

CONF-950919--14

MEASUREMENTS OF ACTINIDE TRANSMUTATION IN THE HARD SPECTRUM OF A FAST REACTOR

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Summary of Paper to be Submitted to
Global 1995
International Conference on Evaluation of Emerging
Nuclear Fuel Cycle Systems
Versailles, France

Submittal Date: November 14, 1994

*Work supported by the U.S. Department of Energy, Reactor Systems, Development and Technology, under Contract W-31-109-Eng-38.

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Measurements of Actinide Transmutation in the Hard Spectrum of a Fast Reactor

Abstract

Measurements of fission and capture in ^{235}U , ^{238}U , ^{239}Pu and ^{237}Np and in their product actinides have been made following irradiation in the metal-fuel core of EBR-II. The reactor has a peak flux around 500keV and the data complement measurements in the softer spectrum of an LMFBR. Irradiations were made at the same time for a set of standard dosimeter samples. These provide a test of calculated spectra and are also used for validation of steel activations and calculated atomic displacement rates. Calculations were made with modern transport codes using ENDF/B-5.2 data. Comparisons are made, using a simple homogeneous model, producing a similar spectrum, using ENDF/B-6.2 and JEFF-2 data.

1. The Experiments

The EBR-II core is relatively small, with a high fuel-enrichment of 70% uranium and consequently a high leakage fraction and a hard spectrum with a peak flux around 500keV. Irradiation measurements with samples of uranium, neptunium and plutonium and their more important product actinides were made in 1994. The principal objective was to verify calculations for the long-lived actinides in a liquid-metal reactor (LMR). Measurements of capture and fission were made for high-purity samples of ^{237}Np , ^{240}Pu , ^{241}Am and ^{243}Am simultaneously with samples of ^{235}U , ^{238}U and ^{239}Pu in neighboring locations. The fission rates were determined by gamma-counting of the fission products and the capture rates by alpha spectrometry and mass spectrometry. The principal measurements were made at the core midplane. Irradiations were made in two positions; at the core center and at the core edge, and each was made at the full power of EBR-II, of 62.5 Mwt. Additional measurements of Pu, U, and Np were made at three axial positions; the bottom and the top of the core and in the axial reflector.

The dosimeter capsules were contained in three special pins within a 37-pin uranium-fueled subassembly. Measurements were made in a center pin, in a corner pin, and in a pin adjacent to the corner. The dosimeters were encapsulated in vanadium and contained in a stainless steel holder. The ^{241}Am and ^{239}Pu samples were in the form of oxide powder, while ^{237}Np and ^{243}Am were cuboidal metallic chips and ^{235}U , ^{238}U and ^{239}Pu were metal foil. Samples were mostly 5 mg to 10 mg in mass but about 1 mg for ^{235}U and ^{240}Pu . The accuracy of measurements before irradiation were set so that the uncertainty in calculated correction for any impurity would be less than 1% of the reaction of interest.

The gamma-counting to determine fission rates, used the fission product yields of ^{95}Zr , ^{103}Ru , ^{131}I , ^{140}La and ^{141}Ce . These data were taken from the ENDF/B-6 file. Corrections were made for the reactor power history in the relatively short runs.

Knowledge of the accuracy in calculated flux, together with the reaction rates, is vital for extrapolation of the data to other locations or to systems with a different spectrum. To this end, dosimeters of Fe, Co, Ni, Cu and Ti were irradiated close to the actinide samples. These samples were chosen from the ASTM Standard Practice (1). The "spectral data" can be used

with the standard spectrum unfolding techniques, or other, more general, least squares fitting codes. The advantage of this latter analysis is that it can use all measurements, not only spectrum measurements, in any reactor with any spectrum.

A complete covariance matrix was constructed for the experimental data. This is important because correlations with ^{235}U , ^{238}U and ^{239}Pu greatly reduce the need for precise knowledge of fluence in the samples. The data for the principal uranium and plutonium isotopes are validated by a large number of integral measurements.

2. Analysis

Calculations were made in great detail using ENDF/B-5.2 data, with modern transport codes. These used

- RZ models with the TWODANT transport code in S_8P_1 quadrature and 28 energy groups. The use of transport methods was necessary because of the high leakage fraction, of about 50%, in the core of EBR-II.
- Corrections for the detailed reactor loading of EBR-II with hexagonal-Z and RZ diffusion models.
- Correction for the heterogeneity between the dosimeter pins, the normal uranium pins and the hexagon of the subassembly, using the European code ECCO (3) and the RCT nodal interpolation core.
- The first and second steps were combined in one calculation using the, newly-developed, hexagonal-Z nodal transport code VARIANT (4).

To compare results from different data files, calculations were made, using a simple homogeneous model having a similar spectrum, between ENDF/B-5.2, ENDF/B-6.2 and JEFF-2 data.

Finally, the set of actinide and dosimeter data were used in the generalised least square fitting code GMADJ (2) to provide uncertainties and to show consistency of the data with other measurements. This analysis also provided additional verification of the accuracy of calculated fluxes and verification of calculated atomic displacements in steel.

3. Summary

The importance of these measurements lies in the hard spectrum of EBR-II. This spectrum is softer than that of the GODIVA benchmark but harder than that of an oxide-fueled LMFBR. Consequently, the threshold fission rates of americium are emphasized and the data are complementary to that from Phoenix and PFR. The data can be most effectively used in conjunction with other data such as from ZEBRA and CFRMF, in the generalised fitting code, GMADJ. This code will also enable interpolation to other spectral regimes.