NEUTRON DOSIMETRY AND DAMAGE CALCULATIONS FOR THE HFIR-JP-9, -12, and -15 IRRADIATIONS - L. R. Greenwood (Pacific Northwest National Laboratory)* and C. A. Baldwin (Oak Ridge National Laboratory)

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 experiments JP-9, -12, and -15. These experiments were conducted in target positions of the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL) for a period of nearly four years. The maximum neutron fluence at midplane was 2.6×10^{23} n/cm^2 (7.1×10^{22} n/cm^2 above 0.1 MeV), resulting in about 60 dpa and 3900 appm helium in type 316 stainless steel.

PROGRESS AND STATUS

Introduction

The JP-9, -12, and -15 experiments were irradiated in target positions of HFIR during cycles 289 through 324 starting July 20, 1990, and ending April 1, 1994, for a net exposure of 763.58 effective full- power days at 85 MW. The experiment was a collaborative effort of the U.S. Fusion Materials Program at ORNL and the Japanese Atomic Energy Research Institute (JAERI). The goal of the experiment was to irradiate primarily transmission electron microscope specimens and round bar tensile specimens to very high dose levels. A complete description of the specimen matrices and irradiation assemblies has been published previously [1].

Neutron dosimetry capsules were inserted at six different elevations in each of the three assemblies (JP-9, -12, and –15). The dosimetry capsules consisted of small 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, 0.1% Co-Al alloy, and 80.2% Mn-Cu alloy. Following irradiation, the monitors were removed from the assemblies and analyzed for gamma activities at ORNL. Because of our previous experience and the anticipated similarity of the dosimetry monitor results, only 7 of the 18 capsules were analyzed; the remainder of the capsules were stored pending further analyses as necessary.

The measured gamma activities were analyzed at Pacific Northwest National Laboratory. 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 resulting estimates of the thermal/epithermal neutron

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fluences were then used to calculate burnup corrections for the threshold fast neutron monitor reactions. Due to the extremely high neutron fluences in these experiments, burnup corrections were quite high for some of the reactions: burnup corrections averaged 40-80% for the thermal/epithermal reactions and 2-70% 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%.

Although the three different irradiations were located in different target positions of HFIR, the activation data all appear to fall on a relatively smooth curve such that flux gradients between the three target positions are less than 10%. Since only 7 of the 18 dosimetry monitors were analyzed, there are insufficient data to determine the small flux gradients between the three assemblies. Consequently, all the data were analyzed together, giving average neutron fluences and damage rates. 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 $a = -9.35 \times 10^{-4}$). Midplane activation rates were then used in the STAY'SL [2] computer code to adjust the neutron flux spectrum determined in previous spectral measurements in the target position in HFIR [3,4]. 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 [5] evaluation. The resulting 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 [3,4].

Neutron damage calculations were performed using the SPECTER computer code [6] 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 [7]. Helium production in stainless steel is thus detailed separately in Table 3.

FUTURE WORK

Additional experiments still in progress in HFIR include MFE-200J-1, MFE-400J-1, and JP20-22.

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Table 1. Activation rates (at/at-s) - HFIR JP-9, -12, and -15

Position/ Monitor	Ht,cm	$^{54}Fe(n,p)^{54}Mn$ (E-11)	$^{46}Ti(n,p)^{46}Sc$ (E-12)	$^{55}Mn(n,2n)^{54}Mn$ (E-13)	$^{59}Co(n,\gamma)^{60}Co$ (E-8)	$^{93}Nb(n,\gamma)^{94}Nb$ (E-9)
JP9 - 2	12.0	5.00	6.89	1.31	4.61	2.03
JP9 - 5	-25.3	2.07	2.92	0.63	3.04	1.23
JP12-20	12.6	4.69	6.69	1.34	4.44	2.01
JP12-23	-8.3	5.16	7.43	1.28	4.89	2.20
JP15-38	13.1	4.79	6.63	1.12	4.25	1.88
JP15-37	22.0	2.91	-	0.68	2.82	1.12
JP15-40	0.0	6.07	-	1.37	5.58	2.49

Table 2. Midplane fluence and damage values for HFIR JP-9, 12, and 15

Neutron Fluence, $\times 10^{22}$ n/cm^2	
Total	26.3
Thermal (<.5 eV)	10.9
0.5 eV - 0.1 MeV	8.39
> 0.1 MeV	7.06
> 1 MeV	3.67

Element	dpa	He,appm
C	50.4	112.4
Al	92.7	43.1
V	66.2	1.4
Cr	58.5	10.0
Fe	51.8	17.8
Ni Fast	55.5	242.5
^{59}Ni	48.2	27349.3
Total	103.7	27591.8
Cu	67.1	15.7

Table 3. Dpa and helium values for 316 SS in HFIR JP-9, -12, -15
(includes ^{59}Ni effect)

Ht (cm)	dpa	He (appm)
0	59.6	3601
3	59.2	3573
6	57.8	3488
9	55.4	3345
12	52.1	3140
15	47.7	2869
18	42.2	2525
21	35.8	2102
24	28.3	1593

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