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PRECRITICAL ANALYSIS OF A POWER-TAILORED FAST-SPECTRUM MOLYBDENUM REFLECTED CRITICAL ASSEMBLY

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PRECRITICAL ANALYSIS OF A POWER-TAILORED FAST-SPECTRUM MOLYBDENUM REFLECTED CRITICAL ASSEMBLY

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1. INTRODUCTION

A series of critical experiments is being performed by Atomics International under contract to Lewis Research Center, Contract number NAS3-12982. The experiments use materials of interest for a small fast-spectrum reactor as depicted in the sketch in figure 1. The materials are lithium-7, nitrogen, uranium-235 and -238 and the refractory metals molybdenum, hafnium, tantalum and tungsten. Figure 2 shows a sketch, as supplied by the contractor, of the critical machine used in the experiments. References 1 and 2 describe the conceptual reactor, the critical machine, the fuel element design, neutronic calculation procedures and results of pre-critical calculations for several of the experiments as anticipated at that time. The results in references 1 and 2 have been used by the contractor as a guide in loading the fuel elements for the experiments.

All of the experiments performed thus far and all of the calculations in references 1 and 2 have a uniform fuel distribution. An experiment for a power-tailored reactor is contemplated. The power-tailoring will be accomplished by a non-uniform fuel distribution radially in order to flatten the power somewhat. The purpose of this report is to decide a fuel loading schedule, based upon the fuel pieces available, which will be critical with only a small amount of excess reactivity, preferably $\leq$ 30 cents. A secondary purpose is to predict the radial power distribution, by fuel element, for the reactor.

The most direct procedure in setting the fuel loading is to normalize the calculated multiplication factors to appropriate experiments performed for which preliminary excess reactivity data are available. Final adjustments in the experimental values are expected to be small.

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2. DESCRIPTION OF THE EXPERIMENTS

Four experimental critical assemblies are appropriate for use in normalizing the computed multiplication factors. These experiments differ only in the amount and type of materials inserted. The first contains a basic complement of 10.1 kilograms of lithium nitride, 4.116 kilograms of hafnium and 174.96 kilograms of oralloy (93.2 percent uranium 235 with the remainder assumed to be uranium 238) distributed uniformly among the 247 fuel elements. The second experiment has, in addition to the above materials, 21.7 kilograms of tantalum foil and 9.54 kilograms of tantalum in the form of 247 rods 0.110 inches (0.279 cm) in diameter. These rods are 14.5 inches (36.8 cm) long and are within the active core length of 14.81 inches (37.62 cm). The third experiment has 300 tantalum rods, in addition to the above materials, added to the interstitial regions of the stationary part of the core. These rods are 0.140 inches (0.356 cm) in diameter and 23.5 inches (59.69 cm) long. Thus they extend into the end reflector regions. The tantalum in the active core region is 18.96 kilograms while 11.12 kilograms appears in the end reflector regions. The fourth experiment has, in addition to the above materials, 15.15 kilograms of tungsten distributed among the 247 fuel elements.

In addition each core contains a small amount of hydrogen and oxygen which appear as impurities in the lithium nitride or from the protective coating on the fuel pieces. The quantity of hydrogen and oxygen is sufficient to be of importance in the calculations.

Table 1 lists the experiments as described above and the experimental excess reactivities of each. Table 2 lists the weights of components of the critical assembly which have been weighed.

Table 3 gives average weights of the fuel pieces and the amount of hydrogen per fuel piece from the protective coating.

The reactor components are identified in figures 3-5. Figure 3 shows a reactor quadrant. Figure 4 shows a fuel element cross section with a full complement of fuel. The 0.110 inch diameter tantalum rod replaces the center fuel rod in these experiments since the fuel loading does not require all seven of the large fuel rods. The hafnium, tantalum and tungsten foil fit within the fuel tube wrapped tightly around the fuel bundle. The lithium nitride goes in the space between the honeycomb tube and fuel tube. Figure 5 shows the fuel element closure method and end reflector design.

3. ANALYSIS METHOD AND RESULTS

Use of Experimental Data. - In order to use the experimental data in Table 1, the excess reactivity is used to obtain effective multiplication factors for each of the four reactors through use of the relation $k = \frac{1}{1-\beta_{eff}\rho_{\$}}$ where β_{eff} is the effective delayed neutron fraction (0.0067) and $\rho_\$$ is the excess reactivity in dollars. However, the composition of the contemplated zoned reactor is different from any of the experiments listed in Table 1. But it is possible to "construct" an experimental excess reactivity for the composition of interest, namely one with only the 21.7 kilograms of tantalum foil (no tantalum rods) and with the 15.15 kilograms of tungsten, in addition to the constituents of experiment number 1 of Table 1. This is done in two steps: (1) experiments 1 and 2 are used to obtain the worth of the tantalum by ratioing the total worth (-49.9 cents) by the proportionate amount desired (21.7/31.24) which results in -34.6 cents for the worth of 21.7 kilograms of tantalum foil. The excess reactivity for this "experiment", denoted as experiment 1', is 154.6 cents; (2) experiments 3 and 4 indicate the worth of the 15.15 kilograms of tungsten foil is worth +45.3 cents. It is assumed that this same worth would be observed had the tungsten been added before the tantalum rods were added. This is probably not true but should be in error by only a few cents. Thus adding these two reactivities to experiment 1, the expected excess reactivity of this "experiment", called experiment 1", is 199.9 cents.

With these two additional "experiments", six are now available.

Normalization Procedure. - Each of the six cases is calculated using the RZ and XY S_4P_o 4 energy group procedure described in references 1 and 2. (Figure 6 shows the RZ calculation geometry incorporating the updated weights and dimensions as well as provision for performing the zoned reactor calculation. Indeed, the fuel volume fractions shown on the figure correspond to the zoned reactor discussed later.)

The results of the XY calculations are shown on figure 7 along with the experimental results discussed above. A constant correction of -0.030 Δ k has been subtracted from each calculated multiplication factor. With this correction a good "fit" to the experiments is observed. The largest discrepancy of -31 cents occurs for experiment 1 which amounts to only about 0.6 kilogram error in fuel loading. The large correction of -0.030 Δ k is consistent with that found in reference 1. In that reference -0.036 Δ k was used which included -0.013 Δ k for the use of low order calculations (S_4P_o 4 group) instead of, say, $S_{16}P_1$ 13 groups. For the zoned reactor discussed below, this correction is only -0.007 Δ k. The correction of +0.006 for the effect of structural material around the reactor, not included in the calculations in reference 1, is found to be the same for the present zoned reactor.

Zoned Reactor Calculations. - With experiment 1" as a base with a correction of -0.030 Δ k the zoned reactor calculations were performed. The loading schedule for each of the three radial zones is shown in Table 4. This loading was chosen subject to two conditions: (1) the maximum number of 0.060 inch fuel wires in the outer zone (zone 3) is 5, and (2) provision must be made to uniformly add fuel worth about 190 cents in order to perform a power distribution measurement with partially rotated fuel drums as called for in the contract. To meet these criteria, only four 0.060 inch fuel wires are used in zone 3, and the addition of one 0.060 inch wire and one 0.026 inch wire in each of the 247 fuel elements will add 3.9 kilograms of fuel worth about 187 cents. If necessary, a few additional 0.026 inch wires could be added.

The XY calculation yielded a multiplication factor of 1.03155 which is sufficient, indicating an excess reactivity of about 23 cents after the -0.03 Δk correction is applied. However, it should be pointed out that the uncertainties in the "construction" of experiments 1' and 1", the effect of redistribution of fuel in the zoned core and the small discrepancies in k observed on figure 7 preclude a definitive statement about the amount of excess reactivity to be expected.

Figure 8 shows the calculated radial power distribution relative to core average for each of the fuel pins in the 30° sector. Calculations performed in arriving at the final zoned configuration reported indicate that the addition of one 0.060 wire in the center zone would change the power distribution by about $^{+}2$ percent in the central region and by about -1 percent in the outermost regions of the core. Hence, it is expected that the power distribution in figure 8 should be valid if minor adjustments in loading are found necessary.

4. CONCLUSIONS

Calculations are presented to estimate the fuel loading requirements for a power-tailored (fuel zoned) reactor experiment to be conducted by Atomics International under Contract NAS3-12982 from Lewis Research Center. The oralloy fuel loading of 174.87 kilograms, distributed in three fuel zones as given on figure 8, should be sufficient. The procedure used in normalizing computed multiplication factors to experimental values should result in uncertainties of only a few cents. Sufficient 0.026 inch fuel wire is available to add to the reactor to provide about 50 cents additional reactivity if required although it is expected that the reactor will be supercritical with the loading proposed.

Power distribution calculations are also presented for the fuel loading schedule proposed. Minor adjustments in the fuel loading will not significantly effect the power distribution reported.

REFERENCES

1. Mayo, Wendell; and Lantz, Edward: Analysis of Fuel Loading Requirements and Neutron Energy Spectrum of a Fast-Spectrum, Molybdenum-Reflected, Critical Assembly. NASA TM X-52762, 1970.

2. Anderson, John L.; and Mayo, Wendell: Effect of Adding Lithium Nitride, Hafnium, Tantalum and Tungsten to a Fast-Spectrum, Molybdenum-Reflected Critical Assembly. NASA TM X-52787, 1970.

TABLE 1

EXPERIMENTAL EXCESS REACTIVITIES

Experiment	Core Description	Excess Reactivity, cents
1	[a]base	189.2
2	21.7 kg Ta + 247 Ta rods 0.110" diameter	139.3
3	300 Ta rods	94.2
4	15.15 kg tungsten	139.5

[a]base case contains 10.1 kg lithium nitride, 4.116 kg Hf, and 174.96 kg oralloy fuel. Material additions are cumulative in experiments 2 through 4.

TABLE 2

MEASURED WEIGHTS OF REACTOR COMPONENTS

Piece	[a]Weight gm	Length cm	Area cm^2	Weight Per Unit Length gm/cm
Cylindrical Mo Reflector (ea.)	178.003	10.015	1.752	17.773
Eccentric Mo Reflector (ea.)	145.647	10.015	1.450	14.543
Fuel tube (ea.)	131.178	58.090	.1236	2.258
Honeycomb tube (ea.)	181.638	59.941	.1703	3.030
Poison Sector (ea.)	38484.0	60.173	38.53	639.56
Triangular filler	1.165	60.198	1.897	19.346
Drum piece (Mo)	41195.0	60.198	69.298	684.33
Stationary Radial Reflector (ea.)	67513.0	60.198	116.509	11215.0
Scram Radial Reflector	66063.0	59.690	114.177	1106.8
Mo wires in each drum	1431.1	60.198	2.336	23.773
Ta fuel centering ring	1.740	---	---	---
[b]Lithium nitride (each fuel tube)	40.96	---	---	---

[a]Weights are averages of groups of pieces

[b]95.62 w/o Li_3^7N, 1.82 w/o Li_2^7O, 2.56 w/o Li^7OH

TABLE 3

AVERAGE WEIGHTS OF FUEL PIECES AND
HYDROGEN CONTENT OF PROTECTIVE COATING

Fuel Piece	Weight gm	Hydrogen Content gm
Large Rods (710 fuel)	102.32	4.974×10^{-4}
0.060 inch diameter wire	13.28	7.77×10^{-4}
0.026 inch diameter wire	2.50	2.631×10^{-4}

TABLE 4

FUEL LOADING SCHEDULE FOR ZONED REACTOR EXPERIMENT

Fuel Zone	Number of Pins	Number of fuel Pieces		Weight kg
		710 fuel	0.060 inch	
1	73	6	1	45.786
2	90	7	0	64.462
3	[a]84	7	4	64.626

[a]includes 66 fuel pins in control drums

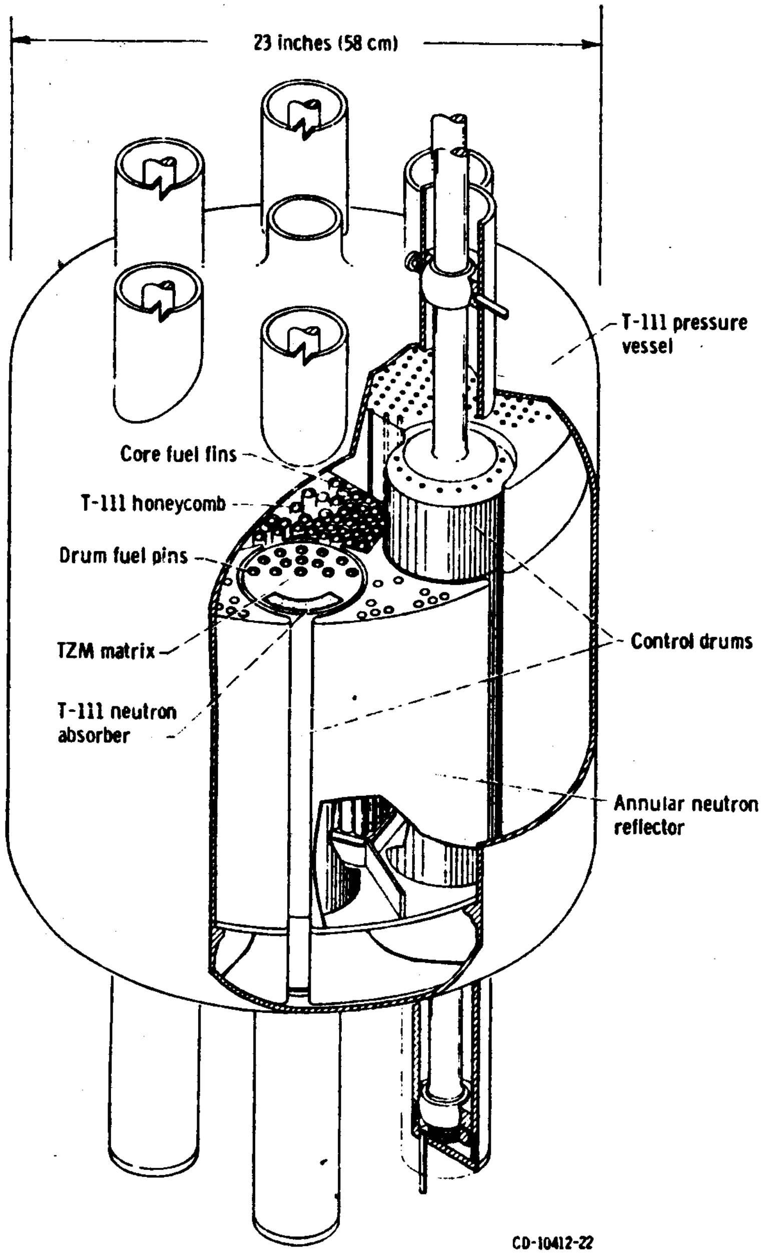


Figure 1. - Conceptual reactor.

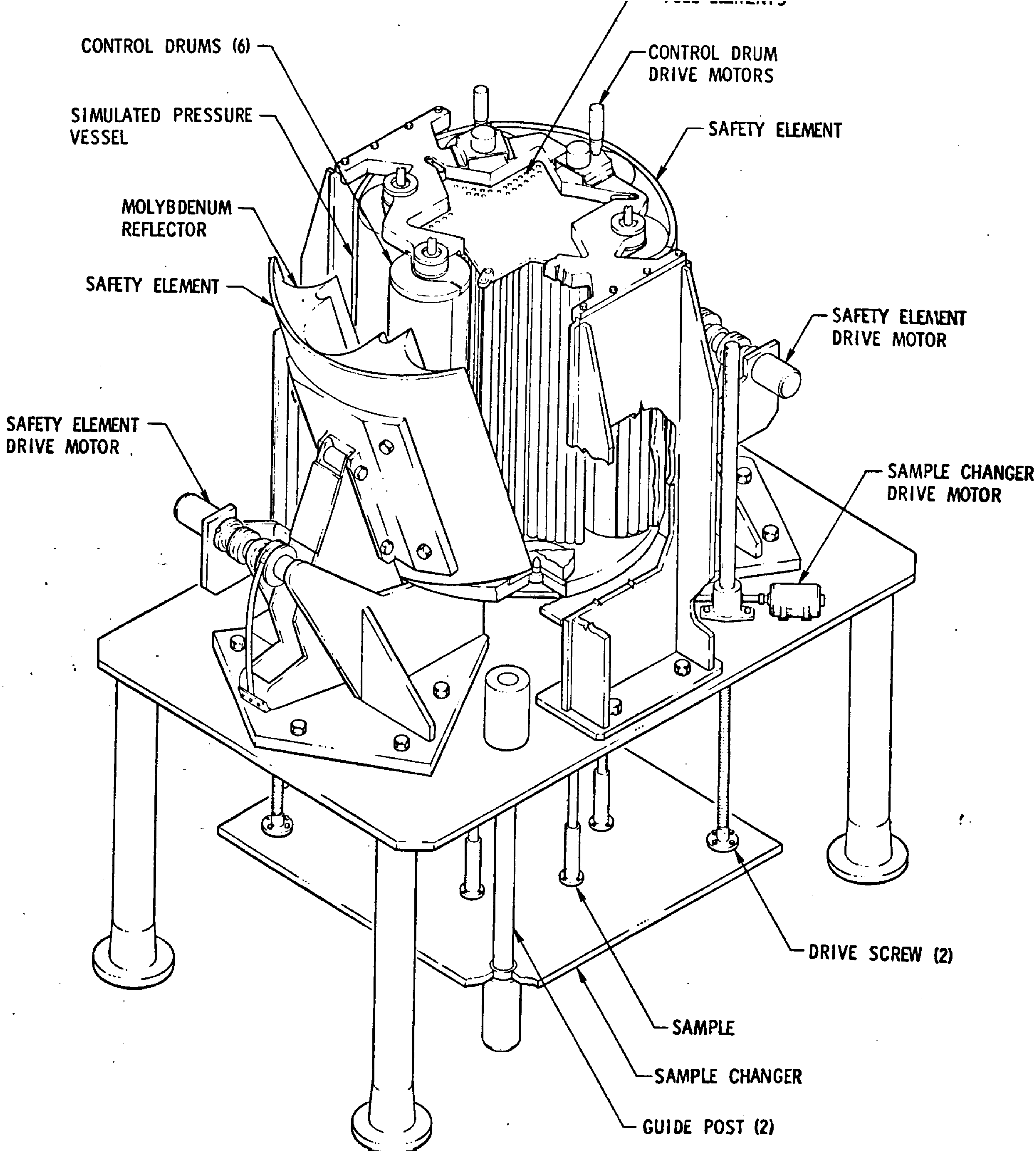


Figure 2. - Critical machine.

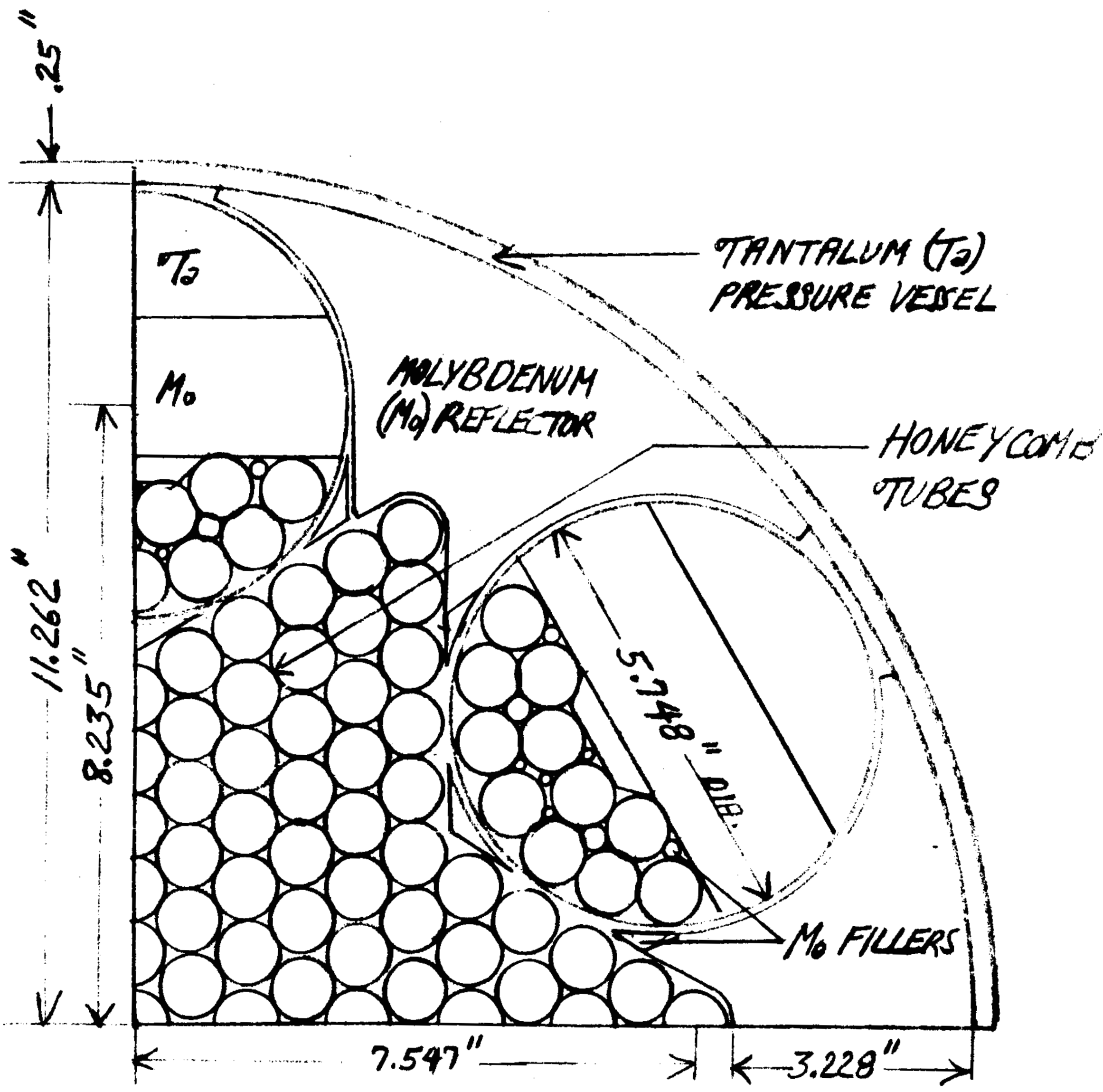


Figure 3. - Cross section of a reactor quadrant.

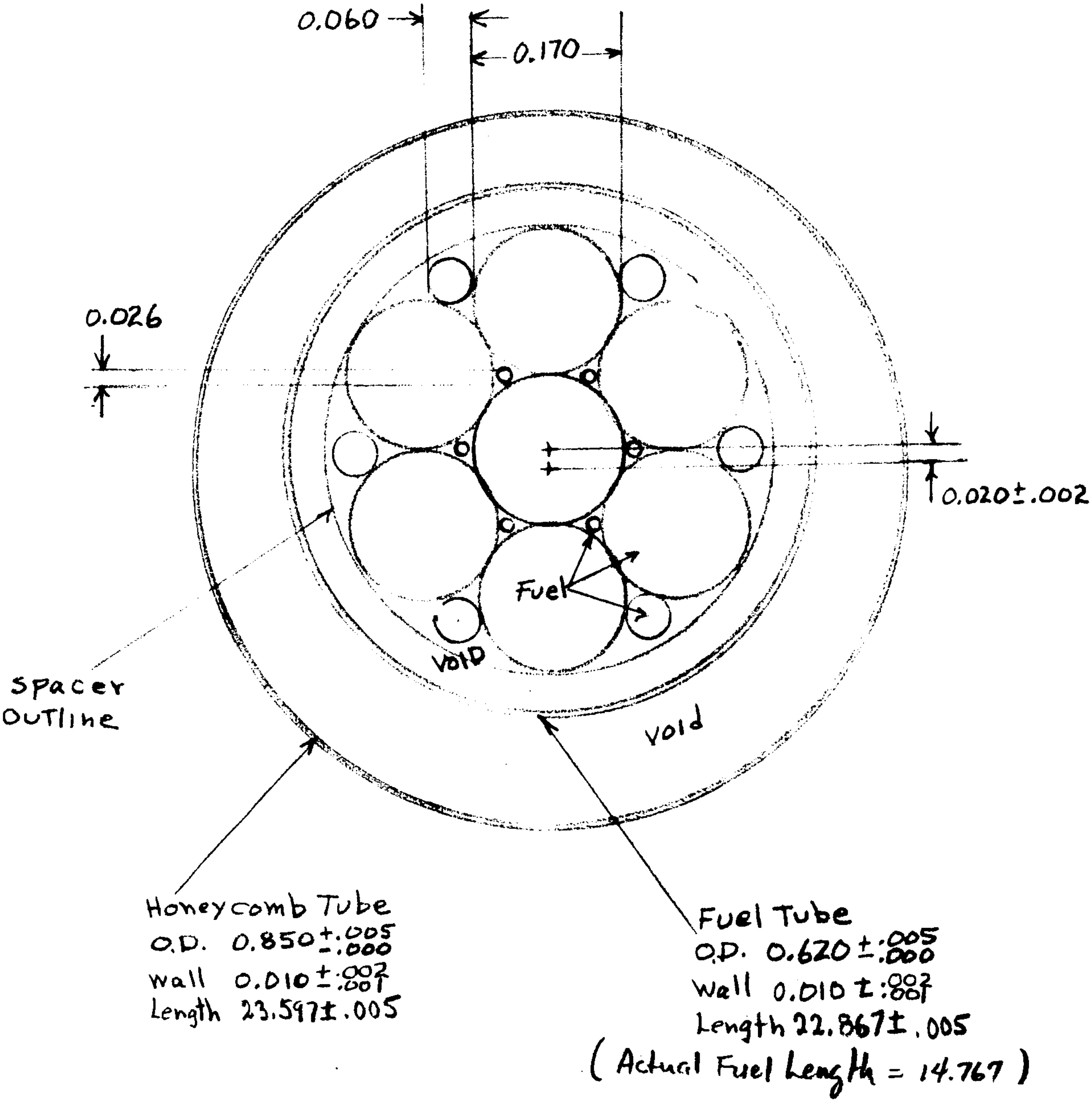


Figure 4. - Fuel element geometry. Dimensions in inches.

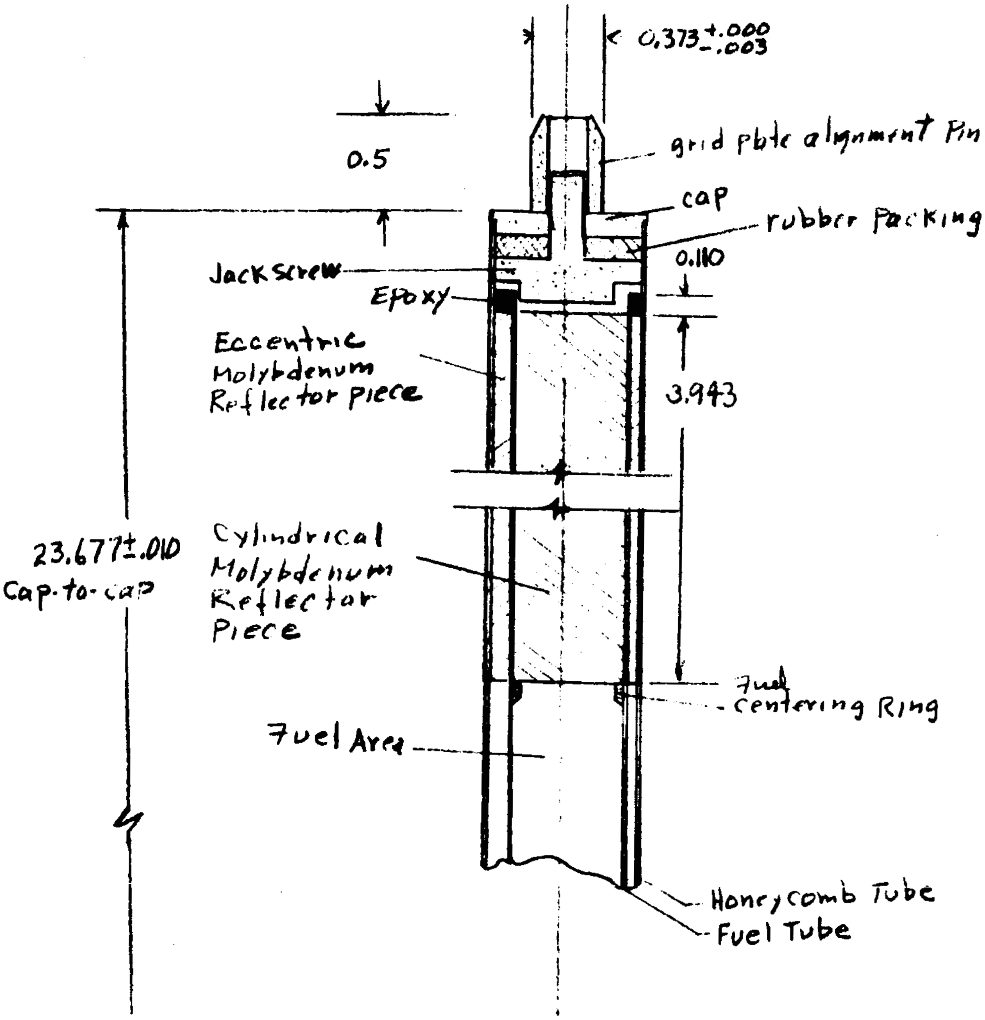


Figure 5. - Fuel element closure method and end reflector design. All dimensions in inches.

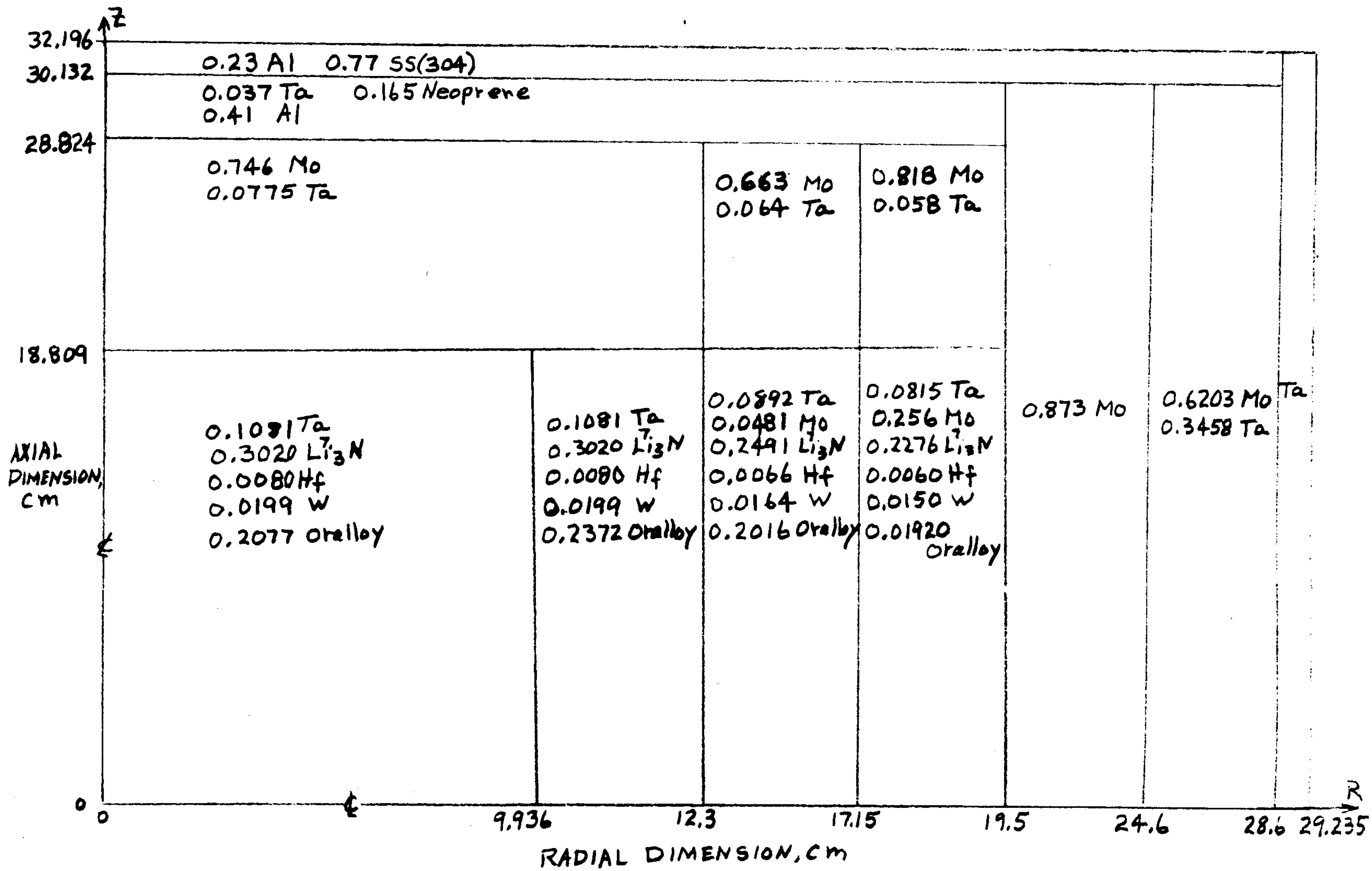


Figure 6 .- R,Z CALCULATION SHOWING VOLUME FRACTIONS OF MATERIALS IN EACH REGION. GEOMETRY IS FOR 174.87 Kilogram Oralloy Zoned Reactor

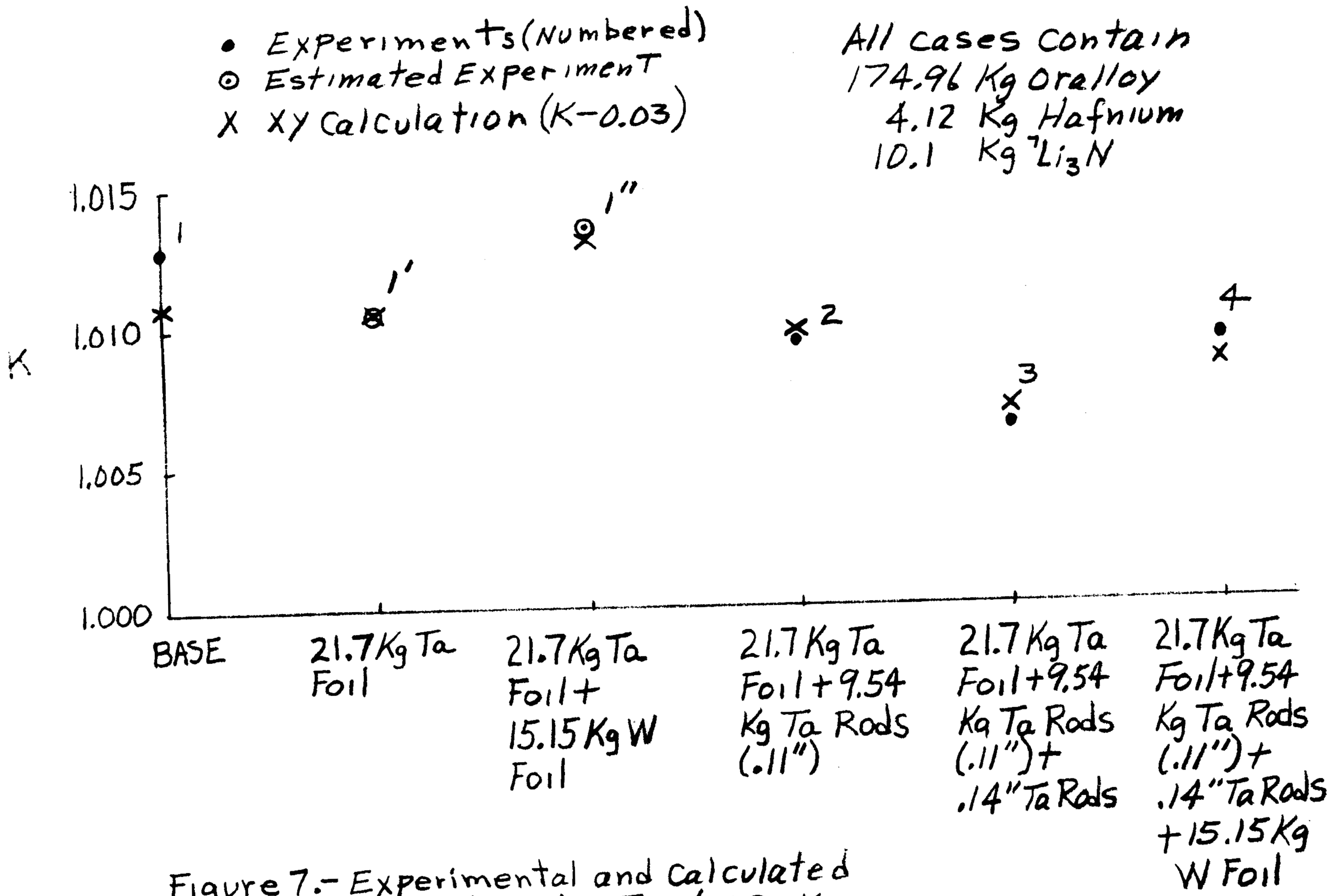
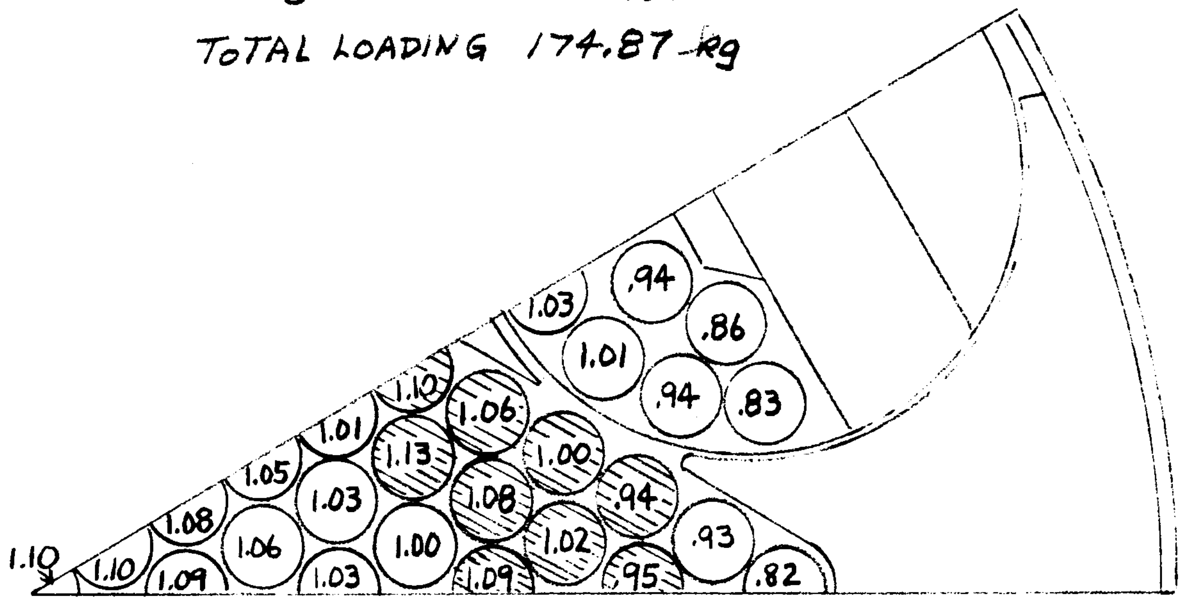


Figure 7.- Experimental and Calculated Multiplication Factors, K

CALCULATED RADIAL POWER DISTRIBUTION RELATIVE TO AVERAGE FOR FUEL-ZONED CRITICAL ASSEMBLY

ZONE	FUEL LOADING gm/Pin
1	627.2
2	716.2
3	769.4

TOTAL LOADING 174.87 kg



ZONE 1
73 PINS

ZONE 2
90 PINS

ZONE 3
84 PINS

Figure 8.-