NEUTRON DOSIMETRY AND DAMAGE CALCULATIONS FOR THE JP-10, 11, 13, and 16 EXPERIMENTS IN HFIR

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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 experiments JP-10, 11, 13, and 16 in the target of the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL). These experiments were irradiated at 85 MW for 238.5 EFPD. The maximum fast neutron fluence >0.1MeV was about 2.1E+22 n/cm^2 for all of the experiments resulting in about 17.3 dpa in 316 stainless steel.

PROGRESS AND STATUS

The fabrication and irradiation of the JP-10, 11, 13, and 16 experiments have been described previously.[1-4] The assemblies were irradiated in the target position of HFIR for cycles 289-291, removed during cycle 292, and reinstalled for cycles 293-300. The net exposure was 20279 MWD over the period from July 20, 1990, to September 19, 1991.

Small dosimetry capsules measuring about 0.05" in diameter by 0.25" in length were located at 6 different positions in each assembly. Each dosimetry capsule contained milligram quantities of Fe, Ni, Ti, Nb, 0.1% Co-Al, and 80.2% Mn-Cu. Following the irradiation, selected capsules from each irradiation were sent to PNL for analysis. Each capsule was disassembled in a hot cell and subsequently gamma counted.

The measured activities were converted to activation rates, as listed in Table 1, by correcting for burnup of the reacting and product atoms, gamma self-absorption, decay of the product isotopes 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. Due to the relatively long exposure, burnup corrections ranged from 20-40% for the thermal/epithermal reactions and from 10-30% 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 fast neutron reactions, $^{54}Fe(n,p)^{54}Mn$ and $^{55}Mn(n,2n)^{54}Mn$, for all four irradiations appear to fall on a smooth curve when plotted versus the height relative to the HFIR midplane. The thermal neutron activities for the ^{59}Co and ^{93}Nb capture reactions also fall on a very similar curve; however, there is clearly a difference of up to 13% in the thermal/epithermal reaction rates. The thermal flux is highest for JP-16, declining in order as JP-13, JP-11, and JP-10. If these variations are averaged, then the average $^{93}Nb(n,\gamma)$ rate has a standard deviation of 4.0%; however, the $^{59}Co(n,\gamma)$ deviates by 7.5%. The best fit to all four reactions results in a global equation A(X) = A(0) (1 - 9.85E-4 X^2) where A(0) is the midplane value and X is the height in cm.

Midplane activation rates were used as input to the STAY'SL computer code[5] to adjust the neutron flux spectrum determined previously in HFIR.[6] 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 ENDF/B-V.[7] The adjusted 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.[6,8]

Neutron damage calculations with the SPECTER computer code[9] were performed for the midplane position. 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.[10] Helium production in 316 stainless steel is listed as a function of height in Table 3.

FUTURE WORK

Dosimeters have been received from the HFIR-JP-23 irradiation and for the COBRA-1A1 irradiation in the Experimental Breeder Reactor II.

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TABLE 1 - Activation Rates (at/at-s) - HFIR-MFE-JP-10, 11, 13, 16

Sample	Ht,cm	$^{54}Fe(n,p)^{54}Mn$ $(x10^{-11})$	$^{93}Nb(n,\gamma)^{94}Nb$ $(x10^{-9})$	$^{59}Co(n,\gamma)^{60}Co$ $(x10^{-8})$	$^{55}Mn(n,2n)^{54}Mn$ $(x10^{-13})$
10-8	11.3	4.78	2.15	4.48	1.52
10-9	4.6	5.45	2.51	5.06	1.61
10-10	- 2.1	5.42	2.52	5.30	1.60
10-11	-16.2	4.06	1.84	4.14	1.24
10-12	-20.3	3.22	1.48	3.32	0.98
11-14	11.3	4.80	2.45	4.68	1.50
11-15	4.6	5.53	2.66	5.34	1.62
11-16	- 2.1	5.45	2.62	5.41	1.60
11-49	-16.2	3.63	2.04	3.92	1.18
11-18	-20.3	3.25	1.51	3.50	
13-25	22.7	2.53	1.19	2.73	0.80
13-26	17.4	3.89	1.80	3.95	1.17
13-28	2.1	5.45	2.63	5.11	1.62
13-29	- 9.7	4.87	2.25	4.31	1.46
13-30	-17.4	3.92	1.75	3.87	1.15
16-43	22.6	2.59	1.19	2.69	
16-44	10.0	4.83	2.16	4.58	1.44
16-45	4.6	5.30	2.40	4.70	1.71
16-46	- 4.6	5.47	2.31	4.82	1.66
16-47	-12.8	4.84	2.16	4.40	1.49
16-48	-19.8	3.25	1.41	3.20	1.03

TABLE 2 - Midplane Fluence and Damage Values for HFIR-MFE-JP-10, 11, 13, 16

Neutron Fluence, $x10^{22}$ n/cm2		Element	dpa	He,appm
Total	7.88	C	15.1	35.4
Thermal (<.5eV)	3.12	Al	27.5	13.5
0.5 eV - 0.1 MeV	2.64	V	19.6	45.4
> 0.1 MeV	2.12	Cr	17.2	3.1
> 1 MeV	1.07	Fe	15.3	5.5
		Ni Fast	16.4	72.6
		59-Ni	12.1	6844.6
		Total	28.5	6917.2
		Cu	19.9	4.9

TABLE 3 -DPA and He Values for 316 SS in HFIR-MFE-JP-10, 11, 13, 16
(Includes ^{59}Ni effect)

Ht (±cm)	dpa	He (appm)
0	17.3	903.4
3	17.2	892.2
6	16.7	858.8
9	16.0	803.1
12	14.9	726.0
15	13.5	628.7
18	11.8	513.2
21	9.8	383.9
24	7.5	248.1

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