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# NONDESTRUCTIVE DETERMINATION OF URANIUM-235 DISTRIBUTION BY FIXED-POSITION GAMMA SCANNING

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## ABSTRACT

A nondestructive method for determining fuel density variation in small, unirradiated, clad $UO_2$ plates is described. Instead of scanning a plate moving past a detection system, a plate is scanned at fixed positions. Where it is not possible to analyze the whole plate, variations are calculated by statistical sampling. A 2-percent variation could be detected at the 99.9-percent confidence level with the specimens described in this report.

# NONDESTRUCTIVE DETERMINATION OF URANIUM-235 DISTRIBUTION BY FIXED-POSITION GAMMA SCANNING

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## SUMMARY

A nondestructive method for determining fuel density variation in small, unirradiated, clad uranium dioxide ($UO_2$) plates is described. Instead of scanning a plate moving past a detection system, a plate is scanned at fixed positions. Where it is not possible to analyze the whole plate, variations are calculated by statistical sampling. A 2-percent variation could be detected at the 99.9-percent confidence level with the specimens described in this report.

## INTRODUCTION

Test plates of uranium dioxide in a tungsten matrix clad with tungsten were to be irradiated at high temperatures in the Plum Brook Reactor. A nondestructive analysis of the fuel uniformity in each plate prior to irradiation was needed to determine if a random variation in fuel density in excess of the 2-percent manufacturing criterion existed.

Gamma scanning is one nondestructive technique that has been used to determine fuel loading in fuel elements (refs. 1 to 3). Generally, a single-channel analyzer is used with a drive mechanism. The fuel plate moves at a uniform rate past the detector. The integrated trace from a recorder is used to calculate the fuel loading. This method can be used to a certain extent to detect variations in fuel density, but the effective collimated area of the equipment described in reference 1 is 3 square inches (1935 sq cm). This apparatus would not be useful in detecting fuel segregation on a small scale. Sensitivity in determining density variations would be dependent on the traverse velocity

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and recorder response. These variables are eliminated in the stationary system described in this report.

Foster and Snyder (ref. 4) describe a method for determining small variations in fuel loading. The attenuation of a cobalt-60 source is measured as a fuel element moves between the source and a sodium iodide crystal. The ability to detect a 2-percent variation in fuel density is stated; however, no confidence level is reported. This method is satisfactory with the type of fuel element described in their report, but a method based on attenuation alone would not be applicable to the specimens described in this report. The response to the matrix would be greater than the response to the fuel because of the relative densities.

In the method described in this report, plates fueled with enriched uranium were mounted with respect to a collimator and sodium iodide detector so that the gamma intensity in small areas of the plates could be measured. The gamma intensity was related to fuel loading density, and the overall uniformity was determined by statistical analysis.

## METHOD

The unirradiated fueled plates are depicted in figure 1. (The plates were to be irradiated in stacks of five plates.) Each plate consisted of tungsten-93 percent enriched $UO_2$ clad with 0.025 millimeter of tungsten. The plates were 40 millimeters long, 25 millimeters wide, and 0.63 millimeter thick. Six stud holes permitted the insertion of stacking pins (see fig. 2).

A schematic of the scanning system apparatus is shown in figure 3. A sodium iodide crystal coupled to a multichannel analyzer was mounted at right angles to a 0.8-centimeter lead shutter. The shutter separated the crystal from the milling table. The plate to be analyzed was mounted on an aluminum block in the jaws of the milling table. The traverse plane of the block and plate was also perpendicular to the crystal. The lead shutter could be moved in the shutter frame, permitting either alinement of a position on the plate through a 0.319-square-centimeter collimator or a background count through a solid region of the shutter with the plate still mounted.

Each plate was taped to the aluminum mounting block. The vertical and horizontal cranks on the milling table were used to aline one of the five selected positions (fig. 2) with the center of the crystal and the collimator. Ten 1-minute counts were made at each position. The shutter was then closed, and five background counts were obtained with the plate still in position. Degraded radiation from the shielded part of the plate contributed to the gross count rate. This interference was eliminated by using only the counts in the 0.184 and 0.143 MeV photopeaks of $U^{235}$. The background in this energy span was no higher with a plate on the block than without.

Since the plates were not flush against the collimator, the scanned area was greater than the collimator area, which was 0.317 square centimeter. By centering the collimator with respect to a stud hole and correlating the drop in the count rate with the area of the stud hole, the collimated area was estimated. A plate that had shown no detectable within-plate variations was selected. The two center holes were used. The scanned area was calculated to be 0.5 square centimeter.

## DISCUSSION OF RESULTS

The counting data were analyzed by two different methods.

### Root-Mean-Square Analysis

The average count rate at each point on a plate was compared with the average count rate for the five positions on the same plate. For convenience, the count rate at a given position was considered to represent the fuel density at that position, and the average count rate for the five positions to represent the average plate density. Since the counting procedure cannot differentiate between differences caused by variations in the $UO_2$-tungsten matrix ratio or by variations caused by differences in thickness of the fueled region, density is related to area rather than volume.

Because the attenuation of the weak gammas is greater in tungsten than in $UO_2$, an observed change in count rate caused by a change in the fuel-matrix ratio will be greater than the corresponding change in fuel concentration. Nonuniformity of cladding thickness has a similar effect. For quality-control purposes, these factors increase confidence in plates that meet specifications, but it is possible that acceptable plates might be rejected.

A within-plate variation of 3.48 percent at the two-sigma or 95-percent confidence level for the 10 plates analyzed was calculated. A between-plate average density variation of 5.20 percent was also observed. The counting precision at the two-sigma level was 1.15 percent.

### A One-Way Analysis of Variance (ANOVA)

The counting data were also analyzed with the ANOVA code (ref. 5). The components of variances were calculated from the ANOVA table. Differences among the average count rates of each of the 10 plates and between the positions on the plates were much larger than could be reasonably accounted for by random variations in the count rate.

The between-plate variances were not homogeneous. Each plate was analyzed separately with respect to the average count rate for the plate, and counting statistics were determined for that plate. Estimates could then be made for the power of the F test (a type of statistical test described in ref. 6) to show significant differences between positions. For this purpose, it was assumed that the count rate at three of the five positions did not deviate from the average for the plate. The count rate at the fourth position was assumed to be 1 percent higher than the average. The count rate at the remaining position was assumed to be 1 percent lower than the average. The power, or probability, of detecting this 1 percent deviation ranged from less than 0.35 to 0.65 in the 10 plates analyzed. When the same test was applied to a 2-percent deviation, the probability of detection was greater than 0.999 for each of the 10 plates. This more rigorous analysis confirmed the results of the previous analysis.

## CONCLUSIONS

Fixed-position gamma scanning was found to provide a reliable nondestructive means of determining fuel density variations of 2 percent or greater in specimens of the type described in the text. When the entire specimen cannot be analyzed because of stud holes or other geometric anomalies, statistical sampling provides a means of calculating the variation in fuel uniformity.

## SUMMARY OF RESULTS

A method for determining variations in $U^{235}$ density in small plates has been developed. Instead of scanning a plate moving past a detection system, the plates are scanned at fixed locations using a sodium iodide crystal, multichannel analyzer, and collimator. Fueled plates used to test the method consisted of uranium dioxide in a tungsten matrix and tungsten clad. The plates were 40 millimeters long, 25 millimeters wide, and 0.635 millimeter thick. Five positions were scanned on each of 10 plates. The area scanned at each location was 0.5 square centimeter. Holes in the plates for stacking pins limited the number of locations that could be scanned without overlap. Statistical procedures were used to determine fuel density variation. In the 10 plates analyzed, a within-plate variation of 3.48 percent and a between-plate variation of

5.20 percent were found at the two-sigma level. Statistical analysis showed that a 2-percent variation could be detected at the 99.9-percent confidence level.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, February 12, 1969,
120-27-04-54-22.

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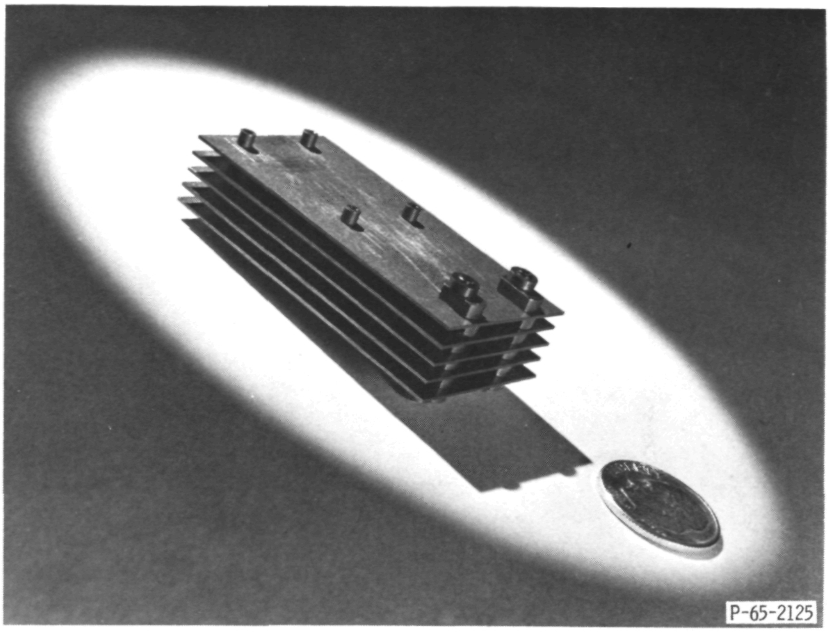


Figure 1. - Assembled fuel element.

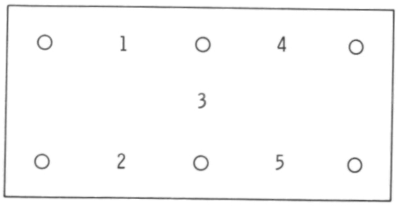


Figure 2. - Fueled plate showing scanning positions.

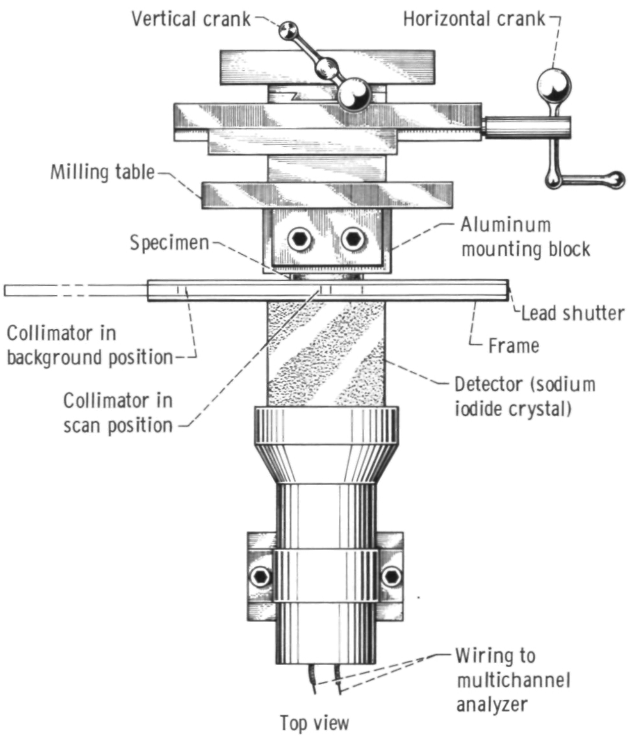


Figure 3. - Schematic of scanning system.

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