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MEASUREMENTS AND CALCULATIONS OF ^{10}B(n,He) REACTION RATES IN A CONROL ROD IN ZPPR

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Measurements and Calculations of $^{10}B(n,He)$ Reaction Rates in a Control Rod in ZPPR

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The helium accumulation fluence monitor (HAFM) technique[1] has been used to measure the $^{10}B(n,He)$ reaction rate within B_4C pellets in a control rod in ZPPR. Knowledge of this reaction rate is important to control rod design studies because helium production leads to control rod swelling, buildup of gas pressure and a reduction in thermal conductivity which can limit the lifetime of a control rod. We believe these to be the first measurements of boron capture within boron pins in a fast reactor spectrum. Previously reported measurements[2] used ^{235}U foils to measure fission rates in a control rod, and to infer boron capture rates.

The ZPPR measurements were made in a mockup of a central control rod in the metallic-fuel physics benchmark assembly ZPPR-15A. The control rod simulated a power reactor design using ZPPR pin calandria. The calandria contained 64 tubes of 9.5 mm diameter. The central 32 tubes were filled with B_4C pellets enriched to 92% in ^{10}B. The outer tubes contained stainless steel rodlets simulating the control rod sheath and guide tubes. The rod pattern is shown in the figure. The mockup control rod was half inserted, with sodium-filled drawers simulating a rod follower in the assembly half opposite the rod.

In using the HAFM technique, ^{10}B in small, sealed, stainless steel capsules was placed inside holes bored into B_4C pellets. The holes were oriented axially on the pellet centerline or radially through a pellet diameter. The HAFMs were placed in various axial locations in each unique pin type; corner, edge, and three interior locations. The axial locations ranged from the first 12 mm of the rod to about 286 mm from the rod tip. The measurements produced reaction rates which were integrated over the 9 mm active length of the HAFMs.

The pellets and HAFMs were irradiated for about 4000 watt hours producing helium in the capsules. Following irradiation the capsules and contents were vaporized in a vacuum system and the amount of helium released was measured by isotope dilution mass spectrometry. The helium atom fractions in the samples were about 10^{-10}, corresponding to about 3×10^{11} helium atoms.

Foils of ^{235}U were also placed between pellets of the mockup control rod in pins symmetrically equivalent to pins containing HAFMs and irradiated, and the fission rates were measured by gamma ray counting. The purpose of the foil measurements was to compare the HAFM and foil techniques for their suitability in verifying the ability of a calculation to predict the $^{10}B(n,He)$ reaction rate distributions since the foil technique is easier to use. Additional ^{235}U foils were irradiated in the core region to characterize the fission rate distribution and to provide a normalization for rates measured in the control rod.

The $^{10}B(n,He)$ and ^{235}U fission rates were calculated at their respective locations using three-dimensional nodal transport methods. In the calandria, there was one node for each pin in the control rod with a coarse (50 mm to 150 mm) axial node spacing. The cross section data were ENDF/B version V Revision 2. The calculated k_{eff} for the critical assembly was 0.9961.

The measured $^{10}B(n,He)$ rate decreased axially by up to 50% between 6 mm from the rod tip and 286 mm from the tip. The capture rate decrease in the radial direction, going from the corner pin to the most interior pin ranged from 10% near the rod tip to 20% at 286 mm from the tip.

The ratios of calculated (C) to experimental (E) reaction rates in the control rod were normalized to an average C/E of unity for 22 measurements of ^{235}U fission in the core region. The C/E values for boron capture varied between 1.00 and 0.90 with an average of 0.957 and a standard deviation of 0.031. There was a trend of decreasing C/E of 3% to 6% with increasing axial depth of 286 mm. There was also an indication of decreasing C/E going from outer to inner pins, although this trend was not definite when compared to the estimated measurement uncertainty of 1% to 2%. The comparisons between experiment and calculation for the axial variation in boron capture within a corner pin and a center pin are shown in the figure. Reaction rates in both pins were normalized to unity for the HAFM nearest the rod tip.

Two comparisons are of interest in the analysis. One is the boron capture in the rod relative to the fission rate in the core region and the other is the boron capture to uranium fission rate in the spectrum of the rod. In ZPPR-15, the average C/E value for boron capture in the rod relative to fission in the core was 0.957 while the average C/E for capture to fission within the rod was 0.875 ± 0.033. An earlier set of HAFM measurements in a small, less prototypic control rod, in ZPPR-12MB gave a C/E value of 0.945 ± 0.012 for capture in the rod relative to fission in the core and 0.914 ± 0.015 for capture to fission in the rod. The ZPPR-12MB calculations used ENDF/B Version IV cross sections. Previous measurements[3] using the HAFM technique in the core region of ZPPR-13 gave C/E values for the $^{10}B(n,He)$ to $^{235}U(n,f)$ ratio of 0.921 ± 0.018. These C/E values for the ^{10}B capture to uranium fission ratio are also consistent with previous work by Farrar and Oliver in other experiments.[4]

Results for the ^{235}U fission measurements between pellets showed trends similar to the trends seen for the $^{10}B(n,He)$ rates. Decreases in fission rates from 25 mm (instead of 6.4 mm for the HAFM measurements) from the rod tip to 280 mm from the tip were about 35% for all pins. Variations in fission rate from a corner pin to an interior pin were about 15% for all planes. The average of 20 C/E values for ^{235}U fission measurements in the control rod was 1.094 ±0.008. There was no significant variation in C/E with either radial or axial location. Both radial and axial fission rate profiles were well predicted within the experimental statistics.

In summary, the ZPPR-15 HAFM measurements provided the first direct measurements of the $^{10}B(n,He)$ reaction rate inside a mockup control rod in a fast reactor spectrum. The calculated boron capture relative to uranium fission within the control rod was 12% lower than experiment but was consistent with studies of boron capture in other environments. Variations in capture rate of up to 50% were predicted within a few percent by transport calculations. Measurements with ^{235}U foils, which are considerably easier to do, showed similar variations within the control rod and were very well predicted.

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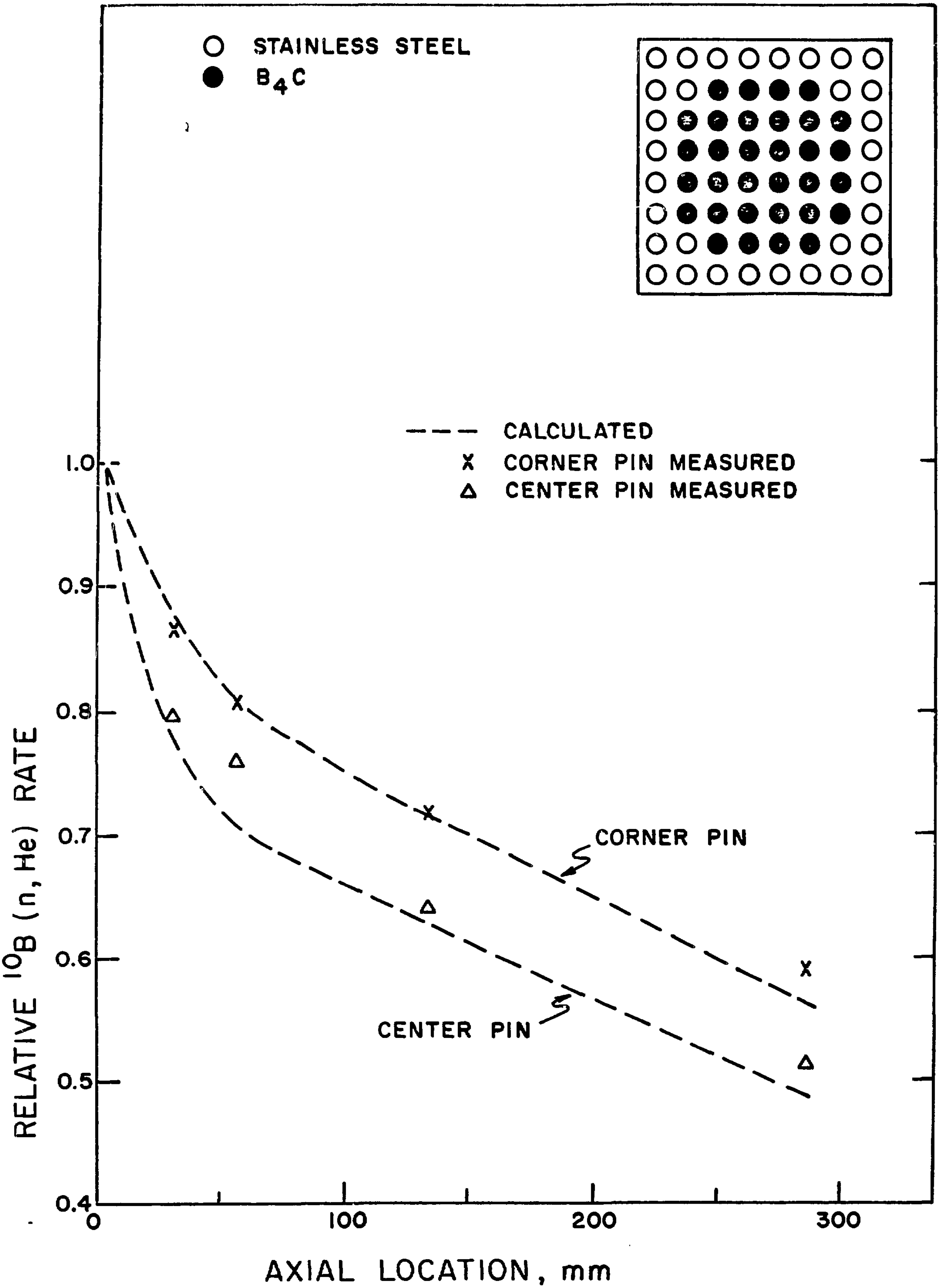
STAINLESS STEEL
B_4C
CALCULATED
CORNER PIN MEASURED
CENTER PIN MEASURED
CORNER PIN
CENTER PIN
RELATIVE ^{10}B (n, He) RATE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0
100
200
300
AXIAL LOCATION, mm