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EVALUATION OF PuO_2 HOMOGENEITY IN PuO_2-UO_2 FAST REACTOR FUEL BY SCANNING ELECTRON MICROPROBE

D. A. Stranik
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ABSTRACT

Quantitative characterization of a $(Pu_{0.25}U_{0.75})O_2$ fuel pellet matrix was accomplished by scanning pellets with an electron microprobe for PuO_2 concentration sizes of PuO_2 enriched or depleted zones and separation distance of such zones. Statistical analyses of the data indicated less than 1 percent probability of occurrence of zones with peak PuO_2 concentration greater than 50 wt% and less than 1 percent probability of occurrence of PuO_2 enriched or depleted zones having diameters greater than 50 microns. This technique enabled a mathematical model to be developed relating fuel pellet characteristics to a figure of merit which describes the homogeneity of mixed oxide fuel in terms of the degree of uniformity of energy deposition (or temperature rise) under reactor transient conditions in the UO_2 content of the fuel. By definition, the local figure of merit, M, at any point in the fuel is equal to the ratio of the local rate of deposition of energy as compared to that which would exist in a homogeneous fuel of average composition. Since the model used in the development of the figure of merit does not allow for diffusion of energy, the figure of merit represents the limiting thermal response of mixed oxide fuel under transient conditions. The model defines a term (D_x) as the product of the calculated local heat generation rate and local UO_2 concentration.

$$D_x = \left[K_3\ \overline{C_{PuO_{2_x}}} + K_4\ \overline{1-C_{PuO_{2_x}}}\right] C_{UO_{2_x}}$$

using

$$K_3 = \frac{1.9*}{1.9 + 0.05} \quad and \quad K_4 = \frac{0.05*}{1.9 + 0.05}$$

$$D_x = \left(0.026 + 0.948\ \overline{C_{PuO_{2_x}}}\right)\left(1-C_{PuO_{2_x}}\right)$$

$$M_x = \frac{D_x}{\overline{D}_x}$$

where $\overline{D}_x$ is that calculated for a homogeneous fuel.

A test was designed to verify the model and to determine the homogeneity of pellets with a wide range of homogeneities based upon previous alpha-autoradiogrphs. The powder preparation varied for the four pellets. Results of the test indicated that the approach was feasible.

In order for industry to use this model to establish homogeneity in the fuel for the FFTF, it was determined that the correlation between figure of merit and alpha-autoradiography would be developed. This would permit the utilization of a relatively inexpensive and simple test method. Standards were made having a range of figures of merit which were then alpha-autoradiographed. These standards of known homogeneity are compared to pellets with unknown homogeneity by using alpha-autoradiographs taken at the same time. From this visual comparison with the standards, a figure of merit for the unknown pellets can be determined. This method of relating the figure of merit to alpha-autoradiography makes the homogeneity specification feasible for industrial measurement and use.

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INTRODUCTION

Evaluation of the effect of variations of concentration within a mixed oxide fuel pellet on the Doppler coefficient and thermal performance requires knowledge of the sizes of plutonium enriched areas, plutonium concentrations and inter-area distances.

The purpose of this report is to provide the theory and the experimental data for measuring homogeneity of fuel pellets based on the functional performance requirements of the fuel in the reactor. The functional performance is the thermal response of the mixed oxide fuel under transient conditions.

Assessment of process capabilities for controlling fuel pellet homogeneity has been limited in the past by the lack of an accurate quantitative measurement method. The volume, the average concentration of plutonium in enriched or depleted zones, and interzone distances have an important effect on performance of the fuel pellet; therefore, these features should be determined by the measurement method. The alpha-autoradiography technique at its present stage of development does not provide the desired accuracy in determining the size of enriched or depleted zones, and provides no quantitative data concerning PuO_2 concentration of such zones.

SUMMARY

A method for quantitative measurement of fuel pellet homogeneity has been developed which in turn has permitted the development of an improved homogeneity specification.

Quantitative characterization of the fuel pellet matrix was accomplished by scanning the pellets with the electron microprobe for PuO_2 concentration, sizes of PuO_2 enriched or depleted zones, and separation distance of such zones.

Pellets from 23 sintered batches of fuel were sampled and analyzed. The $(Pu_{0.25}U_{0.75})O_2$ fuel pellets were fabricated from mechanically blended mixed oxides by ballmilling, pressing, and sintering. Three pellets from each batch were sectioned and scanned using the microprobe. Two were mounted as transverse sections and one as a longitudinal section. The pellets were 0.212 inch in diameter and 0.250 inch in length.

The microprobe data were used in establishing an additional homogeneity model based upon an oxide matrix representative of typical production control capabilities and including the effects of localized heating due to zones of varying size, enrichment, and segregation.

Statistical analyses of the data indicate less than 1 percent probability of occurrence of zones with peak PuO_2 concentrations greater than 50 wt% and less than 1 percent probability of occurrence of enriched or depleted PuO_2 zones having diameters greater than 50 microns.

This mathematical model relates fuel pellet characteristics to a figure of merit which describes the homogeneity of mixed oxide fuel in terms of the degree of uniformity of energy deposition (or temperature rise) under transient conditions in the UO_2 content of the fuel. By definition, the local figure of merit, M, at any point in the fuel is equal to the ratio of the local rate of energy deposition at that point as compared

to that which would exist in a homogeneous fuel of average composition. Since the model used in the development of the figure of merit does not allow for diffusion of energy, the figure of merit represents the limiting thermal response of UO_2 + PuO_2 fuel under transient conditions. A mean value of M of 0.9 was established as meeting FTR requirements.

Microprobe data from three $(Pu_{0.25}U_{0.75})O_2$ fuel pellets with three different degrees of homogeneity were analyzed to test the model. The powder preparation was varied for the four pellets; Pellet 1 was wet ballmilled ∿16 hours, Pellet 2 was dry ballmilled ∿40, Pellet 3 was dry ballmilled ∿20, and Pellet 4 was dry ballmilled ∿10 hours. Results of the test indicate that the four pellets were greater than $\overline{M}$ = 0.95.

DESIGN OF TESTS

Two tests were designed in order to derive the homogeneity model. The first test was designed to determine quantitatively by use of the scanning electron microprobe PuO_2 concentrations, sizes of PuO_2 enriched or depleted zones and the frequency of occurrence. The pellets were irradiation test pellets taken from 23 sintering batches. From the data, a theoretical homogeneity model was established based on heat generation rates and energy disposition within the UO_2-PuO_2 pellets. A second test was designed to verify the model and to determine the homogeneity of several pellets with a wide range of homogeneities based on alpha-autoradiographs.

DISCUSSION

EXPERIMENTAL PROCEDURE

Pellets from 23 sintering batches were selected at random for electron microprobe analyses. The $(Pu_{0.25}U_{0.75})O_2$

fuel pellets were fabricated from mechanically blended mixed oxides, ballmilling, binder addition, pressing, and sintering. Three pellets from each batch were sectioned, polished, and scanned using the microprobe. Two pellets from each sintering batch were mounted as transverse sections and one as a longitudinal section. The pellets were approximately 0.212 inch in diameter and 0.250 inch in length.

The microprobe measurements were obtained using a 1 micron beam diameter and a scanning speed sufficiently slow to eliminate errors due to instrument response time. The narrow beam was used in order to reduce the averaging effect of larger size beams and to better resolve concentration gradients.

The intensity of characteristic X-rays of plutonium and uranium was measured and related quantitatively to percent PuO_2 and UO_2 in the volume of material excited by the electron beam. This volume is in the order of 1 to 1.5 cubic microns.

An electron microprobe, MAC Model 400 S/N 110 was used having three X-ray spectrometers with separate counting channels. The focusing crystals measured X-rays with wave lengths in the 3.4 to 4.2 angstrom range.

A simultaneous reading of peak and background X-ray counts were recorded for plutonium and uranium X-ray. This was done by reading the background on a third spectrometer and relating this background to the background of plutonium and uranium X-rays on the other spectrometers. The relationship of the third spectrometer background reading 4.1583 angstroms to Spectrometer 1 and 2 was as follows:

Background Spectrometer 1 = 3.5 + 0.345 (Spectrometer 3)

Background Spectrometer 2 = 3.5 + 0.827 (Spectrometer 3).

These equations were found by plotting the average plutonium background and average uranium background versus Spectrometer 3 background for various specimen current on a PuO_2-UO_2 pellet. The average plutonium background was found by averaging readings at 1.270 and 1.370 on a LiF calibrated scale using an ADP crystal. The average uranium background was found by averaging readings at 1.450 and 1.520 on a LiF calibrated scale using an ADP crystal. The X-ray intensity from the third spectrometer was measured at a setting of 1.916 on a LiF calibrated scale using a PET crystal. A minimum of five sets of X-ray intensity readings were measured at any one specimen current setting. Five different specimen current settings were used. The detector high voltage was changed for one of the channels to achieve linearity.

The uranium Mα (3.924 angstroms) was measured on Spectrometer 1, plutonium Mβ (3.515 angstroms) on Spectrometer 2, and the background on the third spectrometer.

An accelerating voltage in the range of 15 to 30 kV was used. Interference from high order L lines was eliminated by pulse height analysis.

The relationship of plutonium and uranium concentration to the measured relative M line intensities was found to be linear with no correction needed for absorption, fluorescence, or atomic number. Other investigators have also found this linearity.[1,2]

For the 10 second counting duration there is a 95 percent confidence that 95 percent of the measured X-ray intensities for a 25 wt% sample will be between the following limits, assuming a purely homogeneous matrix:

Counts/sec	wt%
1000	24.50 to 25.50
2000	24.65 to 25.35
4000	24.75 to 25.25

The results of the scans were printed out on charts for analyses. The data were obtained from the charts by recording the PuO_2 concentration and size of each indicated enriched or plutonium depleted zone.

EXPERIMENTAL RESULTS

Pellets from 23 sintered batches of fuel were sampled and analyzed. The $(Pu_{0.25}U_{0.75})O_2$ fuel pellets were fabricated from mechanically blended mixed oxides by ball-milling, pressing, and sintering. Three pellets from each batch were sectioned and scanned using the microprobe. Two were mounted as transverse sections and one as a longitudinal section. The pellets were 0.212 inches in diameter and 0.250 inches in length.

The data printed on strip charts were analyzed by determining the concentration of plutonium enriched zones within the pellet, the size of the PuO_2 enriched or depleted zones at the matrix composition of 25 wt%,and the separation distance of such zones.

The mathematical model for the three-dimensional graph of weight percent PuO_2, width of peak at 25 percent PuO_2 and frequency of occurrence showing the probability of PuO_2 distribution within a pellet is given below: Let the two-dimensional random variable (x,y) have the joint density

$$f(x,y) = \frac{1}{2\Pi\ \sigma_x\sigma_y\ 1-\rho^2}\ e^{-\frac{1}{2(1-\rho^2)}\left[\left(\frac{x-\mu_x}{\sigma_x}\right)^2 - 2\rho\left(\frac{x-\mu_x}{\sigma_x}\right)\left(\frac{y-\mu_y}{\sigma_y}\right) + \left(\frac{y-\mu_y}{\sigma_y}\right)^2\right]}$$

$$-\infty < \chi < \infty,$$
$$-\infty < \chi < \infty,$$

where σ_x, σ_y, μ_x, μ_y, ρ are constants such that

$$-1 < \rho < 1, \qquad -\infty < \mu_x < \infty,$$
$$0 < \sigma_x,$$
$$0 < \sigma_y, \qquad -\infty < \mu_y < \infty,$$

Then the random variable is said to have a bivariate normal distribution.

The bivariate normal distribution of interest is the one for the following two variables:

$x = \log_e$ (width of peak at 25 percent concentration)

y = wt% concentration

Estimates for the constants were obtained from the analysis of microprobe measurements made on ten samples from a series of 23 sintering batches of fuel pellets with 25 wt% PuO_2 concentration. The estimates are:

$$\hat{\mu}_x = 0.223 \qquad \hat{\sigma}_x = 0.916 \qquad \hat{\rho} = -0.0632$$

$$\hat{\mu}_y = 25.0 \qquad \hat{\sigma}_y = 7.0$$

The shape of this three dimensional graph is shown in Figure 1.

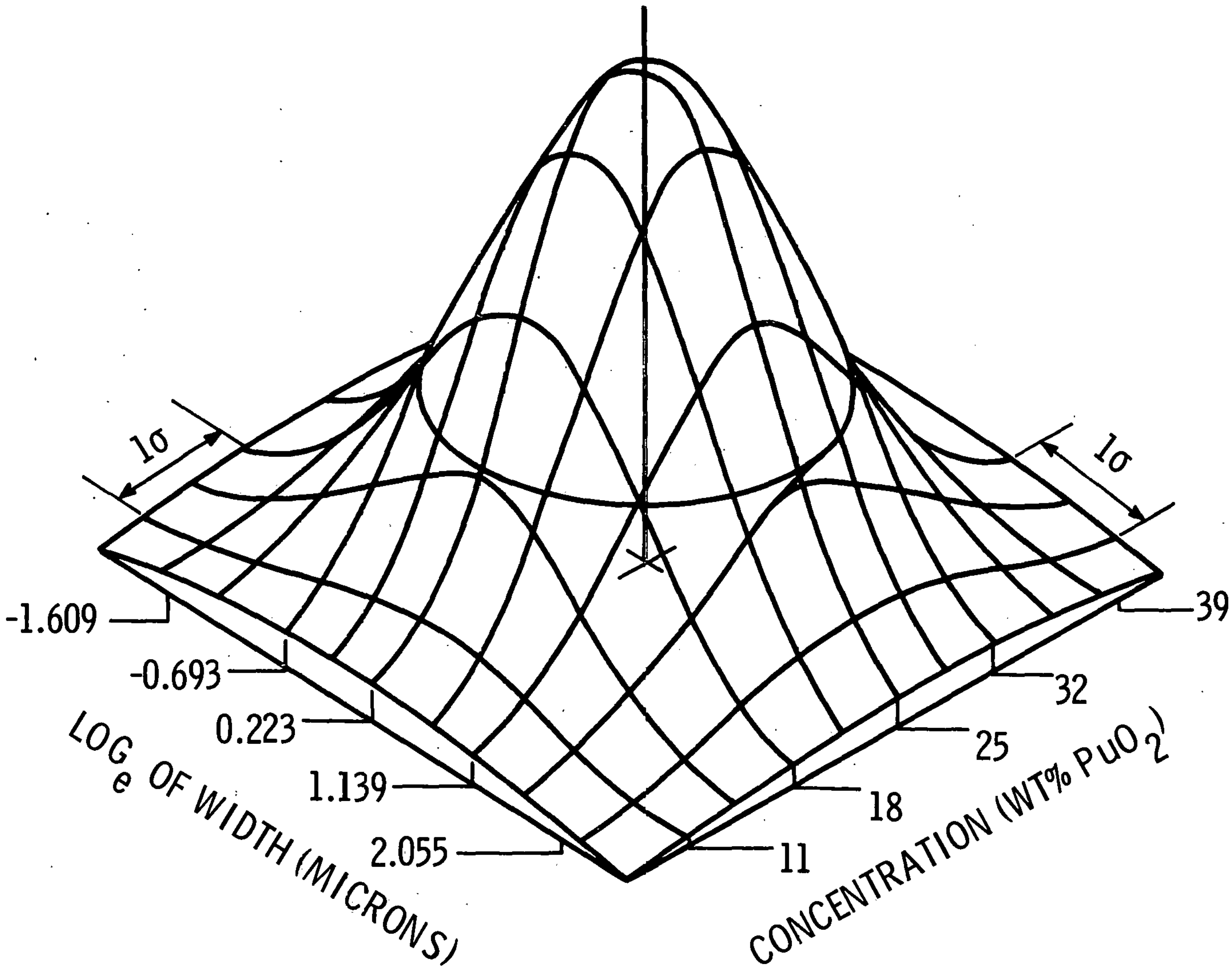

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FIGURE 1. Probability of Fuel Distribution Within Pellet

Statistical analyses of the data indicate less than 1 percent probability of occurrence of zones with peak PuO_2 concentrations greater than 50 wt%. They show less than 1 percent probability of occurrence of enriched or depleted zones having diameters greater than 50 microns. Thus, the fuel was acceptable 99% of the time using a 50 micron particle size specification.

As a result of this work it was determined that a quantitative analysis of the fuel relating to the functional performance of the fuel within the reactor could be obtained. Thus, a mathematical model was developed describing the homogeneity of the mixed oxide fuel as a function of energy deposition within the fuel.

HOMOGENEITY MODEL

The mathematical model developed relates fuel pellet characteristics to a figure of merit. The figure of merit describes the homogeneity of mixed oxide fuel in terms of the degree of uniformity of energy deposition (or temperature rise) under transient conditions in the UO_2 content of the fuel. By definition, *(the local figure of merit, M, at any point in the fuel is equal to the calculated relative rate of energy deposition at that point divided by the deposition rate which would exist in a homogeneous fuel of average composition).* Since the model used in the development of the figure of merit does not allow for diffusion of energy, the figure of merit represents the limiting thermal response of mixed oxide fuel under transient conditions. The model defines a term (D_x) as the product of the calculated local heat generation rate and local UO_2 concentration. A figure of merit (M) is obtained by dividing D_x by an equivalent term $\overline{D_x}$ which is calculated for a theoretically homogeneous fuel.

D_x is defined as: $D_x = K_1 \times \dot{E}_x \times C_{UO_2}$ (1)

where

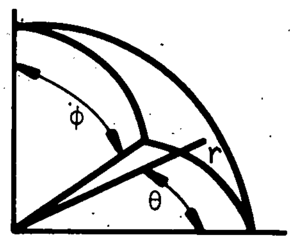
$\dot{E}_x$ = energy deposition rate at point x

The rate of temperature rise at point x is assumed to be directly proportional to $\dot{E}_x$; i.e., the heat capacity of the fuel is constant.

Equation (1) can be rewritten:

$$D_x = K_1 \cdot K_2 \cdot \overrightarrow{FP_x} \cdot C_{UO_{2_x}} \qquad (2)$$

Calculation of FP for UO_2-PuO_2 Fuel



$$d\,\overrightarrow{FP_x} = \frac{K_3 C_{PuO_2}(r,\theta,\phi) + K_4 C_{UO_2}(r,\theta,\phi) \cdot r^2 \sin\phi\, dr\, d\theta\, d\phi}{4\pi r^2}$$

where K_3 and K_4 are constants proportional to the fission cross section of uranium and plutonium, or

$$d\,\overrightarrow{FP_x} = \left[K_3 \overline{C_{PuO_2}}(r) + K_4 \left(1-\overline{C_{PuO_2}}\right)(r)\right] d\,r \qquad (3)$$

where $\overline{C_{PuO_2}}(r)$ is the average PuO_2 content at radius r.

On the basis the fission product track length is 10 microns and energy deposition is uniform along the track and integrating Equation 3 between r = 0 and r = +10 microns

$$\overrightarrow{FP_x} = K_3 \overline{C_{PuO_{2_x}}} + K_4 \left(1-\overline{C_{PuO_{2_x}}}\right) \tag{4}$$

where $\overline{C_{PuO_{2_x}}}$ = average PuO_2 content along a diameter of a 20 micron sphere centered at point x.

Substituting Equation (4) in (2)

$$D_x = \left[K_3 \overline{C_{PuO_{2_x}}} + K_4 \; 1-\overline{C_{PuO_{2_x}}}\right] C_{UO_{2_x}}$$

using $K_3 = \frac{1.9*}{1.9+0.05}$ and $K_4 = \frac{0.05*}{1.9+0.05}$

$$D_x = \left[0.974 \overline{C_{PuO_{2_x}}} + 0.026 \left(1-\overline{C_{PuO_{2_x}}}\right)\right] C_{UO_{2_x}}$$

$$D_x = \left(0.026 + 0.948 \overline{C_{PuO_{2_x}}}\right)\left(1-C_{PuO_{2_x}}\right) \tag{5}$$

where $\overline{C_{PuO_{2_x}}}$ = average PuO_2 content along a diameter of a 20 micron sphere centered at point x.

Thus, for homogeneous fuel,

$$\overline{D_x} = \left(0.026 + 0.948 \overline{\overline{C_{PuO_2}}}\right)\left(1-\overline{\overline{C_{PuO_2}}}\right) \tag{6}$$

where $\overline{\overline{C_{PuO_2}}}$ is the PuO_2 content of the homogeneous mixed oxide fuel.

---

* Effective fission cross sections for fissile and fertile atoms in FFTF.

The relationship between $\overline{\overline{C_{PuO_2}}}$ and $\overline{D}_x$ is shown in Figure 2.
By definition,

$$M_x = \frac{D_x}{\overline{D_x}} \qquad (7)$$

where M is the local figure of merit at point x
and

$$\bar{M} = \frac{1}{N} \sum_{N} \frac{D_x}{\overline{D_x}} \qquad (8)$$

where $\overline{M}$ is the average figure of merit for N determinations.

The value of $\overline{C_{PuO_{2_x}}}$ calculated for any point x on the microprobe trace will be conservative in terms of using Equation (2) to establish a distribution curve for D_x values since the "observed" value of $\overline{C_{PuO_{2_x}}}$ will statistically vary about the true mean value of $\overline{C_{PuO_{2_x}}}$ for a hypothetical 20 micron diameter sphere centered at point x.

This statistical variation will result in an increased spread in the calculated M_x values used to establish a distribution curve

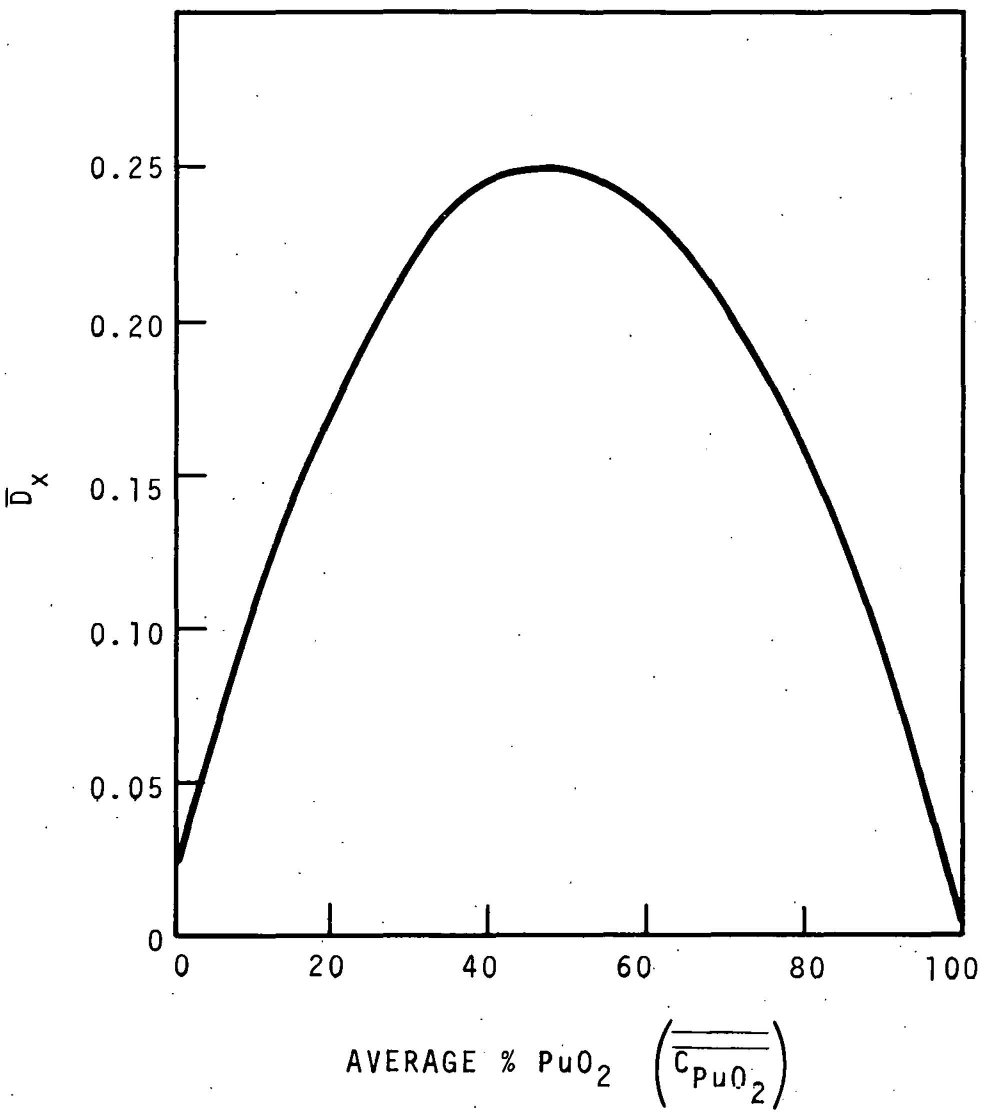


FIGURE 2. Variation of $\overline{D_x}$ with Plutonium Concentration in UO_2-PuO_2 Fuel Pellets

Figure 3 illustrates the type of M_x distribution curve to be expected from a heterogeneous pellet. Two properties of the curve can be used to describe homogeneity requirements: (1) the value of M, and (2) the fraction of M_x values which falls within a specified limit about $\overline{M}$.

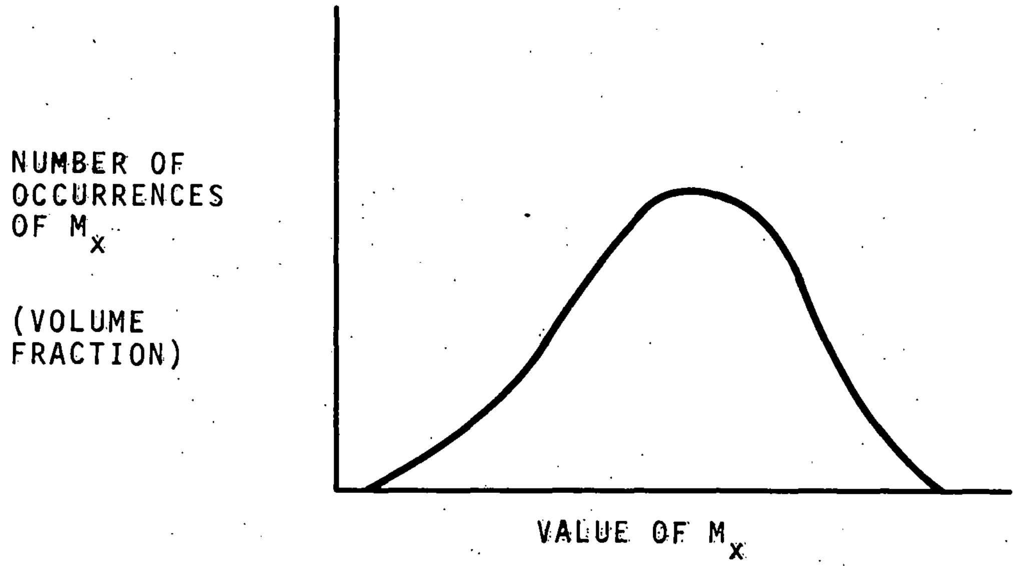
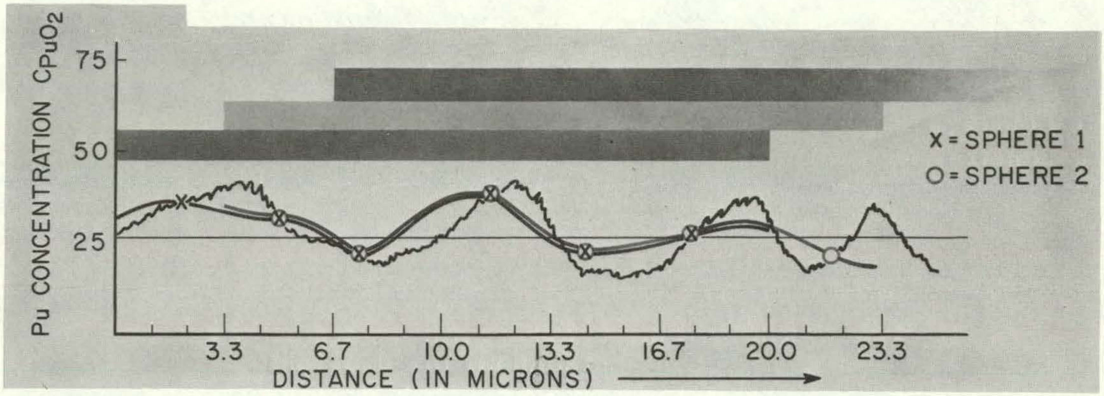


FIGURE 3. Hypothetical Distribution Curve for Figure of Merit M_x in a Heterogeneous UO_2-PuO_2 Fuel Pellet

EXPERIMENTAL RESULTS OF MODEL

The microprobe data from three $(Pu_{0.25}U_{0.75})O_2$ fuel pellets with four different degrees of inhomogeneity were analyzed according to the homogeneity model given above. Pellet 1 was wet ballmilled ~16 hours, Pellet 2 was a typical irradiation test pellet used in PNL-3 fuel pins, dry ballmilled ~40 hours, Pellet 3 was dry ballmilled ~20 hours. Pellet 4 was dry ballmilled ~10 hours. The microprobe traces were analyzed for the average PuO_2 content ($\overline{C_{PuO_2}}$) along 20 micron increments centered at 3.3 micron intervals, and the actual PuO_2 content ($C_{PuO_{2x}}$) at the center of each 20 micron increment (Figure 4).



$$\bar{C}_{PuO_2 \, X(\text{SPHERE 1}) \, 0\mu \text{ TO } 20\mu} \quad \left[\bar{C}_{PuO_2}\Big|_{0}^{3.3} + \bar{C}_{PuO_2}\Big|_{3.3}^{6.7} + \bar{C}_{PuO_2}\Big|_{1.7}^{10.0} + \bar{C}_{PuO_2}\Big|_{10.0}^{13.3} + \bar{C}_{PuO_2}\Big|_{13.3}^{16.7} + \bar{C}_{PuO_2}\Big|_{16.7}^{20.0} \right] \Big/ 6$$

$$C_{PuO_2 \, X(\text{SPHERE 1})} = \text{CONCENTRATION } PuO_2 \text{ WHERE } X = 10 \text{ (SPHERE 1)}$$

$$\bar{C}_{PuO_2 \, O(\text{SPHERE 2})} \quad \left[\bar{C}_{PuO_2}\Big|_{3.3}^{6.7} + \bar{C}_{PuO_2}\Big|_{6.7}^{10.0} + \bar{C}_{PuO_2}\Big|_{10.0}^{13.3} + \bar{C}_{PuO_2}\Big|_{13.3}^{16.7} + \bar{C}_{PuO_2}\Big|_{16.7}^{20.0} + \bar{C}_{PuO_2}\Big|_{20.0}^{23.3} \right] \Big/ 6$$

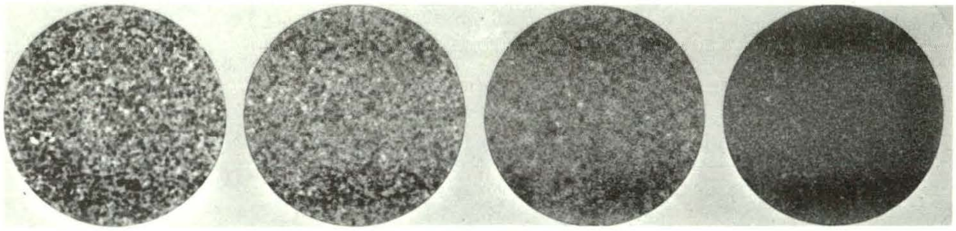
$$C_{PuO_2 \, O(\text{SPHERE 2})} = \text{CONCENTRATION } PuO_2 \text{ WHERE } X = 13.3 \text{ (SPHERE 2)}$$

FIGURE 4. Plutonium Concentration for Theoretic 20 Micron Sphere

The pellets were identified as 4, 3, 2 and 1, and ranged from least homogeneous to most homogeneous, respectively. Alpha-autoradiographs of these pellets are shown in Figure 5. Analyses of the microprobe traces yielded the following data for each pellet.

Pellet Identification	$\overline{M}$	$\sigma_{\overline{M}}$
1	1.0000	0.01726
2	0.9962	0.06404
3	0.9877	0.12986
4	0.96645	0.19295

Results of the test thus indicate that the four pellets were greater than $\overline{M}$ = 0.95. The model also proved that the homogeneity specification could be opened up by use of the figure of merit technique. The M_x frequency distribution histograms for each pellet are shown in Figure 6, 7, 8, and 9.



4 3 2 1

FIGURE 5. Homogeneity Results

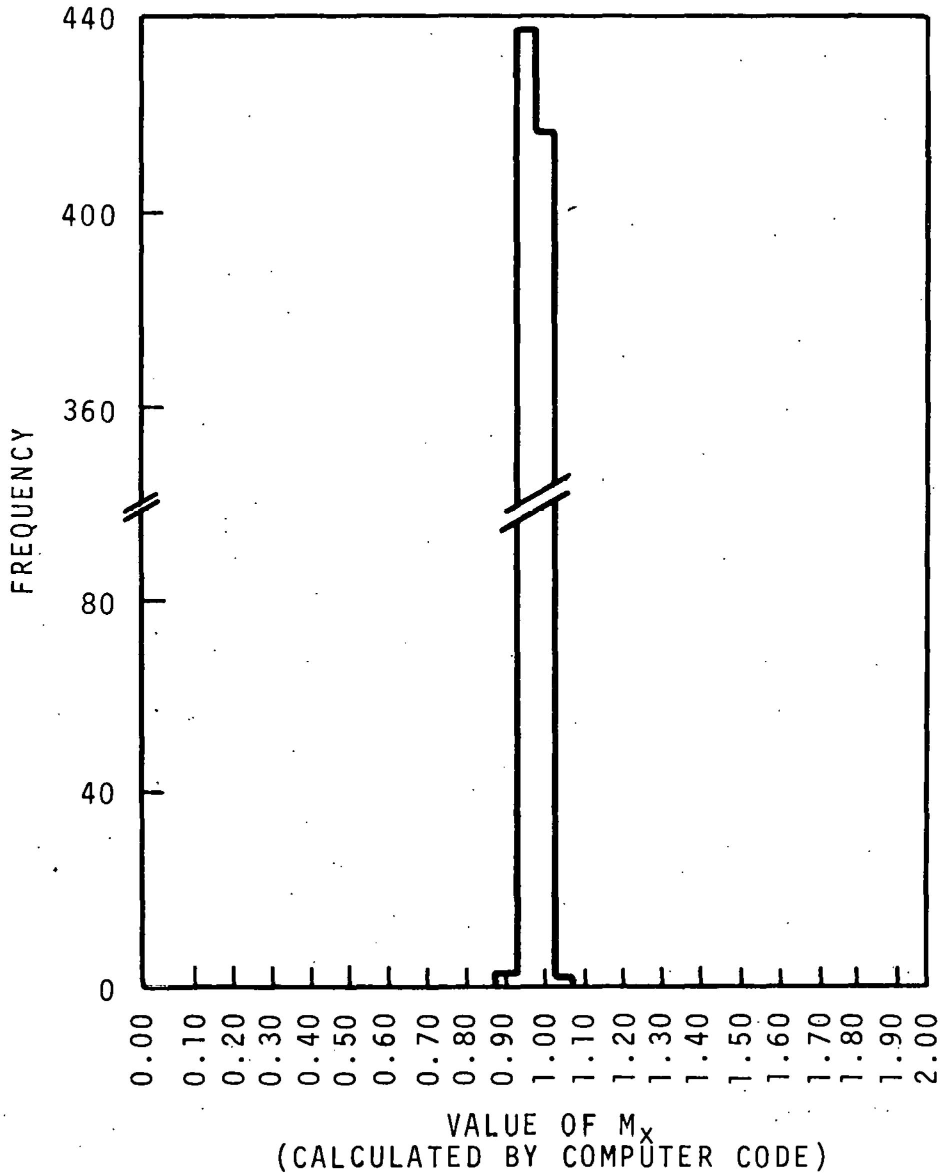


FIGURE 6. Figure of Merit Distribution for Pellet 1

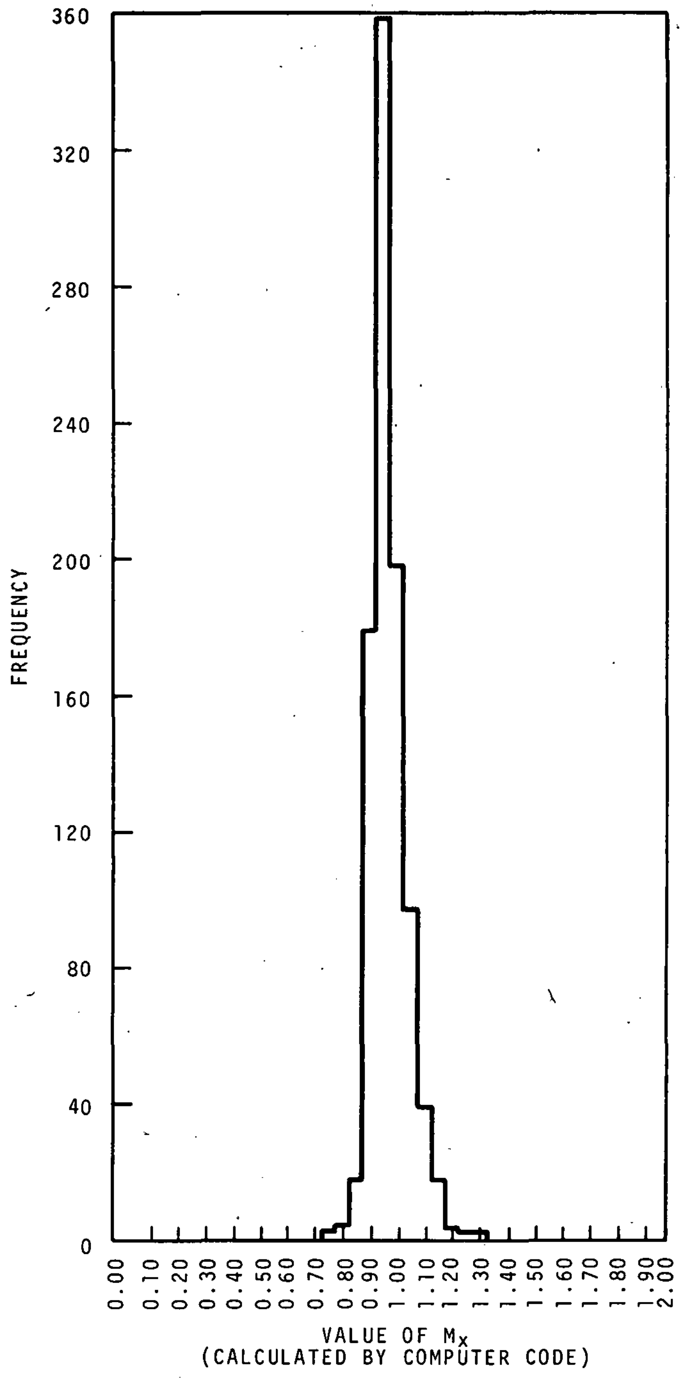


FIGURE 7. Figure of Merit Distribution for Pellet 2

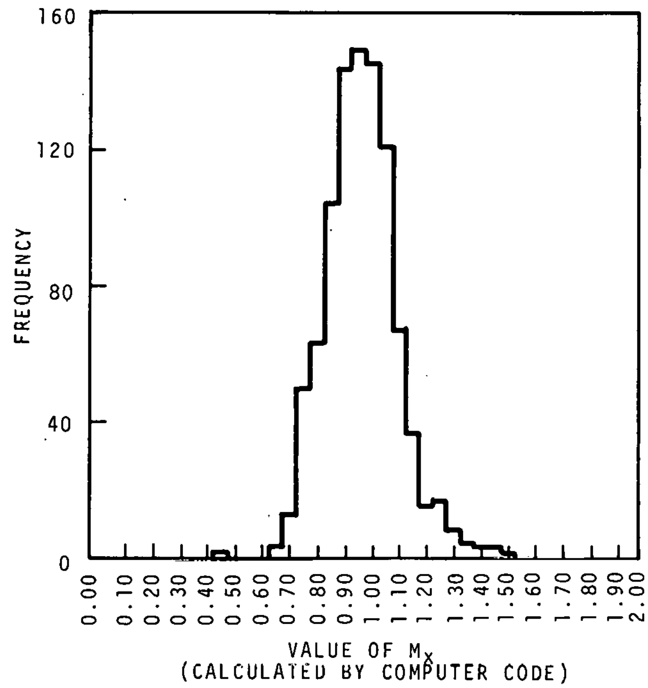


FIGURE 8. Figure of Merit Distribution for Pellet 3

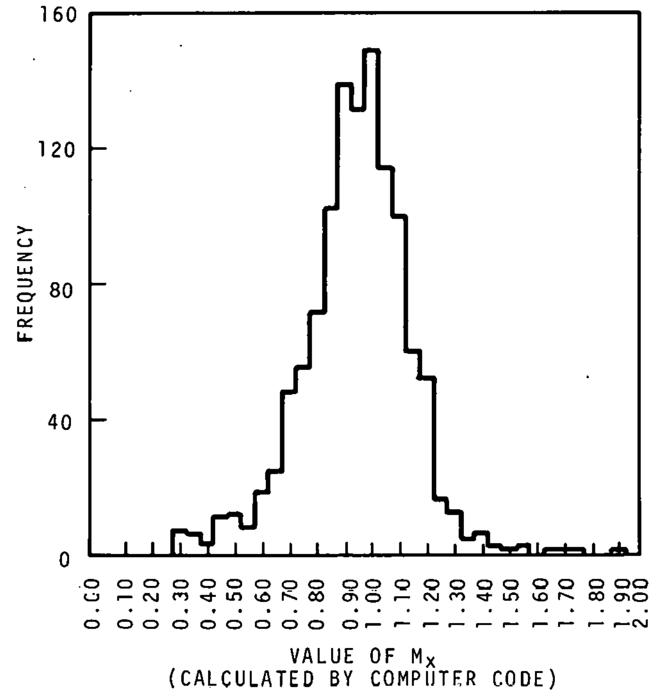


FIGURE 9. Figure of Merit Distribution for Pellet 4

APPLICATION OF HOMOGENEITY MODEL

A computer code was written to calculate the figure of merit of fuel pellets. The code converts the data from the microprobe punch tape into the computer program and calculates the figure of merit. The computer code and the explanations as to the specific functions of the statements in the computer code are given in the Appendix.

In order for industry to use this figure of merit model to establish homogeneity in the reactor fuel, it was determined that the correlation between figure of merit and alpha-autoradiography would be developed. This would permit the utilization of a relatively inexpensive and simple test method. Standards were made having a range of figures of merit which were then alpha-autoradiographed. These standards of known homogeneity are compared to pellets with unknown homogeneity by using alpha-autoradiographs taken at the same time. From this visual comparison with the standards, a figure of merit for the unknown pellets can be determined (see Figure 10). This method of relating the figure of merit to alpha-autoradiography makes the homogeneity specification feasible for industrial measurement and use.

CONCLUSIONS

1. Quantitative characterization of a UO_2-PuO_2 fuel pellet matrix can be accomplished by scanning pellets with an electron microprobe for PuO_2 concentration sizes of PuO_2 enriched or depleted zones, and separation distance of such zones. Statistical analyses of the data indicated less than 1 percent probability of occurrence of zones with peak PuO_2 concentration greater than 50 wt%, and less than 1 percent probability of occurrence of PuO_2 enriched or depleted zones having diameters greater than 50 microns.

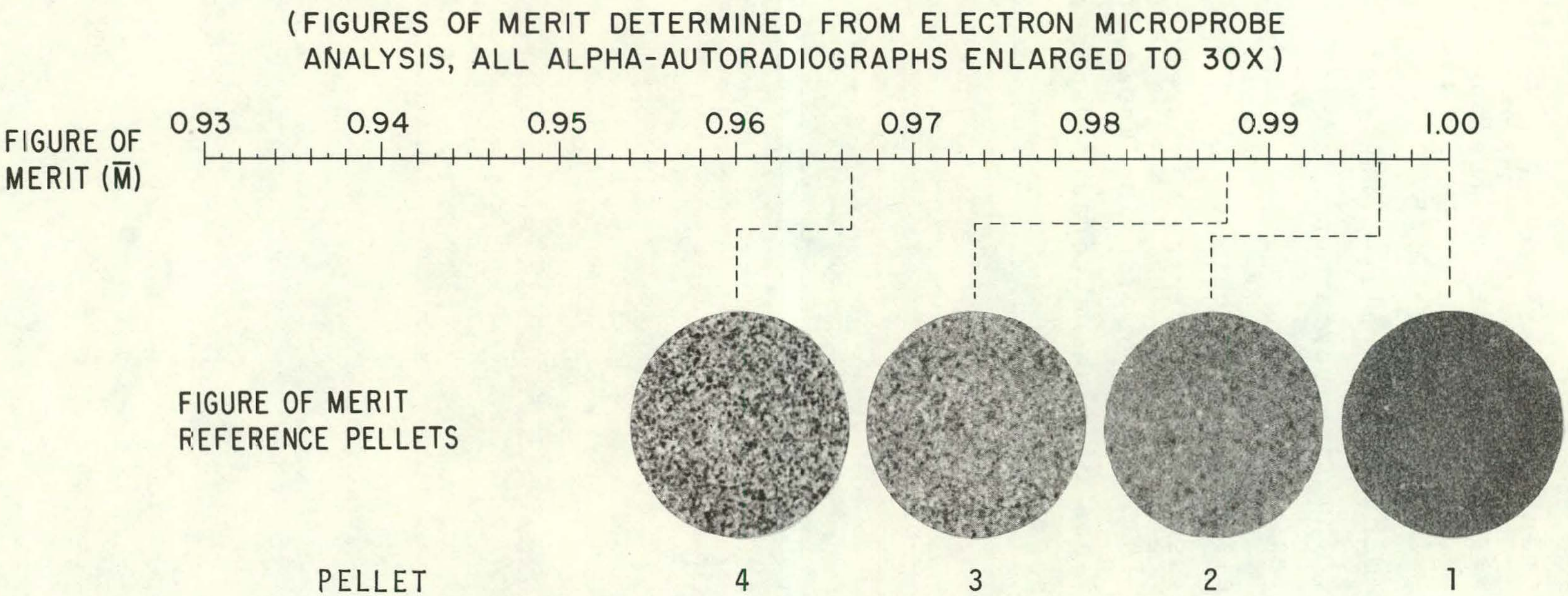


FIGURE 10. Determination of Fuel Pellet Homogeneity Using Figure of Merit Reference Pellets

2. The figure of merit mathematical model is a very good quantitative way to determine the fuel pellet homogeneity using the scanning electron microprobe.

3. The figure of merit model relates the fuel pellet homogeneity to the function performance of in-reactor energy deposition rates.

4. A feasible, relatively inexpensive and simple test method can be used for industrial measurement of fuel homogeneity. This consists of using known standards and visual comparisons of alpha-autoradiographs of unknown pellets and the standards.

ACKNOWLEDGMENTS

The authors wish to acknowledge the efforts of B. Y. Katayama and R. D. Nelson for performing the microprobe work. The mathematics model of the three dimensional graph is largely due to the efforts of R. L. Buschbom.

The development and debugging of the computer code were achieved under the leadership of R. L. Buschbom and J. D. Robinson.

Making the standards and coordinating the running of the standards to obtain the figures of merit are due to the efforts of T. E. Stallwood and J. D. Robinson.

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APPENDIX

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@IT FR5,* MAIN,MAIN
UNIVAC 1108 FORTRAN V LEVEL   2206 0009 F600A - CSC005
THIS COMPILATION WAS DONE ON 25 SEP 70 AT 12:13:25

 MAIN PROGRAM

 STORAGE USED (BLOCK, NAME, LENGTH)

      0001   *CODE    000010
      0000   *DATA    000001
      0002   *BLANK   000000

 EXTERNAL REFERENCES (BLOCK, NAME)

      0003   PTCNV
      0004   PROBE2
      0005   EXIT
      0006   NSTOP$

 STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)



     1.  00101        CALL PTCNV
     2.  00103        CALL PROBE2                                                  *NEW
     3.  00104        CALL EXIT
     4.  00105        END

       END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
 PHASE 1 TIME =   0 SEC.
 PHASE 2 TIME =   0 SEC.
 PHASE 3 TIME =   0 SEC.
 PHASE 4 TIME =   0 SEC.
 PHASE 5 TIME =   0 SEC.
 PHASE 6 TIME =   0 SEC.

 TOTAL COMPILATION TIME =   0  SEC
     MAIN            SYMBOLIC                        14 NOV 69  04:50:46   0   00526206    28     3 (DELETED)
     MAIN    CODE    RELOCATABLE                     14 NOV. 69 04:50:46   1   00526122    48     1 (DELETED)
                                                                           0   00526152    28     2
```

A-1

```
@IT  FR5  PROBE,PROBE
UNIVAC 1108 FORTRAN V LEVEL   2206 0009 F600A - CSC005
THIS COMPILATION WAS DONE ON 25 SEP 70 AT 12:13:26

  SUBROUTINE PROBE      ENTRY POINT 000502

             PROBE2     ENTRY POINT 000534

  STORAGE USED (BLOCK, NAME, LENGTH)

        0001    *CODE    000537
        0000    *DATA    004045
        0002    *BLANK   000000
        0003    UGH      003737
        0004    CHIT     007641
        0005    AUD      007640

  EXTERNAL REFERENCES (BLOCK, NAME)

        0006    OFFSET
        0007    NRDU$
        0010    N101$
        0011    N102$
        0012    NPRT$
        0013    NERR3$

  STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

  0001     000122 10L       0000     004003 102F      0000     003747 11F       0000     003774 12F       0001     000034 142G
  0000     003743 2F        0001     000172 20L       0001     000376 250L      0001     000206 30L       0001     000044 300L
  0001     000012 301L      0000     003746 4F        0000 R 003735 AA        0000 R 003741 AAX       0004 R 000000 AX
  0005 R 000000 AXX       0000 R 003736 BB        0000 R 003740 BBX       0004 R 003720 BX        0005 R 003720 BXX
  0003     000000 DATA      0000 R 000000 F         0000 R 003742 FRAC      0004 R 007640 FRAC2     0003 R 003723 HEAD
  0000 I 003722 I         0000 I 003727 IJ        0000 I 003734 I$        0000 I 003721 J         0000 I 003724 L
  0000 I 003725 LL        0000 I 003720 M         0000 I 003723 MM        0000 I 003726 MODE      0000 R 003737 P
  0003 R 003721 QINC      0003 R 003720 SCALE     0000 R 003730 VA1       0000 R 003731 VA2       0000 R 003732 VB1
  0000 R 003733 VB2       0003 R 003722 XNEG

   (1)  00101          SUBROUTINE PROBE(A,B,C,D)
   2.   00103          COMMON /UGH/ DATA(2000),SCALE,QINC,XNEG,HEAD(12)
   3.   00104          COMMON /CHIT/ AX(2000),BX(2000),FRAC2
```

```
00105          COMMON/ADD/AXX(2000), BXX(2000)
00106          DIMENSION F(2000)
00107          DATA M/0/,J/0/,I/0/,MM/0/,L/0/,LL/0/
00116          DATA MODE/0/,IJ/0/
00121   2      FORMAT(4F10.0/12A6)
00122   4      FORMAT()
00123   11     FORMAT('1' 5X'SPECTROMETER 1' 9X'SPECTROMETER 2' 9X'PERCENT U02'10
00123         *X'PERCENT PU02'8X'NORMALIZED U02'7X'NORMALIZED PU02'//)
00124      12  FORMAT(5X,1PE13.4,10X,1PE13.4,4(8X,1PE13.4))
00125          IF (IJ.EQ.5) GO TO 301
00127          IJ=IJ+1
00130          RETURN
00131   301    CONTINUE
00132          IF (MODE.EQ.1) GO TO 300
00134          READ(5,2) VA1,VA2,VB1,VB2,HEAD
00146          PRINT 11,
00150   300    MODE=1
00151          IF (M.GT.10) GO TO 30
00153          IF (M.EQ.10) GO TO 10
00155          M=M+1
00156          IF (A.LT.2..OR.C.LT.2.) RETURN
00160          MM=MM+1
00161          AA=AA+1.*A-(VA1+VA2*C)
00162          RETURN
00163   10     IF (L.EQ.10) GO TO 20
00165          L=L+1
00166          IF (B.LT.2..OR.C.LT.2.) RETURN
00170          LL=LL+1
00171          BB=BB+1.*B-(VB1+VB2*C)
00172          RETURN
00173   20     AA=AA/MM
00174          BB=BB/LL
00175          M=11
00176   30     IF (A.LT.2..OR.B.LT.2..OR.C.LT.2.) RETURN
00200          IF (D.LT.400..OR.D.GE.500.) RETURN
00202          I=I+1
00203          BX(I)=100.*(1.*B-VB1-VB2*C)/BB
00204          AX(I)=100.*(1.*A-VA1-VA2*C)/AA
00205          F(I)=100. / (AX(I) + BX(I))
00206          AXX(I)=AX(I) * F(I)
00207          BXX(I)=BX(I) * F(I)
00210          IF (BX(I).LT.0..OR.AX(I).LT.0.) GO TO 250
00212          P=P+BXX(I)
00213          PRINT 12, A,B,AX(I),BX(I),AXX(I),BXX(I)
00223          BBX=BBX+BX(I)
00224          AAX=AAX+AX(I)
00225          RETURN
00226   250    I=I-1
00227          RETURN
```

```
   53.  00230            ENTRY PROBE2
   54.  00231            READ(5,2) SCALE,QINC,XNEG
   55.  00236            FRAC=BBX/I
   56.  00237            FRAC2=P/I
   57.  00240            PRINT 102,  FRAC,FRAC2
   58.  00244   102      FORMAT(//5X,'NON-NORMALIZED PUO2 AVG.'1PE13.4,'     NORMALIZED PUO2
   59.  00244           1 AVG.'1PE13.4)
   60.  00245            FRAC2=FRAC2/100.
   61.  00246            CALL OFFSET(I)
   62.  00247            RETURN
   63.  00250            END

       END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
 PHASE 1 TIME =   0 SEC.
 PHASE 2 TIME =   0 SEC.
 PHASE 3 TIME =   0 SEC.
 PHASE 4 TIME =   0 SEC.
 PHASE 5 TIME =   0 SEC.
 PHASE 6 TIME =   0 SEC.

 TOTAL COMPILATION TIME =   1  SEC
    PROBE           SYMBOLIC                      14 NOV 69  04:51:03  0  00531654   28   11 (DELETED)
    PROBE   CODE    RELOCATABLE                   14 NOV 69  04:51:03  1  00531446   72    1 (DELETED)
                                                                       0  00531512   28    7
```

```
WIT  FR5  OFFSET,OFFSET
UNIVAC 1108 FORTRAN V LEVEL   2206 0009 F600A - CSC005
THIS COMPILATION WAS DONE ON 25 SEP 70 AT 12:13:27

   SUBROUTINE OFFSET    ENTRY POINT 000125

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001    *CODE    000145
         0000    *DATA    003762
         0002    *BLANK   000000
         0003    UGH      003737
         0004    CHIT     007641
         0005    ADD      007640

   EXTERNAL REFERENCES (BLOCK, NAME)

         0006    HISTO
         0007    NWDU$
         0010    NIO2$
         0011    NIO1$
         0012    NERR3$

   STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

   0001   000004 110G      0001   000016 115G      0001   000064 136G      0001   000076 144G      0000   003730 19F
   0000   003735 30F       0004   000000 AX        0005 R 000000 AXX       0004   003720 BX        0005 R 003720 BXX
   0000 R 000000 D         0003 R 000000 DATA      0000 R 003726 F         0004 R 007640 FRAC2     0003   003723 HEAD
   0000 I 003720 J         0000 I 003721 JK        0000 I 003727 K         0000 I 003723 L         0003   003721 GINC
   0003   003720 SCALE     0003   003722 XNEG      0000 R 003725 XY        0000 R 003724 YX        0000 R 003722 Z

    1.   00101         SUBROUTINE OFFSET(I)
    2.   00103         COMMON /UGH/ DATA(2000),SCALE,GINC,XNEG,HEAD(12)
    3.   00104         COMMON /CHIT/ AX(2000),BX(2000),FRAC2
    4.   00105         COMMON/ADD/AXX(2000), BXX(2000)
    5.   00106         DIMENSION D(2000)
    6.   00107         DO 10J=11,I
    7.   00112         JK=J-10
    8.   00113         Z=0.
    9.   00114         DO 11 L=JK,J
   10.   00117         Z=Z + BXX(L)
```

```
00120  11     CONTINUE
00122         Z=Z/1100.
00123         YX       = AXX(J-5) / 100.
00124         XY= BXX(J-5) / 100.
00125         D(JK)=(.026+.948*Z)*(1.-XY)
00126  10     CONTINUE
00130         F=(.026+.948*FRAC2)*(1.-FRAC2)
00131         I=I-10
00132         WRITE(6,19)
00134  19     FORMAT(21H1      FIGURE OF MERIT,//)
00135         DO 20J=1,I
00140  20     DATA(J)=D(J)/F
00142         WRITE(6,30)  (DATA(K),K=1,I)
00150  30     FORMAT(10(1PE13.4))
00151         CALL HISTO(I)
00152         RETURN
00153         END

     END OF UNIVAC 1108 FORTRAN V COMPILATION.     0 *DIAGNOSTIC* MESSAGE(S)
PHASE 1 TIME =   0 SEC.
PHASE 2 TIME =   0 SEC.
PHASE 3 TIME =   0 SEC.
PHASE 4 TIME =   0 SEC.
PHASE 5 TIME =   0 SEC.
PHASE 6 TIME =   0 SEC.

TOTAL COMPILATION TIME =   1  SEC
```

```
WIT  FR5  HISTO,HISTO
UNIVAC 1108 FORTRAN V LEVEL   2206 0009 F600A - CSC005
THIS COMPILATION WAS DONE ON 25 SEP 70 AT 12:13:28

  SUBROUTINE HISTO      ENTRY POINT 000763

  STORAGE USED (BLOCK, NAME, LENGTH)

        0001   *CODE    001004
        0000   *DATA    016326
        0002   *BLANK   000000
        0003   UGH      003737

  EXTERNAL REFERENCES (BLOCK, NAME)

        0004   NWDU$
        0005   NI01$
        0006   NI02$
        0007   SQRT
        0010   NPRT$
        0011   NERR3$

  STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

  0000   016103 1F       0000   016140 12F      0000   016145 13F      0000   016167 14F      0001   000017 152G
  0001   000026 156G     0000   016172 16F      0000   016173 18F      0000   016177 19F      0000   016105 2F
  0001   000122 204G     0001   000142 21L      0001   000132 216G     0001   000245 266G     0001   000253 274G
  0000   016107 3F       0001   000270 306G     0001   000274 314G     0001   000302 323G     0001   000321 337G
  0001   000337 352G     0001   000341 355G     0000   016111 4F       0001   000211 40L      0001   000405 410G
  0001   000416 417G     0001   000434 427G     0001   000175 43L      0001   000446 435G     0001   000205 44L
  0001   000540 472G     0000   016115 5F       0001   000730 500L     0001   000732 501L     0001   000567 502L
  0000   016221 503F     0000   016251 505F     0001   000701 506L     0001   000652 507L     0001   000313 51L
  0001   000630 515G     0000   016122 6F       0001   000332 61L      0000   016125 7F       0001   000452 70L
  0001   000401 75L      0001   000370 77L      0000   016130 8F       0000   016135 9F       0000 R 016062 AVE
  0000 R 016024 CONF     0000 R 016102 CONIN1   0000 R 016101 CONIN2   0003 R 000000 DATA     0000 R 015744 FACT
  0003 R 003723 HEAD     0000 R 015530 HIST     0000 I 016043 I        0000 I 007640 IFR      0000 I 016100 IJK
  0000 I 016051 INC      0000 I 015674 ITEST    0000 I 016046 I$       0000 I 016066 J        0000 I 016070 JJ
  0000 I 016060 K        0000 I 000000 KFR      0000 I 016056 KKK      0000 I 016045 KVAR     0000 I 016071 L
  0000 I 016072 LL       0000 I 016073 LLL      0000 I 016052 MM       0000 I 016026 NEGF     0000 I 016044 NVAR
  0000 I 016055 NX       0000 R 016067 PINC     0003 R 003721 QINC     0003 R 003720 SCALE    0000 R 016065 SD
  0000 R 016063 SDS      0000 R 016054 SSX      0000 R 016053 SX       0000 R 016040 SYM1     0000 R 016041 SYM2
  0000 R 016042 SYM3     0000 R 016074 TERP     0000 R 016075 TOL      0000 R 016076 TOL1     0000 R 016077 TOL2
  0000 R 016064 VAR      0000 R 016057 X        0000 R 016050 XINC     0000 R 016061 XN       0003 R 003722 XNEG
  0000 R 016047 XNN      0000 R 003720 ZINC
```

```
00101          SUBROUTINE HISTO (N)
00103   1      FORMAT(1H1,12A6)
00104        2 FORMAT (3F10.0)
00105        3 FORMAT (F11.0)
00106        4 FORMAT (18X,1H.,100A1,1H.)
00107        5 FORMAT (1X,F10.3,I5,3H  .,100A1,1H.)
00110        6 FORMAT (18X,102(1H.))
00111        7 FORMAT (1X,119(1H*)//)
00112        8 FORMAT (1X,F10.3,7X,1H.,100X,1H.)
00113        9 FORMAT (18X,1H.,100X,1H.)
00114       12 FORMAT (////////11H1END OF JOB)
00115       13 FORMAT (////18X,        1HN,7X,3HSUM,9X,10HSUM OF SQ.,8X,4HMEAN,
00115         16X,14HSUM OF DEV.SQ.,5X,8HVARIANCE,3X,15H    STD. DEV.      )
00116       14 FORMAT (9X,   I10,1P6E15.6)
00117       16 FORMAT (2I4)
00120       18 FORMAT (1H+,6H INC =,F9.3)
00121       19 FORMAT (////1X,I5, 88H OBSERVATIONS WERE INCLUDED IN THE ABOVE SU
00121         XMMARY, BUT WERE OUT OF RANGE OF THE HISTOGRAM)
00121   C
00122          COMMON /UGH/ DATA(2000),SCALE,QINC,XNEG,HEAD(12)
00123          DIMENSION KFR(2000),ZINC(2000)
00124          DIMENSION IFR(3000),HIST(100)
00125          DIMENSION ITEST(40),FACT(40),CONF(10),NEGF(10)
00126          DATA SYM1/005050505050505/
00130          DATA SYM2/6HX     /
00132          DATA SYM3/045050505050505/
00134          DATA (ITEST(I),I=1,35)/30,35,40,45,50,55,60,65,70,75,80,85,90,95,1
00134         *00,110,120,130,140,150,160,170,180,190,200,250,300,400,500,600,700
00134         *,800,900,1000,5000/
00136          DATA (FACT(I),I=1,35)/3.350,3.272,3.213,3.165,3.126,3.094,3.066,3.
00136         *042,3.021,3.002,2.986,2.971,2.958,2.945,2.934,2.915,2.898,2.883,2.
00136         *870,2.859,2.848,2.839,2.831,2.823,2.816,2.788,2.767,2.739,2.721,2.
00136         *707,2.697,2.688,2.682,2.676,2.576/
00140          DATA (CONF(I),I=1,9)/1.990,1.987,1.984,1.972,1.968,1.966,1.965,1.9
00140         *62,1.959/
00142          DATA (NEGF(I),I=1,9)/80,90,100,200,300,400,500,1000,5000/
00142   C
00144          IF (N)501,501,15
00147       15 CONTINUE
00150          NVAR=1
00151          DO 500 KVAR=1,NVAR
00151   C
00154          WRITE (6,1) HEAD
00162          WRITE (6,7)
00164          XNN=SCALE
```

```
00165          XINC=1.0/XNN
00166          INC=(QINC*XNN)+0.5
00167          MM=1000/INC
00170          WRITE (6,6)
00172          WRITE (6,18) QINC
00175          WRITE (6,9)
00177          WRITE (6,9)
00201          WRITE (6,9)
00201  C
00203          DO 10I=1,1000
00206          IFR(I)=0
00207       10 CONTINUE
00207  C
00211          SX=0.0
00212          SSX=0.0
00213          NX=0
00214          KKK=0
00214  C
00214  C
00215          DO 40 I=1,N
00220          X=DATA(I)
00221          IF(X) 21,20,21
00224       20 CONTINUE
00225          IF(X.LT.0.0) GO TO 40
00227       21 CONTINUE
00230          SX=SX+X
00231          SSX=SSX+X**2
00232          NX=NX+1
00233          X=X+XNEG
00234          K=(X*XNN)
00235          K=K+1
00235  C
00236          IF (K) 42,42,43
00241       42 CONTINUE
00242          KKK=KKK+1
00243       43 CONTINUE
00244          IF (K-1000) 44,44,45
00247       45 CONTINUE
00250          KKK=KKK+1
00251          GO TO 40
00252       44 CONTINUE
00252  C
00253          IFR(K)=IFR(K)+1
00253  C
00254       40 CONTINUE
00254  C
00254  C
00256          XN=NX
00257          AVE=SX/XN
```

```
00260          SDS=(XN*SSX-SX**2)/XN
00261          VAR=SDS/(XN-1.0)
00262          SD=SQRT(VAR)
00262   C
00263          J=0
00264          PINC=-XNEG-QINC
00265          DO 35 I=1,MM
00270          KFR(I)=0
00271          PINC=PINC+QINC
00272          ZINC(I)=0.0
00273          DO 34 JJ=1,INC
00276          J=J+1
00277          KFR(I)=KFR(I)+IFR(J)
00300       34 CONTINUE
00302          ZINC(I)=PINC
00303       35 CONTINUE
00303   C
00305          DO 37I=1,1000
00310          IFR(I)=0
00311       37 CONTINUE
00311   C
00313          DO 36 I=1,MM
00316          IFR(I)=KFR(I)
00317       36 CONTINUE
00317   C
00317   C
00321          L=0
00322          DO 50I=1,1000
00325          L=L+1
00326          IF (IFR(L))51,50,51
00331       50 CONTINUE
00333       51 CONTINUE
00333   C
00334          LL=L
00334   C
00335          L=1001
00336          DO 60I=1,1000
00341          L=L-1
00342          IF (IFR(L))61,60,61
00345       60 CONTINUE
00347       61 CONTINUE
00350          LLL=L
00350   C
00351          DO 70 I=LL,LLL
00354          DO 71 J=1,100
00357          HIST(J)=SYM1
00360       71 CONTINUE
00360   C
00362          IF (IFR(I)) 77,78,77
```

```
00365      78 CONTINUE
00366         WRITE (6,9)
00370         WRITE (6,8) ZINC(I)
00373         WRITE (6,9)
00375         GO TO 70
00376      77 CONTINUE
00376   C
00377         JJ=IFR(I)
00400         IF (JJ-100)75,75,76
00403      76 CONTINUE
00404         JJ=99
00405         HIST(100)=SYM3
00406      75 CONTINUE
00407         DO 72 J=1,JJ
00412         HIST(J)=SYM2
00413      72 CONTINUE
00413   C
00415         WRITE (6,4) (HIST(J),J=1,100)
00423         WRITE (6,5) ZINC(I),IFR(I),(HIST(J),J=1,100)
00433         WRITE (6,4) (HIST(J),J=1,100)
00441      70 CONTINUE
00441   C
00443         WRITE (6,9)
00445         WRITE (6,9)
00447         WRITE (6,9)
00451         WRITE (6,6)
00453         WRITE (6,13)
00455         WRITE (6,7)
00457         WRITE (6,14) NX,SX,SSX,AVE,SDS,VAR,SD
00470         J=0
00471         DO 498 I=2,35
00474         J=J+1
00475         IF (NX.GE.ITEST(I-1).AND.NX.LT.ITEST(I)) GO TO 502
00477   498   CONTINUE
00501   502   CONTINUE
00502         TERP=(NX-ITEST(J))/(ITEST(J+1)-ITEST(J))*(FACT(J)-FACT(J+1))
00503         TOL=(FACT(J)-TERP)*SD
00504         TOL1=AVE-TOL
00505         TOL2=AVE+TOL
00506         PRINT 503, TOL1,TOL2
00512   503   FORMAT(//,5X'TOLERANCE INTERVAL :'/5X'PROBABILITY IS 0.95 THAT AT
00512        *LEAST 0.99 OF THE DISTRIBUTION WILL BE INCLUDED BETWEEN'F10.3,' AN
00512        *D'F10.3)
00513         IJK=1
00514         DO 506 I=2,9
00517         IF (NX.GE.NEGF(I-1).AND.NX.LT.NEGF(I)) GO TO 507
00521         GO TO 506
00522   507   CONIN2=AVE-CONF(IJK)*(SD/SQRT(NX))
00523         CONIN1=AVE-CONF(IJK)*(SD/SQRT(NX))
```

```
00524  506   IJK=IJK+1
00526        PRINT 505, CONIN1,CONIN2
00532  505   FORMAT(//,5X'CONFIDENCE INTERVAL'/,5X'PROBABILITY IS 0.95 THAT THE
00532       * POPULATION MEAN WILL BE INCLUDED BETWEEN'F10.3,' AND'F10.3)
00532  C
00533        IF (KKK)500,500,499
00536    499 CONTINUE
00537        WRITE (6,19) KKK
00537  C
00542    500 CONTINUE
00544    501 CONTINUE
00545        WRITE (6,12)
00547        RETURN
00550        END

     END OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
PHASE 1 TIME =   1 SEC.
PHASE 2 TIME =   0 SEC.
PHASE 3 TIME =   0 SEC.
PHASE 4 TIME =   0 SEC.
PHASE 5 TIME =   0 SEC.
PHASE 6 TIME =   1 SEC.

TOTAL COMPILATION TIME =   2  SEC
```

The following is a list of explanations as to the specific functions of statements in the computer code used to calculate the figure of merit. The numbers associated with the explanations are the numbers circled in the preceding listing of computer code subroutines.

1. Subroutine Probe (A,B,C,D)--Prepares raw data from electron microprobe for figure of merit calculation and determines average PuO_2 percentage along diameter of pellet.

    18. Reads into code the coefficients for spectrometer background equations (VA1, VA2, VB1, VB2), reads in the nominal PuO_2 percentage of the pellet (PERC), and reads in the heading for the histogram output page.

    24. Sorts out bad data points caused by improperly punched points on paper tape readout by placing limits on the spectrometer readings (A for Spectrometer 1--UO_2, B for Spectrometer 2--PuO_2, and C for Spectrometer 3--background).

    26. Sums 10 spectrometer readings (minus background) from Spectrometer 1 for standard 100 percent UO_2 spheroids.

    30. See 24

    32. Sums 10 spectrometer readings (minus background) from Spectrometer 2 for standard 100 percent PuO_2 spheroids.

    34. Averages standard UO_2 spectrometer readings to give an average reading for Spectrometer 1 which is equivalent to 100 percent UO_2.

35. Averages standard PuO_2 spectrometer readings to give an average reading for Spectrometer 2 which is equivalent to 100 percent PuO_2.

37. See 24

38. Sorts out bad data points, such as those caused by voids, by placing limits on the specimen current (indicated by D).

40. For PuO_2 percentage at each data point, subtracts background, ratios the background corrected PuO_2 spectrometer readings to the average reading for 100 percent PuO_2 and converts this decimal fraction to a percentage.

41. For UO_2 percentage at each data point, subtracts background, ratios the background corrected UO_2 spectrometer readings to the average reading for 100 percent UO_2 and converts this decimal fraction to a percentage.

42. For each data point (each pair of UO_2 and PuO_2 percentages), calculates a normalization factor which ratios the sum of the two relative percentages to 100 percent. This factor compensates for the inherent error ($\sim\pm2$ percent) in the electron microprobe readings.

43. and 44. Normalizes each UO_2 percentage [AXX(I)] and each PuO_2 percentage [BXX(I)] so that the sum at each data point equals 100 percent. This step is the final step in preparing data for use in the figure of merit calculation (in Subroutine Offset). The code uses these normalized values of PuO_2 percentage for the figure of merit calculations.

45. Sorts out bad data points (negative percentages) caused by the inherent error in electron microprobe readings.

46. Sums PuO_2 percentages after they have been normalized to 100 percent.

47. Prints out, for each good data point, the UO_2 spectrometer reading (not including the 100 percent UO_2 standard points), the PuO_2 spectrometer reading (not including the 100 percent PuO_2 standard points), the UO_2 percentage prior to normalization, the PuO_2 percentage prior to normalization, the UO_2 percentage following normalization, and the PuO_2 percentage following normalization.

48. Sums PuO_2 percentages prior to normalization.

49. Sums UO_2 percentages prior to normalization.

55. Averages PuO_2 percentages prior to normalization, giving an overall non-normalized percentage along a diameter of the fuel pellet.

56. Averages normalized PuO_2 percentages, giving an overall normalized percentage along a diameter of the fuel pellet.

57. Prints out the overall non-normalized PuO_2 percentage (FRAC or BBX/I) and the overall normalized PuO_2 percentage (FRAC2 or P/I).

1. Subroutine Offset (I) - Calculates local and overall average figures of merit using PuO_2 percentages supplied by Subroutine Probe.

   10. Sums eleven normalized PuO_2 percentage values for eleven consecutive points along the diameter of a 20 micron sphere (at 2 micron intervals) on the fuel pellet.

   12. Averages eleven PuO_2 percentages and converts average value to a decimal fraction.

   14. Converts PuO_2 percentage at midpoint of 20 micron sphere (middle point of eleven) to a decimal fraction.

   15. Calculates numerator of local figure of merit expression where Z is the average PuO_2 percentage along diameter of 20 micron sphere and XY is the PuO_2 percentage at the center of the sphere.

   17. Calculates denominator of local figure of merit expression where PERC is the nominal PuO_2 percentage (25%) of the fuel pellet.

   22. Calculates local figures of merit for each of a series of points located at 2 micron intervals along a diameter of the fuel pellet.

   23. Prints out a local figure of merit value for each location at 2 micron intervals along a diameter of the fuel pellet (number of local figures of merit will be ten less than the total number of data points examined along the pellet diameter).

1. Subroutine Histo(N)--Sets up histogram for local figure of merit values and calculates statistical characteristics of local figure of merit distribution (including the average figure of merit).

71. Adds all calculated local figures of merit.

72. Adds the squares of all calculated local figures of merit.

94. Calculates average of all local figures of merit, giving the mean figure of merit for the pellet.

95. Calculates the sum of the deviation squared.

96. Calculates the variance for the figure of merit distribution.

97. Calculates the standard deviation for the figure of merit distribution.

172. Prints out the number of local figures of merit calculated, the sum of the local figures of merit, the sum of the squares of the local figures of merit, the average of the local figures of merit, the sum of the deviation squared, the variance, and the standard deviation.

180. Calculates tolerance interval for the figures of merit.

181. Calculates the lower tolerance limit for the figures of merit.

182. Calculates the upper tolerance limit for the figures of merit.

183. Prints out the lower and upper tolerance limits for the local figures of merit.

191. Calculates the upper confidence limit for the figures of merit.

192. Calculates the lower confidence limit for the figures of merit.

194. Prints out the lower and upper confidence limits for the local figures of merit.

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