# NEUTRON DOSIMETRY AND DAMAGE CALCULATIONS FOR THE EBRII COBRA-1A IRRADIATIONS

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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. and Japanese COBRA-1A1 and 1A2 irradiations in the Experimental Breeder Reactor II. The maximum total neutron fluences at midplane were 2.0E+22 and 7.5E+22 n/cm$^2$, for the 1A1 and 1A2 irradiations, respectively, resulting in about 8.0 and 30.3 dpa in stainless steel.

## PROGRESS AND STATUS

The COBRA-1A (Cold B7A Radiation Assembly) subassembly X516, consisting of seven B7A capsules (denoted B388 to B394), was irradiated in EBR-II core position 2B1 from November 26, 1992, to April 1, 1993 for a net exposure of 88.6 EFPD (effective full power days) at a nominal power of 62.5 MW. Three of the capsules, B392-394 (denoted as COBRA-1A1) were then removed from the reactor for analysis. The remaining four capsules, denoted as COBRA-1A2, then continued irradiation in core position 2B1 until September 26, 1994, for a net exposure of 337.3 EFPD. A complete description of the COBRA experimental matrix has been published previously.[1]

Neutron dosimetry capsules designed to measure the neutron energy spectra were located at six different locations, one in irradiation 1A1 (B392) and the rest in 1A2 (B389). Twenty dosimetry capsules designed to measure the neutron fluence gradients were also placed at different locations throughout the subassembly, sixteen in 1A2 and four in 1A1. The precise locations of the capsules are listed in Table 1. The spectral capsules contained small wires of Fe, Ni, Ti, Cu, Nb, 80.2 Mn-Cu, 0.1% Co-Al, $^{235}U$, $^{238}U$, and $^{237}Np$. The gradient capsules contained only Fe and 0.1% Co-Al wires.

After irradiation, each dosimetry capsule was opened in a hot cell and each individual monitor wire was gamma counted to determine the residual activation. The measured activities were converted to activation rates 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 resultant estimates of the thermal/epithermal neutron fluences were then used to calculate burnup corrections for the threshold fast neutron monitor reactions. Burnup corrections were < 10% for the thermal/epithermal reactions and were negligible for the threshold reaction rates. The activation rates are listed in Table 1 for the six neutron spectral locations. The full gradient data are shown in Figure 1. It is interesting to note that the $^{59}Co(n,\gamma)$ activation rates increase away from core center due to the rapidly increasing epithermal neutron flux. All activity values are normalized to full reactor power of 62.5 MW and have a net absolute uncertainty of about 5%.

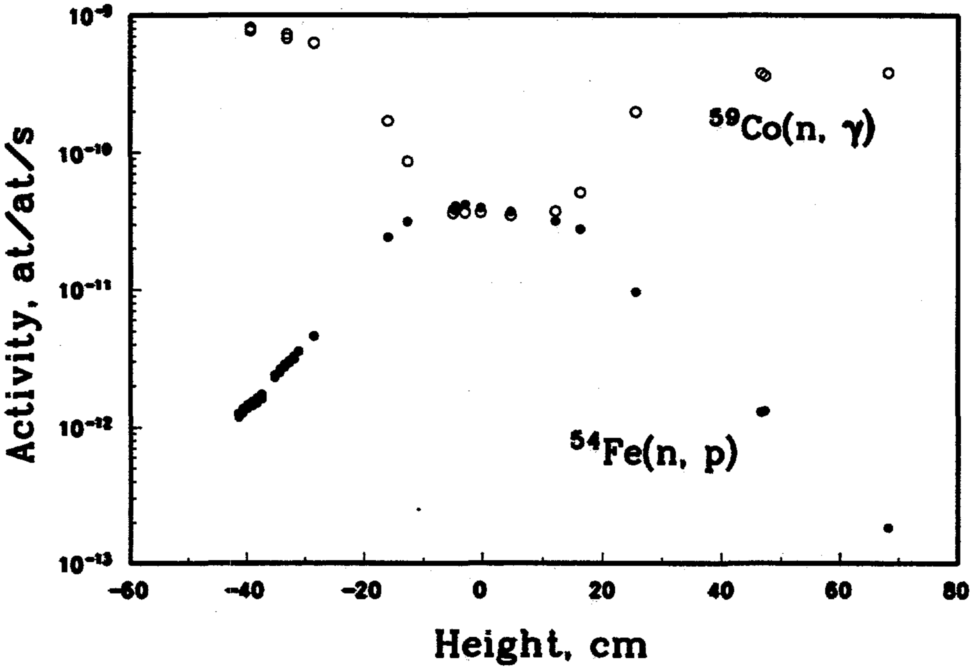


**Figure 1** Activation rates as a function of height in the COBRA-1A subassembly.

Radial flux gradients can be estimated from a comparison of Fe and Co wires located in different irradiation capsules. The plots in Figure 1 show that all of the available data fall on a relatively smooth curve indicating that the radial flux gradients are rather small, as might be expected for an irradiation near core center in Row 2 of EBR II. Detailed analysis of the data show that the fast radial flux gradients average about 3-7%. Variations in the epithermal flux are less than 4%. These radial flux gradients have been neglected in subsequent analyses.

Midplane activation rates were used in the STAY'SL[2] computer code to adjust calculated neutron flux spectra for EBR II. STAY'SL performs a generalized least-squares adjustment of all measured and calculated values including the measured activities, calculated spectra, neutron cross sections, and uncertainties. Neutron cross sections and their uncertainties were generally taken from the ENDF/B-V[3] evaluation. The activation rates and the derived neutron spectra and fluences are in good agreement with the calculated neutron spectra near midplane; however, more spectral adjustment is required away from midplane.

Neutron damage calculations were performed using the SPECTER computer code[4] using the adjusted neutron spectra at the six locations of the neutron spectral dosimeters. The neutron gradient data were then used to determine neutron fluence and damage parameters for other locations, as listed in Tables 2 and 3. The total and fast (> .1 MeV) neutron fluences are listed along with the net dpa (displacements per atom) in iron and stainless steel (Fe-18Cr-8Ni).

Helium production in nickel and nickel-bearing alloys requires a more complicated non-linear calculation.[5] Helium production in stainless steel is listed in Tables 3 and 4. Near the core midplane, the extra helium produced by $^{59}Ni$ is negligible (0.3%). However, due to the increase in epithermal neutrons at outer locations, the nickel reactions increase helium production by 15% at -28.6 cm and by 22% at +46.7 cm. In all cases, the increased helium production due to nickel has no effect on the dpa values. Dpa and helium values for other elements and alloys are available on request.

## FUTURE WORK

Additional experiments are in progress in the High Flux Isotopes Reactor.

## REFERENCES


1. M. L. Hamilton, R. M. Ermi, and C. R. Eiholzer, Preparation of COBRA 1A for Insertion into EBR-II, Fusion Reactor Materials Semiannual Progress Report, DOE/ER-0313/14, pp. 3-13 (1993).

2. F. G. Perey, Least Squares Dosimetry Unfolding: The Program STAY'SL, ORNL/TM-6062 (1977).

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

4. L. R. Greenwood and R. K. Smither, SPECTER: Neutron Damage Calculations for Materials Irradiations, ANL/FPP-TM-197, January 1985.

5. L. R. Greenwood, A New Calculation of Thermal Neutron Damage and Helium Production in Nickel, Journal of Nuclear Materials 116, pp. 137-142 (1983).


TABLE 1 - Activation Rates (at/at-s) - COBRA-1A

| Sample Position | Ht,cm | $^{54}Fe(n,p)^{54}Mn$ (E-11) | $^{46}Ti(n,p)^{46}Sc$ (E-12) | $^{63}Cu(n,a)^{60}Co$ (E-13) | $^{58}Ni(n,p)^{58}Co$ (E-11) | $^{60}Ni(n,p)^{60}Co$ (E-13) |
|---|---|---|---|---|---|---|
| C08-B03 | -28.6 | 0.463 | 0.508 | 0.241 | 0.642 | 0.930 |
| C09-B04 | -16.1 | 2.44 | 3.08 | 1.41 | 3.46 | 5.66 |
| E01-E07 | - 3.1 | 4.20 | 5.20 | 1.77 | 4.06 | 7.23 |
| C11-B10 | 16.2 | 2.79 | 3.62 | 1.69 | 4.10 | 6.99 |
| C12-B11 | 25.6 | 0.972 | 1.15 | 0.539 | 1.45 | 2.29 |
| C13-B12 | 46.7 | 0.130 | 0.138 | 0.067 | 0.206 | 0.306 |

TABLE 1 - Activation Rates (at/at-s) - COBRA-1A, Cont.

| Sample Position | Ht,cm | $^{235}U(n,f)$ (E-9) | $^{238}U(n,f)$ (E-10) | $^{237}Np(n,f)$ (E-9) | $^{93}Nb(n,g)^{94}Nb$ (E-10) | $^{55}Mn(n,2n)^{54}Mn$ (E-14) | $^{59}Co(n,g)^{60}Co$ (E-10) |
|---|---|---|---|---|---|---|---|
| C08-B03 | -28.6 | 4.16 | 1.38 | 0.479 | 2.96 | 1.07 | 6.33 |
| C09-B04 | -16.1 | 3.66 | 1.71 | 1.09 | 2.77 | 6.09 | 1.72 |
| E01-E07 | - 3.1 | 3.21 | 2.20 | 1.43 | 2.26 | 10.79 | 0.368 |
| C11-B10 | 16.2 | 3.03 | 1.58 | 1.13 | 2.05 | 7.23 | 0.511 |
| C12-B11 | 25.6 | 2.55 | 0.775 | 0.549 | 2.30 | 2.38 | 2.00 |
| C13-B12 | 46.7 | 2.09 | 0.354 | 0.151 | 1.94 | 0.327 | 3.81 |

TABLE 2 - Neutron Fluence and DPA - COBRA-1A1 (88.6 EFPD)

| Sample Position | Ht,cm | Total Fluence (E+22 n/cm2) | Fluence >.1 MeV (E+22 n/cm2) | dpa (Iron) | dpa Fe-18Cr-8Ni | He(appm) Fe-18Cr-8Ni |
|---|---|---|---|---|---|---|
| C08-B03 | -28.6 | 1.10 | 0.688 | 2.64 | 2.74 | 0.23 |
| C09-B04 | -16.1 | 1.75 | 1.30 | 6.16 | 6.37 | 1.31 |
| E01-E07 | - 3.1 | 1.97 | 1.56 | 7.70 | 7.95 | 1.89 |
| C11-B10 | 16.2 | 1.57 | 1.23 | 5.93 | 6.12 | 1.58 |
| C12-B11 | 25.6 | 1.04 | 0.701 | 3.00 | 3.10 | 0.51 |
| C13-B12 | 46.7 | 0.603 | 0.308 | 1.12 | 1.17 | 0.07 |

TABLE 3 - Neutron Fluence and DPA - COBRA-1A2 (337.3 EFPD)

| Sample Position | Ht,cm | Total Fluence (E+22 n/cm2) | Fluence >.1 MeV (E+22 n/cm2) | dpa (Iron) | dpa Fe-18Cr-8Ni | He(appm) Fe-18Cr-8Ni |
|---|---|---|---|---|---|---|
| C08-B03 | -28.6 | 4.19 | 2.62 | 10.1 | 10.4 | 0.98 |
| C09-B04 | -16.1 | 6.66 | 4.95 | 23.5 | 24.2 | 5.02 |
| E01-E07 | - 3.1 | 7.50 | 5.94 | 29.3 | 30.3 | 7.20 |
| C11-B10 | 16.2 | 5.98 | 4.68 | 22.6 | 23.3 | 6.04 |
| C12-B11 | 25.6 | 3.96 | 2.67 | 11.4 | 11.8 | 1.99 |
| C13-B12 | 46.7 | 2.30 | 1.17 | 4.26 | 4.47 | 0.30 |