NEUTRON FLUENCES AND RADIATION DAMAGE PARAMETERS FOR THE HFIR-MFE-RB-14J EXPERIMENT – L. R. Greenwood (Pacific Northwest National Laboratory), D. C. Glasgow and C. A. Baldwin (Oak Ridge National Laboratory)

OBJECTIVE

The objective is to provide neutron fluences and radiation damage parameters for experimental samples irradiated in the HFIR-MFE-RB-14J experiment.

SUMMARY

The 14J experiment was conducted in the unshielded removable beryllium (RB) position of HFIR.[1] The irradiation of the assembly occurred for two separated time periods. The first irradiation was from June 3, 1999 to August 27, 1999. The second irradiation period was from January 27, 2000 until June 6, 2000. The total exposure was for 14293 FPD (full power days). Reactor dosimetry capsules were analyzed and the activation data were used to provide the best estimates of the neutron fluences and radiation damage parameters as a function of height relative to midplane of the reactor.

PROGRESS AND STATUS

Neutron Activation Measurements and Fluence Calculation

Ten reactor dosimetry capsules were fabricated containing small segments of Fe, Ti, Cu, Nb, and 1% Co-V alloy wires. Following irradiation, the capsules were opened and the activities in each of the wires were measured at Oak Ridge National Laboratory. Due to a delay between the end of irradiation and the gamma counting, no data was measurable for the Ti monitors. Additionally, a few of the wires were not recovered for the gamma counting of the samples. The measured activities are listed in Table 1.

Table 1 – Measured Activities for the HFIR-14J Irradiation
Data are corrected to the end of irradiation date, June 6, 2000

		1% Co-V Monitor		Fe Monitor		Nb-monitor		Copper Monitor	
Height		Co-60		Mn-54		Nb-94		Co-60	
cm	ID	Bq/mg	Error	Bq/mg	Error	Bq/mg	Error	Bq/mg	Error
39.7	RO					3.61E+3	8.09E+1		
-12.85	8A	9.80E+7	5.79E+5	1.76E+6	5.35E+4	8.58E+4	2.01E+3	2.15E+4	3.11E+2
8.4	RL	1.07E+8	6.43E+5					3.57E+4	5.57E+2
-8.72	OV	1.00E+8	5.18E+5	1.93E+6	5.86E+4	9.82E+4	3.65E+3		
12.52	X7	8.81E+7	5.28E+5			8.13E+4	1.93E+3	2.58E+4	3.92E+2
-20.97	BC			1.16E+6	3.51E+4	5.99E+4	1.40E+3	5.47E+4	7.92E+2
20.65	HF	5.81E+7	3.89E+5	1.17E+6	3.44E+4	5.04E+4	1.20E+3	1.59E+4	2.32E+2
36.5	2E	8.96E+6	7.81E+4	2.13E+5	6.72E+3	7.72E+3	1.88E+2	3.74E+3	5.72E+1
27.6	5I	3.81E+7	2.52E+5	6.58E+5	1.93E+4	2.93E+4	6.94E+2	9.45E+3	1.42E+2
24.4	A5	4.71E+7	3.27E+5					1.36E+4	2.12E+2

The activities listed in Table 1 are produced by the $^{59}Co(n,\gamma)^{60}Co$, $^{54}Fe(n,p)^{54}Mn$, $^{93}Nb(n,\gamma)^{94}Nb$, and $^{63}Cu(n,\alpha)^{60}Co$ nuclear reactions. The reaction rates were calculated for each of the measured data in Table 1 by correcting for the irradiation history, atomic weight, isotopic percentage, gamma absorption, and decay during irradiation. The decay during irradiation correction was determined by calculating the growth and decay of each activation product over the entire irradiation history as shown in reference 1 and summarized above. The measured activation rate for the $^{63}Cu(n,\alpha)^{60}Co$ reaction at -20.97 cm does not fit the rest of the data so this data point was not used in the subsequent analyses and the $^{54}Fe(n,p)^{54}Mn$ data was judged to be more reliable at this location.

The STAY'SL [2] computer code was then used to adjust the neutron energy spectrum at each location using the calculated reaction rates and uncertainties as input. The starting neutron spectrum was adopted from prior measurements in the unshielded RB positions of HFIR. [3] STAY'SL performs a least-squares adjustment to determine the most likely neutron spectrum at each position taking into account the uncertainties and covariances of all of the input data whenever possible. The neutron activation cross sections and covariances were taken from the IRDF2002. [4] An example of the adjusted neutron energy spectra is shown in Figure 1 and the adjusted neutron fluences and uncertainties are listed in Table 2.

Table 2 – Adjusted Neutron Fluences for the HFIR-14J Irradiation

		Thermal		Epithermal		Fast		Fast	
Height		< 0.5 eV		0.5 eV to 0.11 MeV		> 0.1 MeV		> 1 MeV	
cm	ID	n/cm^2	±%	n/cm^2	±%	n/cm^2	±%	n/cm^2	±%
39.7	RO	3.55E+20	10						
-12.85	8A	9.29E+21	8	8.83E+21	12	5.48E+21	12	2.12E+21	12
8.4	RL	1.03E+22	10						
-8.72	OV	1.09E+22	8	1.08E+22	12	5.94E+21	13	2.20E+21	13
12.52	X7	8.31E+21	10			5.43E+21	15	2.06E+21	15
-20.97	BC	6.10E+21	10	5.89E+21	15	3.45E+21	15	1.29E+21	15
20.65	HF	5.13E+21	9	4.92E+21	14	3.11E+21	15	1.26E+21	15
36.5	2E	7.18E+20	12	8.92E+20	15	6.10E+20	15	2.26E+20	15
27.6	5I	3.34E+21	8	2.66E+21	15	1.81E+21	12	7.07E+20	12
24.4	A5	4.09E+21	10			2.84E+21	15	1.07E+21	15

The neutron fluences above 1 MeV were fit with a polynomial to help determine fluences at other locations or where data are not available. The polynomial is of form:

$$F(x) = a\,(1 + bx + cx^2 + dx^3) \qquad (1)$$

a is the fluence at midplane = 2.40E+21 n/cm2

b = - 5.7523e-3, c = -1.0520e-3, and d = 1.4092e-5

Equation 1 can be used to predict the fast neutron fluence and radiation damage parameters discussed later at any height above midplane in the assembly. Neutron fluences calculated with

equation 1 agree with the measured fluences listed in Table 2 within 10% at all of the measured locations. However, the measured values listed in Table 2 are of course more reliable at those locations than using the polynomial fit to the data.

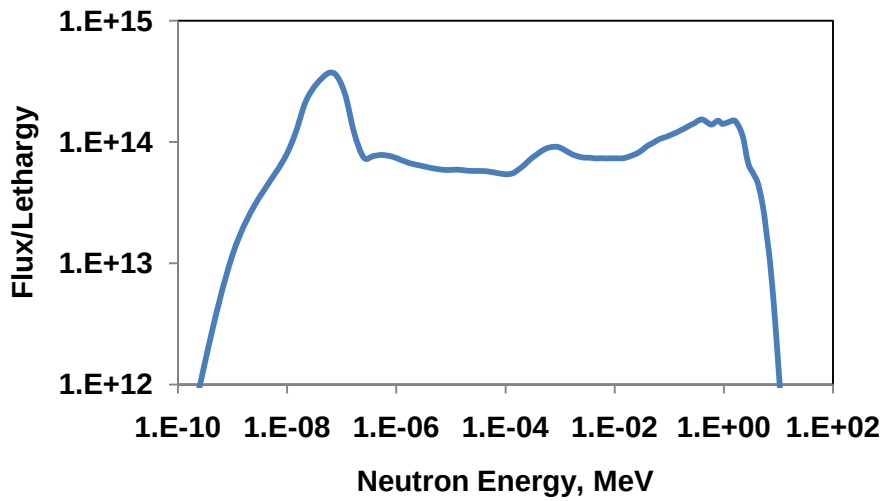

Figure 1 – Adjusted Neutron Spectrum for HFIR-14JP

Radiation Damage Calculations

The adjusted neutron spectrum as shown in Figure 1 was used to calculate radiation damage parameters using the SPECTER computer code.[5] Displacement per atom (dpa) and helium production in appm (atomic parts per million) for several important elements are listed in Table 3. Calculations for nickel include the additional helium production and dpa from the in growth of ^{59}Ni, which has a significant thermal neutron cross section for the production of helium.[6] Table 4 lists calculated dpa and helium production in 316 stainless steel, also taking into account the extra helium and damage from the ^{59}Ni reaction.

Table 3 – Calculated Radiation Damage Parameters for the HFIR-14J Irradiation at Midplane

Element	dpa	He,appm
C	4.54	4.45
Al	7.23	1.74
V	4.94	0.059
Cr	4.12	0.43
Fe	3.64	0.77
Mn	4.78	0.36
Ni Fast	4.12	11.3
Ni-59	1.62	919.4
Ni-Total	5.74	930.7
Cu	4.89	0.65

Table 4 – Calculated Radiation Damage in 316 Stainless Steel for HFIR-14J

Height,cm	dpa	He,appm
-20.97	2.04	37.7
-12.85	3.53	98.6
-8.72	3.91	116.9
0	4.00	121.6
8.4	3.42	93.0
12.52	2.98	73.3
20.65	1.97	35.2
27.6	1.11	12.4
36.5	0.27	0.9
39.7	0.08	0.1

The calculated dpa in 316 stainless steel is shown as a function of height above midplane in Figure 2.

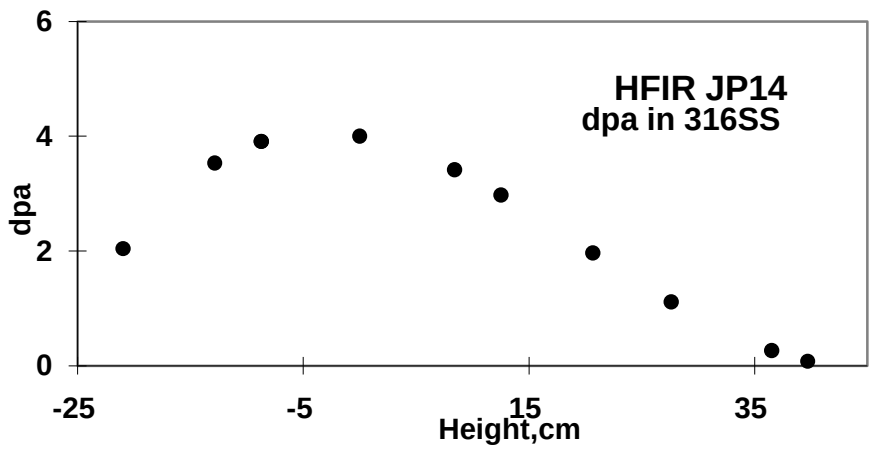

Figure 2 – Calculation of dpa vs. height above midplane

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[6] L. R. Greenwood, A New Calculation of Thermal Neutron Damage and Helium Production in Nickel, Journal of Nuclear Materials 115 (1983) 137-142.