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A TECHNIQUE TO DETERMINE BILLET CORE CHARGE WEIGHT FOR P/M FUEL TUBES

INTRODUCTION

Fabrication of U_3O_8-aluminum fuel tubes for SRP production reactors is scheduled to begin in 1987. Billet cores, now made by the uranium-aluminum alloy casting process, will be made by powder metallurgy (P/M). After compaction, the P/M billet cores will be coextruded to completely seal the enriched uranium fuel in aluminum.

The core length in an extruded tube depends on the weight of powder in the billet core. In the past, the amount of aluminum powder needed to give a specified core length was determined empirically. This report gives a technique for calculating the weight of aluminum powder for the P/M core. Once the charge weight is known, the elastomeric compaction bag can be designed to produce the correct size core.

SUMMARY

An equation has been derived which can be used to determine the amount of aluminum needed for P/M billet core charge weights. Good agreement was obtained when compared to Mark 22 tube extrusion data. From the calculated charge weight, the elastomeric bag can be designed and made to compact the U_3O_8-Al core.

DISCUSSION

P/M billet cores are made from enriched U_3O_8 and aluminum powders. The two constituents are weighed separately to give precise powder contents and blended to form a homogenous mixture of oxide fuel in aluminum. The blended powders are compacted isostatically to make the billet core which is assembled into aluminum components for coextrusion.

The aluminum powder is Alcoa type 101 and is produced by atomization. The particle size distribution is 100 wt % less than 150 μm with 75-90 wt % less than 44 μm. The particle density is nearly theoretical, i.e., 2.7 g/cc.

U_3O_8 powder is made from UO_3 that is produced by denitrating uranyl nitrate in a stirred-bed denitrator at Oak Ridge Y-12 plant. The UO_3 is roasted at 800°C to form U_3O_8. After conversion, U_3O_8 particles are roll ground or pulverized to produce powder less than 150 μm with no more than 40% less than 44 μm. Particle density is about 7.5 g/cc or about 90% theoretical.[1] There is about 10% particle voids present in the U_3O_8 particles.

Billet Core Compaction

Mixed powders are placed into an elastomeric bag for isostatic compaction. The powder must fill the bag or defects will occur in the compacted core. The loose stack density of the powder when put into the bag is a function of the particle size distribution and wt % U_3O_8. The loose stack density is shown in Figure 1 as a function of wt % U_3O_8 in aluminum.[2] For 50 wt % U_3O_8, the loose stack density is approximately 1.8 g/cc or 45% theoretical.

Vibration densifies the powder and is used to obtain a uniform powder density before compaction. Otherwise, the compacted core will have an irregular shape. A 50 wt % mixture vibrated 5 minutes on a syntron vibrator* has a density of 2 g/cc or 49% theoretical. The powder density is increased about 4% by vibration.

Although vibration densifies the mixture, it also has a tendency to separate the two powders. The larger more dense U_3O_8 particles move toward the free surface. Segregation of U_3O_8 can cause high density areas in the core.

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* Model VP51B1, FMC Corporation, Homer City, Pa.

Coextrusion

Compacted cores are assembled into aluminum billet components for coextrusion. The billets are extruded by forcing the material through a conical die at an elevated temperature. As the material moves through the die, large deformations and strains are produced. Tensile strain and accumulated shear greater than 200% may be produced at the die exit.[3] The large deformation causes cracks or voids in the U_3O_8 particles called fabrication voids. The degree of cracking depends on the U_3O_8 particle size with smaller particles (<50 μm) showing less tendency to crack. Increasing the fraction of large U_3O_8 particles, by increasing wt % U_3O_8, causes fabrication voids to increase in extruded tubes.

The void content for extruded U_3O_8 in 101 aluminum cores has been determined using hydrostatic weighing.[4] From the weighings, the core density is calculated and compared with the theoretical density to determine void content. The void fraction for extruded tubes as a function of wt % U_3O_8 is shown in Figure 2 for roll ground U_3O_8 powder. Typical particle size distribution is given in Table I.

Billet Core Charge Calculations

The amount of aluminum powder added to the charge to give 150 inch long core in an extruded tube has been determined empirically in the past. The procedure was to extrude billets having several different core weights and then determine the tube core lengths using a fluoroscope. The optimum charge weight or powder volume was then selected based on the extrusion test data. Only the aluminum weight in the core is varied because the U_3O_8 content is fixed by the oxide enrichment. Each tube must have a specified ^{235}U content which is defined by reactor physics or thermal hydraulics.

Charge Weight Calculation

The total core volume (V_c) for an extruded tube can be determined from the aluminum powder volume (V_{Al}), U_3O_8 powder volume ($V_{U_3O_8}$) and void fraction (fv). The core volume becomes

$$V_c = \frac{1}{1-fv} (V_{Al} + V_{U_3O_8}) \quad (1)$$

where the void fraction variable contains both particle and fabrication voids.

The core ends of extruded tubes are generally tapered as shown in Figure 3. The amount of powder in the tapered ends is not the same as over the active core section. For calculations, the effective core length (l_{eff}) is determined as the sum of half the two core end lengths (l_e) and the active core length (l_A).

$$l_{eff} = \frac{\sum l_e}{2} + l_A \qquad (2)$$

The core end lengths depend on the magnesium content and shape of the billet end plug components. The lengths determined using the fluoroscope are typically 4-6 inches.

The aluminum weight (W_{Al}) needed to give an effective core length can be calculated using the equation

$$W_{Al} = A_c \ \rho_{Al} \ (1-fv) \ l_{eff} - \frac{\rho Al}{\rho_{U_3O_8}} W_{U_3O_8} \qquad (3)$$

where ρ_{Al} and $\rho_{U_3O_8}$ are theoretical densities of aluminum and U_3O_8, $W_{U_3O_8}$ is the weight of U_3O_8 oxide and A_c is the core cross-sectional area of the tube. All of the dependent variables in equation 3 are known except the void fraction which depends on the wt % U_3O_8 in the core and cannot be determined until the aluminum weight is known. To begin calculations, the wt % U_3O_8 in the core is assumed and the void fraction determined from Figure 2. The amount of aluminum is calculated using equation 3 and the wt % U_3O_8 then calculated from the charge weights. The calculated valve for the wt % U_3O_8 is compared with the assumed value of U_3O_8 in the core. If a difference exists, a new value for the void fraction is found based on the calculated wt % U_3O_8 and the aluminum weight recalculated. Several iterations may be required to find the specific aluminum weight needed for the charge.

The aluminum weight was calculated for an extruded tube using equation 3 and metallurgical laboratory inspection data. The agreement is good between the calculated and actual amount of aluminum in the core. Calculations are given in Appendix A.

The elastomeric bag volume (V_b) can be determined now by dividing the powder volume by the loose stack powder density (ρ_{ls}).

$$V_b = \frac{1}{\rho ls} \left(\frac{W_{Al}}{\rho Al} + \frac{W_{U_3O_8}}{\rho U_3O_8}\right) \qquad (4)$$

Theoretical particle densities are used because the loose stack density accounts for voids. After the volume has been determined, the elastomeric compaction bag can be designed and fabricated.

Difference Between Expected and Actual Core Length

Any differences between the expected and actual extruded core length may be due to several reasons. The core diameters may vary along the tube length due to an irregularly shaped billet core or surface defects.

The fabrication void content depends on the oxide particle size above about 50 µm. Strain deformation during extrusion is not constant across the core cross section so orientation or segregation of oxide particles could affect the degree of cracking and fabrication void content.

The compact weight may vary from the specified charge weight because powder could remain inside the blender or compact edges could chip off when the core is removed from the compaction bag.

The effective core length is calculated using half the core end lengths. This assumes symmetrical core ends which may not always be true.

HBP:dwb

REFERENCES

1. H. B. Peacock. Preparation and Physical Properties of U_3O_8, DPST-83-276, January 31, 1983.

2. J. W. McClard and D. R. Leader. Powder Density, DPST-74-580, December 23, 1974.

3. H. B. Peacock. Visioplastic Strain Analysis for Axisymmetric Extrusion, DPST-84-517, May 17, 1984.

4. H. A. Bowman and R. M. Schoonover, "Procedure for High Precision Density Determinations by Hydrostatic Weighing," Journal of Research, Vol 71C, NO. 3, pp 179-197, July-August 1967.

TABLE I

TYPICAL PARTICLE SIZE DISTRIBUTION FOR ROLL GROUND U_3O_8

Mesh Size	Spherical Diameter, μm	wt % less than
-100/+140	105-150	25.2
-140/+170	88-104	9.4
-170/+200	74-87	10.6
-200/+270	53-73	16.7
-270/+325	44-52	3.5
-325		

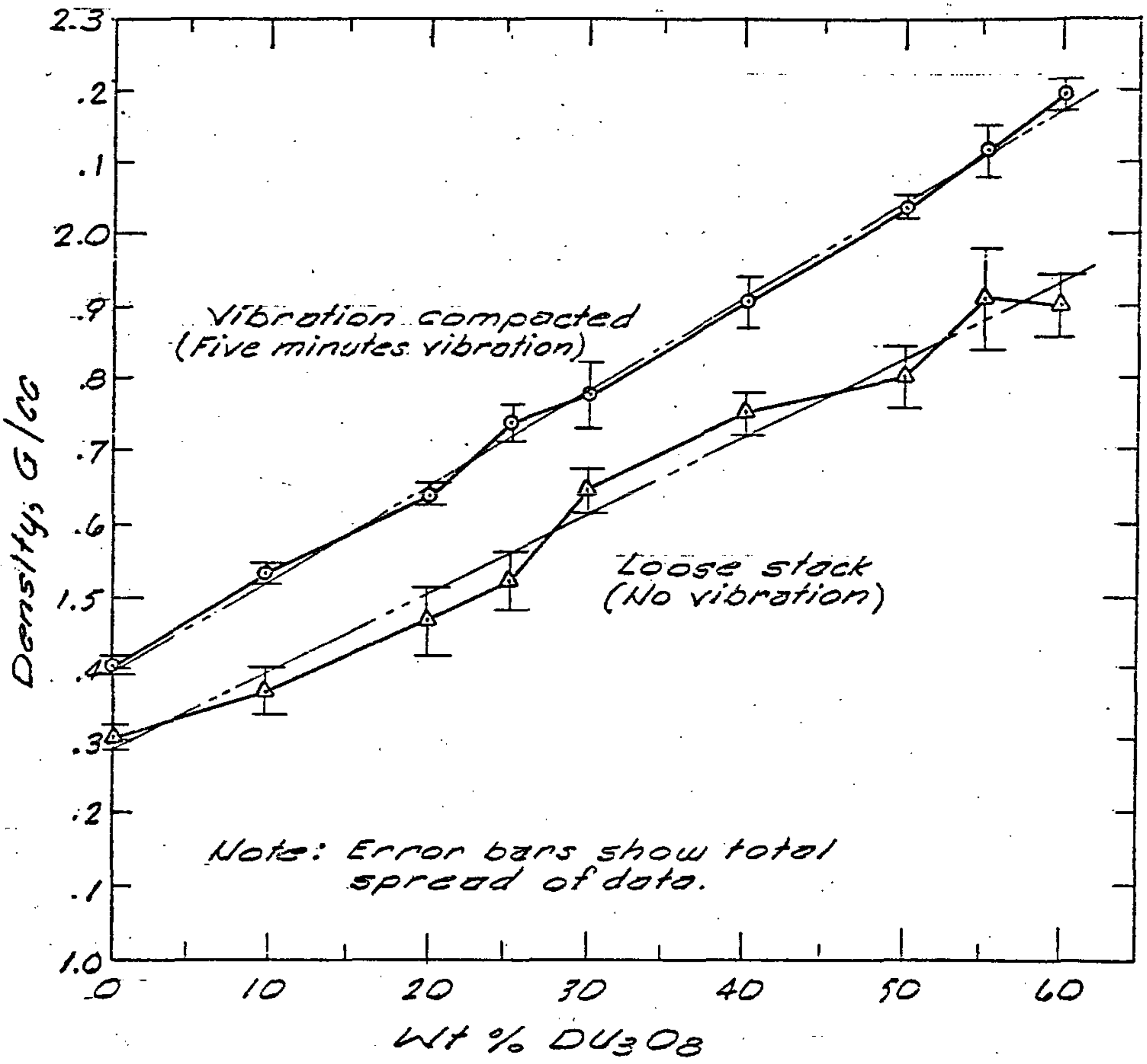

FIGURE 1. DENSITY AS A FUNCTION OF WEIGHT PERCENT DEPLETED U_3O_8 AND ALUMINUM FOR NO VIBRATION AND FIVE MINUTE VIBRATION[2]

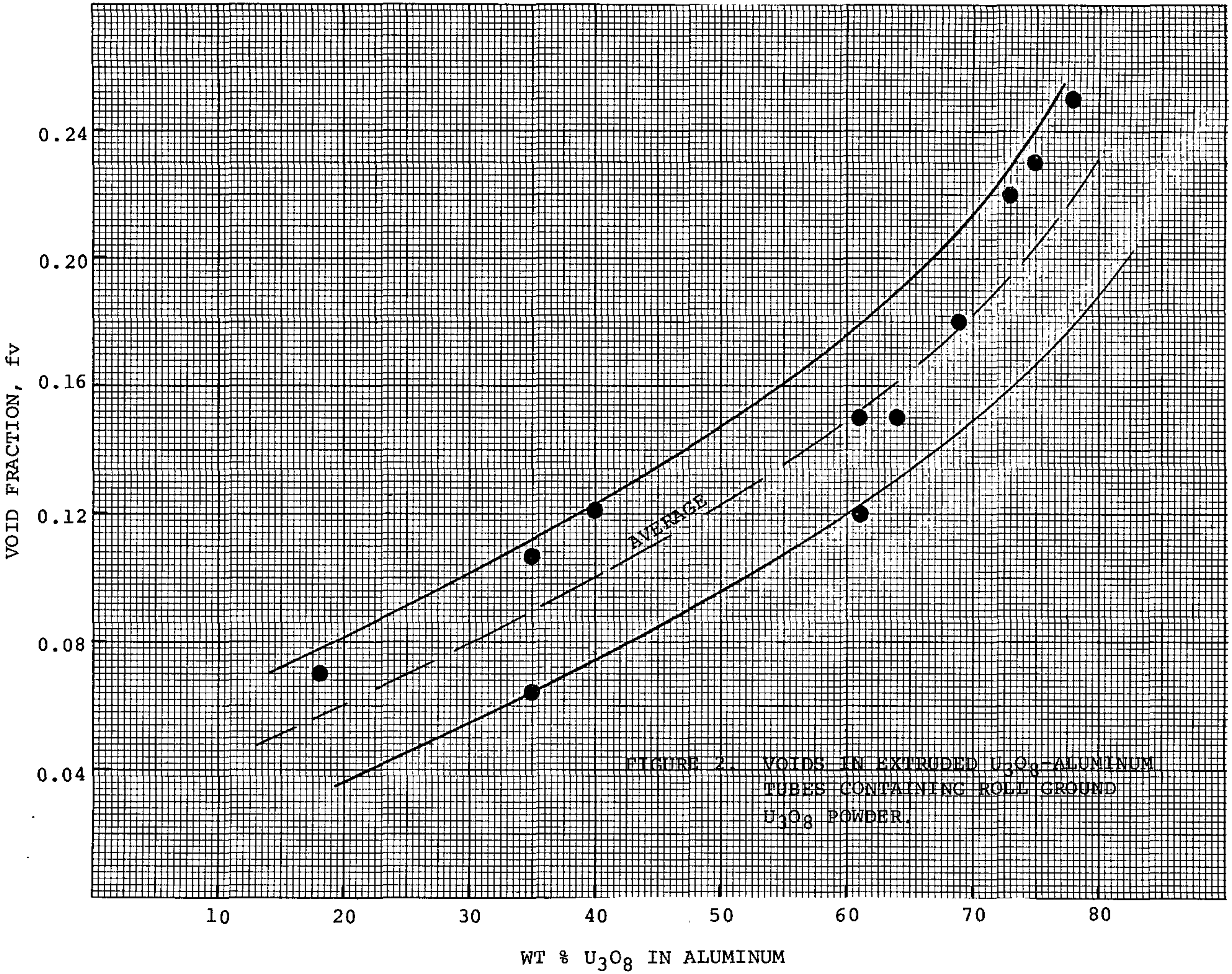

FIGURE 2. VOIDS IN EXTRUDED U_3O_8-ALUMINUM TUBES CONTAINING ROLL GROUND U_3O_8 POWDER.

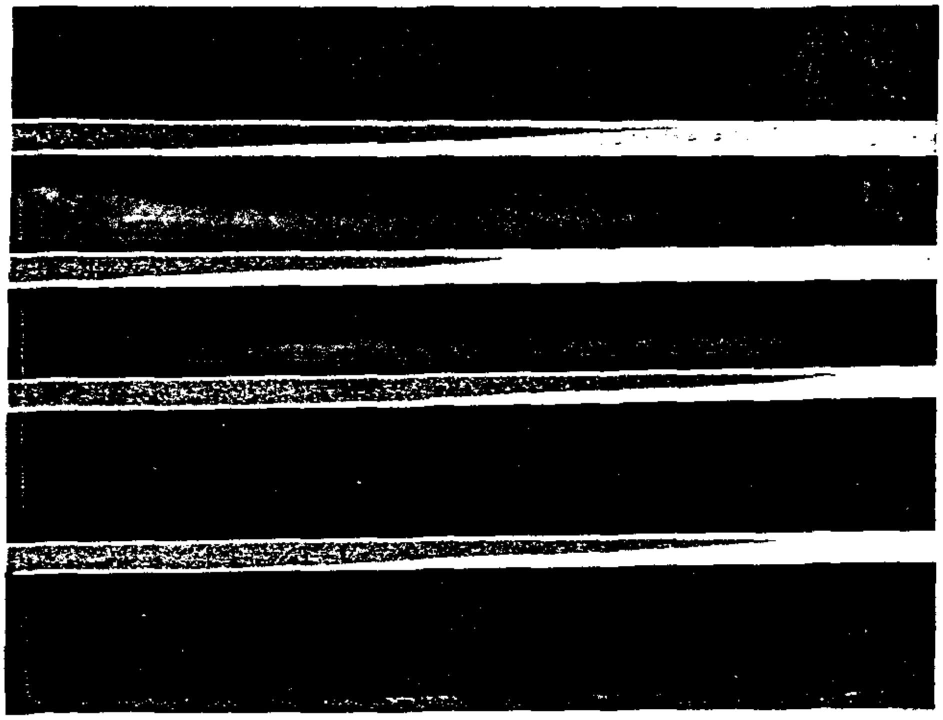

FIGURE 3. CORE ENDS AT 90° INTERVALS AROUND A P/M FUEL TUBE.

APPENDIX A

Charge calculations for Mark 22 Outer Fuel

Metallurgical Lab Data:

Extruded core length	122.4 in
Average core end length	4.9 in
Average core diameters	3.139 in OD
	2.957 in ID

Actual Charge Weights:

U_3O_8	2236 g
Aluminum	3353 g
Wt % U_3O_8	40 %

Calculated Aluminum Weight using Equation 3 and above Metallurgical Lab Data:

$$fv = 0.10^5 \text{ from Figure 2}$$

$$W_{Al} = \frac{\pi}{4}(3.139^2-2.957^2) \times 16.39 \times 2.7\ (1-0.105)\ 118 - \frac{2.7}{8.4}(2236)$$

$$W_{Al} = 3353 \text{ grams}$$