PRELIMINARY REPORT ON THE IRRADIATION CONDITIONS OF THE HFIR JP-23 EXPERIMENT - A. M. Ermi (Westinghouse Hanford Company) and D. S. Gelles (Pacific Northwest Laboratory)[a]

OBJECTIVE

The objective of this effort was to irradiate a series of alloys over the temperature range 300 to 600°C to approximately 10 dpa in the High Flux Isotope Reactor (HFIR). The alloys covered a wide range of materials and treatments.

SUMMARY

The JP-23 test capsule was irradiated in the HFIR during Cycles 322 through 326. The capsule contained eight transmission electron microscopy (TEM) specimen holders, two each at irradiation temperatures of 300, 400, 500, and 600°C. The test capsule was irradiated for a total of 110 effective full power days (EFPD), achieving estimated peak doses of 1.1 x 10^{22} n/cm^2 (E>0.1 MeV) and 8.8 dpa (in stainless steel).

PROGRESS AND STATUS

Introduction

The HFIR JP-23 test was a collaborative experiment co-sponsored by the U.S. Neutron Interactive Materials (NIMs) program and the Japanese Monbusho program. The goal of the experiment was to irradiate metallic TEM specimens to a dose on the order of 8 dpa (in stainless steel) at four temperatures (300, 400, 500, and 600°C) in a HFIR inner target position.

This preliminary report characterizes the irradiation conditions for the JP-23 TEM specimens. Estimated fluences and dpa values are based on previous experiments in HFIR. Once the analysis of the JP-23 dosimetry has been completed, a final report can be issued.

Specimen Information

The JP-23 capsule contained eight TEM specimen holders, all gas-gapped in order to obtain irradiation temperatures of 300, 400, 500, and 600°C. The eight TEM specimen holders were divided between the two program sponsors. A cross-sectional view of a typical TEM specimen holder assembly is shown in Figure 1.

The Japanese specimen matrix consisted of ferritic steels, vanadium alloys, copper alloys, molybdenum alloys, and titanium-aluminum compounds. The major purposes of the Monbusho experiment were to study solid transmutation and helium effects.

The U.S. specimen matrix consisted of vanadium alloys, 316 stainless steels, and isotopically tailored ferritic and austenitic alloys. Isotopic tailoring consists of adding natural nickel, Ni^{59} and/or Ni^{60} (without

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[a]Operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

any other parameter changes) to alter the helium generation response. The major purposes of the NIMs experiment were to study the effects of irradiation in vanadium and 316 stainless steel and to study the effects of helium generation in ferritic and austenitic alloys.

The loading summary for the HFIR JP-23 capsule is given in Table 1. The TEM discs are nominally 3 mm (0.118 in.) in diameter and 0.25 mm (0.010 in.) thick. Exceptions are noted in Table 2. The alloy compositions for the Monbusho specimens are given in Tables 3 through 5, and the compositions for the U.S. specimens are given in Table 6.

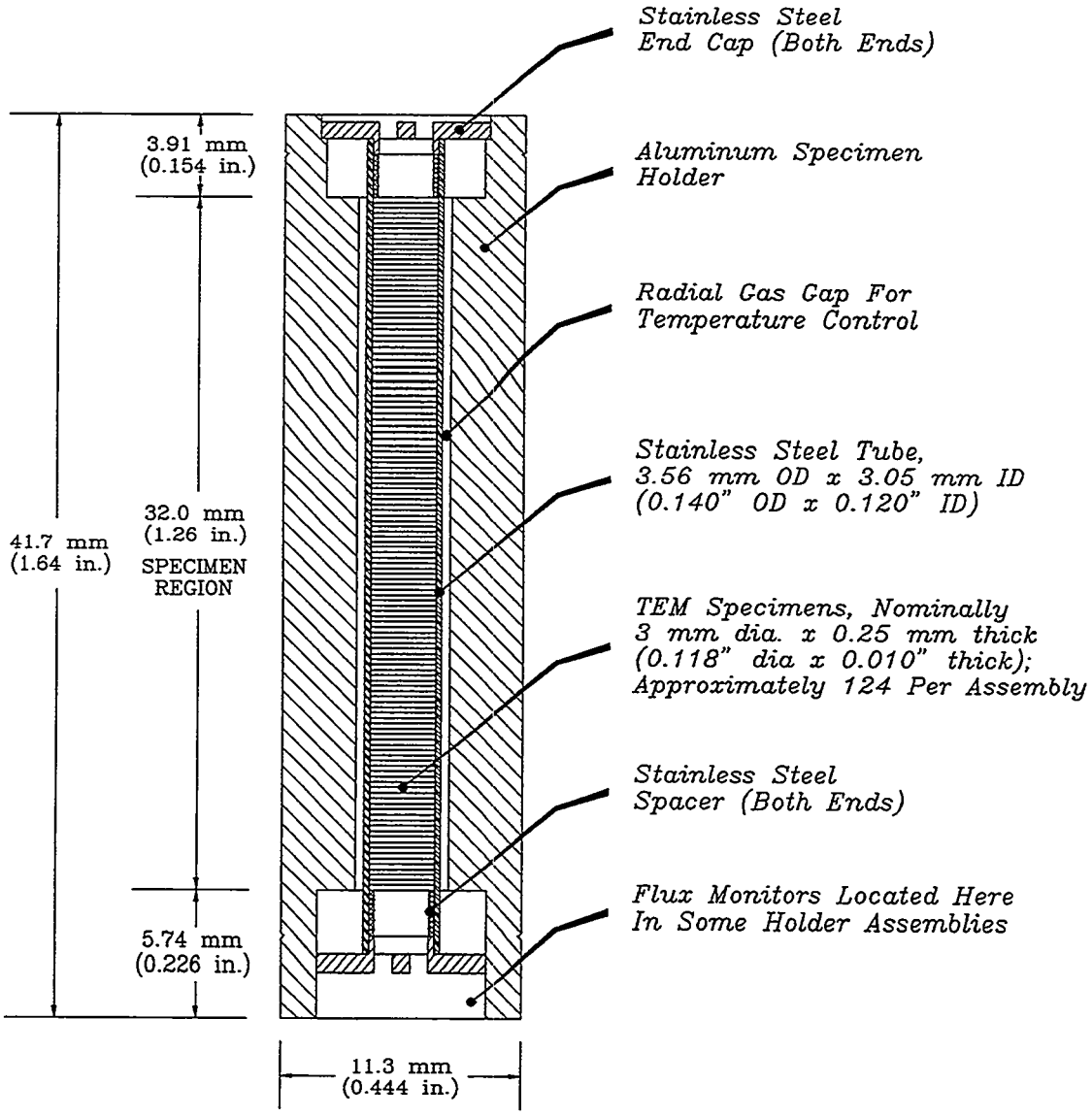


Figure 1. Cross-section of Typical TEM Specimen Holder Assembly

Table 1. Loading Summary for HFIR Capsule JP-23

Position Number	Program Sponsor	Design Temperature	Specimen Type	Specimen Material and No. of Specimens
3	Japanese Monbusho	300°C	TEM	Ferritics 25 Vanadium Alloys 26 Copper Alloys 25 76
4	Japanese Monbusho	400°C	TEM	Ferritics (JPN) 25 Vanadium Alloys 36 Copper Alloys 25 Ti-Al Alloys 15 Ferritics (US) 36 137
5	Japanese Monbusho	500°C	TEM	Ferritics 25 Vanadium Alloys 35 Ti-Al Alloys 15 Mo Alloys 24 99
6	Japanese Monbusho	600°C	TEM	Vanadium Alloys 40 Ti-Al Alloys 15 Mo Alloys 24 79
7	U.S. NIMs	600°C	TEM	Ferritics 47 Austenitics 43 Vanadium Alloys 27 Titanium getters 2 119
8	U.S. NIMs	500°C	TEM	Ferritics 50 Austenitics 44 Vanadium Alloys 27 Titanium getters 2 123
9	U.S. NIMs	400°C	TEM	Ferritics 49 Austenitics 44 Vanadium Alloys 27 Titanium getters 2 122
10	U.S. NIMs	300°C	TEM	Ferritics 50 Austenitics 44 Vanadium Alloys 27 Titanium getters 2 123

Table 2. Dimensions of Non-Standard TEM Discs

Program Sponsor	Material Description	TEM Disc Thickness (If Different From 0.25 mm [0.010 in.])	TEM Disc Diameter (If Different From 3.0 mm [0.118 in.])
Japanese Monbusho	Vanadium Alloys	---	2.5 mm (0.098 in.)
Japanese Monbusho	Copper Alloys	0.20 mm (0.008 in.)	---
Japanese Monbusho	Molybdenum Alloys	0.082 to 0.192 mm (0.003 to 0.008 in.) Average: 0.15 mm (0.006 in.)	---
Japanese Monbusho	Titanium-Aluminum Alloys	0.25 to 0.39 mm (0.010 to 0.015 in.) Average: 0.31 mm (0.012 in.)	---
U.S. NIMs	316L and 316Ti 20% CW Austenitics	0.20 mm (0.008 in.)	---
U.S. NIMs	Titanium Getter Discs	0.18 mm (0.007 in.)	---

Table 3. Alloy Compositions for Japanese Low Activation Ferritic Steels[a]

Material	Fe	Cr	Ni	Mn	Ti	Si	W	V	Ta	C	B	N
JLF-1 / UTY/JLF-1	Bal.	9.0	--	0.5	--	0.05	2.0	0.2	0.07	0.1	--	0.05
NSL21 / NS/L21	Bal.	9.0	0.1	0.3	--	0.1	2.0	0.2	0.1	0.06	--	0.05
F82H / JRI/JTKW-H	Bal.	7.7	--	--	--	--	2.0	0.2	0.04	0.09	--	--
NLF-0 / TU3A	Bal.	9.0	--	0.5	0.1	--	2.0	0.25	--	0.1	--	--
NLF-1 / TU2A	Bal.	9.0	--	0.5	0.1	--	2.0	0.25	--	0.1	0.003	--

[a] All values in weight percents

Table 4. Alloy Compositions for Japanese Vanadium Specimens[a]

Material	V	Ti	Cr	Si	Y	Al	B
Pure V / 88-50	99.9	--	--	--	--	--	--
V-5Ti / 88-54	Bal.	5 a/o	--	--	--	--	--
V-5Cr / 88-55	Bal.	--	5 a/o	--	--	--	--
V-1Cr / 93-71	Bal.	--	1 a/o	--	--	--	--
V-10Cr / 93-72	Bal.	--	10 a/o	--	--	--	--
V-5Ti-1Cr / 93-73	Bal.	5 a/o	1 a/o	--	--	--	--
V-5Ti-5Cr / 93-74	Bal.	5 a/o	5 a/o	--	--	--	--
V-5Ti-5Cr / 90-11	Bal.	5.0	5.0	0.9	0.8	1.0	--
V-100B / 93-002	Bal.	--	--	--	--	--	100 appm
V-500B / 93-003	Bal.	--	--	--	--	--	500 appm
V-2500B / 93-004	Bal.	--	--	--	--	--	2500 appm
V-5Cr-B / 93-005	Bal.	--	5 a/o	--	--	--	100 appm

[a] All values in weight percents except as noted:
a/o = atomic percent
appm = atomic parts per million

Summary of HFIR Operations

The JP-23 test capsule was inserted into HFIR target position G6 (marked on Figure 2) on December 13, 1993. The HFIR was started on December 16th, commencing Cycle 322. The reactor is typically run for 22 day cycles (@ 85 MW) followed by 7 to 10 day outages. The actual reactor operation during the irradiation of the JP-23 test capsule is shown in Table 7. The JP-23 irradiation was concluded at the end of Cycle 326 on June 3, 1994. The test capsule was removed from the core shortly thereafter and stored in the reactor pool area. The test capsule was scheduled to processed at Oak Ridge National Laboratory (ORNL) during August-September 1994. At that time, it is to be transferred to a hot cell for disassembly, removal of the specimen holders, and preparation of the specimen holder tubes for shipment to Hanford. Specimen examination at Hanford will start in 1995.

Summary of Reactor Conditions for HFIR JP-23

Temperatures

The eight gas-gapped specimen holders were designed to operate at temperatures of 300, 400, 500 and 600°C. Results from the thermal analysis and design work for JP-23 were summarized in Reference 1. Since there were no temperature monitoring devices in JP-23, the temperatures assigned to the specimens are the design temperatures. These temperatures are to be considered final since more precise temperature values cannot be assigned to the specimens.

An uncertainty analysis of the design temperatures has never been performed by ORNL for this specific type of experiment. However, a wealth of information does exist from other fusion experiments that have corroborated expected temperatures. Therefore, based on long experience in irradiating many capsules of similar design, ORNL states that it is reasonable to assume that calculated temperatures are accurate within ±25°C.

Table 5. Alloy Compositions for Japanese Cu, Mo, and Ti/Al Specimens[a]

Material	Cu	Ni	Zn	Mn	Mo	Re	Zr	Ti	Al	C
Copper	Bal.	--	--	--	--	--	--	--	--	--
Cu - Cold Worked	Bal.	--	--	--	--	--	--	--	--	--
Cu-5Ni	Bal.	5.0	--	--	--	--	--	--	--	--
Cu-3.5Zn	Bal.	--	3.5	--	--	--	--	--	--	--
Cu-5Ni-2Zn	Bal.	5.0	2.0	--	--	--	--	--	--	--
Cu-0.5Mn	Bal.	--	--	0.5	--	--	--	--	--	--
Cu-2Mn	Bal.	--	--	2.0	--	--	--	--	--	--
Cu-2Mn - Cold Worked	Bal.	--	--	2.0	--	--	--	--	--	--
Mo-2Re / R or SR	--	--	--	--	Bal.	2.0	--	--	--	--
Mo-5Re / R or SR	--	--	--	--	Bal.	5.0	--	--	--	--
Mo-10Re / R or SR	--	--	--	--	Bal.	10.0	--	--	--	--
Mo-41Re / R or SR	--	--	--	--	Bal.	41.0	--	--	--	--
TZM / R or SR	--	--	--	--	Bal.	--	0.10	0.48	--	0.013
Mo / R or SR	--	--	--	--	Bal.	--	--	--	--	--
TiAl	--	--	--	--	--	--	--	50 a/o	50 a/o	--

[a] All values in weight percents except as noted; a/o = atomic percent

Table 6. Alloy Compositions for U.S. Materials[a]

Material	I.D. Code	Final Condition	Fe	Cr	Ni (total)	Ni (Nat.)	Ni-59	Ni-60	Mn	Ti	Si	W	V	Mo	Co	C	N	O
E62R	6A	1040°C/1 h/AC +760°C/1 h/AC	Bal.	12.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
R168	71	1040°C/1 h/AC +760°C/1 h/AC	Bal.	11.7	1.32	--	--	1.32	--	--	--	--	--	--	--	0.004	--	--
R169[d]	73	1040°C/1 h/AC +760°C/1 h/AC	Bal.	12.0	1.5	--	1.5	--	--	--	--	--	--	--	--	--	--	--
R170	74	1040°C/1 h/AC +760°C/1 h/AC	Bal.	11.5	1.54	1.54	--	--	--	--	--	--	--	--	--	0.004	--	--
R178[d]	7P	20% CW	Bal.	17.5	13.69[c]	--	2.06[c]	11.63[c]	1.7	--	0.53	--	--	2.3	--	0.05	--	--
R178[d]	7R	20% CW +1050°C/1 h/AC	Bal.	17.5	13.69[c]	--	2.06[c]	11.63[c]	1.7	--	0.53	--	--	2.3	--	0.05	--	--
R179	7T	20% CW	Bal.	18.4	12.7[b]	2.06[c]	--	11.63[c]	1.57	--	0.56	--	--	2.39	--	0.027	--	--
R179	7U	20% CW +1050°C/1 h/AC	Bal.	18.4	12.7[b]	2.06[c]	--	11.63[c]	1.57	--	0.56	--	--	2.39	--	0.027	--	--
R180a,b[d]	7V	1050°C/½ h/AC +760°C/5 h/AC	Bal.	12.0	2.0	--	2.0	--	0.5	--	0.18	0.5	0.3	1.0	--	0.2	--	--
R181a,b	7X	1050°C/½ h/AC +760°C/5 h/AC	Bal.	12.1	2.39	2.39	--	--	0.54	--	0.18	0.43	0.2	0.91	--	0.15	--	--
BL-47	47	1125°C/1 h/FC	--	4.1	--	--	--	--	--	4.3	0.087	--	Bal.	--	--	0.02	0.022	0.035
BL-62	62	1125°C/1 h/FC	--	--	--	--	--	--	--	3.1	0.066	--	Bal.	--	--	0.0109	0.0086	0.032
BL-63	63	1125°C/1 h/FC	--	4.6	--	--	--	--	--	5.1	0.031	--	Bal.	--	--	0.0073	0.0028	0.044
316L	EA	Solid Solution	Bal.	17.22	14.14	14.14	--	--	1.41	--	0.29	--	--	2.25	--	0.025	--	--
316L	EB	20%CW	Bal.	17.22	14.14	14.14	--	--	1.41	--	029	--	--	2.25	--	0.025	--	--
316Ti	EE	Solid Solution	Bal.	18.0	13.47	13.47	--	--	1.79	0.319	0.80	--	--	2.64	0.033	0.055	--	--
316Ti	EF	20%CW	Bal.	18.0	13.47	13.47	--	--	1.79	0.319	0.80	--	--	2.64	0.033	0.055	--	--
Ti (getter)	--	--	--	--	--	--	--	--	--	99.9	--	--	--	--	--	--	--	--

[a] All value in weight percent
[b] Measured value
[c] Intended Value
[d] Mildly radioactive

Table 7. Summary of HFIR Operation During the JP-23 Irradiation

HFIR Operation							JP-23 Capsule		
Cycle No.	Start Date	End Date	Outage Lengths	MWd	EFPD[a]	dpa[b]	Total MWd	Total EFPD[a]	Total dpa[b]
322	Dec. 16, 1993	Jan. 7, 1994	16 days	1854	21.8	1.75	1854	21.8	1.75
323	Jan. 23, 1994	Feb. 14, 1994	19 days	1874	22.0	1.77	3728	43.8	3.52
324[c]	Mar. 5, 1994	Mar. 15, 1994	4 days	1907	22.4	1.80	5635	66.3	5.33
	Mar. 19, 1994	Apr. 1, 1994	9 days						
325	Apr. 10, 1994	May 3, 1994	5 days	1907	22.4	1.80	7542	88.7	7.13
326[d]	May 8, 1994	May 20, 1994	4 days	1825	21.5	1.72	9367	110.2	8.85
	May 24, 1994	June 3, 1994	---						

[a] Based on 85 MW full power

[b] Peak dpa based on 0.000945 dpa/MWd for stainless steel (from ORNL)

[c] Mid-cycle shutdown for maintenance

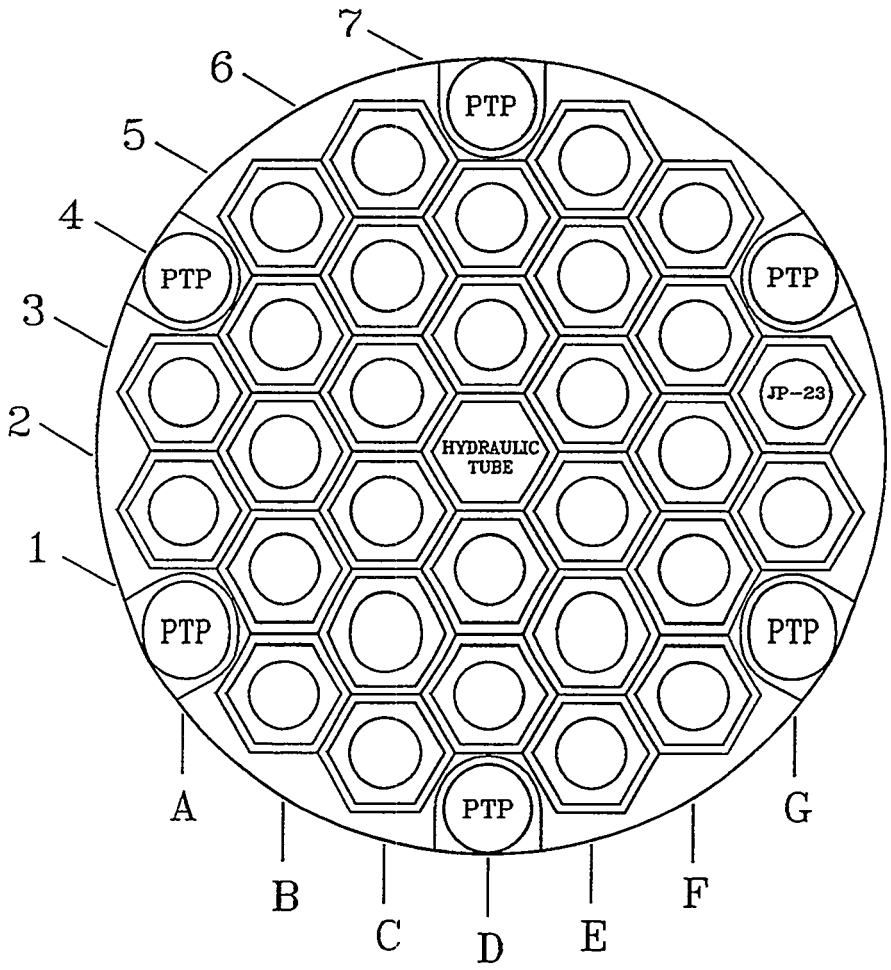
[d] Mid-cycle shutdown due to a pressurizer pump trip

Damage Parameters

Six dosimetry sets were included in the JP-23 capsule. The dosimeter tubes were fabricated from high purity aluminum (99.5%) with nominal dimensions of 9.6 mm (0.38 in.) in length, 1.5 mm (0.058 in.) in diameter and a wall thickness of 0.15 mm (0.006 in.). The dosimeter wires each measured approximately 1.0 to 1.5 mm (0.04 to 0.06 in.) in diameter by 2 mm (0.08 in.) in length, and consisted of milligram quantities of Fe, Ti, Ni, Nb, 0.1% Co-Al, and 80.2% Mn-Cu. The tubes containing the wires were welded in a helium-argon environment. The monitors were placed in holes drilled horizontally through the bottom endcaps of six of the specimen holder assemblies:

JP-23 Position Number	Flux Monitor Number
3	114
4	118
6	120
7	121
8	125
10	129

However, since the dosimetry will not be analyzed for several more months, damage parameters were estimated from results of previous experiments in HFIR. Using a peak fast flux value of 1.10×10^{15} n/cm^2-s (derived from Reference 2), a peak dpa value of 8.85 (from ORNL), and the estimated normalized flux profile illustrated in Figure 3 (also derived from Reference 2), fast flux, fast fluence, and dpa profiles were generated (Figures 4, 5, and 6 and Table 8). These values could then be used to assign damage parameters to the JP-23 specimens (Table 9). Also included in Table 9 are the temperatures and other pertinent information for each specimen holder.



PTP – Peripheral Target Position
JP-23 – Test Located In Position G6

Position Designation	Radial Distance From Center
C3, C4, D3, D5, E4, E5	1.689 cm
B3, C2, C5, E3, E6, F5	2.926 cm
B2, B4, D2, D6, F4, F6	3.378 cm
A2, A3, B1, B5, C1, C6, E2, E7, F3, F7, G5, G6	4.465 cm
A1, A4, D1, D7, G4, G7 (PTPs)	5.067 cm

Figure 2. HFIR Target Position Designations, Showing the JP-23 Test.

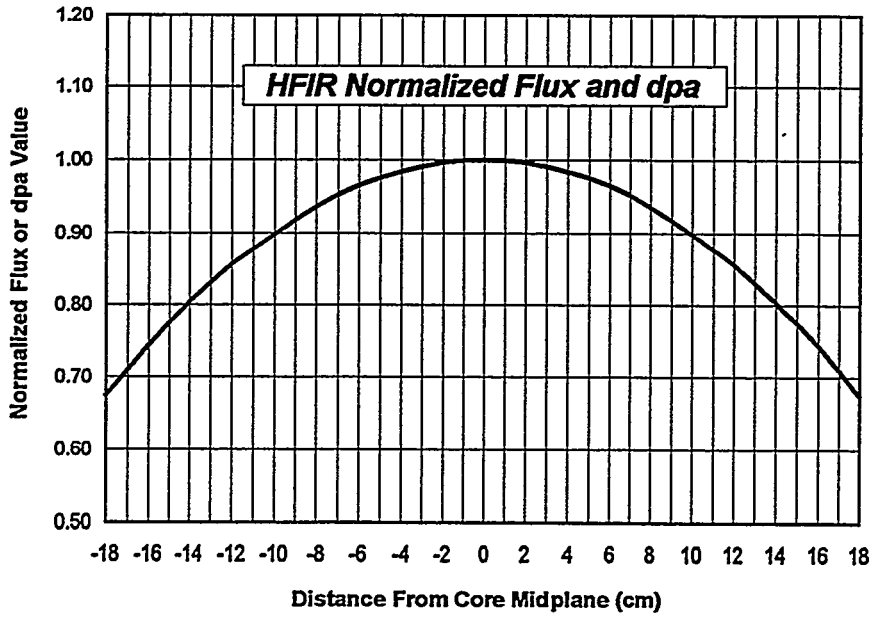


Figure 3. Estimated Normalized Flux and dpa Profile for HFIR

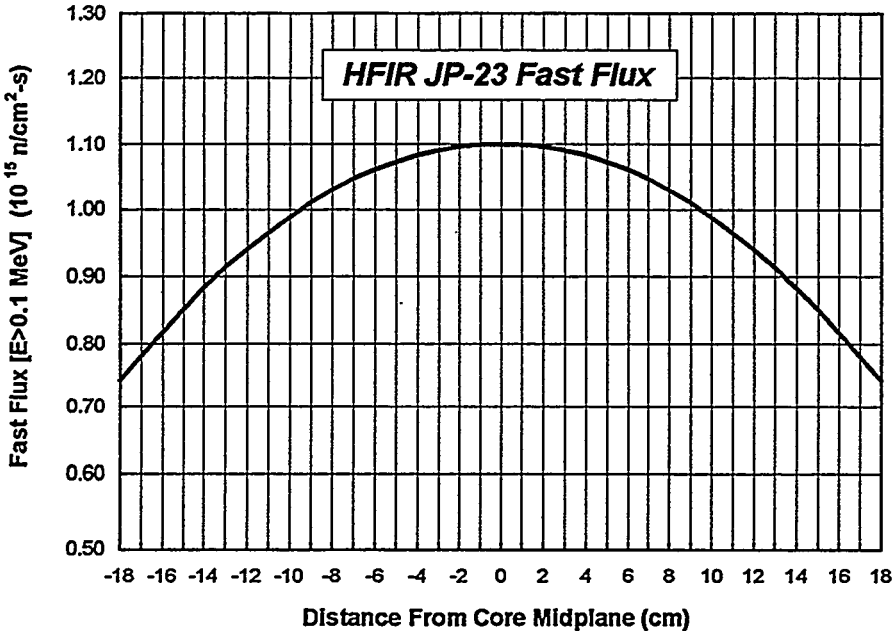


Figure 4. Estimated Fast Flux Profile for the JP-23 Test

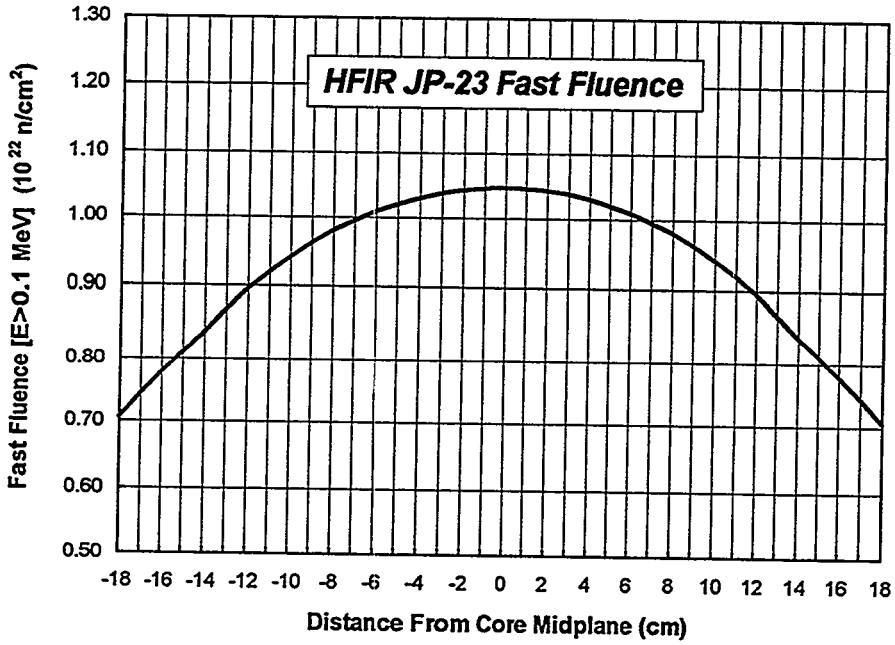


Figure 5. Estimated Fast Fluence Profile for the JP-23 Test

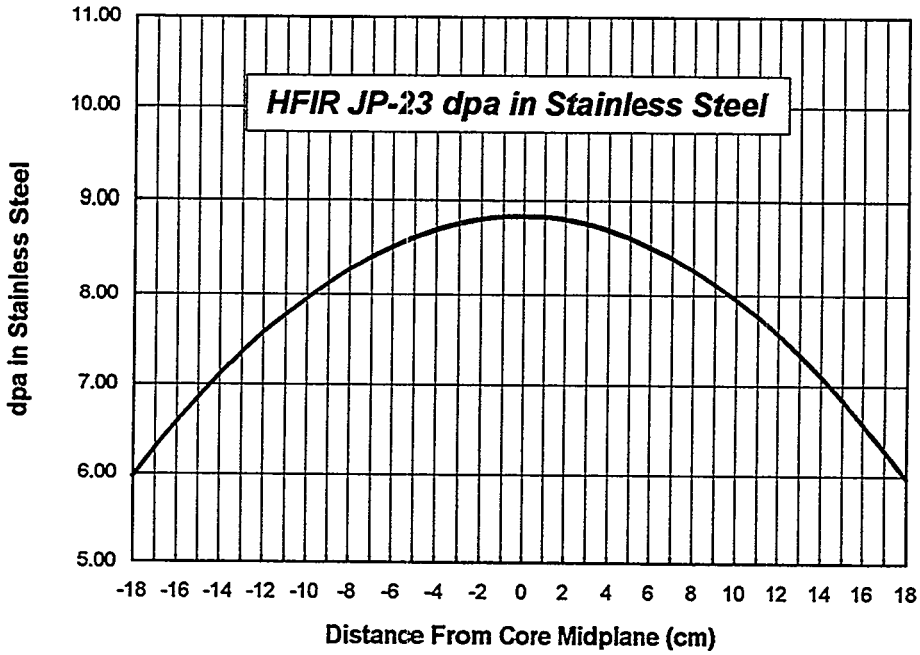


Figure 6. Estimated dpa (in stainless steel) Profile for the JP-23 Test

Table 8. Estimated Flux, Fluence, and dpa Data for the HFIR JP-23 Test
Based on 9367 MWd for HFIR Cycles 322-326

Distance From Horizontal Midplane (cm)	Normalized Flux or dpa Profile Value	Fast Flux, E>0.1 MeV (10^{15} n/cm^2-s)	Fast Fluence, E>0.1 MeV (10^{22} n/cm^2)	dpa in Stainless Steel
+18	0.674	0.741	0.706	5.97
+17	0.710	0.781	0.744	6.28
+16	0.743	0.817	0.778	6.58
+15	0.774	0.851	0.811	6.85
+14	0.803	0.883	0.841	7.11
+13	0.830	0.913	0.869	7.35
+12	0.855	0.941	0.895	7.57
+11	0.877	0.965	0.919	7.76
+10	0.898	0.988	0.941	7.95
+9	0.918	1.010	0.961	8.13
+8	0.936	1.030	0.980	8.29
+7	0.951	1.046	0.996	8.42
+6	0.964	1.060	1.010	8.53
+5	0.975	1.073	1.021	8.63
+4	0.984	1.082	1.031	8.71
+3	0.991	1.090	1.038	8.77
+2	0.996	1.096	1.043	8.82
+1	0.999	1.099	1.046	8.84
0	1.000	1.100	1.047	8.85
-1	0.999	1.099	1.046	8.84
-2	0.996	1.096	1.043	8.82
-3	0.991	1.090	1.038	8.77
-4	0.984	1.082	1.031	8.71
-5	0.975	1.073	1.021	8.63
-6	0.964	1.060	1.010	8.53
-7	0.951	1.046	0.996	8.42
-8	0.936	1.030	0.980	8.29
-9	0.918	1.010	0.961	8.13
-10	0.898	0.988	0.941	7.95
-11	0.877	0.965	0.919	7.76
-12	0.855	0.941	0.895	7.57
-13	0.830	0.913	0.869	7.35
-14	0.803	0.883	0.841	7.11
-15	0.774	0.851	0.811	6.85
-16	0.743	0.817	0.778	6.58
-17	0.710	0.781	0.744	6.28
-18	0.674	0.741	0.706	5.97

- Based on 85 MW full power
- Profile from Reference 2
- Peak flux based on 85% of 100 MW values from Reference 2
- Peak dpa based on 0.000945 dpa/MWd for stainless steel (from ORNL)

Table 9. Summary of Estimated HFIR JP-23 Irradiation Parameters

JP-23 Position Number	Program Sponsor	Irrad. Temp.		Distance From Reactor Midplane, cm (inches)	Fast Fluence [E>0.1 MeV] n/cm^2	dpa in SS
			Top:	+16.2 (+6.37)	0.77 x 10^{22}	6.5
3	Japanese Monbusho	300 °C	Mid:	+14.6 (+5.74)	0.82 x 10^{22}	6.9
			Bot:	+13.0 (+5.11)	0.87 x 10^{22}	7.3
			Top:	+12.0 (+4.73)	0.90 x 10^{22}	7.6
4	Japanese Monbusho	400 °C	Mid:	+10.4 (+4.10)	0.93 x 10^{22}	7.9
			Bot:	+8.8 (+3.47)	0.96 x 10^{22}	8.2
			Top:	+7.8 (+3.09)	0.98 x 10^{22}	8.3
5	Japanese Monbusho	500 °C	Mid:	+6.2 (+2.46)	1.01 x 10^{22}	8.5
			Bot:	+4.6 (+1.83)	1.02 x 10^{22}	8.7
			Top:	+3.7 (+1.45)	1.03 x 10^{22}	8.7
6	Japanese Monbusho	600 °C	Mid:	+2.1 (+0.82)	1.04 x 10^{22}	8.8
			Bot:	+0.5 (+0.19)	1.05 x 10^{22}	8.8
	----- Reactor Core $\mathcal{L}$ ----------					
			Top:	−0.5 (−0.19)	1.05 x 10^{22}	8.8
7	U.S. NIMs	600 °C	Mid:	−2.1 (−0.82)	1.04 x 10^{22}	8.8
			Bot:	−3.7 (−1.45)	1.03 x 10^{22}	8.7
			Top:	−4.6 (−1.83)	1.02 x 10^{22}	8.7
8	U.S. NIMs	500 °C	Mid:	−6.2 (−2.46)	1.01 x 10^{22}	8.5
			Bot:	−7.8 (−3.09)	0.98 x 10^{22}	8.3
			Top:	−8.8 (−3.47)	0.96 x 10^{22}	8.2
9	U.S. NIMs	400 °C	Mid:	−10.4 (−4.10)	0.93 x 10^{22}	7.9
			Bot:	−12.0 (−4.73)	0.90 x 10^{22}	7.6
			Top:	−13.0 (−5.11)	0.87 x 10^{22}	7.3
10	U.S. NIMs	300 °C	Mid:	−14.6 (−5.74)	0.82 x 10^{22}	6.9
			Bot:	−16.2 (−6.37)	0.77 x 10^{22}	6.5

AME / August 25, 1994

CONCLUSIONS

The JP-23 test capsule has been irradiated in the HFIR during Cycles 322 through 326. The capsule contained eight transmission electron microscopy (TEM) specimen holders, two each at irradiation temperatures of 300, 400, 500 and 600°C. The test was irradiated for a total of 110 Effective Full Power Days (EFPD), achieving estimated peak doses of 1.1 x 10^{22} n/cm^2 (E>0.1 MeV) and 8.8 dpa (in stainless steel).

FUTURE WORK

Specimens from the JP-23 experiment will be distributed to experimenters.

REFERENCES

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