NEUTRON DOSIMETRY AND DAMAGE CALCULATIONS FOR THE HFIR-JP-23 IRRADIATIONS

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OBJECTIVE

To provide dosimetry and damage analysis for fusion materials irradiation experiments.

SUMMARY

Neutron fluence measurements and radiation damage calculations are reported for the joint U.S.- Japanese experiment JP-23, which was conducted in target position G6 of the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL). The maximum neutron fluence at midplane was 4.4E+22 n/cm^2 resulting in about 9.0 dpa in type 316 stainless steel.

PROGRESS AND STATUS

The JP-23 experiments were irradiated in the G6 target position of HFIR during cycles 322 through 326, starting December 16, 1993, and ending June 3, 1994, for a net exposure of 110.2 effective full power days at 85 MW. The experiment was a collaborative effort co-sponsored by the U. S. Neutron Interactive Materials Program at PNNL and the Japanese Monbusho Program. The goal of the experiment was to irradiate TEM specimens at four temperatures of 300, 400, 500, and 600°C. A complete description of the specimen matrix and irradiation assembly has been published previously.[1]

Neutron dosimetry capsules were inserted in the bottom cavities of each TEM specimen holder, each of which measured 4.17 cm in length. The dosimetry capsules consisted of small, welded aluminum tubes measuring about 1.3 mm in diameter and 6.4 mm in length. Each tube contained small monitor wires of Fe, Ni, Ti, Nb, and 0.1% Co-Al alloy. Six capsules were irradiated with the JP-23 specimens; however, only five were recovered during disassembly. Each capsule was opened in a hot cell at PNNL and each individual monitor wire was gamma counted to determine the residual activation.

The measured activities were converted to activation rates as listed in Table 1 by correcting for nuclear burnup, gamma self-absorption, decay during and after irradiation, isotopic abundance, and atomic weight. Burnup corrections are based on an iterative procedure for the thermal/epithermal monitor reactions. The resultant estimates of the thermal/epithermal neutron fluences were then used to calculate burnup corrections for the threshold fast neutron monitor reactions. Burnup corrections averaged 20-30% for the thermal/epithermal reactions and 5-15% for the threshold reaction rates. The activation rates listed in Table 1 are normalized to full reactor power of 85 MW and have a net absolute uncertainty of about 5%.

The activation rates in Table 1 were fit to a polynomial function of form $f(x) = f(0)\,[\,1 + a\,x^2\,]$, where x is the vertical height from reactor centerline in cm. All of the data are reasonably well fit by the average polynomial (coefficient $a = -1.139 \times 10^{-3}$). Midplane activation rates were then used in the STAY'SL computer code to adjust the neutron flux spectrum determined in previous spectral measurements in the target position in HFIR.[3] STAY'SL performs a generalized least-squares adjustment of all measured and calculated values including the measured activities, calculated spectra, and neutron cross sections. Neutron cross sections and their uncertainties were generally taken from the ENDF/B-V[4] evaluation. The resultant neutron fluence values are listed in Table 2. The activation rates and the derived neutron spectra and fluences are in excellent agreement with previous measurements in the target position of HFIR.[3]

Neutron damage calculations were performed using the SPECTER computer code[5] at the midplane position of HFIR. Midplane dpa and helium (appm) values are also listed in Table 2. The fluence and damage values at other experimental positions can be calculated by the gradient equation given above. Damage parameters for other elements or compounds have been calculated and are readily available on request.

Helium production in nickel and nickel alloys requires a more complicated non-linear calculation.[6] Helium production in stainless steel is detailed in Table 3.

FUTURE WORK

Additional experiments still in progress in HFIR include MFE-200J-1 and MFE-400-J1 as well as JP9-16 and JP20-22. Activation data from the MFE-60J and -330J irradiations in HFIR and neutron flux monitors from the COBRA irradiation in EBR-II are currently being analyzed at PNNL.

REFERENCES

1. A. M. Ermi and D. S. Gelles, Preliminary Report on the Irradiation Conditions of the HFIR JP-23 Experiment, Fusion Reactor Materials Semiannual Progress Report, DOE/ER-0313/17, pp. 35-49 (1995).

2. F. G. Perey, Least Squares Dosimetry Unfolding: The Program STAY'SL, ORNL/TM-6062 (1977).

3. L. R. Greenwood, Alloy Development for Irradiation Performance Semiannual Report, DOE/ER-0045/11, pp. 30-37 (1983).

4. Evaluated Nuclear Data File, Part B, Version V, National Nuclear Data Center, Brookhaven National Laboratory.

5. L. R. Greenwood and R. K. Smither, SPECTER: Neutron Damage Calculations for Materials Irradiations, ANL/FPP-TM-197, January 1985.

6. L. R. Greenwood, A New Calculation of Thermal Neutron Damage and Helium Production in Nickel, Journal of Nuclear Materials 116, pp. 137-142 (1983).

TABLE 1 - ACTIVATION RATES (AT/AT-S) - HFIR JP-23

$^{46}Ti(n,p)^{46}Sc$ (E-12)	$^{55}Mn(n,2n)^{54}Mn$ (E-14)	$^{59}Co(n,\gamma)^{60}Co$ (E-9)	$^{93}Nb(n,\gamma)^{94}Nb$ (E-10)
1.18	2.70	3.44	3.06
1.49	3.39	3.85	3.84
1.59	3.60	4.26	4.25
1.72	3.82	3.94	4.33
1.74	4.01	4.02	4.37
1.65	3.82	4.38	4.29
1.57	3.65	3.58	3.92
1.24	2.95	a	3.09

[a] Wire not recovered in hot cell.

TABLE 2 - Midplane Fluence and Damage Values for MFE-60J/330J

Neutron Fluence, n/cm2-s		Element	dpa	He, appm
Total	3.95E+22	C	14.1	13.9
Thermal (<,5eV)	4.71E+21	Al	22.5	5.4
0.5 eV - 0.1 MeV		V	14.6	0.18
>0.1 MeV	1.94E+22	Cr	12.4	1.3
>1 MeV	7.04E+21	Fe	11.1	2.4

Ni Fast	12.3	34.2
59-Ni	0.5	276.0
Total	12.8	310.2
Cu	14.7	2.0

TABLE 3 - DPA and He Values for 316 SS in MFE-60J/330J
(Includes ^{59}Ni effect)

Ht (cm)	dpa	He (appm)
0	11.5	42.0
3	11.4	41.3
6	11.0	38.9
9	10.4	35.0
12	9.5	29.9
15	8.4	23.8
18	7.0	17.2

316SS = Fe(0.645), Ni(0.13), Cr(0.18), Mn(0.019), Mo(0.026) wt%

TABLE 4 - Maximum DPA and Helium Production in ORR/HFIR Irradiations
(Calculations for 316 Stainless Steel)

	dpa	He (appm)		dpa	He (appm)
ORR-6J	6.9	75.3	ORR-7J	7.4	102.0
HFIR-60J-1	11.6	112.5	HFIR-330J-1	11.6	122.5
Total	18.5	187.8	Total	19.0	224.5