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THIRD ANNUAL PROGRESS REPORT ON UNITED STATES-JAPAN COLLABORATIVE TESTING IN THE HIGH FLUX ISOTOPE REACTOR AND THE OAK RIDGE RESEARCH REACTOR FOR THE PERIOD ENDING SEPTEMBER 30, 1986

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ABSTRACT

The third year of the program of U.S./Japan collaborative testing in the HFIR and ORR was completed on schedule and within costs. Irradiation of all eight phase-I HFIR target capsules was completed. Postirradiation examination was completed on five of the eight capsules. The instrumented Target Temperature Capsule was designed, built, and installed in HFIR. Preliminary results showed that the measured temperatures were within 15% of those predicted. The spectrally tailored capsules, MFE-6J and -7J, operated in ORR as planned throughout the year. Conceptual designs and preliminary test matrices were developed for the Phase II irradiation program.

1.0 INTRODUCTION

1.1 Background

This is the third annual report on the five-year program of U.S.-Japan collaborative testing in the High Flux Isotope Reactor (HFIR) and the Oak Ridge Research Reactor (ORR). Previous reports[1,2] discussed the implementing agreement, the objectives and scope of the program, and the annual status.

1.2 Objectives

The objectives of the program are to: (1) design, conduct, and evaluate joint irradiation experiments in the HFIR and ORR; (2) investigate the response of Japanese and U.S. structural alloys to high levels of displacement damage and helium content in the HFIR; and (3) investigate the response of U.S. and Japanese prime-candidate alloys (PCA and JPCA) irradiated in the ORR and in the HFIR with the neutron spectrum tailored to produce a He:dpa ratio characteristic of fusion. A secondary objective is to study basic radiation damage mechanisms under well-controlled conditions.

1.3 Scope

Phase I of the program is based upon (a) eight HFIR target capsules covering the temperature range 300 to 600°C and damage levels up to ~50 displacements per atom (dpa), (b) two spectrally tailored capsules in the ORR covering the temperature range 60 to 400°C and damage levels up to 30 dpa. Phase II of the program involves a second set of eight target capsules and a continuation of the spectrally tailored experiments. During the past year, the U.S. side proposed that the spectrally tailored experiments being carried out in the ORR should be transferred to the new RB* irradiation facilities in the HFIR. This change is in anticipation of the permanent shutdown of the ORR within the next two to three years. In addition, experiments in the new RB* facilities will reach damage levels of 10 to 12 dpa in one year, compared with three years in the ORR. The Japanese side agreed to this change, and work has started on designing four new spectrally tailored capsules capable of achieving temperatures in the range 60 to 400°C in the HFIR.

The status of the original eight Phase-I HFIR target capsules and the two ORR spectrally tailored capsules is discussed in the following sections. Planning for the Phase-II HFIR capsules and the four RB* capsules is also described.

2.0 PHASE I HFIR CAPSULES

2.1 Irradiation Parameters

A description of the HFIR Phase-I capsules and the complete test matrix was reported previously.[1] All eight capsules have completed irradiation; final damage levels at the reactor center-line positions are given in Table 2.1. More detailed information on the damage levels of the individual specimens in capsules JP2, JP4, JP5, JP6, JP7, and JP8 is given in Tables 2.2 through 2.7. The specimen descriptions and compositions were reported previously.[1]

Table 2.1. Status of U.S./Japan HFIR Capsules

Capsule	Date irradiation completed	Reactor exposure[a] (MWd)	Damage level[b] (dpa)
JP1	02-01-85	33,600	33
JP2	12-17-85	57,500	57
JP3	05-28-85	34,000	33
JP4	04-18-86	57,900	57
JP5	08-12-86	58,200	57
JP6	11-14-85	36,700	36
JP7	12-17-85	34,700	34
JP8	09-07-86	58,200	57

[a]Reactor power: 100 MW.
[b]Displacement-per-atom. Peak level in type J316 stainless steel (13.5 wt % Ni).

Table 2.2. Damage levels and helium contents for HFIR Capsule JP2

Position	Distance from HFIR center line (cm)	Specimen: Type	Specimen: Temperature (°C)	Specimen: Alloy	Specimen No.	Damage level (dpa)	Helium content (appm)
1	23.2	Tensile	300	PCA	EL36	28	2031
2	18.8	Tensile	400	PCA	EL37	38	2884
3	14.3	Tensile	500	PCA	EL39	46	3533
4	9.6	Fatigue	430	PCA	EC157	53	4005
5	4.6	Fatigue	430	316	AA3	55	3471
6	0	TEM[a] disks	300	J316[b]		57	3667
7	4.6	Fatigue	430	JPCA	FE3	56	4180
8	9.6	Fatigue	430	JPCA	FE4	53	3904
9	14.3	Tensile	500	JPCA	TB4	46	3446
10	18.8	Tensile	400	JPCA	TB5	38	2817
11	23.2	Tensile	300	JPCA	TB6	27	1973

[a]Transmission electron microscopy.

[b]This holder contained several alloys.

2.2 Tensile Specimen Measurements

During the current year, postirradiation examination was completed on capsules JP1 and JP3. Capsules JP6, JP7, and JP2 were disassembled. Length changes and immersion densities were measured on the tensile specimens from capsules JP2, -3, -6, and -7 (Table 2.8). The precision of these measurements is not very high (±0.2% density change), and there are several discrepancies between the two sets of measurements. Neither technique represents a reliable method for determining small changes in density. A precision densitometer (with a capability of determining density changes of ±0.1%) for measuring densities of TEM disks was brought into operation at the end of this reporting period. This is the preferred technique for determining the swelling behavior of these materials.

Table 2.3. Damage levels and helium contents for HFIR Capsule JP4

Level	Alloy	Condition	Identity	Nickel (at. %)	Boron (wt ppm)	Distance from HFIR center-line (cm)	Damage level (dpa)	Helium content (appm)
				Specimen Type: SS-1				
1	Ref. 316	20% CW	AB-41,-42,-45	11.71	4	22.7	28	'647
	EP 838	20% CW	EP-05	4.28	5	22.7	26	683
2	EP 838	20% CW	EP-06,-10	4.28	5	18.1	36	956
	PCA	B3	EL-0,-2	15.41	10	18.1	40	3004
3	PCA	A3	EC-284	15.41	10	13.6	48	3640
	PCA-20	25% CW	HV-01	15.30	10	13.6	48	3616
	PCA-13	25% CW	HA-1	15.14	0	13.6	48	3570
	PCA-19	25% CW	HT-01	18.95	0	13.6	49	4418
4	T9 Mod/2Ni	NT4	TB-01,-02	2.05	0	9.1	48	734
	HT-9	NT1	SB-2,-3	0.40	0	9.1	49	323
5	HT-9/2Ni	NT2	SD-01,-02	2.14	0	4.6	51	804
	T9 Mod	NT3	TA-01,-04	0.10	0	4.6	50	264
				Specimen Type: TEM Strips				
6	JPCA	PA-2	PA-2	14.81	31	0.0	58	4262
	JPCA	PC-1	PC-1	14.81	31	0.0	58	4262
	C	CS-1	CS-1	14.84	0	0.0	58	4239
	JPCA	PC-3	PC-3	14.81	31	0.0	58	4262
	K	KS-1	KS-1	16.70	0	0.0	59	4739
	JPCA	PS-2	PS-2	14.81	31	0.0	58	4262
	J316	SC-1	SC-1	12.81	0	0.0	57	3692
	J316	SS-1	SS-1	12.81	0	0.0	57	3692
	PCA	A-1	ED	15.41	10	0.0	58	4329
	PCA	B3	EL	15.41	10	0.0	58	4329
	PCA-13	25% CW	HA	15.41	0	0.0	58	4319
	PCA-19	25% CW	HT	18.96	0	0.0	60	5348
	PCA-20	25% CW	HV	15.30	0	0.0	58	4363
	PCA-22	25% CW	HX	15.11	0	0.0	58	4311
				Specimen Type: SS-1				
7	J316	15% CW Weld	D-46,-47,-48	12.81	0	4.6	56	3625
	J316	SA Weld	D-16	12.81	0	4.6	56	3625
8	J316	SA Weld	D-17,-18	12.81	0	9.1	53	3415
	JPCA	SA Weld	CLW-1,-2	14.81	31	9.1	53	3944
9	JPCA	SA Weld	CLW-3	14.81	31	13.6	48	3528
	JPCA	CW Weld	DLW-1,-2,-3	14.81	31	13.6	48	3529
10	J316	SA	D-1,-2	12.81	0	18.1	39	2517
	J316	CW	D-31,-32	11.81	0	18.1	39	2517
11	JPCA	SA	CL-1,-2	14.81	31	22.7	29	2077
	JPCA	CW	DL-1,-2	14.81	31	22.7	29	2077

Table 2.4. Damage levels and helium contents for HFIR Capsule JP5

Position	Distance from HFIR center line (cm)	Specimen			Specimen No.	Damage level (dpa)	Helium content (appm)
		Type	Temperature (°C)	Alloy			
1	23.2	Tensile	300	PCA-A3	EC-34	28	2043
2	18.8	Tensile	400	PCA-A3	EC-31	39	2923
3	14.3	Tensile	500	PCA-A3	EC-32	47	3577
4	9.6	Fatigue	430	PCA-A3	EC-153	53	4053
5	4.6	Fatigue	430	Ref. 316	AA-27	56	3512
6	0.0	TEM[a] disks	400	J316[b]		57	3708
7	4.6	Fatigue	430	JPCA	FE-10	57	4229
8	9.6	Fatigue	430	JPCA	FE-11	53	3950
9	14.3	Tensile	500	JPCA	TE-7	47	3489
10	18.8	Tensile	400	JPCA	TE-8	39	2854
11	23.2	Tensile	300	JPCA	TE-9	28	2002

[a]Transmission electron microscopy.

[b]This holder contained several alloys.

Table 2.5. Damage levels and helium contents for HFIR Capsule JP6

Position	Distance from HFIR center line (cm)	Specimen			Specimen No.	Damage level (dpa)	Helium content (appm)
		Type	Temperature (°C)	Alloy			
1	23.2	Tensile	600	PCA	EL24	16	1057
2	18.8	TEM[a] disks	500	PCA[b]		23	1606
3	14.3	Tensile	500	316	AA42	27	1646
4	9.6	Fatigue	430	PCA	EC156	32	2353
5	4.6	Fatigue	430	PCA	EC161	34	2551
6	0.0	TEM[a] disks	600	J316[b]		36	2327
7	4.6	Fatigue	430	JPCA	FE12	34	2499
8	9.6	Fatigue	430	JPCA	FE13	32	2307
9	14.3	Tensile	500	JPCA	TE10	28	1995
10	18.8	Tensile	400	JPCA	TE11	23	1578
11	23.2	Tensile	300	JPCA	TE12	16	1046

[a]Transmission electron microscopy.

[b]This holder contained several alloys.

Table 2.6. Damage levels and helium contents for HFIR Capsule JP7

Position	Distance from HFIR center-line (cm)	Specimen Type	Specimen Temperature (°C)	Specimen Alloy	Specimen No.	Damage level (dpa)	Helium content (appm)
1	23.2	Tensile	600	PCA	EC-36	16	1056
2	18.8	Tensile	500	PCA	EL-29	23	1604
3	14.3	Tensile	500	PCA	EL-31	28	2034
4	9.6	Fatigue	550	316	AA-54	31	1905
5	4.6	Fatigue	550	PCA	EF-5	34	2554
6	0.0	TEM[a] disks	500	J316[b]		34	2186
7	4.6	Tensile	600	JPCA	TE-16	34	2497
8	9.6	Tensile	600	JPCA	TE-17	32	2305
9	14.3	Tensile	500	JPCA	TE-18	28	1993
10	18.8	Tensile	400	JPCA	TE-19	23	1577
11	23.2	Tensile	300	JPCA	TE-20	16	1045

[a]Transmission electron microscopy.

[b]This holder contained several alloys.

Table 2.7. Damage levels and helium contents for HFIR Capsule JP8

Position	Distance from HFIR center-line (cm)	Specimen Type	Specimen Temperature (°C)	Specimen Alloy	Specimen No.	Damage level (dpa)	Helium content (appm)
1	23.2	Tensile	600	PCA-B3	EL-26	28	2043
2	18.8	Tensile	600	PCA-B3	EL-35	39	2923
3	14.3	Tensile	500	PCA-B3	EL-25	47	3577
4	9.6	Fatigue	430	PCA-A3	EC-163	53	4053
5	4.6	Fatigue	430	316	AA-53	56	3512
6	0.0	TEM[a] disks	500	J316[b]		57	3708
7	4.6	Tensile	600	JPCA	TE-21	57	4229
8	9.6	Tensile	500	JPCA	TE-22	53	3950
9	14.3	Tensile	430	JPCA	TB-12	47	3488
10	18.8	Tensile	400	JPCA	TE-23	39	2854
11	23.2	Tensile	300	JPCA	TE-24	28	2001

[a]Transmission electron microscopy.

[b]This holder contained several alloys.

Table 2.8. Length and density changes of tensile specimens in HFIR JP3, JP6, JP7, and JP2 capsules

Specimen No.	Alloy	Condition[a]	Irradiation Temperature (°C)	Length, mm		Increase (%)	Density Change, %	
				Initial	Final		$3\ \Delta L/L_0$	$\Delta V/V_0$
				Capsule JP3				
EL30	PCA	B3	300	39.34	39.39	0.14	0.4	0.5
EL34	PCA	B3	400	39.34	39.52	0.47	1.4	0.3
EC29	PCA	A3	500	39.35	39.43	0.20	0.6	0.4
TB7	JPCA	PS2	500	39.41	39.45	0.10	0.3	0.8
TB8	JPCA	PS2	400	39.40	39.46	0.15	0.5	0.4
TB9	JPCA	PS2	300	39.40	39.43	0.08	0.2	0.3
				Capsule JP6				
TE12	JPCA	PC2	300	39.40	39.43	0.08	0.2	0.2
TE11	JPCA	PC2	400	39.39	39.44	0.13	0.4	0.1
TE10	JPCA	PC2	500	39.40	34.43	0.08	0.2	0.1
EL24	PCA	B3	600	39.34	39.36	0.05	0.2	0.1
AA42	316	20% CW	500	39.31	39.36	0.13	0.4	0.1
				Capsule JP7				
TE20	JPCA	PC2	300	39.39	39.46	0.18	0.5	0.0
TE19	JPCA	PC2	400	39.40	39.46	0.15	0.5	0.1
IE18	JPCA	PC2	500	39.40	39.48	0.20	0.6	0.1
IE17	JPCA	PC2	600	39.40	39.45	0.13	0.4	0.2
TE16	JPCA	PC2	600	39.41	39.45	0.10	0.3	0.1
EC36	PCA	A3	600	39.35	39.41	0.15	0.5	0.0
EL29	PCA	B3	600	39.34	39.39	0.13	0.4	0.2
EL31	PCA	B3	500	39.34	39.40	0.15	0.5	0.2
				Capsule JP2				
TB6	JPCA	PS2	300	39.38	39.47	0.23	0.7	0.1
TB5	JPCA	PS2	400	39.39	39.54	0.38	1.1	0.1
TB4	JPCA	PS2	500	39.39	39.58	0.48	1.4	0.1
EL36	PCA	PS2	300	39.34	39.44	0.25	0.8	0.1
EL37	PCA	B3	400	39.34	39.39	0.13	0.4	0.1
EL39	PCA	B3	500	39.34	39.70	0.92	2.8	2.1

A3 — SA at 1100°C + 25% CW.
B3 — SA at 1100°C + 8 h at 800°C + 25% CW.
PS2 — SA at 1100°C.
PC2 — PS2 + 15% CW.

Tensile tests were completed on specimens from Capsules JP-1, -2, -3, and -6, and on some specimens from JP-7. Testing was carried out in vacuum at the nominal irradiation temperature at a strain rate of 4.2×10^{-4} s^{-1}. This equipment is shown in Fig. 2.1. The results are summarized in Table 2.9. These data were discussed in a semiannual progress report[3] and also at the Third U.S./Japan Workshop in Tokyo.[4]

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Fig. 2.1. In-cell tensile testing facility.

Table 2.9. Summary of tensile tests from HFIR JP capsules

Specimen No.	Alloy	Temperature (°C)		Damage Level (dpa)	Strength, MPa		Elongation, %	
		Irradiation	Test		Yield	Ultimate	Uniform	Total
Capsule JP1								
EL15	PCA	300	300	16	933	933	0.21	5.1
EL21	PCA	400	400	22	993	1000	0.31	4.4
EL28	PCA	500	500	27	695	792	5.1	7.7
TE1	JPCA	300	300	16	878	889	0.53	7.9
TB2	JPCA	400	400	22	878	888	0.38	6.4
TB1	JPCA	500	500	27	650	732	4.7	8.2
Capsule JP3								
TB9	JPCA	300	300	15	876	889	0.39	8.6
TB8	JPCA	400	400	22	896	910	0.44	6.0
TB7	JPCA	500	500	27	631	724	7.2	11.7
EL30	PCA	300	300	16	945	947	0.19	5.3
EL34	PCA	400	500	22	931	931	0.21	3.6
EC29	PCA	500	400	27	793	895	5.1	7.1
Capsule JP6								
TE12	JPCA	300	300	16	889	903	0.63	7.2
TE11	JPCA	400	400	23	952	972	0.42	5.5
TE10	JPCA	500	500	28	678	765	7.1	11.4
AA42	316	500	500	27	681	807	8.7	10.6
EL24	PCA	600	600	16	567	643	4.2	6.0
Capsule JP7								
EC36	PCA	600	600	16	585	643	3.06	3.81
EL29	PCA	600	600	23	417	528	5.87	7.37
EL31	PCA	500	500	28	658	756	5.45	8.40
TE16	JPCA	600	600	34	519	582	3.68	5.18
Capsule JP2								
EL36	PCA	300	300	28	933	947	0.69	4.53
EL37	PCA	400	400	38	976	979	0.41	3.95
EL39	PCA	500	500	46	706	769	4.4	6.57
TB4	JPCA	500	500	46	620	682	5.76	7.79
TB5	JPCA	400	400	38	857	871	0.55	5.69
TB6	JPCA	300	300	27	770	789	2.43	9.93

2.3 Fatigue Specimen Measurements

Fatigue tests were performed on hourglass fatigue specimens using a servo-hydraulic, closed-loop testing system installed in a hot cell (Fig. 2.2). The system has a four-column load frame capable of 220 kN. It is equipped with an ultrahigh vacuum system pumped by a turbomolecular pump capable of pressures of 10^{-8} to 10^{-6} Pa during elevated-temperature testing. Specimen heating is accomplished by a radio-frequency induction with a load coil surrounding the specimen. Strain is measured by a diametral extensometer which fits between two windings of the load coil. Tests were performed at the irradiation temperatures of 430 and 550°C. Periodically, tests were done on unirradiated control specimens in the

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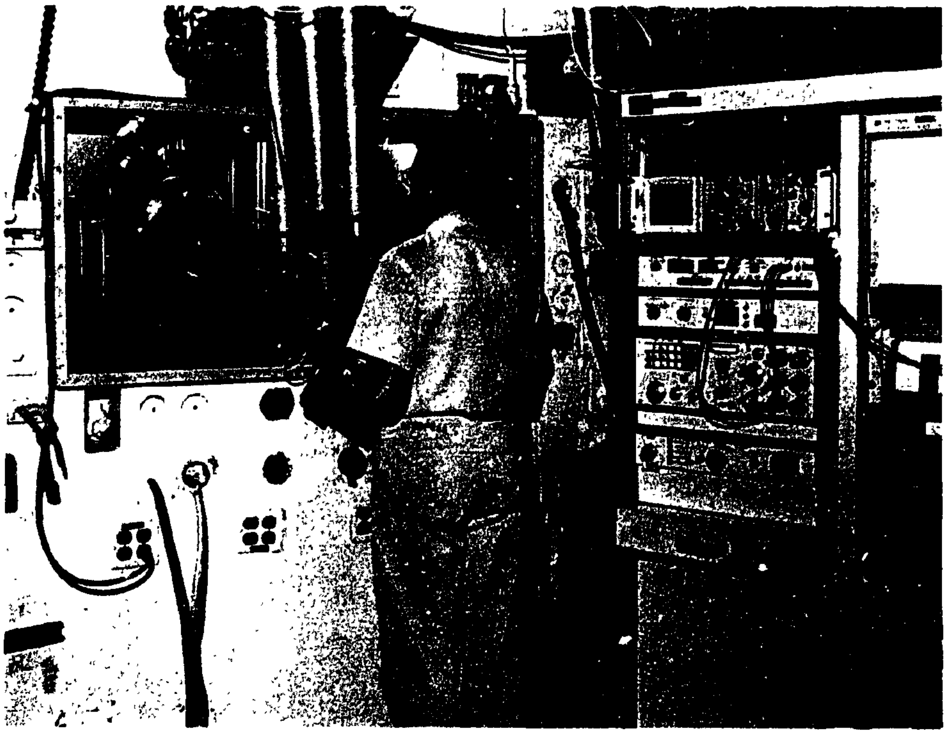

Fig. 2.2. In-cell measurement of fatigue properties.

same apparatus. Results are given in Table 2.10. Some of the specimens in the test matrix were taken from a U.S. capsule, HFIR-CTR-36. A preliminary assessment of these results was presented at the Sixth U.S.-Japan Workshop on Fusion Materials.[4]

Transmission-electron-microscopy (TEM) disks from all of the disassembled capsules were sorted. Twenty U.S. disks from position 2 of capsule JP6 were sent to Hanford Engineering Development Laboratory (HEDL) for reirradiation in the Materials Open Test Assembly (MOTA) of the Fast Flux Test Facility (FFTF). These specimens, irradiated in HFIR at 500°C to about 23 dpa and 1600 appm He, will be reirradiated at 520°C to about 60 and 100 dpa with little additional helium generation. A listing of the disks transferred to MOTA is given in Table 2.11.

During this reporting period, TEM examination was carried out on a variety of austenitic stainless steels following irradiation to ~35 dpa at temperatures of 300, 400, 500, and 600°C. Attention was focused on both the U.S. and Japanese heats of PCA and AISI 316 in both solution annealed and cold worked conditions. The development of the cavity, dislocation, and precipitate components has been reported in detail in semiannual progress reports.[5-9] A paper describing these results was presented at the Second International Conference on Fusion Reactor Materials (ICFRM-2) in Chicago[10] and also at the Sixth U.S.-Japan Workshop on Fusion Materials in Tokyo.[4]

3.0 HFIR IRRADIATION FACILITIES IMPROVEMENT (HIFI) PROJECT

This project, funded primarily under the U.S. program, is aimed at making major improvements in the materials irradiation facilities at the HFIR. Phase I of the project involves providing the capability to carry

Table 2.10. Results of fatigue tests

Specimen	Irradiation Capsule	Alloy	Temperature (°C)	Exposure (dpa)	Total Strain Range (%)	No. of Cycles to Failure
FE14		JPCA, PC2	430	0	1.0	32,305
FE1	JP1	JPCA, PC2	430	33	1.0	9,000
FE15		JPCA, PC2	430	0	0.5	1,330,161
FE2	JP1	JPCA, PC2	430	31	0.5	31,596
FE36		JPCA, PC2	430	0	2.0	7,904
FE5	JP3	JPCA, PC2	430	33	2.0	594
FE6[a]	JP3	JPCA, PC2	430	31		
FE12	JP6	JPCA, PC2	430	34	0.35	657,179
EF5	JP7	PCA, B2	550	34	1.0	6,129
EF20		PCA, B2	550	0	1.0	37,015
EF2	HFIR-CTR-36	PCA, B2	550	30	0.5	65,453
EF7		PCA, B2	550	0	0.5	344,077
EC145	HFIR-CTR-36	PCA, A3	550	30	1.0	4,270
EC149	HFIR-CTR-36	PCA, A3	550	30	0.5	120,006
EC155		PCA, A3	550	0	1.0	24,443
AA5	HFIR-CTR-36	316	550	30	0.5	61,748
AA54	JP7	316	550	30	1.0	7,030
AA3	JP2	316	430	55	1.0	4,323

[a]Broken accidentally during loading into fatigue machine.

Table 2.11. TEM disks from capsule JP6 to be irradiated in the Materials Open Test Assembly (MOTA)

Disk No.	Alloy	Identification	Disk No.	Alloy	Identification
41	PCA B3	EL84	51	CW PCA11	FY69
42	DO 316 CW	AL72	52	CW PCA12	FZ40
43	EP 838	EP52	53	CW PCA13	HA66
44	CW PCA1	FC40	54	CW PCA16	HD80
45	CW PCA3	FG99	55	CW PCA17	HE67
46	CW PCA6	FN85	56	CW PCA18	HF60
47	CW PCA8	FS77	57	CW PCA19	HT13
48	CW PCA9	FV98	58	CW PCA20	HV25
49	CW PCA00	HH04	59	CW PCA21	HW38
50	CW PCA10	FX76	60	CW PCA22	HX04
			61	CW D9 J697	GH12

out irradiation experiments in the target region. These facilities will allow the specimen temperatures in a mockup U.S.-Japan capsule to be measured and compared with design temperatures, and also provide a means for determining nuclear heating rates in stainless steel as a function of axial core position, and time, in the HFIR fuel cycle. This project requires the design and fabrication of new reactor components to replace the target holder, outer shroud, target tower, target hole plug, quick-access hatch, shroud flange, track assemblies, and removable beryllium. Some of these components are shown in Figs. 3.1 and 3.2. The general arrangement is shown schematically in Fig. 3.3. Phase I was completed on schedule and the first experiment, the Target Temperature Test (TTT), was inserted in the reactor in August 1986. This experiment contains

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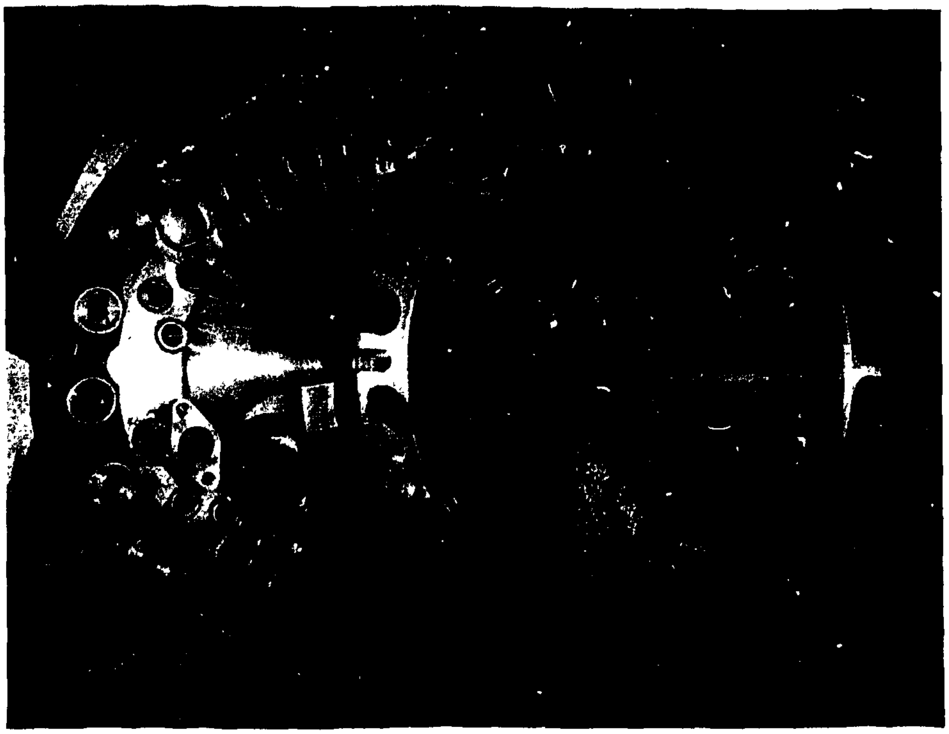

Fig. 3.1. Outer shroud assembly for the HFIR.

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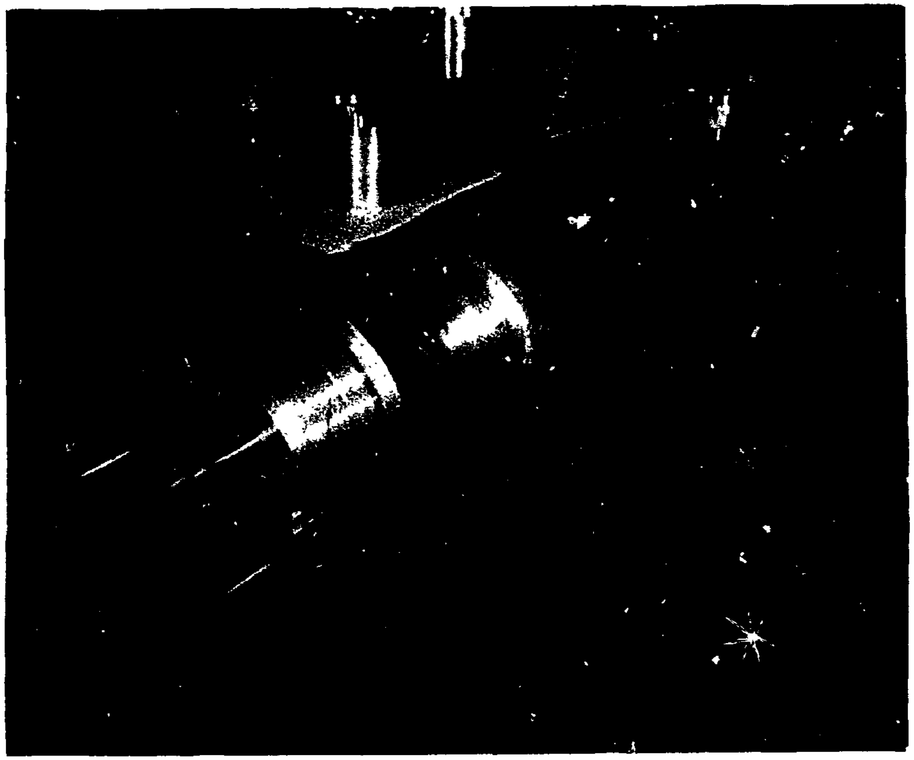

Fig. 3.2. Target tower assembly for the HFIR.

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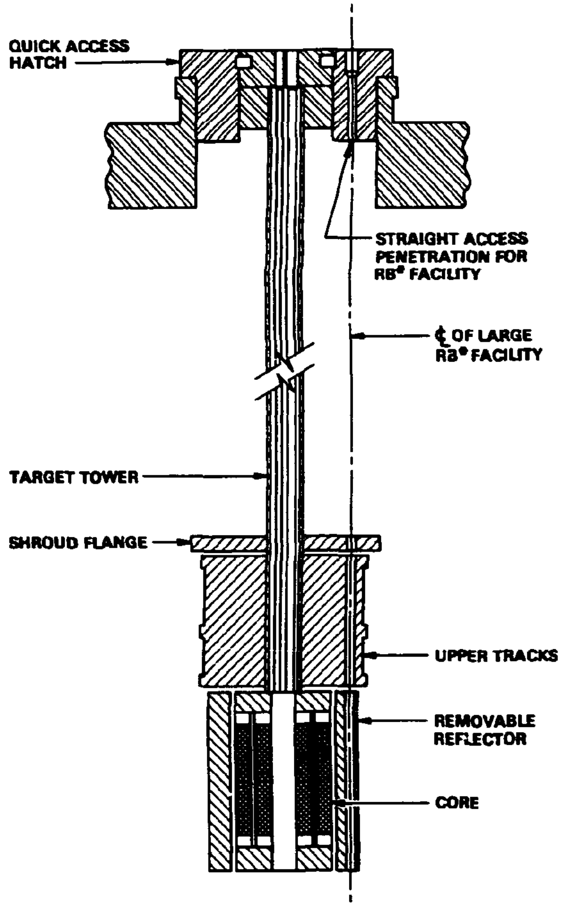

Fig. 3.3. General arrangement of core target tower and quick-access hatch in the HFIR.

fatigue and tensile specimens identical to those used in Capsules JP-1 through -8, with control gas gaps set to achieve temperatures ranging from 300 to 500°C. During this reporting period, two HFIR irradiation cycles were completed. Initial results showed that specimen temperatures at the beginning of the experiment were within 15% of the design values. This capsule is scheduled for a five-cycle irradiation and will provide valuable information on the stability of the thermal conditions as a function of irradiation time. The design of this experiment and initial results were reported in semiannual progress reports.[11,12]

The objective of Phase II of the HIFI project is to replace the existing four 37-mm-diam irradiation positions in the beryllium reflector with eight new positions, each with a diameter of 48 mm. These new RB* positions are designed to accommodate the spectrally tailored experiments currently in progress in the core of the ORR reactor.

Fabrication of a new beryllium reflector was completed (Fig. 3.4), and a new quick-access hatch was also completed (Fig. 3.5). The new hatch provides straight-line instrumentation access to each of the RB* facilities and will permit rotation of experiments for radial flattening of the fluence during irradiation. The present status of the project is summarized in Fig. 3.6. Completion is expected by June 19, 1987. A full description of the HIFI project was presented at ICFRM-2.[13]

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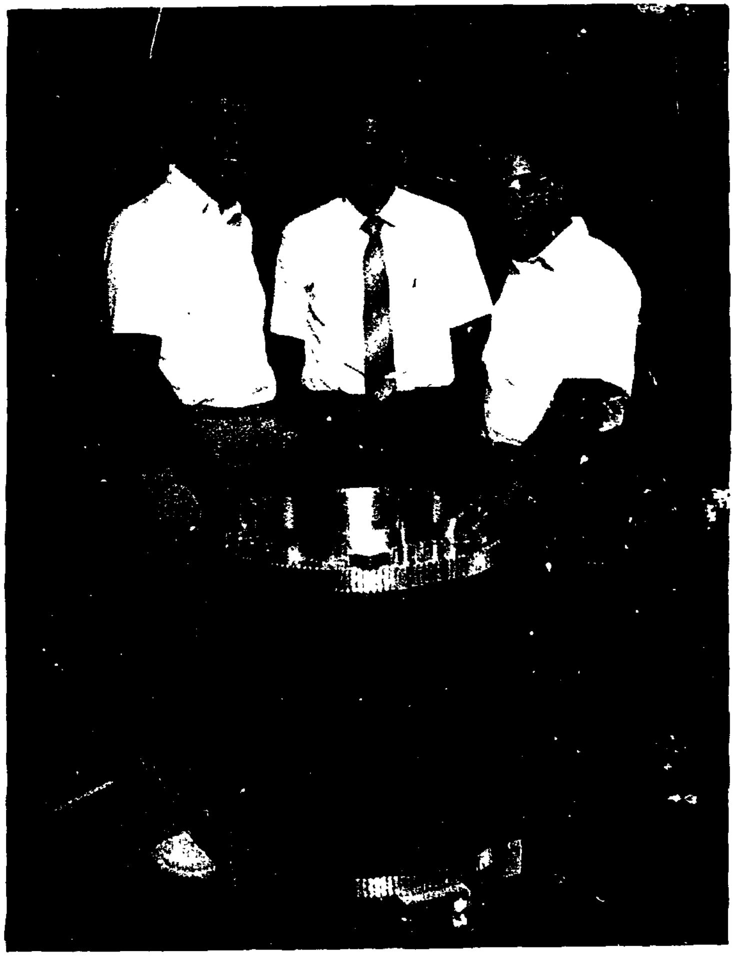

Fig. 3.4. New removable beryllium reflector for the HFIR.

ORNL-PHOTO 3935-86

Fig. 3.5. New quick-access hatch for the HFIR.

HIFI PROJECT
ACCELERATED MFE SCHEDULE
(Current year $000)

SCHED1.CAL BHM
Rev. 9/26/86

	FY-86 Q1 OND : Q2 JFM : Q3 AMJ : Q4 JAS	FY-87 Q1 OND : Q2 JFM : Q3 AMJ : Q4 JAS	FY-88 Q1 OND : Q2 JFM : Q3 AMJ : Q4 JAS	EST COST ($1000)
REACTOR COMPONENTS				
1.0 DESIGN				
1.1 CONCEPTUAL	completed FY-1985			
1.2 DETAILS				
1.2.1 TARGET TOWER	completed 5:			5
1.2.2 ACCESS HATCH	completed 5:			5
1.2.3 REMOV BE	completed 53			53
1.2.4 TRACK ASSY	completed 53			53
1.2.5 OUTER SHROUD	completed 27			27
1.2.6 SHROUD FLANGE	completed 27			27
1.2.7 MISC	completed 5:			5
1.3 STRESS ANALYSIS	completed 58			58
2.0 FABRICATION				
2.1 ACCESS HATCH	completed 85			85
2.2 TARGET TOWER	completed 64			64
2.3 EXTRA BE MACH.	: delayed	[---:--]: 54:		54
2.4 OUTER SHROUD	completed 80			80
2.5 SHROUD FLANGE	completed 25			25
2.6 TRACK ASSY	:50 [---:---	---:---] 54:		104
2.7 MISC	52 [-:---:---	---:---] 73:		125
3.0 ETD SURVEL.	[---:---:-70:---	---:---:-59:-]		129
4.0 INSTALLATION				
4.1 ACCESS HATCH	completed 5:			5
4.2 TARGET TOWER	completed 5:			5
4.3 TRACK & RB		[---]: 56		56
4.4 MISC	: [-:-]	[---:---:--]:		
EXPERIMENTS				
5.0 DESIGN				
5.1 RB* INST FACILITY	delayed[--53---	--]:		53
5.2 TARGET TEMP CAP	completed 53			53
5.3 MFE 60	delayed 32[---:---	-] :		32
5.5 MFE 300	delayed 42[---:---	---] 23:		65
5.4 MFE 200		[---:---:-] 56		56
5.6 MFE 400		[---:---:-] 56		56
5.7 ADD ANALYSES	delayed[--42---	---] 5 :		47
6.0 PROCURE RB*INST FACILITY	:16 [---:---	---] 67:		83
7.0 FABRICATION & ASSY				
7.1 FACILITIES				
7.1.1 INST TARGET	completed 11			11
7.1.2 INST RB*		[--:---:-] :29		29
7.2 CAPSULES				
7.2.1 TARGET TEMP	completed 53			53
7.2.2 MFE 60		[---:---:-] :117	[---:---]123	240
7.2.4 MFE 300	: delayed	[---:---:-] :147	[---:---]152	299
7.2.3 MFE 200		: 98: [-:---	---]60 : 60[---	->218
7.2.5 MFE 400		: 98: [-:---	---]60 : 60[---	->218
8.0 INSTALL & OPERATE				
8.1 TARGET TEMP	completed : [-]			
8.2 MFE 60		[=:===	===] : [===	=>
8.4 MFE 300		:117: [=:===	===]18 : 64[===	=>199
8.3 MFE 200			[===:===]	
8.5 MFE 400			129[===:===]	129
9.0 NEUTRONICS ANALYSES				
9.1 FACILITY	delayed [:-42	---:--]:		42
9.2 TARGET TEMP EFFECTS	delayed [:-27	---:--]:		27
9.3 BEAM TUBE EFFECTS	completed FY-1985			
FISCAL YEAR TOTALS	1040	1107	726	2875*

* Plus $155 K spent in FY-1985 on design and neutronic analysis.

Fig. 3.6. Status of HIFI project.

4.0 PHASE II OF THE HFIR IRRADIATION PROGRAM

The initial plan for Phase II of the collaborative irradiation program was to build eight HFIR capsules during FY 1987. However, at the Steering Committee Meeting in March 1986 this plan was revised for budgetary reasons, and it was decided to build these capsules over a period of several years. The present plan for schedule and costs is shown in Fig. 4.1.

In Phase I of the irradiation program equal cost sharing was achieved by providing equal numbers of each type of irradiation specimen for both partners. In order to provide greater flexibility to experimenters and to address a wider range of radiation damage questions, a different approach has been adopted for Phase II experiments. In the Phase II program, the space in the eight capsules is apportioned so that the product (specimen volume times neutron fluence) is the same for each partner. The allocation of space and the peak fluence for each capsule are shown in Table 4.1. The value factor assigned to each capsule accounts for the specimen volume, the irradiat . time, and the distribution of flux about the core center line.

Table 4.1. Distribution of space in Phase II Capsules

Capsule No.	Peak Fluence (dpa)	Percentage of Space Occupied by Specimens		Value Factor	
		U.S.	Japan	U.S.	Japan
JP-9	100	86	14	0.884	0.116
JP-10	34	5	95	0.057	0.943
JP-11	34	5	95	0.057	0.943
JP-12	100	86	14	0.884	0.116
JP-13	34	5	95	0.057	0.943
JP-14	56	5	95	0.057	0.943
JP-15	100	86	14	0.884	0.116
JP-16	34	5	95	0.057	0.943

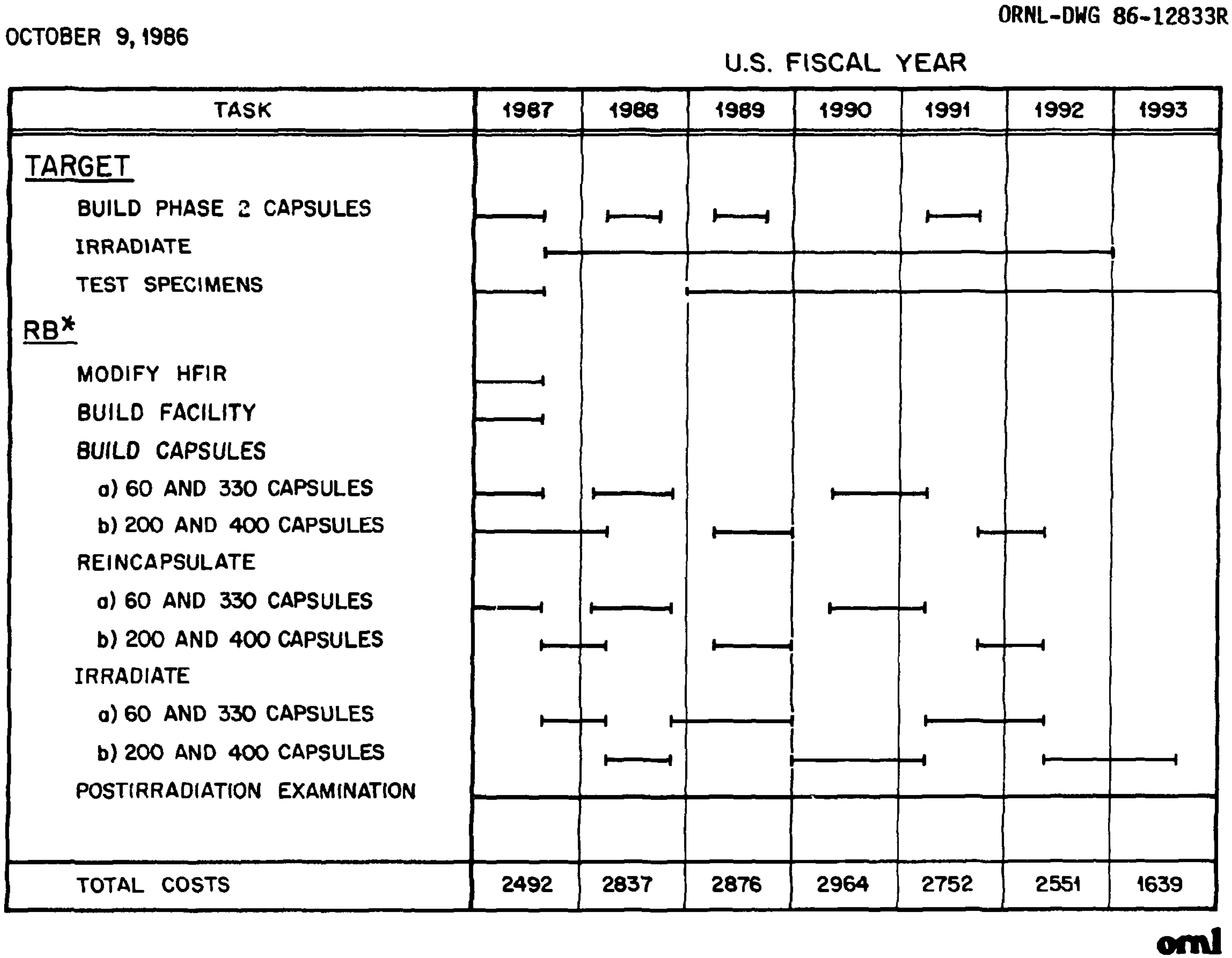

Fig. 4.1. Schedule and costs for the HFIR capsules.

The irradiation volume available to the Japanese side is almost twice that available to the U.S. experimenters; however, this imbalance is compensated for by the higher fluences which the U.S. specimens will receive.

The primary technical interest of the Japanese side is to determine the effects of displacement damage and helium on the behavior of welds. Using both JPCA and AISI 316 stainless steels, tensile specimens (SS-1) are being prepared from welded sheet material such that the weld lies across the center of the gage section. Several welding techniques are being utilized to investigate the effects of radiation on weld integrity. In addition, 3-mm-diam disk specimens are being prepared from the fusion zone, heat-affected zone, and base metal; these will be used to investigate microstructural evolution and swelling behavior in these various regions. Disk specimens will also be included of various experimental ferritic and austenitic steels and molybdenum alloys. Hourglass fatigue specimens of JPCA will be included in several capsules to complete the fatigue investigation carried out in Phase I.

The majority of the U.S. specimens will be carried in three capsules, JP-9, -12, and -15, which are designed to achieve a goal fluence of 100 dpa. Capsule JP-9 will carry round tensile specimens of ferritic/martensitic steels doped with sufficient nickel to generate a helium/dpa ratio of ~10. The other two capsules will carry a variety of alloys which have been isotopically tailored[14] to produce a range of He/dpa ratios (<0.1, 10, 20, 70). This unique experiment is the first-ever reactor experiment with helium generation rate as the single variable. For specimens in adjacent positions, temperature, dose, dose rate, alloy chemistry, and microstructure will all be constant. Disk specimens of both ferritic/martensitic and austenitic steels will be included. The experiment addresses long-standing basic questions on the role of helium in microstructural evolution and will explore the high fluence swelling behavior of the most swelling-resistant materials currently available. A preliminary test matrix for the Phase II HFIR capsules is shown in Table 4.2. Procurement of capsule hardware and final definition of the test matrix and alloy compositions will be carried out in the next reporting period.

5.0 SPECTRALLY TAILORED EXPERIMENTS

5.1 Performance of the ORR Capsules

Two spectrally tailored capsules, MFE-6J and -7J, are currently being irradiated in the ORR. Capsule MFE-7J, which is being irradiated at 330 and 400°C, utilizes a liquid metal (NaK) heat-transfer medium. Capsule MFE-6J has an outer region in which the specimens are in contact with the ORR cooling water at 60°C. In the inner region, which operates at 200°C, heat transfer is effected through a 6061 aluminum alloy holder. The capsule designs, test matrices, and experimental objectives were described earlier.[1,2]

The MFE-6J capsule operated routinely throughout the year with temperatures in the inner capsule ranging from 175 to 200°C. The results of the temperature monitoring were reported in semiannual progress reports.[15,16]

Three-dimensional neutronics calculations to monitor the radiation environment of the MFE-6J and -7J capsules were carried out for each ORR

Table 4.2. Preliminary matrix for HFIR Phase II capsules

JP-9 (100 dpa)	JP-10 (33 dpa)	JP-11 (33 dpa)	JP-12 (100 dpa)	JP-13 (33 dpa)	JP-14 (55 dpa)	JP-15 (100 dpa)	JP-16 (33 dpa)
Specimen Position 1							
500°C	500°C	500°C	300°C	400°C	500°C	500°C	600°C
TEM	T	T	TB	T	T	TB	T
Specimen Position 2							
300°C	500°C	600°C	300°C	430°C	500°C	500°C	500°C
TB	TEM	TEM	TB	F	T	TB	T
Specimen Position 3							
400°C	430°C	430°C	300°C	400°C	600°C	500°C	430°C
TB	F	F	TEM	T	TEM	TEM	TB
Specimen Position 4							
500°C	300°C	400°C	300°C	430°C	600°C	500°C	300°C
TB	T	TEM	TEM	F	TEM	TEM	T
Specimen Position 5							
500°C	400°C	500°C	300°C	500°C	500°C	500°C	400°C
TB	T	T	TEM	T	T	TEM	T
Specimen Position 6							
500°C	400°C	500°C	400°C	500°C	500°C	600°C	400°C
TEM	TEM	TEM	TEM	TEM	TEM	TEM	TEM
Specimen Position 7							
500°C	400°C	500°C	400°C	500°C	500°C	600°C	400°C
TB	T	T	TEM	T	T	TEM	T
Specimen Position 8							
500°C	300°C	500°C	400°C	430°C	400°C	600°C	300°C
TB	TEM	TEM	TB	F	T	TEM	T
Specimen Position 9							
400°C	300°C	500°C	400°C	430°C	300°C	600°C	430°C
TB	T	T	TB	F	TEM	TB	TB
Specimen Position 10							
300°C	430°C	430°C	400°C	400°C	400°C	600°C	500°C
TB	F	F	TB	T	T	TB	T
Specimen Position 11							
300°C	600°C	400°C	400°C	400°C	500°C	600°C	600°C
TB	T	T	TB	T	TEM	TB	T

TEM = disk specimens for swelling and microstructure.
TB = round bar tensile specimen. T = SS-1 sheet tensile specimen.
F = hourglass fatigue specimens.

cycle and the results reported in semiannual reports.[17,18] The projected damage levels and helium concentrations for MFE-6J and -7J are shown in Figs. 5.1 and 5.2, respectively. At the end of this reporting period, AISI 316 specimens had achieved 4.8 dpa and 33 appm He in MFE-6J, and 5.3 dpa and 57 appm He in MFE-7J. Calculations indicate that the solid aluminum core piece should be placed around the MFE-7J experiment in October 1986 and around the MFE-6J experiment in September 1987.

5.2 Transfer of the Spectrally Tailored Capsules to HFIR

As described in Sect. 3.0, the new instrumented RB* irradiation facilities will become available in June 1987. These facilities have

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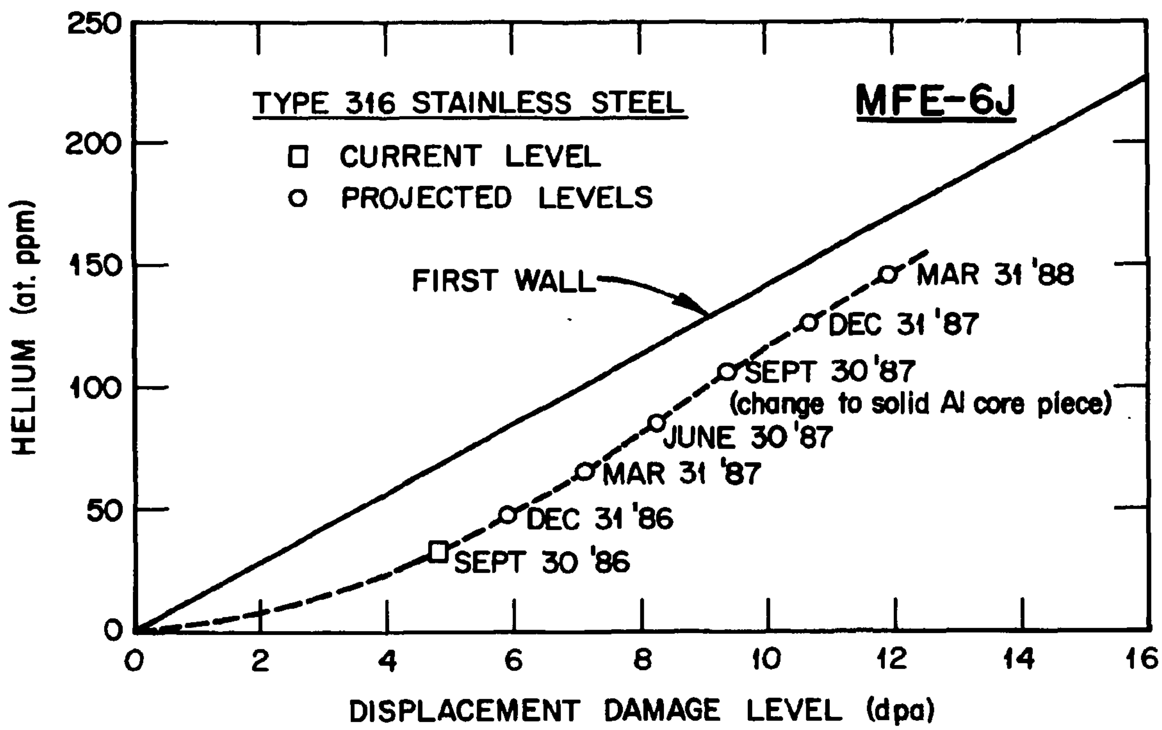

Fig. 5.1. Helium and displacement levels in the ORR-MFE-6J experiment.

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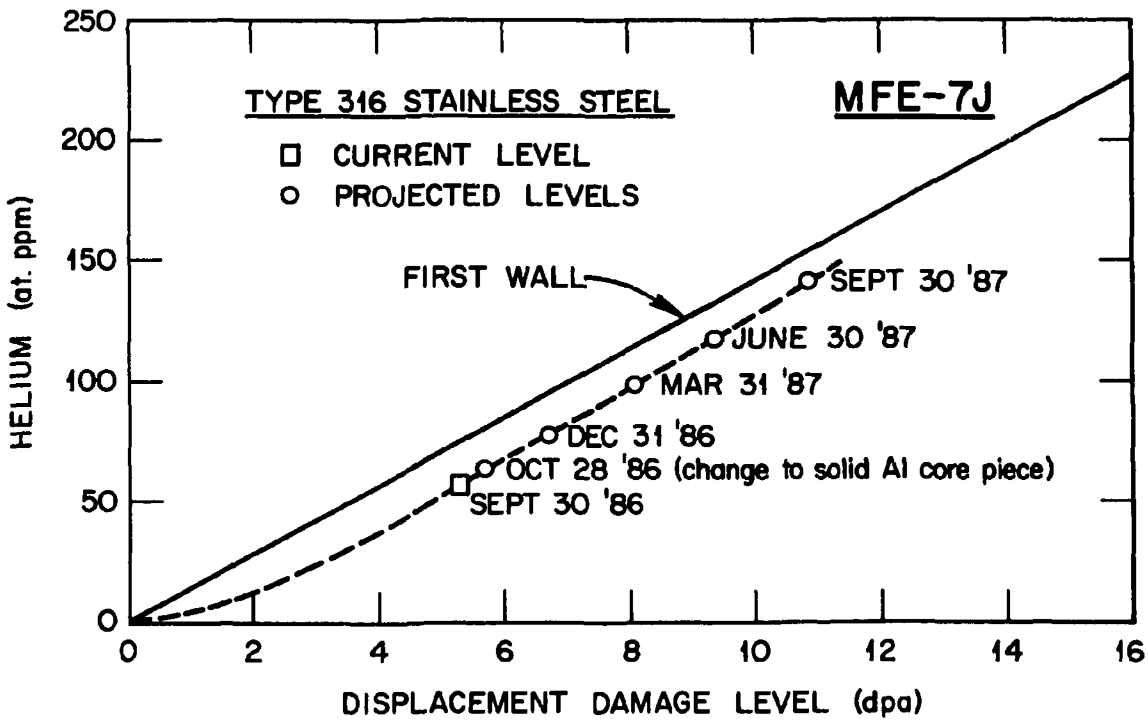

Fig. 5.2. Helium and displacement damage levels in the ORR-MFE-7J experiment.

been designed to irradiate spectrally tailored capsules at a flux that is 2 to 3 higher than that currently available in the ORR. With the ORR approaching the end of its useful life, it was decided in March 1986 to remove the 6J and 7J experiments from the ORR after reaching a damage level of 5 dpa and to reencapsulate them for continuing irradiation in the HFIR RB* positions. At that time, irradiation creep measurements will be carried out and a limited number of tensile and disk specimens removed for testing and examination. Four separate capsules will be designed and built to operate at 60, 200, 330, and 400°C. These capsules will be irradiated, two at a time, in RB* positions to achieve further dose increments of 10 and 20 dpa. The 60 and 330°C capsules will be irradiated first, beginning in July 1987, followed by the 200 and 400°C capsules approximately one year later. The proposed schedule and costs for the RB* irradiation program are shown in Fig. 4.1, p. 20, this report.

The designs for the new RB* capsules are based upon the concept of a solid heat-transfer medium that was successfully demonstrated in the 200°C section of the MFE-6J capsule, which is currently operating satisfactorily in the ORR. Preliminary design concepts were described in a semiannual progress report.[18] Design and fabrication drawings for all four RB* capsules are scheduled to be complete by August 1987.

6.0 CONCLUSIONS

The third year of the U.S.-Japan Collaborative Program was completed on schedule and within budget. The eight Phase I target capsules completed their planned irradiations in HFIR and the two spectrally tailored capsules continued irradiation within their designed temperatures in the ORR. Disassembly of five of the Phase I capsules was completed and considerable progress made in the areas of tensile testing, fatigue testing, densitometry, and transmission electron microscopy. The results of this work was reported in detail in semiannual reports. The initial phase of the HIFI project was successfully completed on schedule and the first instrumented capsule (TTT) was inserted in a HFIR target position. The initial result showed that specimen temperatures were gratifyingly close to design temperatures, thus confirming the validity of the HFIR capsule design methodology. The second phase of the project involving the development of the RB* irradiation facilities is proceeding on schedule in preparation for the transfer of the spectrally tailored capsules from the ORR. Conceptual designs were completed for the four spectrally tailored capsules to be irradiated at 60, 200, 330, and 400°C in the HFIR RB* positions. A preliminary test matrix was developed for Phase II of the HFIR irradiation program.

ACKNOWLEDGMENTS

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