FAST-NEUTRON SPECTRA MEASUREMENT

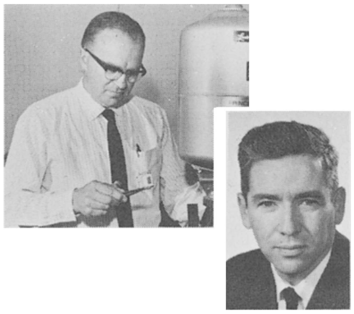
An improved method of measuring proton recoil tracks in nuclear emulsions without interference from chemical fog or gamma-ray background permits calculation of a fast-neutron spectrum in the 0.3- to 2.5-MeV range.

James H. Roberts is Professor of Physics at Northwestern University where his research specialties are nuclear emulsion techniques and solid-state track detectors. A. N. Behkami, from Iran, recently completed his studies at Northwestern and presently holds a post-PhD Fellowship at the Nuclear Structure Laboratory at the University of Rochester.

APPLYING PREDICTION ANALYSIS

A prediction analysis technique can determine, in advance of a proposed experiment, the accuracy with which a radioactive half-life can be measured.

John R. Wolberg, r, (PhD, MIT, 1962) is a senior lecturer at Technion, Israel Institute of Technology, where he works in reactor physics and control, desalination, and radiology. Gad Hetsroni (PhD, Michigan State University, 1962), also a senior lecturer, does research in experimental design, two-phase flow, turbulence, and desalination.



MULTI-ELEMENT DETECTORS

Chemically loaded epoxy resin disks permitted simultaneous activation of six elements and determination of cadmium ratios by high-resolution γ spectrometry using a Ge(Li) diode.

Pieter de Lange, now at the Atomic Energy Board in Pretoria, worked in both nuclear and neutron physics in five countries since receiving his Doctorate at the University of Pretoria in 1959. C. B. Bigham (PhD, University of Liverpool, 1954) works on the Intense Neutron Generator at AECL's Accelerator Physics Branch. Prior to an IAEA appointment in Argentina, he measured neutron cross sections, neutron spectra, and lattice parameters for the CANDU reactors.

LETTER TO THE EDITOR

IRRADIATION BEHAVIOR OF HOLLOW-CORE METALLIC-URANIUM FUEL ELEMENTS

Dear Sir:

Reduction of irradiation-induced swelling is one of the keys to the successful performance of metallic-uranium fuel elements. This letter describes the interim results of a continuing irradiation test of metallic-uranium fuel elements that have shown no volume increase when irradiated to >6500 megawatt-days per ton (MWd/t), 3.9×10^{20} fissions/cm^3, under power reactor conditions.

The alloying of uranium with iron, aluminum, silicon, molybdenum, chromium, and other elements in varying amounts, and the application of external restraints through system pressure or high-strength cladding have been effective in reducing the innate swelling of pure uranium by one or two orders of magnitude in the temperature range[1-4] 400 to 600°C. However, even with these improvements, at exposures of economic interest for metallic uranium, i.e., $\approx$ 10 000 MWd/t and greater, the swelling would reach values that could result in plastic strain failures of the cladding on solid rods[5] and possibly buckling of the inner-bore cladding of tubular elements.[4]

To further reduce the external volume increase, the fuel elements in this irradiation test incorporate a longitudinal void in the center of a Zircaloy-2-clad coextruded uranium rod. The fuel elements are rods 0.45-in. o.d. by 6.25-in. long. Two thicknesses of cladding 0.025 and 0.050 in. and three uranium void volumes, nominally 5, 10, and 20%, are being tested. Two uranium alloys, U + 150 ppm Fe + 100 ppm Si and U + 350 ppm Fe + 800 ppm Al, are utilized in the study. This test is being conducted in a water loop facility in the Engineering Test Reactor, operating at a water temperature of 260°C and a pressure of 2000 psi.

Interim measurements show that each of the 34 elements irradiated in this test has experienced an initial decrease in external volume followed by a reversal in the direction of volume change at an exposure of approximately 2000 MWd/t. To the present maximum exposure of 6500 MWd/t, all elements continue to exhibit an external volume less than their pre-irradiation volume. Furthermore, all elements are behaving roughly the same regardless of void volume, cladding thickness, or alloy content. Figure 1 shows the general behavior of the volume of these hollow-core uranium fuel elements as a function of exposure. It is anticipated that behavior differences may appear as the test proceeds. These elements with the smaller void volumes and 0.025-in.-thick Zircaloy-2 cladding have presently accumulated only 4000 MWd/t due to a lower flux in their irradiation position.

The volume swelling of a is l uranium rod,[6] a tubular uranium fuel element,[4] and a hollow core U_3Si rod,[7] all three having been irradiated in hot pressurized water are shown as curves in Fig. 1, as is the volume swelling[8] of UO_2.

At these exposures, the hollow-core fuel elements have swelled less externally than any solid rod or tubular uranium fuel elements. The degree of potential improvement depends on the validity of extrapolating the data thus far obtained to higher exposures. It would appear that the "hollow-rod" concept shows great potential for extending the permissible exposure of uranium fuel elements well beyond 10 000 MWd/t.

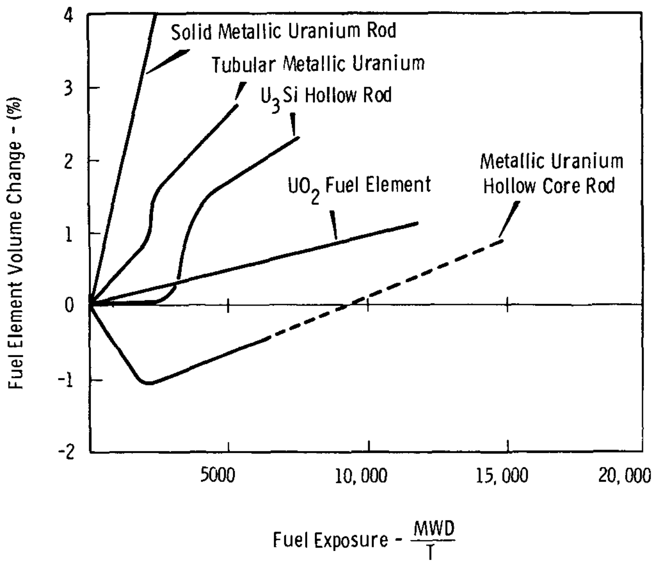


Fig. 1. Irradiation behavior of hollow-core uranium fuel elements.

Selected elements will be removed for destructive examination as they reach 10 000 MWd/t, but duplicates will continue to higher exposures to establish the burnup limitations as a function of void volume, cladding thickness, and alloy content.

J. W. Weber

Battelle Memorial Institute
Pacific Northwest Laboratory
Richland, Washington

December 13, 1967

ACKNOWLEDGMENTS

This work was supported by the USAEC under contract AT(45-1)-1830.

REFERENCES

1. R. D. LEGGETT, T. K. BIERLEIN, B. MASTEL, and H. A. TAYLOR, "Basic Swelling Studies," to be published in Proceedings of AIME Symposium on Radiation Effects (September 1965).

2. R. S. BARNES, R. G. BALLAMY, B. R. BOTCHER, and P. G. MARDON, "The Irradiation Behavior of Uranium and Uranium Alloy Fuels," *Proc. Intern. Conf. Peaceful Uses At. Energy, Geneva*, **11**, 218 (1965).

3. R. D. LEGGETT, C. R. HANN, and B. MASTEL, "Basic Swelling Studies," Quarterly Progress Report, January, February, March 1966, Reactor Fuels and Materials Development Programs, BNWL-CC-694, p. 6.1, Battelle Northwest (1966).

4. C. L. ANGERMAN and W. R. McDONELL, "Irradiation Behavior of Uranium Fuel Tubes in a Pressurized Heavy-Water Reactor," *Nucl. Sci. Eng.*, **28**, 42 (1967).

5. J. W. WEBER, "Plastic Stability of Zr-2 Fuel Cladding," to be published in Proceedings of ASTM 1966 Symposium on Effects of Radiation on Structural Metals (July 1966).

6. T. T. CLAUDSON, G. T. GEERING, J. W. GOFFARD, and J. E. MINOR, "Operational Performance of Bonded and Unbonded Uranium Fuel Rods," *Nuclear Metallurgy*, Vol. VI, *AIME Symposium on Effects of Irradiation on Fuel and Fuel Elements* (1959).

7. M. A. FERADAY, G. H. CHALDER, and K. D. COTMAN, "Irradiation Behavior of U_3Si," *Trans. Am. Nucl. Soc.*, **10**, 123 (June 1967).

8. J. H. GITTUS, *Metallurgy of the Rarer Metals-Uranium*, Fig. 13.88a, p. 501 (1963).