Current and Planned Reactor Safety Research Sponsored by the Nuclear Regulatory Commission's Division of Reactor Safety Research, NUREG-75-058 (June 1975).
2. D. J. Diamond, G. S. Lellouche, M. M. Levine, Rod Drop and Scram In Boiling Water Reactory (Part 1), BNL-16717, (April 1972).

TABLE VI

REQUESTED MEASUREMENT REQUIREMENTS FOR RIA 1-2 FUEL ROD INSTRUMENTATION

MEASUREMENT	INSTRUMENT	NUMBER OF INSTRUMENTS PER ROD	INSTRUMENT LOCATION	FUEL ROD NUMBERS TO BE INSTRUMENTED	DESIRED INSTRUMENT RANGE	DESIRED INSTRUMENT ACCURACY	DESIRED RESPONSE TIME (s)	COMMENTS
Rod Internal Pressure	Pressure Transducer	1	Upper Plenum	802-1, 802-2, 802-4,	0-17.2 MPa	+5%	0.002	
Cladding Surface Temperature	Thermocouple	2	(to be specified)	802-1, 802-2	300-2100 K	+1%	0.01	Laser weld TC's desired
Plenum Temperature	Thermocouple	1	Upper Plenum	802-2	300-1000 K	1.5%	0.02	

TABLE V

MEASUREMENT REQUIREMENTS FOR THE RIA 1-2 TEST TRAIN HARDWARE INSTRUMENTATION

MEASUREMENT	INSTRUMENT	INSTRUMENT LOCATION	DESIRED INSTRUMENT RANGE	DESIRED INSTRUMENT ACCURACY (% of full scale)	DESIRED RESPONSE TIME (s)	COMMENTS
Coolant Pressure	Pressure Transducer	Near outlet of IPT flow tube	0-69 MPa	$\pm 5\%$	3×10^{-8}	Transient pressure response should be measured
Coolant Pressure	Pressure Transducer	Near outlet of IPT flow tube	0-17.2 MPa	$\pm 5\%$	3×10^{-8}	To measure normal system pressure & pressure pulse. Should be calibrated at 550 K
Coolant Flow	Turbine Flow Meter	Inlet of each flow shroud	63-820 cm ³ /s	$\pm 2\%$	N/A	
13 Coolant Inlet Temperature	Thermocouple	Two thermocouples near inlet of flow shrouds	300-600 K	$\pm 1.5\%$	N/A	
Coolant Outlet Temperature	Thermocouple	Outlet of each flow shroud	300-600 K	$\pm 1.5\%$	N/A	
Coolant Differential Temperature	Thermocouple Pairs	Inlet and outlet of each flow shroud	0-20 K	$\pm 1\%$	N/A	
Relative Neutron Flux	SPND's	Two vertical columns of	9×10^{16} n/cm ² ·s	$\pm 3\%$	0.002	
Neutron Flux	(0.51% Co-Al) for steady-state; 100% Cobalt for transient	Outer surface each flow shroud (180° orientation)	1.7×10^{18} nvt 1.2×10^{15} nvt	- -	- -	0.51% Co-Al flux wires should be replaced with 100% cobalt wires before transient
Cladding Axial Strain	LVDT	Lower end of each rod	0-20nm	$\pm 5\%$	0.003	Should be calibrated for 550 K conditions

TABLE I
SERIES 1 RIA TESTS⁽¹⁾

Test Number	No. Rods	Burnup (MWd/MTM)	Fuel Type	Pellet Density (%)	Pellet OD (in.)	Gap (Mils)	Total Enthalpy ⁽²⁾ (Cal/cm ³)	Objectives and Comments
RIA 1-1	2	5,000	UO ₂	94	0.338	6.5	3120	To provide a comparison of irradiated and unirradiated fuel behavior using Saxton MAPI rods at the expected incipient failure energy.
	2	0	UO ₂	94	0.338	6.5		
RIA 1-2	4	5,000	UO ₂	94	0.338	6.5	3650 ⁽³⁾	To test irradiated MAPI rods at a nominally higher energy than Test 1 to better locate the incipient failure energy. Two rods will be pressurized to BWR EOL conditions.
RIA 1-3 ⁽⁵⁾	2	5,000	UO ₂	94	0.338	6.5	*(3)	To test MAPI rods at a third energy level and provide data for zero burnup BWR size rods.
	2	0	UO ₂	94	0.416	9		
RIA 1-4 ⁽⁵⁾	16 ⁽⁶⁾	0	UO ₂	95	0.416	9	*(3)	To test behavior of clustered rods for comparison with independent rods results.
RIA 1-6 ⁽⁴⁾	2	5,000	UO ₂	94	0.338	6.5	*(3)	To use Saxton MAPI rods at a larger enthalpy insertion for direct comparison with Test 1 to 3
	2	0	UO ₂	94	0.338	6.5		

(1) All tests in this series will be performed from BWR hot standby conditions.

(2) Energy density at 0.9 of the pellet radius.

(3) Enthalpy to depend upon results of previous tests.

(4) High burnup low enriched UO₂ rods will be employed in Test 6 if desired enthalpy insertions can be reached and if further study of the enthalpy effect on MAPI rods is considered to be of lower priority.

(5) Tests 3 and 4 may include unirradiated BWR-size rods with specially fabricated cladding; timing of the cluster test is dependent on hardware availability.

(6) Identification of number of fuel rods for Test 4 will follow determination of minimum enrichments required to achieve desired energies.