NEUTRON DOSIMETRY AND DAMAGE CALCULATIONS FOR THE HFIR-MFE-200J-1 IRRADIATION - 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 experiment MFE-200-J-, which was conducted in the removable beryllium (RB*) position of the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL). The maximum neutron fluence at midplane was 4.1×10^{22} n/cm^2 (1.9×10^{22} n/cm^2 above 0.1 MeV), resulting in about 12 dpa and 28 appm helium in type 316 stainless steel.

PROGRESS AND STATUS

Introduction

The MFE-200-J-1 experiment was irradiated in the RB* position of HFIR during cycles 313 through 332 starting November 21, 1992, and ending January 11, 1995, for a net exposure of 440.59 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 was to continue spectral tailoring irradiations started in the ORR-MFE-6J and -7J experiments using a 4.2 mm thick Hf liner in the RB* position to limit the further production of helium from the ingrown ^{59}Ni. A complete description of the specimen matrices and irradiation assemblies has been published previously [1].

Neutron dosimetry capsules were inserted at 14 different positions located at relative angles of 0, 90, 180, and 270° in the assembly. 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 14 monitor capsules were analyzed; the remainder of the capsules were stored pending further analyses, as necessary.

The measured gamma activities were subsequently analyzed at Pacific Northwest National Laboratory. The 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 were based on an iterative procedure for the thermal/epithermal monitor reactions. The resulting estimates of the thermal/epithermal neutron fluences were then used to calculate burnup corrections for the threshold fast neutron

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monitor reactions. Burnup corrections were quite small, averaging 5-10% for the thermal/epithermal reactions and < 6% 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 3%.

The experimental assembly was initially oriented in the reactor with the 0° side facing the center of the core. The entire assembly was rotated after each reactor cycle (about 22 days) to minimize any potential radial flux gradients caused by the orientation of the assembly. Looking at the data in Table 1, it is apparent that there are some small radial flux effects. Monitors 77 and 81 were both located at the same elevation, +3.01 cm, at 0° and 90°, respectively. However, the data clearly show that the fast flux at the 90° position averages 8.5% higher than at 0°. The thermal flux gradient at 90° averages only 2.5% higher than at 0°. These were the only two monitors at the same elevation. If symmetry around the core centerline is assumed, then we can further compare sets of monitors at symmetric elevations. The activities for the symmetric monitors at 90° at ± 3.0 cm are in excellent agreement. More generally, the ratios of fast neutron activities at 90, 180, and 270° to that at 0° are 1.085, 1.061, and 1.075, respectively; the same ratios for thermal reactions are 1.025, 0.908, and 0.947, respectively. Since complete results for all of the monitors are not available, we decided to simply average the data at the different angles. Consequently, all the data were analyzed together, giving average neutron fluences and damage rates as a function of elevation for the entire assembly. 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 $a = -1.32 \times 10^{-3}$). Radial gradients suggest that the variations from the average fluxes are on the order of 5%.

Midplane activation rates were used in the STAY'SL [2] computer code to adjust the neutron flux spectrum determined in previous spectral measurements in the RB* 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 removable beryllium positions 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.

It should be noted that the present results consider only the irradiation of specimens in the 200-J-1 irradiation. Specimens that were previously irradiated in ORR-MFE-6J or -7J would have an additional dpa and helium production that needs to be calculated on a case-by-case basis for specified sample locations in the successive experiments.

FUTURE WORK

Additional experiments still in progress include MFE-400-J1 and JP20-22.

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Table 1. Activation rates (atom/atom-s) - HFIR-MFE-200-J-1

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-14)	$^{59}Co(n,\gamma)^{60}Co$ (E-9)	$^{93}Nb(n,\gamma)^{94}Nb$ (E-10)
0°-21	15.1	0.91	1.22	2.86	2.64	2.94
270°-73	9.1	1.26	1.55	3.61	3.46	3.43
0°-77	3.0	1.33	1.65	3.81	3.86	3.76
90°-81	3.0	1.45	1.82	4.05	3.94	3.87
90°-84	-3.0	1.46	1.82	4.03	3.94	3.81
180°-101	-9.1	1.27	1.53	3.49	3.56	3.05
270°-106	-15.1	1.05	1.27	3.02	2.80	2.45

Table 2. Midplane Fluence and Damage Values for HFIR-MFE-200-J-1

Neutron Fluence, $\times 10^{22}$ n/cm^2	
Total	4.09
Thermal (< 0.5 eV)	0.35
0.5 eV - 0.1 MeV	1.81
> 0.1 MeV	1.94
> 1 MeV	0.705

Element	dpa	He,appm
C	14.4	12.1
Al	22.7	4.7
V	15.0	0.16
Cr	12.5	1.2
Fe	11.2	2.1
Ni Fast	12.4	31.5
^{59}Ni	0.3	167.5
Total	12.7	199.0
Cu	14.9	1.8

Table 3. DPA and helium values for 316 SS in HFIR-MFE-200-J-1 (includes ^{59}Ni effect)

Ht (cm)	dpa	He (appm)
0	11.6	27.5
3	11.5	27.0
6	11.1	25.4
9	10.5	22.9
12	9.53	19.5
15	8.33	15.5

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