NEUTRON DOSIMETRY AND DAMAGE CALCULATIONS FOR THE TRIST ER-1 EXPERIMENT IN HFIR - 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 TRIST ER-1 experiment, which was conducted in the removable beryllium position in the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL). The maximum neutron fluence at midplane varied from 1.38 to 1.57x 10^{22} n/cm^2 resulting in about 2.4 to 2.8 dpa in Al_2O_3.

PROGRESS AND STATUS

The ER-1 experiment was irradiated in the Temperature-Regulated In-Situ Test (TRIST) facility in the Removable Beryllium (RB*, without thermal neutron shielding) position of the HFIR during cycles 344 through 346. The irradiation started March 8, 1996, and ended June 28, 1996, for a net exposure of 75.78 effective full power days at 85 MW. The goal of the experiment was to determine radiation induced electrical degradation (RIED) in Al_2O_3 ceramic insulators. A complete description of the specimen matrix and irradiation assembly has been published previously.[1,2,3]

Neutron dosimetry capsules were inserted in between the specimen holders, as shown in reference 1 and illustrated in figure 1. The dosimetry capsules consisted of small, welded aluminum tubes measuring about 1.5 mm in diameter and 6.4 mm in length. Each tube contained small monitor wires of Cu, Fe, Ni, Ti, Nb, 80.2% Mn-Cu alloy, and 0.112% Co-Al alloy. Five dosimetry capsules were positioned in grooves 180° apart on each side of the experimental assembly, which measured about 3.2 cm in diameter. Dosimeters were also placed at two additional radial locations (90° to the other positions) at midplane to determine the radial flux gradients. The experimental assembly had 12 equally spaced grooves around the outside circumference. Dosimetry capsules were located at five different elevations between grooves 1 and 2 and between grooves 7 and 8, as shown in figure 1. Dosimetry capsules were placed at midplane between grooves 4 and 5 and between grooves 10 and 11. In an effort to minimize radial flux gradient effects, the experimental assembly was rotated 180° two times (after each cycle). After irradiation, each capsule was opened in a hot cell at ORNL and each individual monitor wire was gamma counted to determine the residual activation. Due to the delay between the end of irradiation and the opening of the capsules for analysis, the shorter-lived isotopes could not be detected. The activation results were then forwarded to PNNL for analysis.

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,

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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 5-10%. 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%.

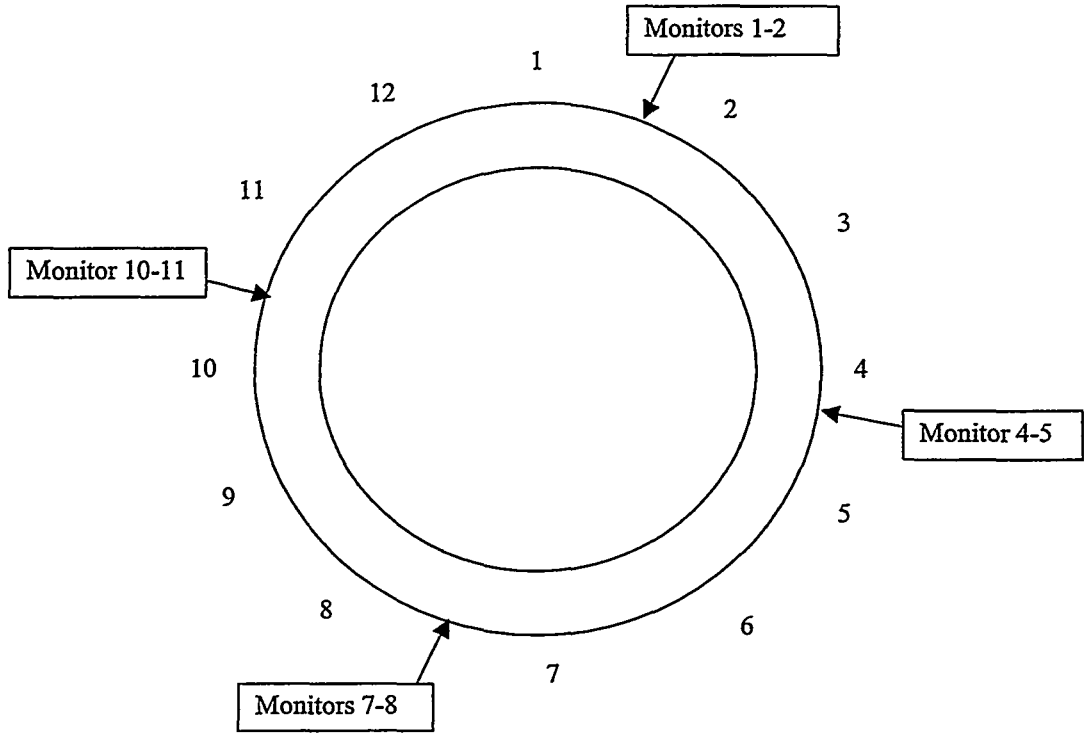

Figure 1. Top view of the neutron flux monitor locations for the TRIST ER-1 experiment. The numbers refer to axial grooves around the circumference of the assembly, which was rotated each cycle.

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, separately for the measured activation rates in grooves 7/8 and 1/2. . All of the data are reasonably well fit by the average polynomial (coefficient $a = -1.08 \times 10^{-3}$). Figure 2 shows the activity data for the $^{54}Fe(n,p)^{54}Mn$ reaction for the axial locations between grooves 1-2 (solid line) and between grooves 7-8 (dotted line), which were 180° apart. As can be seen, the activities differ by about 18% between these two positions. The flux monitors located at 90° to these grooves, also shown on the figure, fall between these two positions. The flux in between grooves 4-5 is about midway between grooves 7-8 and 1-2 whereas the flux in between grooves 10-11 is nearly identical (2% higher) to grooves 1-2. This radial flux pattern repeats for all of the measured activities except that the thermal neutron gradients appear to be much lower (5-10%).

Table 1. Activation Rates (at/at-s) – TRIST ER-1

Monitor-Grooves	Ht,cm	$^{54}Fe(n,p)$ ^{54}Mn (E-11)	$^{46}Ti(n,p)$ ^{46}Sc (E-12)	$^{63}Cu(n,\alpha)$ ^{60}Co (E-13)	$^{55}Mn(n,2n)$ ^{54}Mn (E-14)	$^{59}Co(n,\gamma)$ ^{60}Co (E-8)	$^{93}Nb(n,\gamma)$ ^{94}Nb (E-9)
J12 1-2	21.34	0.652	0.86	0.39	1.91	1.15	0.50
J13 7-8	21.34	0.773	1.04	0.47	2.20	1.07	0.48
J16 1-2	9.17	1.22	1.64	0.74	3.45	2.50	1.03
J17 7-8	9.17	1.43	1.96	0.86	4.11	2.52	1.06
J19 7-8	0.00	1.72	2.26	1.00	4.61	3.18	1.31
J20 1-2	0.00	1.44	1.90	0.86	3.88	2.69	1.26
J25 4-5	0.00	1.55	2.13	0.92	4.39	3.37	1.28
J27 10-11	0.00	1.45		0.89			
J24 1-2	-12.17	1.20	1.57	0.71	3.29	2.54	1.02
J21 7-8	-12.17	1.39	1.90	0.84	4.01	2.53	1.05
J26 1-2	-21.34	0.744	1.00	0.45	2.18	1.69	0.68
J23 7-8	-21.34	0.900	1.19	0.54	2.63	1.71	0.65

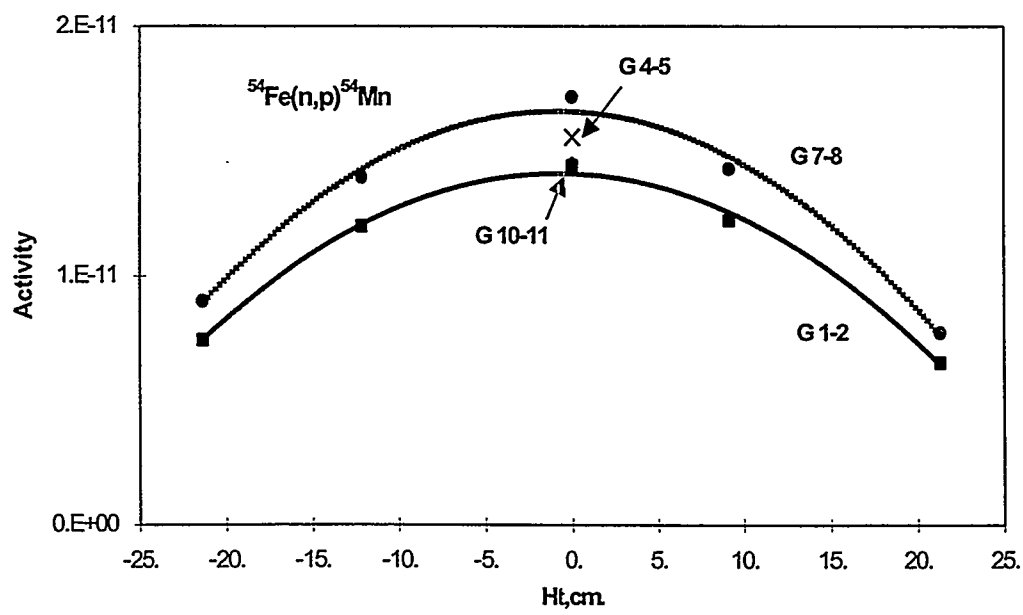

Figure 2. Measured activation rates vs. reactor elevation for the $^{54}Fe(n,p)^{54}Mn$ reaction. Data from grooves 7-8 are shown by the circles and dotted line; grooves 1-2 are shown by squares and the solid line; the X is for grooves 4-5 and a triangle is for grooves 10-11.

Midplane activation rates were then used in the STAY'SL[4] computer code to adjust the neutron flux spectrum determined in previous spectral measurements in the RB* position in HFIR.[5] 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[6] 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 HFIR RB* position.[5]

Neutron damage calculations were performed using the SPECTER computer code[7] 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. The dpa values for Al2O3 were calculated using the SPECOMP computer code[8] using threshold energies of 25 eV for Al and 65 eV for O.

Table 2. Midplane Fluence and Damage Values for TRIST ER-1

Neutron Fluence,x10^{21} n/cm^2			Element	dpa		He,appm	
Grooves:	7-8	1-2		7-8	1-2	7-8	1-2
Total	15.71	13.83	C	2.6	2.2	2.4	2.0
Thermal (<.5 eV)	6.92	5.80	Al	4.1	3.6	0.9	0.8
0.5 eV - 0.1 MeV	5.33	5.03	V	2.8	2.5	0.03	0.03
> 0.1 MeV	3.46	3.00	Cr	2.4	2.1	0.2	0.2
> 1 MeV	1.34	1.14	Fe	2.1	1.8	0.4	0.4
			Ni Fast	2.4	2.1	6.5	5.5
			59-Ni	0.8	0.6	454.3	331.9
			Total Ni	3.2	2.7	460.8	337.4
			Cu	2.8	2.4	0.4	0.3
			316SS*	2.3	2.0	60.2	44.2
			Al_2O_3	2.8	2.4	7.7	6.5

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

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