CONF-860421--4

PROGRAM OF UNITED STATES-JAPAN COLLABORATIVE TESTING IN HFIR AND ORR*

J. L. Scott,† M. L. Grossbeck,† A. Hishinuma,‡ T. Kondo,‡
A. F. Rowcliffe,† and M. P. Tanaka‡

†Metals and Ceramics Division, Oak Ridge National Laboratory,
P. O. Box X, Oak Ridge, TN 37831

‡Department of Fuels and Materials Research,
Japan Atomic Energy Research Institute,
Tokai-mura, Ibaraki-ken 319-11, Japan

CONF-860421--4

DE86 008531

Abstract

The objective of the program of U.S.-Japan collaborative testing in HFIR and ORR is to investigate the response of austenitic stainless steels to levels of neutron radiation damage anticipated in fusion reactors. Emphasis is placed on United States and Japanese type 316 stainless steels and prime candidate alloys (PCA), but improved alloys are also included. The program consists of eight HFIR target capsules and two ORR spectral tailoring capsules with test temperatures of 60 to 600°C and fluences of 30 to 50 dpa. Helium contents after irradiation match or exceed those produced in a fusion reactor. Types of data to be obtained include tensile, fatigue, crack growth, irradiation creep, swelling, and microstructural evolution. Five HFIR capsules have been irradiated, and testing is under way. Less than 1% swelling is observed for type 316 stainless steels and PCA alloys irradiated to about 30 dpa at 300 to 500°C.

*This research was sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc., and by the Japan Atomic Energy Research Institute.

Introduction

It is generally conceded that the effort needed to develop suitable materials for fusion reactors is much too large and expensive to be supported by any one country alone. For this reason international collaboration is generally viewed to be highly desirable. The Japanese recognize a special need for conducting irradiation experiments in the High Flux Isotope Reactor (HFIR) and the Oak Ridge Research Reactor (ORR) because high levels of atomic displacements from fast neutrons and high helium contents via the reactions, $^{58}Ni(n,\alpha)$, $^{56}Ni(n,\alpha)$, are achieved simultaneously in nickel-containing alloys such as the austenitic stainless steels. There is no mixed-spectrum fission reactor in Japan with the total flux equal to that of HFIR (peak 5×10^{19} neutrons/$m^2 \cdot s$), and other mixed-spectrum reactors are unavailable for spectral tailoring as is done in ORR.

In August 1978, Japan Atomic Energy Research Institute (JAERI) staff contacted the Oak Ridge National Laboratory (ORNL) expressing an interest in initiating irradiation test capsules in HFIR. The objective was to obtain an engineering data base on austenitic stainless steels, especially annealed and cold-worked types 316 and PCA alloys, for the Japanese Fusion Engineering Reactor (FER) and the U.S. Engineering Power Reactor (EPR). After lengthy negotiations and planning, a five-year program was initiated November 8, 1983. By that time the additional need was recognized for data on more advanced alloys for fusion reactor service; this objective was included in the program.

Scope and Test Matrix

Phase I of the experimental program consists of eight HFIR capsules and two ORR spectral-tailoring capsules with space equally shared between the United States and Japanese programs. Phase II will begin in 1987 with the addition of eight HFIR capsules. Each HFIR capsule contains eleven axial positions, each containing a tensile specimen, a fatigue specimen, or a tube containing transmission electron microscopy (TEM) specimens. Four capsules have already been irradiated to an exposure of 30 dpa, while the remaining four capsules will be irradiated to exposures of 50 dpa. In one capsule the specimens are exposed to HFIR cooling water at about 60°C. The other seven capsules were arranged so that specimen temperatures are in the range 300 to 600°C. Temperatures were calculated based on previous calibrations and passive temperature monitors, but an instrumented capsule will be operated in the summer of 1986 to provide even better measurements. The test matrix for the HFIR capsules is shown in Table 1. Compositions of the primary alloys being tested are shown in Table 2. In addition to these alloys there is a large number of advanced PCAs, ferritic steels, and other experimental alloys included in the form of TEM disks. Space limitations preclude a discussion of these alloys in this paper, but they are fully described elsewhere [1,2].

Originally the two spectral-tailoring capsules were to be irradiated in ORR to exposures of 30 dpa with interim examinations at 10 and 20 dpa. It is now planned to modify the HFIR so that spectral tailoring can be done in the beryllium reflector region. Tests requiring three years in the ORR can be done in 14 months in the HFIR so that time and money will be saved by transfering the capsules to HFIR. The present plan calls for the transfer to be made after an exposure of 5 dpa (October 1986). This will permit interim data to be obtained at this damage level. Each ORR capsule provides two different irradiation temperatures so specimens are being irradiated at 60, 200, 330, and 400°C. Approximately 650 specimens are being irradiated at each temperature. The ORR test matrix is given in Table 3.

Capsule Description and Schedule

The capsule design for the U.S.-Japan HFIR experiments is similar to that used routinely at ORNL for the U.S. Alloy Development Program. The specimens, which consist of rod tensile and hourglass fatigue specimens and tubes containing TEM disks, are placed in carefully machined aluminum specimen holders. A helium gap between the specimens and the carefully contoured holders provides the thermal resistance to obtain desired temperatures through nuclear heating. Previous calculations are used to determine the correct nuclear heating rates and helium gaps.

The first two HFIR capsules were installed in the HFIR in January 1984; thereafter, two additional capsules were installed each quarter of a year until all eight were in the reactor. The irradiation duration is about 14 months for 30 dpa capsules and about two years for 50 dpa capsules. The overall schedules including postirradiation examination are shown in Fig. 1.

The ORR spectral tailoring capsules are of radically different designs. The high-temperature (330/400°C) capsules shown in Fig. 2 utilize NaK as the heat transfer medium. Temperatures are controlled by adjusting the composition of a He-Ne mixture in the control gas annulus and are measured by thermocouples (TE-1 through TE-6). A vacuum-filled plug insulates the lower 400°C region from the upper 330°C region. Since NaK will not reliably wet stainless steel below 300°C, an alternate design had to be used for the low-temperature capsule. For the 60°C region, specimens are exposed directly to the reactor coolant water. For the 200°C region an aluminum holder contains precise holes for pressurized tubes (irradiation creep) and TEM disk holders and carefully milled slots for sheet tensile, swelling, and sheet fatigue specimens. The holder is cooled with water on both the inside and outside surfaces, and there is a gas gap through which a He-Ne mixture is used for temperature control.

Both the low-temperature (MFE-6J) and high-temperature (MFE-7J) capsules were inserted in the ORR on June 28, 1985, and are now being irradiated.

Results

Results to date are limited because only the first two HFIR capsules, JP-1 and JP-3, have been disassembled. Swelling rates were measured by: (1) length changes of the tensile specimens, (2) immersion densities of the tensile specimens, (3) immersion densities of TEM disks, and (4) microstructural analysis by transmission electron microscopy. Results are shown in Table 4. In general, good agreement was found between the different methods of estimating swelling. All specimens showed less than 1% swelling at the 30 dpa level. Additional microstructural information can be found in a companion paper at this conference [3].

It was found that similar results were obtained for the Japanese and United States austenitic stainless steels with similar composition and starting microstructures.

In addition, an excellent working relationship has been established between ORNL and JAERI, and both sides have benefited greatly by the collaboration.

Conclusions

1. A collaborative testing program of United States and Japanese austenitic stainless steels for fusion application is ongoing.

2. Eight HFIR capsules and two ORR spectral-tailoring capsules have completed or are undergoing irradiation.

3. Initial results on type 316 stainless steel and PCA alloys in the solution annealed and cold-work conditions irradiated to 30 dpa at 300, 400, and 500°C show less than 1% swelling.

4. Similar results were obtained for the United States and Japanese alloys.

Acknowledgment

The authors would like to acknowledge the help of Dr. T. C. Reuther, DOE, Dr. E. E. Bloom, ORNL, and Dr. J. Shimokawa, JAERI, in initiating this collaboration. They would also like to thank Frances Scarboro for typing the manuscript.

References

[1] J. L. Scott et al., "First 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, 1984," ORNL/TM-9768, Oak Ridge National Laboratory (October 1985).

[2] J. L. Scott et al., "Second 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, 1985," Oak Ridge National Laboratory (in press).

[3] M. P. Tanaka, P. J. Maziasz, A. Hishinuma, and S. Hamada, "Microstructural Development of Solution-Annealed PCA Irradiated in HFIR at 300 to 400°C," paper presented at this conference.

List of Figures

Table 1. Distribution of HFIR specimens

Irradiation Temperature (°C)	30 dpa			50 dpa		
	Tensile[a]	Fatigue[a]	Disk Packet	Tensile[a]	Fatigue[a]	Disk Packet
Specimens for United States						
55	0	0	0	20[b]	0	6[c]
300	2	0	0.5[d]	2	0	0.5[d]
400	3	0	0.5	2	0	0.5
430	0	6	0	0	6	0
500	3	0	1.5	3	0	0.5
550	0	2	0	0	0	0
600	3	0	0.5	2	0	0
TOTALS	11	8	3.0	29	6	1.5
Specimens for Japan						
55	0	0	0	20[b]	0	8[c]
300	4	0	0.5[d]	3	0	0.5[d]
400	4	0	0.5	3	0	0.5
430	0	6	0	1	4	0
500	4	0	0.5	3	0	0.5
550	0	0	0	0	0	0
600	2	0	0.5	1	0	0
TOTALS	14	6	2.0	31	4	1.5

[a]Rod specimens, identical to those used in previous HFIR experiments, except as noted.

[b]Sheet tensile specimens (SS-1).

[c]Rectangular strips, 42 × 1.5 × 0.25 mm for TEM disks.

[d]Disk size, 3 mm diameter × 0.25 mm thick; 0.5 packet contains ~50 disks.

Table 2. Compositions of the Primary Alloys for the U.S./Japan Collaboration

Alloy	Heat	Content, wt %[a]												
		Cr	Ni	Mo	Mn	Si	Ti	Nb	C	N	P	Co	B	S
U.S. PCA	K-280	14.0	16.2	2.3	1.8	0.4	0.24		0.05	0.01	0.01		0.001	0.003
JPCA		14.22	15.60	2.28	1.77	0.50	0.24		0.06	0.004	0.027	0.002	0.003	0.005
Ref. 316	X-15893	17.3	12.4	2.1	1.7	0.70		0.08	0.05		0.04	0.35	0.004	0.015
J316		16.75	13.52	2.46	1.80	0.61	0.005		0.058		0.028	<0.1		0.003

[a]Balance iron.

Table 3. Test Matrix for the MFE-6J and -7J Capsules

Specimen Type	Source	Number of Specimens			
		60°C	200°C	330°C	400°C
Pressurized tubes	ORNL[a]	34	15	39	33
	JAERI[b]	4	10	6	6
Tube blanks	ORNL	6	6	6	6
	JAERI	3	3	3	3
Disk packets	ORNL	4	4	8	9
	HEDL[c]	0	0	4	4
	JAERI	5	7	6	6
Sheet tensiles (44.5 mm)	ORNL	29	34	11	13
	JAERI	64	56	73	65
Sheet tensiles (25.4 mm)	ORNL	44	44	16	22
	HEDL	35	35	30	30
Sheet fatigue	JAERI	56	24	56	40
Crack growth	JAERI	18	18	10	10
	HEDL	18	18	0	0
Rod tensiles	JAERI	0	0	4	0
Hourglass fatigue	JAERI	0	0	0	5

[a]Oak Ridge National Laboratory.

[b]Japan Atomic Energy Research Institute.

[c]Hanford Engineering Development Laboratory, operated by the Westinghouse Hanford Corporation.

Table 4. Swelling Data on United States and Japanese Type 316 and PCA Alloys

Alloy	Condition	Irradiation Temperature (°C)	Swelling ΔV/V (%)	Number of Measurements
JPCA	SA	500	0.55	4
JPCA	SA	400	0.38	5
JPCA	SA	300	0.22	4
JPCA	20% CW	400	0.29	1
JPCA	20% CW	300	0.28	4
JPCA	20% CW + 2 h @ 800°C	400	0.10	1
PCA	25% CW	500	0.48	2
PCA	25% CW	400	0.32	1
PCA	8 h @ 800°C + 25% CW	500	0.76	2
PCA	8 h @ 800°C + 25% CW	400	0.44	5
PCA	8 h @ 800°C + 25% CW	300	0.19	3
J316	SA	400	0.18	1
J316	SA	300	0.19	2
J316	20% CW	400	0.18	1
J316	20% CW	300	0.51	1
316	20% CW	400	0.83	1

ORNL-DWG 86-8354

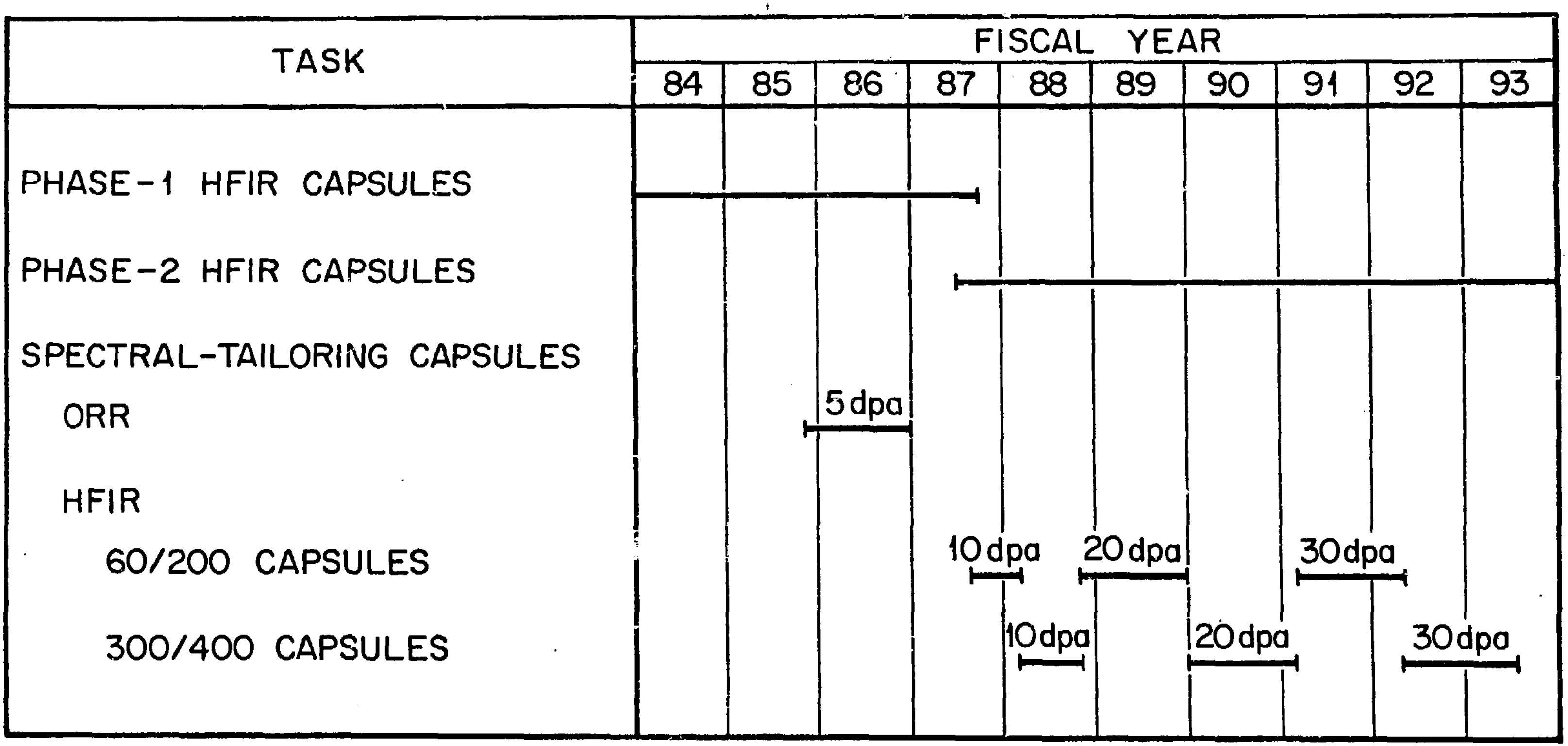

Fig. 1. Schedule of U.S.-Japan collaborative testing in ORR and HFIR.

ORNL–DWG 79–3082R FED

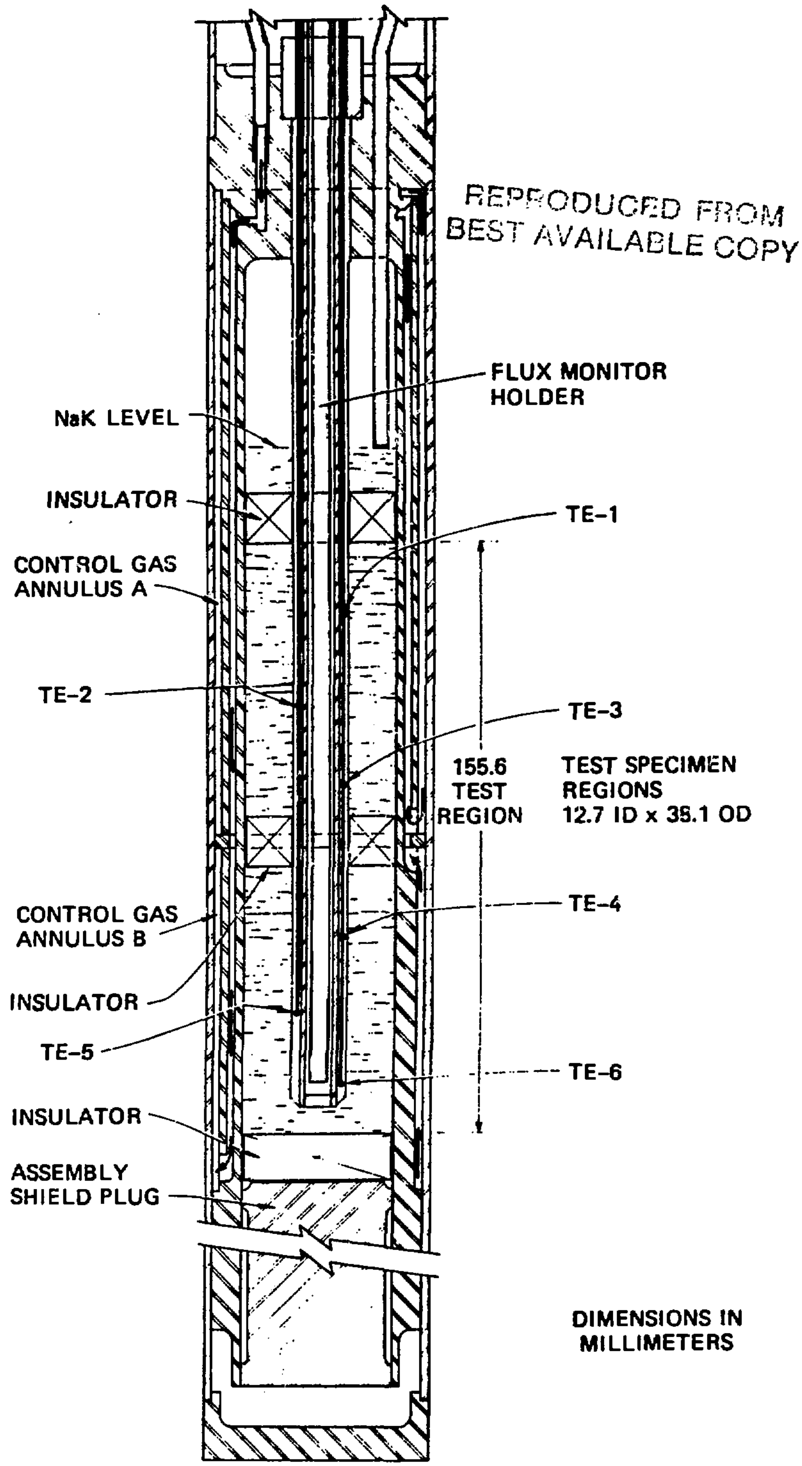

Fig. 2. Test region.