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Addendum 2

Experiment Operations Plan for a Loss-of-Coolant Accident Simulation in the National Research Universal Reactor

Materials Test 2

Prepared by G. E. Russcher, J. O. Barner, G. M. Hesson, C. L. Wilson,
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Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

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ABSTRACT

A loss-of-coolant accident (LOCA) simulation program is evaluating the thermal-hydraulic and mechanical effects on pressurized water reactor (PWR) test fuel bundles. This Experiment Operation Plan (EOP) Addendum 2, together with the referenced EOP, describes the desired operating conditions and additional hazards review associated with the four-part MT-2 experiment. The primary portions of the experiment, MT-2.2 and MT-2.3, will evaluate the following:

1) the mechanical deformation of pressurized fuel rods subjected to a slow LOCA, using reflood water for temperature control, that is designed to produce cladding temperatures in the range from 1033 to 1089K (1400 to 1500^{O}F) for an extended time, and

2) the effects of the deformed and possibly failed cladding on the thermal-hydraulic performance of the test assembly during simulated LOCA heating and reflooding.

The secondary portions of the experiment, MT-2.1 and MT-2.4, are intended to provide thermal-hydraulic calibration information during two-stage reflood conditions for 1) relatively low cladding temperatures, <839K (1050^{O}F), on nondeformed rods, and 2) moderately high cladding temperatures, <1089K (1500^{O}F), on deformed rods.

SUMMARY

Pacific Northwest Laboratory (PNL) is conducting a series of LOCA-simulation experiments in the U-2 loop of the National Research Universal (NRU) reactor at Chalk River Nuclear Laboratories (CRNL), Chalk River, Ontario. The third experiment of the series is Materials Test Two (MT-2). The primary objectives of MT-2 are to evaluate 1) the deformation and failure behavior of a controlled reflood LOCA simulation that can produce PWR fuel cladding temperatures of about 1061K (1450°F) for up to 200 s, MT-2.2; and 2) the effects of cladding deformation (from MT-2.2) on the coolability and thermal-hydraulic characteristics of the rods during subsequent heatup and reflood, MT-2.3. Secondary objectives of MT-2 are to provide thermal-hydraulic calibration data during two-stage reflood for 1) relatively low cladding temperatures on non-deformed rods, MT-2.1; and 2) moderately high cladding temperatures on deformed rods, MT-2.4. The latter thermal-hydraulic test is being performed to obtain information that is adequate to control a simulated LOCA, similar to MT-2.2, and is controlled with two-stage reflood water. The PWR fuel bundle contains 31 full-length fuel rods, 11 of which are pressurized test fuel rods. This brief addendum is provided to document revisions to the MT-2 plan and safety rationale.[1]

PNL will provide the materials test train, the test fuel assembly, the Data Acquisition and Control System (DACS), test instrumentation, post-irradiation examination using the Disassembly Examination and Reassembly Machine (DERM), data reduction and analysis, and management of the LOCA simulation program. Atomic Energy of Canada, Limited (AECL) will provide CRNL test facilities, irradiation space in the NRU reactor, modifications of NRU loops, operation of the NRU loops and reactor, and support of the CRNL test facilities.

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1.0 INTRODUCTION

Pacific Northwest Laboratory (PNL)[(a)] is conducting an experimental program for the Nuclear Regulatory Commission (NRC), Division of Reactor Safety Research, Fuel Behavior Branch, to evaluate the consequences of hypothetical loss-of-coolant accidents (LOCA) in a pressurized water reactor (PWR). Pacific Northwest Laboratory will provide the materials test trains, the test fuel assemblies, postirradiation examination of the test trains, data reduction and analysis, and management of the LOCA simulation program. Atomic Energy of Canada, Limited (AECL) will provide test facilities and irradiation space in the Canadian National Research Universal (NRU) Reactor at the Chalk River Nuclear Laboratories (CRNL), Chalk River, Ontario.

A LOCA in a commercial PWR involves four major, distinct phases: blowdown, heatup, reflood, and quench. Each of these phases involves a path-dependent process that is a function of 1) the type of event that initiated the accident, and 2) the reactor operating conditions at the time the LOCA was initiated. During the most damaging LOCA phases, heatup and reflood, the highest fuel cladding temperatures are reached, with the maximum pressure differential occurring across the fuel cladding wall. The pressurized cladding will deform and rupture when the critical pressure/temperature/time combinations are attained.

The primary portion, MT-2.2, of this second materials test of the experimental program will evaluate the thermal-hydraulic effects of a simulated LOCA that produces Zircaloy cladding temperatures of about 1061K (1450^{o}F) in the high alpha region for an extended period. The MT-2.2 experiment is intended to provide upper limit deformation damage data for LOCAs of current concern for licensing and also provide nuclear heated, full-length LOCA data for comparison to out-of-reactor electrically heated simulated LOCAs. The basic description of MT-2 operating plans is provided in Reference 1 and these plans are modified herein. Operating conditions to provide the desired cladding temperature and an exposure of up to 200 s were determined based upon results from the first experiments in the program, Prototypic Thermal-Hydraulic (PTH). In order to maximize the time spent in the desired temperature range and maintain control over the cladding temperature, the fuel bundle heatup will be provided by steady-state NRU reactor operation and the cladding temperature will be controlled by varying the reflood water flow to the test loop. During this operation test fuel rod cladding is expected to balloon and possibly rupture.

To evaluate the effects of these LOCA-deformed fuel rods on the thermal-hydraulics of the bundle, a subsequent transient (MT-2.3) will immediately follow MT-2.2. MT-2.3 will use the same operating conditions developed for PTH-101, one of the Prototypic Thermal-Hydraulic (PTH) tests.[2] MT-2.3 will consist of a heatup phase, when steam cooling is shutoff, followed by coolant reflooding at 0.099 m/s (3.9 in./s) after a delay of 30 s. The resultant thermal-hydraulic characteristics will be compared with PTH-101. The MT-2.3 transient is not expected to induce a significant number of additional cladding ruptures or additional experiment hazards.

Two additional thermal-hydraulic test series are planned as part of MT-2 to provide two-stage reflood calibration data for variable reflood rate tests that are to be conducted later in the overall program. The MT-2.1 test series will be performed at relatively low cladding temperatures, <839K (1050^{o}F), on the nondeformed rods prior to test MT-2.2. The MT-2.4 test series will be conducted at moderately high cladding temperatures, <1089K (1500^{o}F), on the deformed rods after the MT-2.3 experiment.

This addendum to the reference EOP[1] addresses the changes to the MT-2 test train configuration, instrumentation, and the planned operations. The additional potential safety hazards are also addressed.

The reference Safety Analysis Report[3] provides a description of the LOCA simulation major safety issues and an overview of the experiments that are planned for the program. Information presented here (Hazards Review, Section 4.0) shows that differences between MT-2 and previous experiments are either insignificant safety issues or they are enveloped by the safety analysis presented before. Because the experiment safety issues have been adequately analyzed, reviewed and reported,[3,4,5] no additional safety analyses are required for MT-2. In this operations plan addendum, changes to the test train or experiment operation are referenced to the appropriate, previously published safety documents.

2.0 EXPERIMENT OBJECTIVES

The primary objective of the MT-2 experiment is to evaluate the deformation behavior of a simulated LOCA that produces fuel cladding temperatures in the range from 1033K (1400^{o}F) to 1089K (1500^{o}F) for an extended time. Operation at these conditions should maximize the amount of fuel cladding strain. The cladding is expected to balloon more extensively and over a greater axial distance than observed in MT-1. Consequently, the hydraulic blockage may be significantly greater.

A secondary objective of MT-2 is to evaluate the coolability of the ballooned fuel rods during subsequent heatup and reflood, MT-2.3. Comparison of fuel temperatures, cladding temperatures, coolant flow rates, and inlet coolant pressures between MT-2.3 and PTH-101 should identify thermal-hydraulic behavioral differences caused by cladding ballooning. Due to cladding lift-off, the change in fuel/cladding gap conductivity should be evident from fuel centerline and fuel cladding temperature measurements. The results from MT-2 should be applicable for use in fuel behavior computer models for LOCA safety analyses and PWR fuel performance predictions.

Tertiary objectives of MT-2 are to provide thermal-hydraulic data during two-stage reflood cooling of nondeformed rods at relatively low cladding temperatures, MT-2.1, and reflood cooling of deformed rods at moderately high cladding temperatures, MT-2.4. If results from these two thermal-hydraulic tests are correlatable, the thermal-hydraulic tests currently planned to be performed prior to the simulated LOCAs using variable-stage reflood can be expected to be significantly reduced or eliminated.

3.0 DESIGN DIFFERENCES

In general, the MT-2 experiment will be very similar to the MT-1 experiment and the reference EOP[1,5] is applicable in most ways. There are two reasons for the design changes that have been instituted.

a) To meet the revised experiment objective, it will be necessary to use interactive reflood cooling control to provide long-term Zircaloy cladding temperatures in the high alpha range.

b) The test train for MT-2 was previously used for MT-1, consequently some of the failed instruments were removed and others were replaced by an improved design.

3.1 MATERIALS TEST TRAIN AND INSTRUMENTATION

After careful inspection of MT-1 and rework of most failed instrumentation, it was decided that the test train used for experiment MT-1 will be reused for experiment MT-2. Many thermocouples (TCs) mounted in and on test fuel rods used leads that were routed through high pressure connectors. Nearly all of them failed (due to connector leakage) during the MT-1 experiment. Consequently, all these TC leads are now routed directly to feed-through junctions at the reactor head closure. None of these sensors is designated for the NRU trip circuitry.

In addition, three steam probe TCs were removed from the test train during its renovation for MT-2, because they interfered with the reassembly of the fuel rod bundles. Table 3.1 provides a summary of the MT-2 instruments that provide data for DACS recording, together with their location in the materials test train. Also noted on Table 3.1 are failed sensors that have not been replaced or repaired due to the (high radiation field) rework operations required.

The eleven test fuel rods and liquid level detector rod that compose the MT-2 cruciform bundle replaced the test fuel rod bundle from MT-1. These test fuel rods contain helium pressurized to 3.2 MPa (465 psia) and unirradiated fuel of the same design and fabrication previously used in the MT-1 experiment.[1]

TABLE 3.1. Instrumentation Summary

No.	DACS Name	Location in.	Location Component	No.	DACS Name	Location in.	Location Component
1	TC-1-4D-IN	-0.95[a]	MT[a]	37	TC-9-1F-S-C	48.32	MT
2	TC-1-6A-IN	-0.95	MT	38	TC-10-4D-SP-4	55.28	MT[c]
3	TC-1-1F-IN	-0.95	MT	39	TC-10-6A-S-C	55.28	MT
4	TC-2-6F-S-C	8.03	Failed	40	TC-10-6F-S-C	55.28	MT
5	TC-2-1A-S-C	8.03	MT	41	TC-10-1F-S-C	55.28	MT
6	UNDEFINED		[b]	42	TC-10-1A-S-C	55.28	Failed
7	TC-3-5B-OR-1	13.28	MT	43	TC-11-6C-OR-4	60.53	MT
8	TC-3-5E-OR-2	13.28	MT	44	TC-11-4F-OR-1	60.53	MT
9	TC-3-2E-OR-3	13.28	MT	45	TC-11-1D-OR-2	60.53	MT
10	TC-3-2B-OR-4	13.28	MT	46	TC-11-3A-OR-3	60.53	MT
11	TC-3-6A-S-C	13.28	MT	47	TC-11-6F-S-C	60.53	MT
12	TC-3-1F-S-C	13.28	MT	48	TC-11-1A-S-C	60.53	MT
13	TC-4-6F-S-C	18.53	MT	49	UNDEFINED		[b]
14	TC-4-1A-S-C	18.53	MT	50	TC-12-5B-SP-3	68.32	MT
15	TC-5-6A-S-C	27.32	MT	51	TC-12-5E-SP-4	68.32	MT
16	TC-5-IF-S-C	27.32	MT	52	TC-12-2E-SP-1	68.32	MT
17	UNDEFINED		[b]	53	TC-12-2B-SP-2	68.32	Removed[q]
18	TC-6-6A-S-C	34.28	Failed	54	TC-13-4D-SP-4	76.28	MT[c]
19	TC-6-6F-S-C	34.28	MT	55	TC-13-3B-IR-2	76.28	MT[p]
20	TC-6-1F-S-C	34.28	MT	56	TC-13-6C-IR-2	76.28	MT[d]
21	TC-6-1A-S-C	34.28	Failed	57	TC-13-4F-IR-4	76.28	MT[d]
22	TC-7-6C-OR-4	39.53	MT	58	TC-13-1D-IR-2	76.28	MT[d]
23	TC-7-4F-OR-1	39.53	Failed	59	TC-13-3A-IR-4	76.28	MT[d]
24	TC-7-1D-OR-2	39.53	MT	60	TC-13-6A-S-C	76.28	MT
25	TC-7-3A-OR-3	39.53	MT	61	TC-13-6F-S-C	76.28	MT
26	TC-8-5B-OR-1	42.24	Failed	62	TC-13-1F-S-C	76.28	Failed
27	TC-8-5E-OR-2	42.24	MT	63	TC-13-1A-S-C	76.28	MT
28	TC-8-2E-OR-3	42.24	MT	64	TC-14-4D-SP-4	89.32	MT[c]
29	TC-8-2B-OR-4	42.24	MT	65	TC-14-5B-SP-3	89.32	MT
30	TC-8-6F-S-C	42.24	Failed	66	TC-14-5E-SP-4	89.32	MT
31	TC-8-1A-S-C	42.24	MT	67	TC-14-2E-SP-1	89.32	MT
32	TC-9-5B-OR-1	48.32	MT	68	TC-14-2B-SP-2	89.32	Removed[q]
33	TC-9-5E-OR-2	48.32	MT	69	TC-15-4D-SP-4	97.28	MT[c]
34	TC-9-2E-OR-3	48.32	MT	70	TC-15-3B-IR-4	97.28	MT[p]
35	TC-9-2B-OR-4	48.32	MT	71	TC-15-6C-IR-4	97.28	MT[e]
36	TC-9-6A-S-C	48.32	MT	72	TC-15-4F-IR-2	97.28	MT[e]

TABLE 3.1. (contd)

No.	DACS Name	Location in.	Location Component	No.	DACS Name	Location in.	Location Component
73	TC-15-1D-IR-4	97.28	MT(e)	109	TC-17-2B-IR-4	118.28	MT(f)
74	TC-15-3A-IR-2	97.28	MT(e)	110	TC-17-6A-S-C	118.28	MT
75	TC-15-6A-S-C	97.28	MT	111	TC-17-6F-S-C	118.28	MT
76	TC-15-6F-S-C	97.28	MT	112	TC-17-1F-S-C	118.28	MT
77	TC-15-1F-S-C	97.28	Failed	113	TC-17-1A-S-C	118.28	MT
78	TC-15-1A-S-C	97.28	MT	114	UNDEFINED		(b)
79	TC-16-4D-SP-4	110.32	MT(c)	115	TC-18-4B-OR-3	139.28	MT
80	TC-16-5B-SP-3	110.32	MT	116	TC-18-5C-OR-3	139.28	MT
81	TC-16-5E-SP-4	110.32	Failed	117	TC-17-5D-OR-3	118.28	MT(c)(p)
82	TC-16-2E-SP-1	110.32	MT	118	TC-18-4E-OR-4	139.28	MT
83	TC-16-2B-SP-2	110.32	Removed(q)	119	TC-18-3E-OR-4	139.28	MT(p)
84	TC-16-6A-C-3	110.32	MT	120	TC-17-2D-OR-1	118.28	MT(c)(p)
85	TC-16-6F-C-4	110.32	MT	121	TC-18-2C-OR-1	139.28	MT(p)
86	TC-16-1F-C-1	110.32	MT	122	TC-18-5C-IR-4	139.28	MT
87	TC-16-1A-C-2	110.32	MT	123	TC-17-5D-IR-4	118.28	MT(c)
88	TC-17-4C-IR-3	118.28	MT	124	TC-18-4E-IR-1	139.28	MT
89	TC-17-4D-SP-4	118.28	MT(c)	125	TC-18-3E-IR-1	139.28	Failed(p)
90	TC-17-3D-IR-5	118.28	MT(p)	126	TC-17-2D-IR-2	118.28	MT
91	TC-15-3C-IR-2	97.28	MT(c)(p)	127	TC-18-2C-IR-2	139.28	MT(p)
92	TC-17-4C-IR-C	118.28	MT	128	TC-18-6A-S-C	139.28	MT
93	TC-17-3D-IR-C	118.28	MT(p)	129	TC-18-6F-S-C	139.28	MT
94	TC-15-3C-IR-C	97.28	MT(c)(p)	130	TC-18-1F-S-C	139.28	Failed
95	TC-17-4C-IR-1	118.28	MT	131	TC-18-1A-S-C	139.28	MT
96	TC-17-3D-IR-3	118.28	MT(p)	132	TC-20-OT-1	167.70	MT
97	TC-15-3C-IR-7	97.28	MT(c)(p)	133	TC-20-OT-3	167.70	MT
98	TC-15-5B-IR-3	97.28	MT(c)(e)	134	TC-20-OT-2	167.70	MT
99	TC-17-5E-IR-4	118.28	MT(f)	135	TC-21-HT-1	187.23	MT
100	TC-15-2E-IR-1	97.28	MT(c)(e)	136	UNDEFINED		
101	TC-17-2B-IR-2	118.28	MT(f)	137	TC-15-3C-IR-1	97.28	MT(c)(p)
102	TC-15-5B-IR-C	97.28	MT(c)	138	TC-17-3D-IR-4	118.28	MT(p)
103	TC-17-5E-IR-C	118.28	MT	139	SRCS-TC-RF-AC		TE(r)
104	TC-15-2E-IR-C	97.28	MT(c)	140	SRCS-TC-RF-DR		TE(r)
105	TC-17-2B-IR-C	118.28	MT	141	UNDEFINED		(b)
106	TC-15-5B-IR-1	97.28	MT(c)(e)	142	SPND-3-6F-S-3	13.28	MT
107	TC-17-5E-IR-2	118.28	MT(f)	143	SPND-3-1A-S-1	13.28	MT
108	TC-15-2E-IR-3	97.28	MT(c)(e)	144	LVDT-19-4D-LL-D	157.0	MT(g)(p)

TABLE 3.1. (contd)

No.	DACS Name	Location in.	Location Component
145	SPND-6-6A-S-2	34.28	MT
146	SPND-6-IF-S-4	34.28	Failed
147	UNDEFINED		[b]
148	SPND-10-6A-S-2	55.28	MT
149	SPND-10-6F-S-3	55.28	MT
150	SPND-10-IF-S-4	55.28	MT
151	SPND-10-1A-S-1	55.28	MT
152	SPND-12-1F-C	68.32	Failed
153	UNDEFINED		[b]
154	SPND-13-6A-S-2	76.28	Failed
155	SPND-13-6F-S-3	76.28	MT
156	SPND-13-1F-S-4	76.28	MT
157	SPND-13-1A-S-1	76.28	Failed
158	UNDEFINED		[b]
159	SPND-15-6A-S-2	97.28	MT
160	SPND-15-6F-S-3	97.28	MT
161	SPND-15-1F-S-4	97.28	MT
162	SPND-15-1A-S-1	97.28	Failed
163	SPND-16-1F-C	110.32	Failed
164	UNDEFINED		[b]
165	SPND-17-6A-S-2	118.28	Failed
166	SPND-17-6F-S-3	118.28	MT
167	SPND-17-1F-S-4	118.28	Failed
168	SPND-17-1A-S-1	118.28	MT
169	UNDEFINED		[b]
170	SPND-18-6F-S-3	139.28	MT
171	SPND-18-1A-S-1	139.29	MT
172	UNDEFINED		[b]
173	PS-19-4C-C	157.0	MT[p]
174	PS-19-4C-C-1	157.0	MT[p]
175	PS-19-3D-C	157.0	MT[p]
176	PS-19-3D-C-1	157.0	MT[p]
177	PS-19-4B-C	157.0	MT[p]
178	PS-19-4B-C-1	157.0	MT[p]
179	PS-19-5D-C	157.0	MT[p]
180	PS-19-5D-C-1	157.0	MT[p]

No.	DACS Name	Location in.	Location Component
181	PS-19-4E-C	157.0	MT[p]
182	PS-19-4E-C-1	157.0	MT[p]
183	PS-19-3E-C	157.0	MT[p]
184	PS-19-3E-C-1	157.0	MT[p]
185	PS-19-2D-C	157.0	MT[p]
186	PS-19-2D-C-1	157.0	MT[p]
187	PS-19-2C-C	157.0	MT[p]
188	PS-19-2C-C-1	157.0	MT[p]
189	PS-19-3B-C	157.0	MT[p]
190	PS-19-3B-C-1	157.0	MT[p]
191	TC-90-HD-1	336.0	H/L-24[i]
192	TC-90-HD-2	336.0	H/L-24
193	TC-90-HD-3	336.0	H/L-24
194	TC-90-HD-4	336.0	H/L-24
195	UNDEFINED		
196	UNDEFINED		
197	PTK-19-3C-C	157.0	MT[p]
198	PTS-19-5C-C	157.0	MT[p]
199	UNDEFINED		
200	UNDEFINED		
201	SRCS-FR-LO-W	-337.0	FE-4[j]
202	SRCS-FR-HI-GH	-333.0	FE-3
203	STBY-FL-OW	382.0	FE-9
204	U2LP-PR-ES-S-1	447.0	PDT-90
205	U2LP-TA-PS-DR-1	+447.0 -1176.0	PDT-90
206	SRCS-S-TC-IN-1	-180.0	TE-2
207	SRCS-S-TC-OT-1	+363.0	TE-3
208	SRCS-S-PS-IN-1	-82.0	PT-5
209	SRCS-S-PS-OT-1	+369.0	PT-6
210	SRCS-S-FR-1	+950.0	FY-6
211	SRCS-S-FR-IN-1	-432.0	FV-1
212	SRCS-S-FR-OT-1		FI-2[k]
213	SRCS-TC-RF-LP-1	-450.0	TE-17
214	SRCS-TC-RF-TA-1	-225.0	TE-18
215	U2LP-FL-OW-1	-1560.0	FT-4D
216	SRCS-FR-LO-B	-409.0	FE-4B

TABLE 3.1. (contd)

No.	DACS Name	Location in.	Location Component
217	SRCS-S-PS-OT-2	+950.0	PT-4
218	UNDEFINED		
219	ACUM-WT	-238.0	WIS[l]
220	UNDEFINED		
221	U2LP-TC-IN-1	-1176.0	TE-78
222	U2LP-TC-OT-1	+447.0	TE-79
223	UNDEFINED		
224	UNDEFINED		
225	SRCS-FR-HI-B	-413.0	FE-3B
257	SRCS-DE-LT-A	Transient Signal	LCS[m]
258	SRCS-RF-TR-IP	Low RF	LCS[n]
289	PSD-1-IN-1		DACS[e]
290	PSD-2-S-1		DACS
291	PSD-3-OR-1		DACS
292	PSD-3-S-2		DACS
293	PSD-4-S-1		DACS
294	PSD-5-S-1		DACS
295	PSD-6-S-1		DACS
296	PSD-7-OR-1		DACS
297	PSD-8-OR-1		DACS
298	PSD-8-S-2		DACS
299	PSD-9-OR-1		DACS
300	PSD-9-S-2		DACS

No.	DACS Name	Location in.	Location Component
301	PSD-10-S-1		DACS
302	PSD-11-OR-1		DACS
303	PSD-11-S-2		DACS
304	PSD-12-SP-1		DACS
305	PSD-13-IR-1		DACS
306	PSD-13-S-2		DACS
307	PSD-14-SP-1		DACS
308	PSD-15-IR-1		DACS
309	PSD-15-S-2		DACS
310	PSD-16-SP-1		DACS
311	PSD-16-C-2		DACS
312	PSD-17-IR-1		DACS
313	PSD-17-IR-2		DACS
314	PSD-17-IR-3		DACS
315	PSD-17-IR-4		DACS
316	PSD-17-S-5		DACS
317	PSD-18-OR-1		DACS
318	PSD-18-IR-2		DACS
319	PSD-18-S-3		DACS
320	PSD-20-OT-1		DACS
321	PSD-17-SD-6		DACS
322	PSD-19-IR-C		DACS
323	PSD-19-IR-2		DACS
324	UNDEFINED		
325	UNDEFINED		

TABLE 3.1. (contd)

(a) Materials test (MT) assembly, elevation (in.) relative to the bottom of the fuel column.
(b) Sensor removed, replaced by the liquid level detector.
(c) Sensor relocated from the location of the PTH test train.
(d) Level 13 trip circuit thermocouples.
(e) Level 15 trip circuit thermocouples.
(f) Level 17 trip circuit thermocouples.
(g) LVDT Linear Variable Differential Transformer for the liquid level detector.
(h) DACS average pseudo sensor (calculated signal).
(i) NRU head mounted at location L-24.
(j) Sensor element, located in the U-2 loop or steam/reflood loop relative to the test fuel column bottom, measured along the hydraulic channel. See AECL Flowsheet, E-4531-F-1 rev. 9, January 28, 1981.
(k) Bypass steam loop, location irrelevant.
(l) Hydraulic head, below the fuel column bottom.
(m) Loop control system signal for forced transient operation.
(n) Low reflood water inventory signal, also trips the NRU reactor.
(p) New instrument, installed with MT-2 fuel bundle.
(q) Sensors removed to facilitate reassembly of MT-2 fuel bundle.
(r) Reflood loop TCs to monitor isothermal conditions, accumulator to drain.

The liquid level detector is the same design as used in MT-1, and the twenty guard fuel rods that surround the test fuel bundle are the same ones that were used in the MT-1 experiment.

Note that none of the NRU trip sensors have been changed or affected by MT-2 design changes. Table 3.2 is reproduced[1] to provide specific trip setpoint criteria. Specific trip setpoint values are tabulated in Section 5.0, Operating Procedure Summary.

3.2 LOOP FACILITIES AND LOOP CONTROL SYSTEM

The reflood coolant supply system has been rebuilt to provide better control of coolant temperature during the simulation of LOCA reflood and quench phases. It will provide water from the reflood accumulators at a setpoint temperature of 300K ($80^{o}F$) to repeat conditions used in PTH-101.

In addition, the reflood loop will use a bleedflow through the loop and its drain valves to provide more uniform loop temperature control during the

TABLE 3.2. Trip Setpoint Criteria for Operating and Non-Functional Fuel Cladding Thermocouples

Summary Operating Conditions	Criteria and Safety Margins (SM)	Sensor Instrument Levels: Level 17	Level 15	Level 13
		DACS Thermocouple Numbers		
		315,PSD-17-IR-4[a] (99,101,107,109)	308,PSD-15-IR-1 (71,72,73,74, 98,100,106,108)	305,PSD-13-IR-1 (56,57,58,59)
		Trip Setpoint Temperatures		
2 $\leq$ Operating TCs on each of levels 13, 15, 17	Standard SM = 56K (100°F)	1333K (1940°F)	1361K (1990°F)	1361K (1990°F)
2 $\leq$ Operating TCs on each of levels 15 and 17	Standard SM = 56K (100°F)	1333K (1940°F)	1361K (1990°F)	
2 $\leq$ Operating TCs on each of levels 15 and 17, or levels 13 and 17	Alternate SM = 84K (150°F)	1305K (1890°F)	1333K (1940°F)	1333K (1940°F)
2 $\leq$ Operating TCs on only level 15 or 17 or 13	Fall-Back SM = 111K (200°F)	1305K (1890°F)	1305K (1890°F)	1305K (1890°F)

(a) These pseudo sensor data (PSD) are the calculated time-average of the DACS sensor-numbered data that follow (99, 101, 107, 109).

transient reflooding operation. This bleedflow will be calibrated by CRNL prior to the test so that LCS setpoint reflood rates will provide effective flow to the MT-2 test train, as prescribed in Section 5.0. Two new immersion TCs in the reflood loop will provide reflood coolant temperature (at the accumulators and at the loop drain) data recorded on DACS terminals #139 and #140. Calibration of the reflood loop will include a lower flow operating range, 0.007 to 0.025 m/s (0.3 to 1.0 in./s). Operability and reproducibility will be demonstrated with the MT-2 test train installed.

The LCS will be used during the MT-2 experiment to control preconditioning and pretransient operations in the same manner it has been previously used. Operating conditions for the several parts of the experiment are summarized in Section 5.0. The first part of transient operation is composed of three benign low-temperature thermal-hydraulic transients (MT-2.1.1, MT-2.1.2, and MT-2.1.3) which each use two-stage reflood cooling (and various slow reflood rates) and a reactor power of approximately 4.0 MW. For for the second part (MT-2.2), the LOCA heatup phase is also controlled by variable reflood water flow rates. The reflood methods are described in Section 5.0. Test MT-2.2 uses a reactor power of approximately 7.5 MW. When steady-state operation (pretransient) is regained the third part, transient MT-2.3, will be initiated. With 20 s forewarning (for DACS transient mode switching), the LCS will shut off steam cooling to the test train. After a 30 s reflood delay, the LCS will initiate reflood flow to the test train at an effective rate of 0.099 m/s (3.9 in./s). The parameters for the LCS to provide these controls are (with prior calibration) the same as used in PTH-101, including the reflooding termination time.[5] The fourth (optional) part of transient operation is composed of three moderate-temperature, thermal-hydraulic transients (MT-2.4.1, MT-2.4.2, and MT-2.4.3), using deformed-cladding fuel rods. Reflooding rates are a repeat of those used at low temperatures on undeformed fuel rods. However, fuel cladding temperature is not permitted to exceed 1089K (1500^{o}F).

3.3 NRU REACTOR OPERATIONS

Reactor operations and trip setpoint controls will be essentially the same as used in experiment MT-1 and reported in the reference EOP.[1] The only difference for MT-2 operations will be an interim period of low reactor power operation, as shown in Figure 3.1. The time during initial pretransient operations, with the U-1 steam loop connected, will provide the opportunity required for the calorimetric calibration of the steam system and the reflood flow control with the LCS. See Figure 3.1 for a schematic overview of reactor operation during the MT-2 experiment, including thermal-hydraulic transients MT-2.1 and MT-2.4.

The NRU reactor loading for the MT-2 experiment will also require the core configuration used in previous LOCA simulation experiments. These requirements are described in Reference 6.

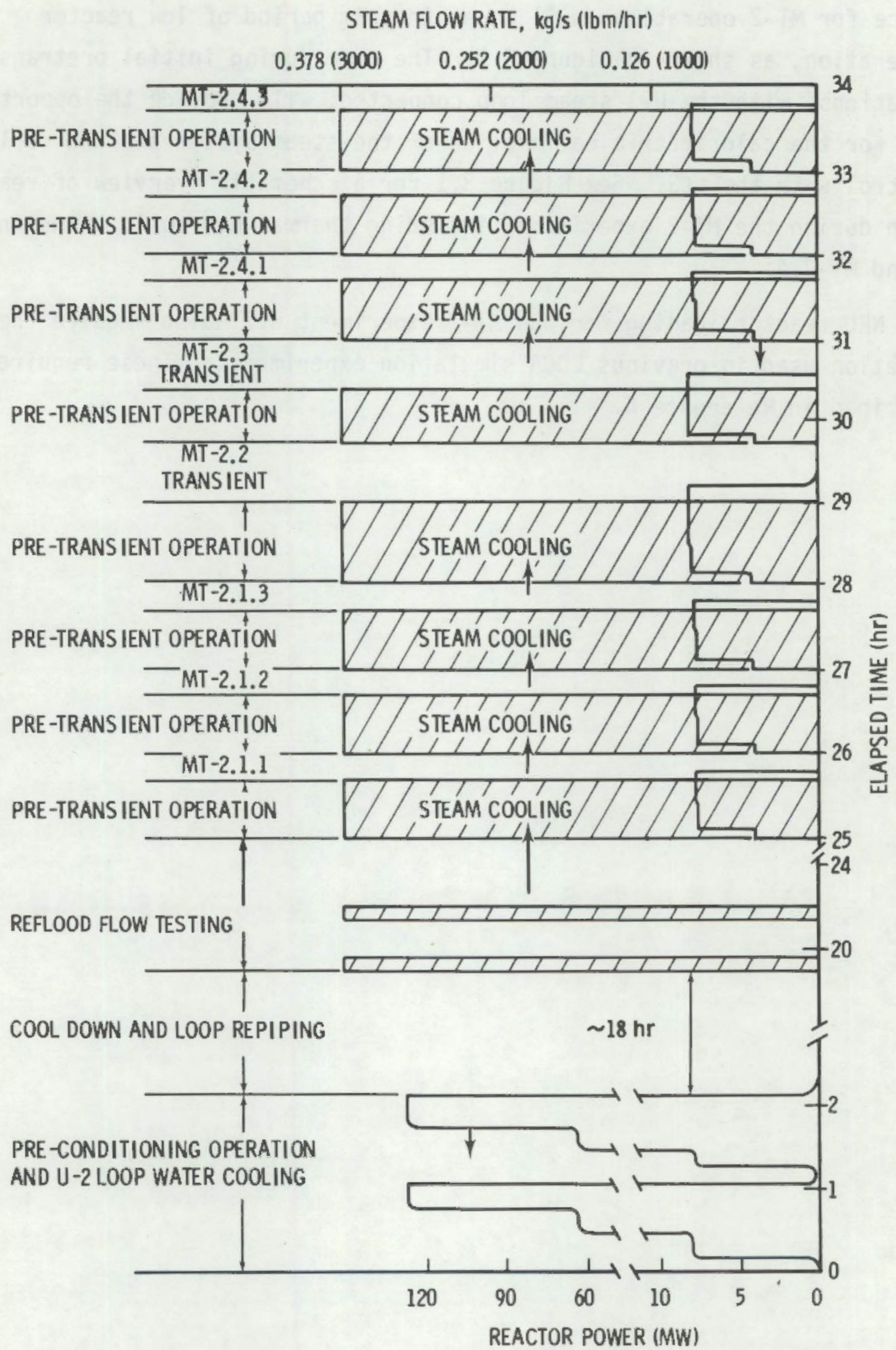

FIGURE 3.1. Experiment and NRU Operations Schematic

4.0 HAZARDS REVIEW

MT-2 fuel rods may rupture during the experiment. Only eleven test fuel rods are pressurized with helium and consequently are expected to balloon during the first moderately high-temperature transient operation, MT-2.2. Although cladding deformation may be greater than observed in MT-1, with a longer sausage-like configuration extending from level 15 to level 17, more severe ruptures are not expected. Rather, cladding pin-hole or crack openings are expected to cause fuel rod depressurization. Fuel fragment dispersal is expected to be insignificant (no worse than MT-1) because the test assembly grids will trap any large fragments of fuel pellets, and only fuel fines or fission products will be released to the coolant loop and catch-tank system.

The first part of MT-2 transient operation consists of a series of low-temperature thermal-hydraulic transients within the operating range of PWR fuel. These transients (MT-2.1.1, MT-2.1.2, and MT-2.1.3) are designed to evaluate the operating characteristics of controlled variable reflooding. Operation is limited to the fuel cladding temperature range [<839K (1050^{o}F)] where any failure or deformation can be safely precluded.

During the second portion of transient operation (MT-2.2), variable reflood cooling will be interactively operated so that peak fuel cladding temperatures will be maintained in the range from 1033 to 1089K (1400 to 1500^{o}F) for up to 200 s. During this period, when fuel cladding is expected to balloon, its temperature will drop and the fuel temperature will rise. Steady-state heat transport calculations provide a conservative estimate of the maximum credible fuel temperatures that might be possible. Figure 4.1 shows centerline fuel temperatures that could be produced as a function of cladding deformation. Two fuel/cladding gaps are noted: a) the deformation corresponding to rod-to-rod contact and b) the maximum cladding deformation observed in MT-1. These calculations show that even if the fuel rods were fully deformed and ruptured (with steam replacing the helium), the maximum credible fuel centerline temperature would be less than 2144K (3400^{o}F).

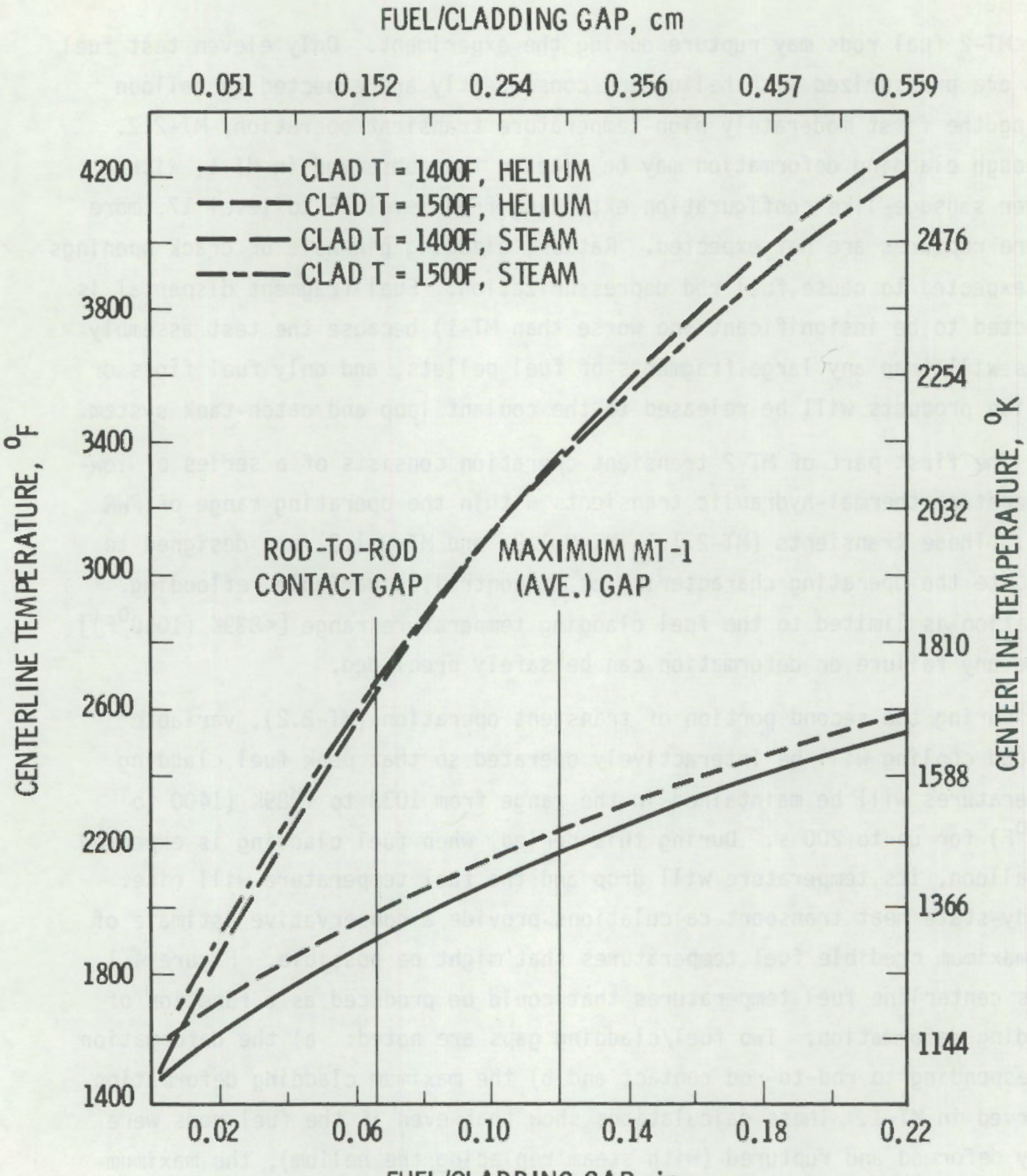

FIGURE 4.1. Steady-State Fuel Temperature for Ballooned MT-2 Fuel Rods

The third portion, MT-2.3, of this experiment is expected to follow the same operating scenario as its prototype, PTH-101. The only significant difference is that its test fuel rod cladding will be ballooned and operating at lower cladding temperatures. No additional fuel deformation or rupture is expected to occur for two reasons: a) ballooned fuel rods will be, in effect, depressurized and b) due to cladding liftoff, the peak cladding temperatures will be significantly lower (below the high alpha range). Although the fuel will be operating hotter than in PTH-101, it will still be much cooler than in steady-state operation, represented in Figure 4.1 [less than 2144K (3400^{0}F)]. Because fission product release at this temperature is greater than at temperatures experienced by either PTH-101 or MT-1, it is being evaluated. During the MT-2.3 transient, the maximum fuel cladding temperature is expected to be less than 1061K (1450^{0}F). In PTH-101, the peak fuel cladding temperature exceeded 1033K (1400^{0}F) for less than 25 s, and neither test fuel nor guard fuel rod cladding temperature exceeded 1089K (1500^{0}F).

The total fission product inventory in the MT-2 fuel bundle will be minimized to limit radiation exposure to both CRNL and PNL staffs working with the test train. The integrated exposure in the NRU reactor will be limited to 1.0 (effective) full-power hour.

Other safety analysis reports[1,4] are valid for the MT-2 experiment because the operating conditions to be used are within the envelope of the cases previously analyzed and reported.

5.0 OPERATING PROCEOURE SUMMARY

5.1 PRECONDITIONING OPERATIONS

5.1.1 Piping Configuration

5.1.1.1 Install test assembly (MT-1) in L-24 NRU reactor position.

5.1.1.2 Connect U-2 loop to L-24 position.

5.1.1.3 Pressure test the test train head seal.

5.1.2 Loop Facilities Preparations

5.1.2.1 Fill and electrically preheat the U-2 loop.

5.1.2.2 Provide water chemistry as shown in Table 5.1.

5.1.2.3 Calibrate loop instruments (see Table 5.2).

5.1.2.4 Confirm trip circuit operability.

5.1.2.5 Implement trip setpoints and report to the experiment director when ready for operation (see Table 5.3).

5.1.3 NRU Reactor Preparation

5.1.3.1 Load NRU reactor fuel assemblies and absorber assemblies, as required.[6]

5.1.3.2 Input NRU reactor linear and log rate trip setpoints, as required by CRNL.

TABLE 5.1. Water Chemical Requirements

Requirement	Applicability	Recommended Limits
Deionized supply	Preconditioning water coolant	$\leq 1 \times 10^{-5}$ Mho
Impurity concentrations	• Halides	$\leq$1 ppm
	• Oxygen	$\leq$100 ppm
	• All other elements	$\leq$100 ppm

TABLE 5.2. Loop Instrument Calibration

Sensor	Loop Parameter	DACS	Instrument Range	Acceptable Accuracy
U-2 Loop				
TE-78	Inlet Temperature	221	311 to 533K (70 to 500°F)	±1K (±2°F)
TE-79	Outlet Temperature	222	323 to 589K (122 to 600°F)	±1K (±2°F)
FT-40	Flow	215	3.9[a] to 19.3[b] kg/s (36,400 to 131,400 lbm/hr)	±0.4 kg/s (±2000 lbm/hr)
PDT-90	Outlet Pressure	204	5.52 to 8.96 MPa (800 to 1300 psia)	±0.3 MPa (±50 psia)
PDT-90	Test Assembly Pressure Drop	205	0.021 to 0.172 MPa (3 to 25 psi)	±2 MPa (±0.3 psi)
Steam/Reflood Loop				
TE-2	Inlet Coolant Temperature	206	394 to 700K (250 to 300°F)	±1K (±2°F)
TE-3	Outlet Coolant Temperature	207	422 to 973K (300 to 1300°F)	±6K (±10°F)
FY-6	Steam Flow Rate, Reflood Boiling	210	0 to 0.378 kg/s (0 to 3000 lbm/hr)	±0.014 kg/s (±100 lbm/hr)
FV-1	Steam System Control Flow Rate, Inlet	211	0 to 0.378 kg/s (0 to 3000 lbm/hr)	±0.014 kg/s (±100 lbm/hr)
FI-2	Steam System Control Flow Rate, Outlet	212	0 to 0.032 kg/s (0 to 250 lbm/hr)	±0.0013 kg/s (±10 lbm/hr)
PT-5	Steam Inlet Pressure	208	0 to 0.69 MPa (0 to 100 psia)	±0.034 MPa (±5 psia)
PT-6	Steam Outlet Pressure	209	0.069 to 0.345 MPa (0 to 50 psia)	±0.017 MPa (±2.5 psia)
PT-4	Steam Pressure Control, Outlet Region	217	0 to 0.69 MPa (0 to 100 psia)	±0.034 MPa (±5 psia)
FI-4	Reflood Coolant, Low Flow Rate	201	0.013 to 0.254 m/s (0.5 to 10 in/s)	±5%
FI-3	Reflood Coolant, High Flow Rate	202	0.013 to 0.305 m/s (0.5 to 12 in/s)	±5%
FI4b	Reflood Coolant, Low Flow Rate (backup)	224	0.013 to 0.254 m/s (0.5 to 10 in/s	±5%
FI3b	Reflood Coolant, High Flow Rate (backup meter)	223	0.013 to 0.305 m/s (0.5 to 12 in/s)	±5%
FE-9	Standby Reflood Coolant Flow	203	0.013 to 0.305 m/s (0.5 to 12 in/s)	±10%
TE-17	Reflood Coolant Temperature Control Valve Inlet	213	305 to 322K (90 to 120°F)	±5%
TE-18	Reflood Coolant Temperature Control Valve Outlet	214	305 to 322K (90 to 120°F)	±5%

(a) At a temperature of 589K (600°F).
(b) At a temperature of 394K (250°F).

TABLE 5.3. Preconditioning Trip Setpoints

Parameter	Operating Limits	Trip Setpoint
Outlet coolant temperature	552 K (534°F)	561 K (550°F)
Pump subcooling temperature--Low	83 K (150°F)	28 K (50°F)
Coolant flow--Low	15.5 kg/s[(a)] (123,000 lbm/hr)	13.4 kg/s[(a)] (106,300 lbm/hr)
Surge tank level--Low	TBD[(b)]	30
Surge tank pressure--High	TBD[(b)]	8.90 MPa (1275 psig)
Cladding temperature[(c)]		
Level 13	1200 K (1700°F)	1361 K (1990°F)
Level 15	1200 K (1700°F)	1361 K (1990°F)
Level 17	1200 K (1700°F)	1333 K (1940°F)

(a) At a temperature of 517 K (472°F).
(b) To be determined by CRNL.
(c) Fuel cladding setpoints selected but not required until transient operation.

5.1.3.3 Adjust the neutron detector scatter plug, as required.

5.1.3.4 Establish mean power trip setpoints, as required.

5.1.3.5 Confirm that all trip setpoints are activated and report when ready for operation to the experiment director.

5.1.4 DACS Computer Preparation

5.1.4.1 Load labeled, certified disk packs and mount a labeled, certified tape on the tape drive.

5.1.4.2 Start a dummy test and set the DACS to idle mode.

5.1.4.3 Set the steady state scan rate at 1 second.

5.1.4.4 Set the immediate display scan rate at 4 seconds.

5.1.4.5 Set the graphic display scan rate at 5 seconds.

5.1.4.6 Format the steady state immediate display.

5.1.4.7 Identify and remove failed sensors from both displays.

5.1.4.8 Verify trip circuit operability.

5.1.4.9 Set Keithly amplifiers to the 1.0 scale and verify that SPND coefficients are correct.

5.1.5 Preconditioning Operating Procedure (Each step is to be followed in order.) NOTE: Total time at full reactor power is to be limited to 1.0 hour, full-power equivalent.

5.1.5.1 End the dummy test and start a new test on the DACS.

5.1.5.2 Start up the loop, using sparge pumps to provide initial flow [16.3 kg/s (129,400 lbm/hr)] and initial pressurization [8.62 MPa (1250 psia)].

5.1.5.3 Change the DACS mode to steady state and turn on the videotape recorder.

5.1.5.4 Adjust the inlet temperature to 517K ± 3K (472^{o}F ± 5^{o}F).

5.1.5.5 Print the DACS sensor status report and REDACE printout for review for ΔT heat loss check.

5.1.5.6 Increase the reactor power to 63.5 MW.

5.1.5.7 Perform a power calibration, using a REDACE printout and OACS data (loop flow rate x test assembly ΔT).

5.1.5.8 Print the DACS sensor status report and REDACE printout for review.

5.1.5.9 Increase the reactor power to 127 MW ±5%.

5.1.5.10 Adjust test assembly inlet temperature to 517K ± 3K (472^{o}F ± 5^{o}F).

5.1.5.11 Print the DACS sensor status report and the REDACE printout.

5.1.5.12 Perform a power calibration.

5.1.5.13 Conditionally trip the reactor.

5.1.5.14 Using a REDACE print frequency of 30s, increase the reactor to full power in 2 steps: 63.5 MW and 127 MW ± 5%, maintaining test assembly inlet temperature at 517K ± 3K (472^{o}F ± 5^{o}F).

5.1.5.15 Print the DACS sensor status report.

5.1.5.16 Recheck power calibrations.

5.1.5.18 Trip the reactor.

5.1.5.19 Make a hardcopy of the CRT immediate display and graphic display showing the hottest centerline thermocouples. Change DACS to idle mode. Make a tape copy when ending the test. Make a disk image copy. Make a historical request for all the data required to run the transient test.

5.1.5.20 If time permits, repeat 5.1.5.14 through 5.1.5.18.

5.1.5.21 Shutdown the loop facilities to prepare for piping rearrangement. Return DACS to steady-state and scan the sensors 1/min. until reflood flow tests are initiated.

5.2 REFLOOD FLOW, PRETRANSIENT AND TRANSIENT OPERATIONS

5.2.1 Piping Configuration

5.2.1.1 Connect the reflood loop to L-24 NRU reactor position.

5.2.1.2 Connect the U-1 steam supply to the reflood loop.

5.2.2 Loop System Preparations

5.2.2.1 Start up the U-1 loop.

5.2.2.2 Insure that U-2 make up tanks (which supply water to the U-1 loop) are full.

5.2.2.3 Preheat the steam/reflood loop to 408K (275^{o}F).

5.2.2.4 Fill reflood accumulators, at 305 ± 11K (90^{o}F ± 20^{o}F).

5.2.2.5 Verify that the supply of nitrogen used for accumulator pressurization is adequate.

5.2.2.6 Calibrate loop instruments, as shown in Table 5.2. Enter conversion factors and units in the test log.

5.2.2.7 Implement the trip setpoints as shown in Table 5.4 for the pre-transient and transient phases of the experiment. The trip pseudo sensors used on DACS to represent the high cladding temperature trip circuits and sensors are detailed on Table 5.5.

5.2.3 NRU Reactor Preparations (CRNL)

5.2.3.1 Confirm that two linear rate and two log rate neutron flux detectors (ion chambers) are being recorded for the experimenter in the NRU reactor control room.

5.2.3.2 Confirm that the REDACE data will be taken on demand or at a 30s frequency when requested.

5.2.3.3 Establish mean power trip setpoints as required.

5.2.3.4 Confirm that all trip setpoints are activated and report to the experiment director when ready for experiment operation.

5.2.4 DACS Computer Preparation

5.2.4.1 Load the DACS with a labeled certified tape and disks.

5.2.4.2 Start a dummy test and set the DACS mode to idle.

5.2.4.3 Set the steady state scan rate at 1 second.

5.2.4.4 Set the transient scan rate at 40 ms.

5.2.4.5 Set the immediate display scan rate at 4 seconds.

5.2.4.6 Set the graphic display scan rate at 5 seconds.

5.2.4.7 Format the steady state immediate display, with the following sensors:

DACS No.	Sensor Name	DACS No.	Sensor Name
55	TC-13-3B-IR-2	90	TC-17-3D-IR-5
91	TC-15-3C-IR-2	93	TC-17-3D-IR-C
94	TC-15-3C-IR-C	138	TC-17-3D-IR-4
97	TC-15-3C-IR-7	120	TC-17-2D-OR-1
7D	TC-15-3B-IR-4	126	TC-17-2D-IR-2
88	TC-17-4C-IR-3	123	TC-17-5D-IR-4
92	TC-17-4C-IR-C		

TABLE 5.4. Pretransient And Transient Trip Setpoints

Parameter	Location	Use	Operating Limits	Trip Setpoint
Hanger Tube Temperature - High	LCS	Pretransient Transient	691 K(785°F) 1275°F	839 K(1050°F)
Outlet Pipe Temperature - High	LCS	Pretransient Transient	672 K(750°F)	700 K(800°F)
Fuel Cladding Temperature - High[a]				
Level 13 305 PSD-13-IR-1	DACS	Pretransient	1305 K(1890°F)	1361 K(1990°F)
Level 15 308 PSD-15-IR-1	DACS	Transient	1305 K(1890°F)	1361 K(1990°F)
Level 17 315 PSD-17-IR-4	DACS		1278 K(1840°F)	1333 K(1940°F)
Standby Reflood Flow - Low	LCS	Transient	90	0.5 in./s
Accumulator Inventory - Low	LCS	Transient	22.7 Kg(50 lbm)	11.3 Kg(25 lbm)

(a) Standard trip setpoint criterion, see Table 3.3 for nonfunctional TC criteria.

TABLE 5.5. Cladding High Temperature Trip Sensors

Level	Sensor Thermocouples	DACS Sensor Number	DACS Pseudo Sensor
13	TC-13-6C-IR-2	56	305 PSD-13-IR-1
	TC-13-4F-IR-4	57	305 PSD-13-IR-1
	TC-13-1D-IR-2	58	3D5 PSD-13-IR-1
	TC-13-3A-IR-4	59	305 PSD-13-IR-1
15	TC-15-6C-IR-4	71	308 PSD-15-IR-1
	TC-15-4F-IR-2	72	308 PSD-15-IR-1
	TC-15-1D-IR-4	73	308 PSD-15-IR-1
	TC-15-3A-IR-2	74	308 PSD-15-IR-1
	TC-15-5B-IR-3	98	308 PSD-15-IR-1
	TC-15-2E-IR-1	100	308 PSD-15-IR-1
	TC-15-5B-IR-1	106	308 PSD-15-IR-1
	TC-15-2E-IR-3	108	308 PSO-15-IR-1
17	TC-17-5E-IR-4	99	315 PSD-17-IR-4
	TC-17-2B-IR-2	101	315 PSD-17-IR-4
	TC-17-5E-IR-2	107	315 PSD-17-IR-4
	TC-17-2B-IR-4	109	315 PSO-17-IR-4

5.2.4.8 Format the transient graphic display.

5.2.4.9 Identify and remove any failed sensors from displays, pseudo sensors and trip circuits.

5.2.4.10 Reset Keithley amplifiers to the 0.1 scale and change SPND coefficients. Reduce by a factor of 10.

5.2.4.11 Report to the experiment director when ready for pretransient experiment operation.

5.2.5 Reflood Flow Test Operating Procedure (To be followed in sequence.)

5.2.5.1 Calibrate the reflood prefill controls to fill the test nozzle annulus up to level 0. Prefill and drain.

5.2.5.2 Place the DACS in the steady state mode.

5.2.5.3 Increase test section steam flow to 0.378 kg/s (3000 lbm/hr), and control test section backpressure at 0.276 MPa (40 psia).

5.2.5.4 Enter all reflood flow test operational parameters (Table 5.6) in the LCS.

5.2.5.5 Print a sensor status report and ensure that the test assembly thermocouples are $\geq$366K (200^{0}F).

5.2.5.6 Reproduce the CRT immediate display and the graphic display.

5.2.5.7 Turn on the videotape recorder.

5.2.5.8 Switch the DACS to the transient mode 20 seconds before using the verbal command, "BEGIN THE TRANSIENT," (directed to the LCS operator) and record the time.

5.2.5.9 LCS operator initiates transient.

5.2.5.10 Reproduce the CRT immediate display and the graphic display, as required.

5.2.5.11 Stop the test when reflood water passes the thermocouples at level 20.

5.2.5.12 Change the DACS mode to steady state for 5 minutes, then to idle.

5.2.5.13 Make a historical request on the DACS and reproduce copies of the following data:

- reflood rate (DACS sensors 201, 202, 203, 223, and 224)
- steam flow-rate (DACS sensors 210, 211, and 212)
- thermocouples at each level (DACS sensors 213, 214, 289, 291, 296, 297, 299, 302, 304, 305, 308, 313, 317, and 320)

5.2.5.14 Dump all DACS sensors through the transient for each 5 seconds.

5.2.5.15 Repeat the above steps 5.2.5.1 to 5.2.5.14 using the fast reflood rate. See Table 5.6.

TABLE 5.6. Parameters for Reflood Flow Tests for MT-2

Test Parameter	Reflood Tests					
	Pre-Transient			Post-Transient		
	RT-1	RT-2	RT-3	RT-4	RT-5	RT-6
Reflood Rate m/s (in/s)	0.5	1.0	2.0	0.5	1.0	2.0
Delay Time (s)	0	0	0	0	0	0
Peak Cladding Temperature, K (^oF)	450 K (350^oF)	450 K (350^oF)	450 K (350^oF)	450 K (350^oF)	450 K (350^oF)	450 K (350^oF)
Reflood Terminus Time (s)	165	30	16	165	30	16
Initial Cladding Temperature, K (^oF)	422 K (300^oF)	422 K (300^oF)	422 K (300^oF)	422 K (300^oF)	422 K (300^oF)	422 K (300^oF)

5.2.5.16 Turn off the video recorder and record the counter location.

5.2.5.17 Make a tape copy on the DACS, and make a disk image copy on tape, as time permits.

5.2.5.18 As necessary, repeat DACS Computer preparation (5.2.4) and Loop System Preparation (5.2.2) before proceeding to section 5.2.6, Pretransient Operating Procedure.

5.2.6 Pretransient Operating Procedure (To be followed in sequence.)

5.2.6.1 Set LCS controls for reflood flow rates and delay time (for appropriate two-step reflooding according to Table 5.7).

5.2.6.2 Check accumulators levels/wts.

5.2.6.3 Set the two reflood rates as given in Table 5.7, and be prepared to provide subsequent flow rates.

5.2.6.4 Start a new test on the DACS. Change the DACS mode to steady state.

5.2.6.5 Ensure that the REDACE scan frequency for NRU data is 30 seconds.

5.2.6.6 Start up the NRU to the low neutron level.

5.2.6.7 Set the test section steam flow (Table 5.7) and backpressure, if not already there.

5.2.6.8 Increase NRU reactor power to 4.0 MW. With the reactor power at nominally 50% of the pretransient power, scan the DACS CRT immediate display for the hottest thermocouple and reproduce the display.

5.2.6.9 Ensure that the test assembly inlet temperature stabilizes at 436K ± 3K (330^{o}F ± 10^{o}F).

5.2.6.10 Increase the NRU reactor power on automatic control to 5.7% full power, only for MT-2.2 test.

5.2.6.11 Adjust the reactor power to obtain a steady state inlet-to-outlet ΔT of 451K (320^{o}F).

TABLE 5.7. Experiment Operating Conditions

	Preconditioning	Reflood Calibration	Pretransient	Transient MT-2.1.1	PT	Transient MT-2.1.2	PT	Transient MT-2.1.3	PT[a]	Transient MT-2.2	PT[a]	Transient MT-2.3
Reactor Power	130 MW	0	~4.0 MW	-4.0 MW	(d)	-4.0 MW	(d)	~4.0 MW	(a)	-7.5 MW[a]	(a)	-7.5 MW[a]
Coolant	U-2 water	U-1 steam/ reflooding	U-1 steam	U-1 steam/ reflooding	(d)	U-1 steam/ reflooding	(d)	U-1 steam/ reflooding	(a)	U-1 Steam/ Reflooding	(a)	U-1 Steam/ Reflooding
Coolant Flow	0-16.3 kg/s (0-129,400 lbm/hr)	0-378 kg/s (0-3000 lbm/hr)	0.189 kg/s (1500 lbm/hr)	0	(d)	0	(d)	0	(a)	0	(a)	0
Reflood Delay	N.A.[b]	0	N.A.	0	(d)	0	(d)	0	(d)	(b)	(d)	30 s[c]
Reflood Rates/Level	N.A.	(0.5, 1.0, 2.0)	N.A.	10.0 in./s to 30 in., and 1.2 in./s, variable	(d)	10.0 in./s to 30 in., 1.0 in./s, variable	(d)	10.0 in./s to 30 in., 0.5 in/s, variable	(d)	variable[e]	(d)	0.099 m/s[c] (3.9 in./s)
Reflood Flow Times	N.A.	variable	N.A.	variable	(d)	variable	(d)	variable	(d)	variable[e]	(d)	540 s
Peak Cladding Temperature Control Point	700 K (800°F)	450 K (320°F)	727 K[c] (850°F)	975°F	(d)	975°F		975°F	(d)	1089 K (1500°F)	(d)	1089 K (1500°F)
Reactor Conditional Trip Criteria for Peak Clad Temperature	Peak Cladding Temperature	N.A.	Peak Cladding Temperature	1050°F	(d)	1050°F		1050°F	(d)	Peak Cladding Temperature 1200 K (1500°F)	(d)	Peak Cladding Temperature 1089 K (1500°F)

a) Reactor power selected to provide average test assembly power 1.24 kw/m (0.38 kw/ft) at 0.378 kg/s (3000 lbm/hr).
b) Not applicable.
c) Specified to reproduce PTH-101 conditions.
d) Repeat previous pretransient conditions.
e) Control sequence and parameters to be selected after the MT-2.1 series is evaluated.

5.2.6.12 Check the peak cladding temperature, steam flow, test assembly inlet temperature, and outlet pressure.

5.2.6.13 Reproduce the CRT immediate display and the graphics display.

5.2.6.14 Activate the videotape recorder.

5.2.7 Transient Operating Procedure (To be followed in sequence.)

5.2.7.1 Change to the transient operating mode on the DACS. Twenty seconds later, issue the verbal command, "BEGIN THE TRANSIENT," (directed to the Loop Control System Operator) and record the time in the DACS log.

5.2.7.2 The LCS operator begins the transient.

5.2.7.3 Check peak cladding temperature control points (Table 5.7), and vary the reflood flow rates to remain below the conditional trip temperature.

5.2.7.4 Shut down the reactor when the test assembly quench is complete, or time exceeds 200 sec at peak cladding temperature.

5.2.7.5 Shut off reflood water flow.

5.2.7.6 Record reflood water used (accumulator weight difference).

5.2.7.7 Insure that tripping the reactor has returned control to the DACS (transient forcing signal #257 = D).

5.2.7.8 Return the DACS mode to steady state for 5 minutes. Return the DACS to idle mode, ending the data record.

5.2.7.9 Copy the following historical data on the DACS.

- Make a videotape and hardcopy of the hottest pseudo sensors.
- Make a videotape and hardcopy of the last 2 pseudo sensors to quench.
- Plot the hottest pseudo sensor versus time.
- Plot the last 2 pseudo sensors to quench versus time.
- Plot loop data (DACS sensors 201, 202, 203, 210, 211).

- Dump all DACS data to tape for the transient at 5 second intervals.

5.2.7.10 End the test on the DACS.

5.2.7.11 Turn off the videotape recorder and record the location.

5.2.7.12 Make a tape copy of the DACS data.

5.2.7.13 Make a disc image copy of the DACS data.

5.2.7.14 Return to Section 5.2.6, Pretransient Operating Procedure for successive two-step reflood tests (MT-2.1.1 through MT-2.3 and MT-2.4.1 through MT-2.4.3).

5.2.7.15 Terminate the experiment and remove the test train to the bay using established CRNL procedures.

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6. Atfield, M. D., memo to NRU Superintendent. October 2, 1980. "Reactor Loading for Battelle LOCA Simulations Tests." Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada.

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A loss-of-coolant accident (LOCA) simulation program is evaluating the thermal-hydraulic and mechanical effects on pressurized water reactor (PWR) test fuel bundles. This Experiment Operation Plan (EOP) Addendum 2, together with the referenced EOP, describes the desired operating conditions and additional hazards review associated with the four-part MT-2 experiment. The primary portions of the experiment, MT-2.2 and MT-2.3, will evaluate (1) the mechanical deformation of pressurized fuel rods subjected to a slow LOCA, using reflood water for temperature control, that is designed to produce cladding temperatures in the range from 1033 to 1089K(1400 to 1500^{o}F) for an extended time, and (2) the effects of the deformed and possibly failed cladding on the thermal-hydraulic performance of the test assembly during simulated LOCA heating and reflooding. The secondary portions of the experiment, MT-2.1 and MT-2.4, are intended to provide thermal-hydraulic calibration information during two-stage reflood conditions for (1) relatively low cladding temperatures, <839K (1050^{o}F), on nondeformed rods, and (2) moderately high cladding temperatures, <1089K (1500^{o}F), on deformed rods.

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