NEUTRON DOSIMETRY AND DAMAGE CALCULATIONS FOR THE ATR-A1 IRRADIATION

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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 collaborative U.S./Japan ATR-A1 irradiation in the Advanced Test Reactor (ATR) at Idaho National Engineering Laboratory (INEL). The maximum total neutron fluence at midplane was 9.4×10^{21} n/cm^2 (5.5×10^{21} n/cm^2 above 0.1 MeV), resulting in about 4.6 dpa in vanadium.

PROGRESS AND STATUS

The ATR-A1 experiment was designed to obtain mechanical property data, including in-reactor creep, on vanadium alloys irradiated at about 200 and 300 °C.[1] The drop-in type capsule was irradiated from December 2, 1995 to May 5, 1996 for a total of 135.95 effective full power days at an average power of 25 MW. Each subcapsule contained a gadolinium filter measuring 1.7 mm in thickness to reduce the thermal neutron flux in order to mitigate transmutation effects.

Neutron dosimetry capsules were inserted at five different elevations in the assembly. At two positions (-2.4 cm and –57.1 cm), six different dosimetry monitors consisting of Fe, Ti, Nb, Cu, 80.2%Mn-Cu, and 0.1%Co-Al were used to determine the neutron energy spectrum. The other three dosimetry capsules only contained Fe and 0.1% Co-Al to determine the flux gradients.

After irradiation, the gamma activities in each monitor wire were measured and then 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 fluences were then used to calculate burnup corrections for the threshold fast neutron monitor reactions. Thanks to the gadolinium filter, burnup corrections were quite small averaging 1-3% for the thermal/epithermal reactions and < 1% for the threshold reaction rates. The activation rates listed in Table 1 are normalized to a reactor power of 25 MW and have a net absolute uncertainty of about 3%. Upon analysis, the copper dosimeter irradiated at –2.4 cm was found to be an empty capsule so that we could not obtain data for this flux monitor.

The activation rates in Table 1 were fit to a polynomial function of form $f(x) = f(0) [1 - a x - b x^2]$, where x is the vertical height from reactor centerline in cm, as shown in Figure 1. All of the data are reasonably well fit by the average polynomial coefficients $a = 1.39 \times 10^{-3}$ and $b = 2.16 \times 10^{-4}$. The ratio of activation rates for the thermal and fast neutron reactions does not change appreciably over the height of the irradiation assembly. This suggests that the neutron energy spectrum remains relatively constant while the absolute flux values decrease about a factor of

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two from midplane to the top or bottom of the assembly. Midplane activation rates were thus used in the STAY'SL[2] computer code to adjust the neutron flux spectrum. 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[3] evaluation. The starting neutron spectrum was determined from an unfiltered spectrum calculated by B. Schnitzler[4], using a simple approximation to determine the effect of the gadolinium filter. The adjusted neutron fluence values are listed in Table 2 and the spectra are shown in Figure 2. As can be seen in the figure, the shape of the neutron spectrum remains about the same from midplane to the end of the assembly, except for the very low energy neutrons.

Neutron damage calculations were performed using the SPECTER computer code[5] at the midplane position of ATR. Midplane dpa and helium (appm) values are listed in Table 2. The measured value of 4.6 dpa for vanadium is very close to the planned exposure of 4.7 dpa. 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.

Due to the presence of the gadolinium filter, the transmutation of vanadium to chromium is only 0.046% at midplane.

FUTURE WORK

Additional experiments are being planned for the ATR.

REFERENCES

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3. Evaluated Nuclear Data File, Part B, Version V, National Nuclear Data Center, Brookhaven National Laboratory.

4. B. Schnitzler, Idaho National Engineering Laboratory, private communication, 1998.

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Table 1. Activation Rates (at/at-s) – ATR-A1 – 25 MW

Position/Monitor	Ht,cm	$^{54}Fe(n,p)^{54}Mn$ (E-11)	$^{59}Co(n,\gamma)^{60}Co$ (E-9)	$^{46}Ti(n,p)^{46}Sc$ (E-12)
AS-1	57.3	0.463	0.375	
AS-10	-2.4	2.17	2.08	2.86
AS-12	-18.2	2.03	1.85	
AS-16	-36.8	1.72	1.44	
AS-17	-57.1	0.789	0.662	1.01
Position/Monitor	**Ht,cm**	$^{55}Mn(n,2n)^{54}Mn$ (E-14)	$^{93}Nb(n,\gamma)^{94}Nb$ (E-10)	$^{63}Cu(n,\alpha)^{60}Co$ (E-14)
AS-1	57.3			
AS-10	-2.4			
AS-12	-18.2	6.05	2.94	
AS-16	-36.8			
AS-17	-57.1	2.28	0.975	4.94

Table 2. Midplane Fluence and Damage Values for ATR-A1

Neutron Fluence, $\times 10^{21}$ n/cm^2	
Total	9.41
Thermal (<.5 eV)	0.012
0.5 eV - 0.11 MeV	3.93
> 0.11 MeV	5.46
> 1 MeV	2.55

Element	dpa	He,appm
C	3.9	5.0
Al	7.1	2.0
V	4.6	0.068
Cr	4.2	0.53
Fe	3.8	0.93
Ni Fast	3.9	14.6
^{59}Ni	0.0	0.6
Total	3.9	15.2
Cu	4.8	0.77
316SS	3.9	2.7

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

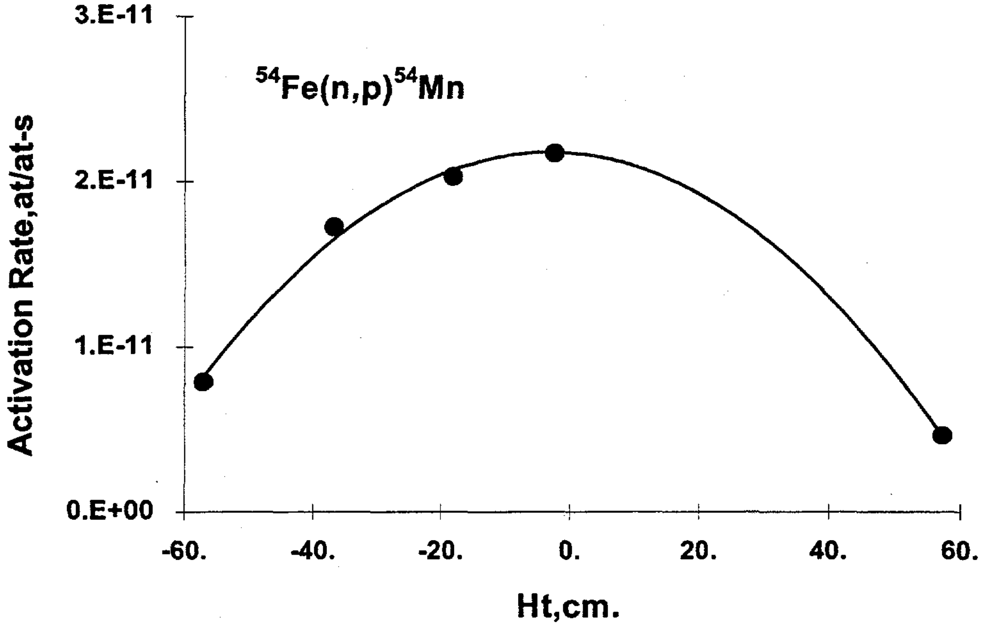

Figure 1. Activation rate of ^{54}Mn from the $^{54}Fe(n,p)$ reaction vs. elevation in the ATR-A1 assembly. The trendline is a polynomial, as described in the text.

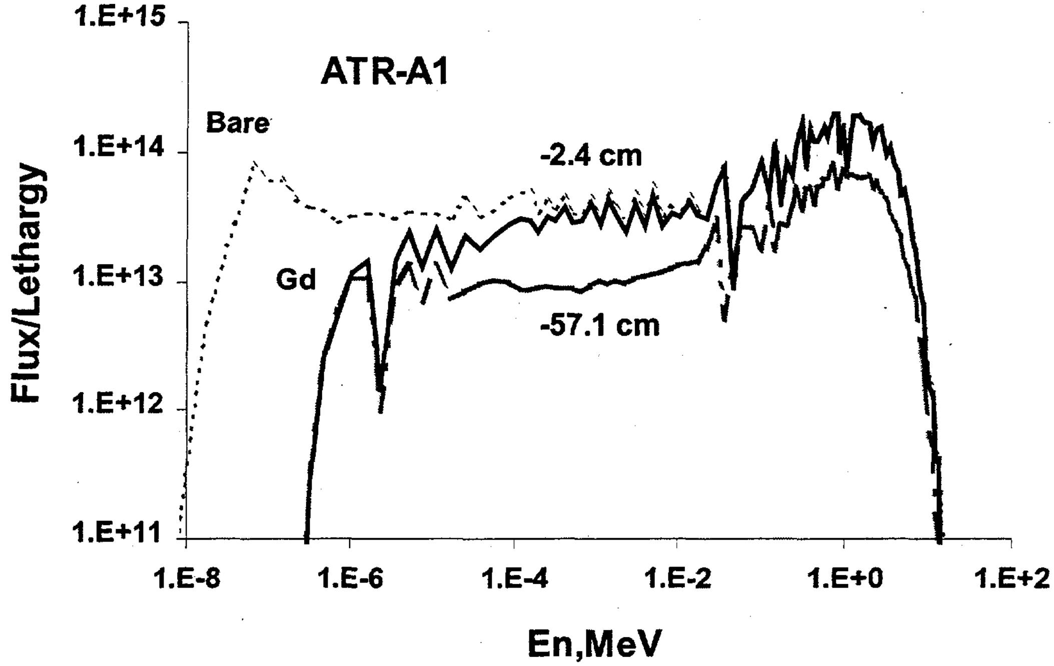

Figure 2. Neutron energy spectra adjusted by STAY'SL at –2.4 (solid line) and –57.1 cm (dashed line) below midplane in the ATR-A1 assembly. Note the effects of the Gd filter at low neutron energies. The bare, unfiltered neutron spectrum at –2.4 cm is shown as a dotted line.