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MASTER

**MATERIAL BUCKLING MEASUREMENTS ON
GRAPHITE-URANIUM SYSTEMS AT HANFORD:
A SUMMARY TABULATION**

D. E. WOOD

MAY, 1961

HANFORD LABORATORIES

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

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ON GRAPHITE-URANIUM SYSTEMS AT HANFORD:
A SUMMARY TABULATION

By

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Nuclear Physics Research
Physics and Instrument Research and Development
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ABSTRACT

This report summarizes measurements of material bucklings for graphite-uranium systems at Hanford. It provides a comprehensive listing and a guide to the original data sources. Complete information on physical and nuclear properties of the lattice and the geometry of the exponential assembly is included, along with some of the auxiliary data taken.

The fuel sizes vary from 0.925 to 2.5 inches diameter for five different fuel geometries. The lattice spacings vary from 4-3/16 to 15 inches. Over 300 measurements of material buckling are included.

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INTRODUCTION

Exponential measurements of material bucklings for graphite-uranium lattices have been in progress since the earliest days of the Nuclear Age. The classic experiments of the Manhattan Project have been summarized by Davenport.⁽⁷⁾ These experiments, started in 1941, lead to the selection of the original Hanford lattice, and aided in confirming the postulate that a self-sustaining chain reaction could be created using natural uranium. These measurements are primarily of historical interest since later studies not only have covered the same range in more detail, but also have used graphite and uranium of higher purity. A new series of experiments was started in 1951 in connection with new reactor construction at Hanford to provide a better lattice for plutonium production and to increase the available knowledge of lattice constants. This new series has been continued and extended to larger fuel sizes and to complex fuel geometries. Although many other techniques for obtaining lattice data have been developed, the exponential method still has enough advantages to make buckling measurements worthwhile. The main refinement in present day exponential experiments is the tendency to use exponentials to obtain more information than the basic material buckling, such as control rod strengths, temperature effects, multiregion problems, and mixed fuel loadings.

The time scale of the various measurements is shown in Figure 1. The period of measurements on each fuel type and enrichment is shown without a further breakdown into the individual lattice spacings covered. Measurements were not necessarily made over the full time span.

Most of the measurements are reported in formal documents or publications (see References), although some are available only in Quarterly or Monthly Reports, and a few can be found only in the original notebooks.

FIGURE 1
Time Span for Exponential Experiments at Hanford

The primary references are Davenport⁽⁷⁾ (solid rods up to 1.66-inch diameter in 8-foot piles), Block and Richey⁽²⁸⁾ (1.66-inch rods in 4-foot piles), Endres and Wood⁽³⁵⁾ (1.92- and 2.5-inch rods in 4-foot piles), Endres and Block⁽³²⁾ (0.5-inch clusters), Block⁽³⁰⁾ (0.925-inch clusters), Clayton⁽⁴⁾ (hollow rods), Clayton⁽⁶⁾ (enriched fuel), Endres and Wood⁽³⁷⁾ (2.5-inch internally moderated fuel), and Endres and Wood⁽³⁹⁾ (tube-and-tube fuel in 8-foot piles). The original references should be consulted for detailed study of the measurements since all details and methods are not included here. Furthermore, the different reports of the same measurements do not necessarily agree, either because of misprints or a later refined analysis of the data. In the present work an attempt has been made to record the best values of the physical and nuclear parameters, but success in this attempt can not be guaranteed.

OBJECTIVE

This report is written to provide a listing of buckling measurements on graphite-uranium lattices at Hanford in tabular summary form. Over 300 buckling measurements have been made covering a wide range of fuel sizes and geometries, lattice spacings, enrichments, and coolant fractions. The last previous summaries were written in 1956,^(7, 11) so a reasonably current listing is needed to reduce the need for constant reference to the widely scattered reports of individual measurements. It is intended that this summary shall be complete enough so that future work will require only the addition of a few tables to the present summary rather than a completely new listing.

SUMMARY

Buckling measurements on graphite-uranium systems at Hanford are listed in tabular form for a wide range of experimental parameters. Fuel diameters from 0.925 to 2.5 inches, lattice spacings from 4-3/16 to 15 inches, fuel geometries from solid rods to two concentric tubes, enrichments from natural uranium to 1.44 per cent enriched uranium (and a few fully enriched fuels alloyed with aluminum), and several coolant fractions

of light water, air, and occasionally monoisopropylbiphenyl, have been studied in the program summarized here. The sizes of exponential piles have varied from 4 feet square to 8 by 10 feet with the height from 7 to 10 feet.

The bucklings are reported along with a wide variety of physical and geometrical information for the lattices and piles. Additional experimental parameters included are the cadmium ratio, extrapolation distance (distance beyond the physical pile edge where the analytic continuation of the flux goes to zero), and the standard deviations of the measured values. Some of these parameters are not available for all piles.

The tabulation is restricted to buckling measurements and does not include results of fine structure measurements which were made in many of the earlier studies. Other lattice parameters such as L^2 , k_∞ , and f are similarly excluded. Measurements of diffusion length have been evaluated by Lee;⁽⁸⁾ other lattice parameters are not yet available in summary form. Earlier diffusion length studies are reported by Block,⁽¹⁾ and a measurement of buckling as a function of temperature is reported by Lloyd and Richey.⁽⁹⁾

Wherever possible, reference to documents or articles containing the data are included as well as the numbers of the original notebooks containing processed data.

METHODS

The experimental techniques are detailed in the references and are discussed here only where methods were changed between the various sets of measurements.

The basic pile is an 8-foot cube of the lattice supported by a graphite base containing the neutron sources. A smaller pile (4 feet long, 4 to 6 feet wide, and 6 to 8 feet high) is used whenever the amount of material available is limited or the buckling is so large that a critical assembly would be formed. When the available fuel is inadequate even for a 4-foot pile, a "core" or "buffer" method is used. In the "core" method, an array

of the test lattice is surrounded on four sides by different fuel in the same lattice spacing. Measurements in the core region then are used to determine the buckling. In the "buffer" method, one or two layers of different fuel are used at the top and bottom of the lattice but not at the sides. Either method is accurate if both the buckling and cadmium ratio are matched for the test lattice and for the buffer. The configuration of the core and buffer experiments are indicated in the appropriate diagrams of Section III.

The placement of the neutron sources has varied somewhat to suit the requirements of the experiments. In the early experiments the four sources were placed just below the lattice region at the nodes of the third harmonic ($X = \pm a/4$, $Y = \pm b/4$)* to minimize the harmonic corrections. Separate traverses were used to correct for various sources of background. Later the sources were lowered about halfway down the base, and the "cadmium shutter" traverse was used to correct for background. The cadmium shutter is placed in slots between the base and the exponential region. Early in 1957, traverses in the 4-foot piles indicated that fast neutrons leaving the base were scattering back into the exponential region. The sources then were moved to within 1 inch of the vertical center line (the "clustered" source position) to minimize leakage. Later studies⁽³⁹⁾ indicated that the effective pile size is different for the split and clustered source positions when the traverses are analyzed with thermal source theory.

The deficiency of the thermal source theory is the assumption that neutrons are born at thermal energies at the source position. The fast neutrons actually produce a diffuse source of thermal neutrons. The harmonic corrections thus are based on an incorrect source condition unless the diffuse source is considered.

The effective pile size is defined as the physical size plus twice the extrapolation distance, λ . For the 8-foot pile measurements a series of horizontal traverses⁽³⁾ gave an average value of 1 inch for λ . The largest lattice spacing used in this study was 8-3/8 inches. When 4-foot pile

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* This location is called the "split" source position.

measurements were started several known lattices were measured and the value of λ was determined by the effective size required to give the same buckling from both 4-foot and 8-foot piles. Horizontal traverses also were taken. Both methods indicated that a slightly larger value of λ , 1.15 inches, was appropriate for the 4-foot piles. When the clustered sources were used for the 4-foot pile measurements with 1.66-inch solid rod, the comparison of bucklings for 8-foot and 4-foot piles indicated that the value of λ should be 1.66 inches. All measurements on the larger fuels (1.92 and 2.5 inches) included values of λ for each lattice. The traverses parallel to the fuel columns indicated that $\lambda_{||}$ was constant at 1.03 inches, but traverses perpendicular to the fuel showed that $\lambda_{\perp}$ had to be measured for each lattice. Errors in buckling due to errors in λ for various pile sizes are listed in Table I as an indication of the importance of precise knowledge of λ , especially for the smaller piles.

TABLE I
ERRORS IN BUCKLING FROM UNCERTAINTIES IN λ

Pile Width or Length (feet)	Uncertainties in λ (inches)					
	0.05	0.1	0.2	0.3	0.5	1.0
	<u>Error* in Buckling (10^{-6} cm^{-2})</u>					
4	2.7	5.5	11.0	16.5	27.6	55.1
5	1.4	2.8	5.6	8.4	14.1	28.2
6	0.8	1.6	3.3	4.9	8.2	16.4
7	0.5	1.0	2.1	3.1	5.2	10.3
8	0.3	0.7	1.4	2.1	3.5	6.9
10	0.15	0.3	0.7	1.1	1.5	3.5

* The error in buckling includes the effect of the uncertainty in λ on each side of the pile, and the error should be applied separately to the width or length of the pile.

DISCUSSION

The data available on graphite-uranium exponential measurements at Hanford have been divided into three sections covering lattice geometry, nuclear parameters, and details of pile construction.

Section I on lattice geometry is arranged according to fuel geometry with a table of uranium dimensions and a table of cell dimensions for each fuel type. The fuel diameter is listed in inches since this is the normal method of referring to the various fuels. All other dimensions are in centimeters. The solid and equivalent densities of the uranium are listed. The equivalent density is the result obtained if the uranium is assumed to fill the end cap space without changing the radius. The surface-to-mass ratios are calculated from the solid density. Figures 2 and 3 are pictures of some of the fuels used. Dimensions of the aluminum, coolant, and graphite are listed in the second table for each type of fuel. The process tube inside radius includes the fuel supporting ribs (if any), which are assumed to be distributed uniformly on the inside of the process tube. The cross-sectional areas of all components and the total aluminum-to-uranium volume ratio are recorded. The total aluminum volume and aluminum-to-uranium ratio include the end caps which are assumed to be distributed uniformly over the length. The volume of water usually is measured and does not necessarily agree with the aluminum dimensions.

The aluminum used is Type 2S (99.2 per cent aluminum) with a nominal density of 2.7. The graphite purity is indicated by the diffusion length (perpendicular to the extrusion axis) of 54.2 cm referred to a standard density of 1.60. The graphite density is 1.647 for lattice spacings of 7, 7-1/2, 8, 14, and 15 inches, and 1.658 for all others. Atomic ratios are derived using atomic densities of 0.04783×10^{24} atoms/cc for uranium at density 18.9, 0.0602×10^{24} atoms/cc for aluminum at density 2.7, 0.0335×10^{24} molecules/cc for water at density 1.0, and 0.0803×10^{24} atoms/cc for graphite at density 1.60.

The outside radius of the graphite is determined from the area equivalent to the square or rectangular lattice and listed in Table I-6 for all lattice spacings used.

FIGURE 2
Fuel Elements Used in Exponential Experiments

2.50"
Solid

1.92"
Solid

2.50" x 1.60"   1.17"
Tube and Rod

2.50" x 2.00"   1.66" x 1.12"
Tube and Tube

FIGURE 3

Large Fuel Elements Used in Exponential Experiments

Section II containing the nuclear parameters is arranged in the same order as Section I. A separate table for each fuel size and enrichment lists the material bucklings and cadmium ratios versus lattice spacing for each aluminum-to-uranium ratio. The aluminum-to-uranium ratios are in the same order in both sections. Volume and atom ratios of aluminum-, water-, and carbon-to-uranium are listed, along with the approximate completion date of the measurement. Where applicable, the reference reporting the results is included together with the number of the notebook where the processed data and details are stored. All notebooks are stored in the Exponential Pile Laboratory at the present time. The cadmium ratios were measured with a BF_3 tube and were always taken at the edge of the cell on a line between centers of fuel elements.

The B_{11} listed is the vertical relaxation length determined from a least squares fit to the corrected count rates. The analysis is limited to the region where the cadmium ratio is essentially constant. The buckling then is related to the B_{11} through the effective pile size, which is found by adding twice the extrapolation distance to the physical pile size. Recent measurements include the measured value of λ , the cell position where the traverse was taken, and the calculated standard deviations in λ and B^2 . The cell position of the horizontal traverse is keyed to the cell diagram in Figure II-1.

The first part of the third section on pile geometry is a list of lattice spacings used for each fuel. The front face diagram then is given for each different kind of pile. Several piles are combined with appropriate footnotes wherever possible. Counting slot positions, source positions, and pile dimensions are tabulated with the diagrams. Pictures of a few of the piles are included. Since most of the bases are similar, only a few of them are shown. Counter slots are shown by smaller circles than fuel.

The precision of the measurements is not the same for all sets of measurements. The 4-foot pile measurements are survey type studies intended to find relative values, but not necessarily absolute values of the buckling. The extrapolation distances are not too well known for the early

4-foot piles, so only the relative values are significant. The larger lattice spacings ($>8\text{-}3/8$ inches) in the 8-foot piles did not include measurements of λ and may not be as precise as the smaller lattice spacings. However, the 8-foot piles are large enough so that an error in λ would not be very serious. The use of clustered sources now is known to result in larger values of λ , and older measurements with clustered sources have not been corrected for this effect. In general the best values of B^2 come from 8-foot piles with split sources and an assumed λ of 1 inch. This value of λ was confirmed by an extensive series of horizontal traverses with split sources. The error expected in these measurements is about $4 \times 10^{-6} \text{ cm}^{-2}$, which consists of independent errors of 2 to $3 \times 10^{-6} \text{ cm}^{-2}$ from the vertical traverse and an uncertainty in λ of 0.3 inch in each direction. The next best values of B^2 come from smaller piles (4 to 8 feet) with measured values of λ for every configuration. Here the usual errors are 3 to $5 \times 10^{-6} \text{ cm}^{-2}$ in the vertical traverse, 0.1 inch in λ parallel to the process tube, and 0.3 inch in λ perpendicular to the process tubes. The combined error is around $10 \times 10^{-6} \text{ cm}^{-2}$ in B^2 . The errors for other situations can be derived from recent studies of variation in the extrapolation distance and the effects of the position of the source. The evaluation of these systematic errors is not yet complete.

SYMBOLS AND ABBREVIATIONS USED IN DATA SECTIONS

N.U.	Natural uranium
V-Al/U, V-H ₂ O/U, V-C/U	Volume ratios of aluminum, water, and carbon to uranium
A-Al/U, A-H ₂ O/U, A-C/U	Atom (or molecule) ratios of aluminum, water, and carbon to uranium
S and U	Separated and unseparated, referring to the rods in a cluster fuel assembly
S/M	Surface-to-mass ratio in cm ² /gram, using actual density, before end cap correction.
I, E, I and E	Coolant location referring to hollow fuel: internal, external, or internal and external coolant
ρ	Density, grams/cm ³
ρ_e	Equivalent density corrected for end caps, grams/cm ³
L.S.	Lattice spacing, inches
B ₁₁	Vertical relaxation length, cm
CR	Cadmium ratio for a BF ₃ proportional counter at the center of the cell edge.
D, W, M	Coolant: air, water, or monoisopropyl-biphenyl
B ²	Material buckling, 10 ⁻⁶ cm ⁻²
Ref.	Reference document or publication
N.B.	Reference notebook
N _B	Number of points fitted to obtain B ₁₁
N _{λ}	Number of points fitted to obtain λ
$\lambda_{ }$, $\lambda_{\perp}$	Extrapolation distance, parallel and perpendicular to the process tubes, as measured by the argument of the fitted cosine less the physical pile size, in cm. The number listed is the average of both sides.
L _{λ}	Location in the cell of the horizontal traverse (see Figure II-1, page 43).

$\sigma(\lambda)$	Standard deviation on λ , measured by the residual deviations from the fitted cosine, cm
$\sigma(B^2)$	Standard deviation on B^2 including the combined deviations on λ and B_{11} , 10^{-6} cm^{-2}
X	Distance from center of pile, perpendicular to tubes, cm
Y	Distance from center of pile, parallel to tubes, cm
Z	Distance from source plane, cm
P	Distance from bottom of lattice (or shutter plane) to source plane, cm
Q	Total height of base (distance from bottom of lattice to floor), cm
a	Average pile width, cm. Layers are not always exactly equal so an average is taken for the whole pile.
b	Pile length, cm. Stock graphite is used so the length is always 4 or 8 feet. Slight variations indicate that the fill layers between tubes were perpendicular to the tube layers for stability so that the average lengths are slightly different.
Δ	Distance from the center of the last process tube to the edge of the pile less half the lattice spacing. This is a measure of the deviation of the pile size from an integral number of lattice cells.
IR	Inside radius in cm
OR	Outside radius in cm

DATA SECTION I

LATTICE GEOMETRY TABLES

TABLE 1A

SOLID RODS: URANIUM GEOMETRY

Case	Diameter (inches)	Enrichment (w/o U ²³⁵)	Radius (cm)	Area (cm ²)	Length (cm)	ρ (grams/cm ³)	Double End Cap Thickness (cm)	ρ_e (grams/cm ³)	S/M (cm ² /grams)
1	0.925	N.U.*	1.175	4.337	19.43	18.91	1.02	17.98	0.090
2	0.925	1.007	1.175	4.337	10.16	18.91	1.02§	18.1	0.090
2A	0.925	1.007	1.175	4.337	10.16	18.91	None	18.91	0.090
3	1.17	N.U.	1.49	6.975	19.43	18.90	1.02	18.09	0.071
4	1.336	N.U.	1.697	9.048	21.15	18.90	1.56	17.6	0.062
5	1.336	0.94	1.697	9.048	15.24	18.90	0.95	17.8	0.062
6	1.343	4.46**	1.706	9.143	15.24	2.807§§	1.70	2.525	0.417§§
7	1.343	7.5**	1.706	9.143	21.06	2.885§§	1.95	2.640	0.406§§
8	1.36	N.U.	1.727	9.370	10.27	18.75	0.94	17.14	0.062
9	1.66	N.U.	2.11	13.96	10.16	18.75	None	18.75	0.051
10	1.66	1.007	2.11	13.96	10.16	18.90	None	18.90	0.051
11	1.923	N.U.	2.442	18.73	15.24	18.89	None	18.89	0.043
12	2.5	N.U.	3.175	31.67	15.24	18.86	None	18.86	0.033

* Natural uranium: 0.711 w/o U²³⁵

** Weight per cent of fully enriched uranium (93 per cent U²³⁵) in aluminum. The weights of U²³⁵ in the fuel elements are 16.45 and 38.33 grams, respectively, for cases 6 and 7, and the weights of U²³⁵ per unit length are 1.079 and 1.820 grams/cm with no correction for end caps.

§§ The values, 2.807 and 2.885, are densities of the alloy. Surface-to-mass ratios of cases 6 and 7 are those of the alloy and not of the uranium content.

§ Spacer inserted after every second fuel element--one spacer per 21.34-inch length.

TABLE 1B
SOLID RODS: RADII AND AREAS

Case	Radii (cm)						Aluminum				Coolant	
	Uranium	Can IR	Can OR	Process Tube IR	Process Tube OR	Graphite IR	Can Area	Process Tube Area	Total Al Area (Including end caps)	V-Al/U	Annulus Thickness	Area
1	1.175	1.18	1.27	1.50	1.59	1.922	0.68	0.87	1.76	0.427	0.208	1.80**
1	1.175	1.18	1.27	1.40	1.55	1.567	0.68	1.36	2.25	0.545	0.123	1.03
1	1.175	1.18	1.27	1.75	1.91	1.922	0.68	1.75	2.64	0.639	0.490	4.66
1	1.175	1.18	1.27	1.40	1.55	1.922	0.68	1.36	3.12\$\$	0.757	0.123*	1.03*
1	1.175	1.18	1.27	1.40	1.55	1.922	0.68	1.36	4.00\$	0.968	0.123*	1.03*
2	1.175	1.18	1.27	1.50	1.59	1.922	0.68	0.87	1.76	0.424	0.208	1.93
2	1.175	1.18	1.27	1.40	1.55	1.567	0.68	1.36	2.25	0.542	0.123	1.03
2	1.175	1.18	1.27	1.75	1.91	1.922	0.68	1.75	2.64	0.636	0.490	4.61
2	1.175	1.18	1.27	2.02	2.20	2.215	0.68	2.31	3.20	0.771	0.750	7.84
2A	1.175	1.18	1.27	1.40	1.55	1.567	0.68	1.36	2.04	0.470	0.123	1.03
3	1.49	1.50	1.59	1.75	1.91	1.922	0.87	1.75	2.93	0.438	0.165	1.73
4	1.697	1.74	1.83	2.02	2.20	2.215	1.26	2.31	4.19	0.491	0.190	2.41
5	1.697	1.74	1.83	2.02	2.20	2.215	1.26	2.31	4.10	0.481	0.190	2.41
6	1.706	1.706	1.81	2.02	2.20	2.215	1.15	2.31			0.213	2.57
7	1.706	1.706	1.81	2.02	2.20	2.215	1.15	2.31			0.213	2.57
8	1.727	1.74	1.83	2.13	2.20	2.215	1.01	0.97	2.77	0.323	0.296	3.73
8	1.727	1.74	1.83	2.02	2.20	2.215	1.01	2.31	4.11	0.480	0.190	2.33
9	2.11	2.13	2.20	None	None	2.215	0.97	None	0.97	0.069	None	None
9	2.11	2.13	2.20	2.534	2.70	2.714	0.952	2.73	3.68	0.264	0.334	5.06
10	2.11	2.13	2.20	None	None	2.215	0.97	None	0.97	0.069	None	None
11	2.442	2.451	2.54	2.855	3.048	3.067	1.395	3.579	4.974	0.264	0.315	5.338
12‡	3.175	3.186	3.275	3.833	4.002	4.035	1.806	4.159	5.965	0.185	0.558	12.46

* Coolant in the inner annulus only.

** Water values in References 6 and 7 do not agree with the aluminum dimensions since the values are based on measured water quantities and are more accurate than the aluminum dimensions.

\$ Includes a second process tube 1.75 x 1.91 cm, area 1.75 cm².

\$\$ Includes a second process tube 1.50 x 1.59 cm, area 0.87 cm², split and bent to fit around the regular process tube.

‡ The can OR is corrected for aluminum runners instead of the process tube IR.

TABLE 2A
CLUSTERED RODS: URANIUM GEOMETRY

Case	Diameter (inches)	Enrichment	Radius (cm)	Area of One Rod (cm ²)	Length (cm)	ρ (grams/cm ³)	Double End Cap Thickness (cm)	ρ_e (grams/cm ³)	S/M (one rod) (cm ² /gram)	Center-to-Center Spacing (cm)	Number of Rods
1	0.500	N. U.	0.635	1.267	30.48	18.86	None	18.86	0.167	1.646	7S
2	0.925	N. U.	1.175	4.337	19.43	18.91	1.02	17.98	0.090	2.725	7S
3	0.925	N. U.	1.175	4.337	19.43	18.91	1.02	17.98	0.090	2.548	7U
4	0.925	N. U.	1.175	4.337	19.43	18.91	1.02	17.98	0.090	2.725	6U
5	0.925	N. U.	1.175	4.337	19.43	18.91	1.02	17.98	0.090	2.764	5S

Cases 1, 2, and 5 have water gaps between rods (separated).

Cases 3 and 4 have the clad rods in contact (unseparated).

Clusters of seven rods have a central rod surrounded by a ring of six rods.

Clusters of six rods are the same as the seven-rod clusters with the central rod missing.

Clusters of five rods are a ring of five with no central rod.

TABLE 2B
CLUSTERED RODS: RADII AND AREAS

Case	Radii (cm)						Aluminum					
	Uranium	Can IR	Can OR	Process Tube IR	Process Tube OR	Graphite IR	Can Area	Process Tube Area	Total Al Area (Including end caps)	V-Al/U	Coolant Area	Number of Rods
1	0.635	0.640	0.757	2.534	2.699	2.714	3.594	2.712	6.306	0.711	7.57	7S
2	1.175	1.18	1.274	4.178	4.343	*	5.08	4.42	10.97	0.379	19.16	7S
3	1.175	1.18	1.274	3.835	4.001	*	5.08	4.09	10.68	0.369	10.45	7U
4	1.175	1.18	1.274	3.835	4.001	*	4.35	4.09	9.74	0.394	15.61	6U
5	1.175	1.18	1.274	3.835	4.001	*	3.63	4.09	8.80	0.427	20.71	5S

The can area, total aluminum area, and Al/U ratio are all calculated using the total number of rods in cluster.

* The graphite holes for the 0.925-inch clusters were square holes with small pieces of graphite used to make the voids smaller. The equivalent radius of the square hole is listed below for each lattice spacing studied:

<u>Separated 7 Rod</u>	<u>Unseparated and 5 Rod Separated</u>
7 in. - 4.806 cm	7 in. - 4.806 cm
10-3/8 in. - 5.105 cm	10-3/8 in. - 4.953 cm
14 in. - 4.806 cm	14 in. - 5.017 cm

Polyethylene spacers were used to position the fuel for Cases 1 and 2. The equivalent areas (uniformly distributed) are 0.158 cm² for Case 1 and 0.50 cm² for Case 2. The polyethylene is included with the coolant area.

TABLE 3A
HOLLOW RODS: URANIUM GEOMETRY

Case	Diameter (inches)	Enrichment	IR (cm)	OR (cm)	Area (cm ²)	Length (cm)	ρ (grams/cm ³)	Double End Cap Thickness (cm)	ρ_e (grams/cm ³)	S/M^* (cm ² /grams)
1	1.36 x 0.50	N.U.	0.635	1.727	8.11	10.27	18.75	0.94	17.14	0.0714
2	1.37 x 0.48	N.U.	0.610	1.740	8.344	20.32	18.9	1.60	17.5	0.0693
3	1.37 x 0.48	N.U.	0.610	1.740	8.344	20.32	18.9	1.60	17.5	0.0693
4	1.66 x 0.81	N.U.	1.029	2.108	10.63	10.16	18.75	None	18.75	0.0664
5	1.66 x 0.94	1.007	1.194	2.108	9.481	10.16	18.9	None	18.9	0.0739
6	1.66 x 1.12	N.U.	1.422	2.108	7.609	10.16	18.60	None	18.60	0.0936
7	2.50 x 1.60	N.U.	2.032	3.175	18.70	15.24	18.78	None	18.78	0.0568

* Outside surface only

TABLE 3(a)A
SOLID TO HOLLOW FUEL COMPARISON*: URANIUM GEOMETRY

Case	Diameter (inches)	Enrichment	IR (cm)	OR (cm)	Area (cm ²)	Length (cm)	ρ (grams/cm ³)	Double End Cap Thickness (cm)	ρ_e (grams/cm ³)	S/M (cm ² /grams)
1	1.356 x 0.414	N.U.	0.526	1.722	8.448	21.15	18.90	1.56	17.60	0.068§
2	1.336	N.U.	---	1.697	9.048	21.15	18.90	1.56	17.60	0.062
3	1.37 x 0.481	N.U.	0.611	1.740	8.344	21.15	18.90	1.56	17.60	0.069§
4	1.336	N.U.	---	1.697	9.048	21.15	18.90	1.56	17.60	0.062

* Special study to compare bucklings; no attempt was made to get absolute values for this set of measurements.

§ Outer surface only

TABLE 3B

HOLLOW RODS: RADII AND AREAS

Case	Radii (cm)										Aluminum					Coolant				
	U OR	U IR	Outer Can IR	Outer Can OR	Process Tube IR	Process Tube OR	Inner Can IR	Inner Can OR	Graphite IR	Inner Can Area	Outer Can Area	Process Tube Area	Total Al Area	V-Al/U	Core Radius	Outer Annulus Thickness	Area (core)	Area (annulus)	Total Area	Coolant Location
1	1.727	0.635	1.74	1.83	2.02	2.20	None	None	2.215	None	1.01	2.31	4.11	0.554	None	0.19	None	2.33	2.33	E
2	1.740	0.610	1.74	1.87	2.13	2.20	0.48	0.61	2.215	0.446	1.473	0.97	3.66	0.473	0.48	0.26	0.72	3.16	3.88	I and E
3	1.740	0.610	1.74	1.87	2.13	2.20	0.48	0.61	2.215	0.446	1.473	0.97	3.66	0.473	0.48	0.26	0.72	3.16	3.88	I and E
3	1.740	0.610	1.74	1.87	2.06	2.24	0.48	0.61	2.264	0.446	1.473	2.36	5.05	0.654	0.48	0.22	0.72	2.73	3.45	I and E
4	2.108	1.029	2.13	2.20	None	None	0.87	1.02	2.215	0.89	0.97	None	1.86	0.175	0.87	None	2.38	None	2.38	I
5	2.108	1.194	2.13	2.20	None	None	0.87	1.02	2.215	0.89	0.97	None	1.86	0.196	0.87	None	2.38	None	2.38	I
6	2.108	1.422	2.13	2.20	None	None	1.26	1.40	2.215	1.18	0.97	None	2.15	0.283	1.26	None	4.96	None	4.96	I
7	3.175	2.032	3.188	3.28	3.833	4.002	1.924	2.013	4.035	1.10	1.869	4.159	7.128	0.381	1.19	0.553	11.63	12.36	23.99	I and E

Cases 2, 3 and 7: The OR of the can is corrected for Al runners instead of the IR of the process tube.

TABLE 3(a)B

SOLID TO HOLLOW FUEL COMPARISON: RADII AND AREAS

Case	Radii (cm)										Aluminum					Coolant				
	U OR	U IR	Outer Can OR	Outer Can IR	Process Tube OR	Process Tube IR	Inner Can OR	Inner Can IR	Graphite IR	Inner Can Area	Outer Can Area	Process Tube Area	Total Al Area	V-Al/U	Core Radius	Outer Annulus Thickness	Area (core)	Area (annulus)	Total Area	Coolant Location
1	1.722	0.526	1.854	1.722	2.20	2.02	0.52	0.39	2.215	0.382	1.48	2.31	4.76	0.605	0.394	0.166	0.487	2.02	2.51	I and E
2	1.697	---	1.830	1.697	2.20	2.02	--	--	2.215	---	1.47	2.31	4.40	0.522	---	0.190	---	2.30	2.30	E
3	1.740	0.611	1.872	1.740	2.24	2.06	0.61	0.48	2.264	0.446	1.47	2.32	4.83	0.622	0.48	0.188	0.724	2.35	3.09	I and E
4	1.697	---	1.830	1.697	2.24	2.06	--	--	2.264	---	1.47	2.32	4.41	0.523	---	0.230	---	2.81	2.81	E

TABLE 4A

TUBE AND ROD ELEMENTS URANIUM GEOMETRY

Case	Tube Diameter (inches)	Rod Diameter (inches)	Enrichment	Tube Outside Radius (cm)	Tube Inside Radius (cm)	Rod Radius (cm)	Tube Area (cm ²)	Rod Area (cm ²)	Total Area (cm ²)	Tube Length (cm)	Rod Length (cm)	ρ Tube (grams/cm ³)	ρ Rod (grams/cm ³)	ρ Average (grams/cm ³)	Double End Cap	S/M (cm ² /grams)
1	2.50 x 1.60	0.50	N.U.	3.175	2.032	0.635	18.70	1.266	19.97	15.24	30.48	18.78	18.65	18.76	None	0.056
2	2.50 x 1.60	1.175	N.U.	3.175	2.032	1.492	18.70	6.975	25.68	15.24	19.37	18.78	18.95	18.82	None	0.041

Surface-to-mass ratios in these cases are determined from the outside cylinder only.
The masses used are from the tube and the rod together.

TABLE 4B

TUBE AND ROD ELEMENTS RADII AND AREAS

Case	Radius (cm)												Aluminum					Coolant						
	U Rod	U Tube	U Tube	Outer Can	Outer Can	Inner Can	Inner Can	Outer Can	Outer Can	Process	Process	Graphite IR	Can Area	Inner Can Area	Outer Can Area	Process Tube	Total Al Area	V-Al/U	Inner Annulus Thickness	Outer Annulus Thickness	Inner Area	Outer Area	Total Area	Polyethylene
	IR	IR	IR	IR	IR	(Tube) IR	(Tube) IR	(Tube) IR	(Tube) OR	Tube IR	Tube OR		(Rod)	(Tube)	(Tube)	Area	Area	Area	Area	Area	Area	Area	Area	
1	0.635	2.032	3.175	0.640	0.757	1.924	2.013	3.188	3.280	3.837	4.002	4.035	0.513	1.10	1.869	4.159	7.64	0.382	1.167	0.553	9.83	12.36	22.19	0.26*
2	1.492	2.032	3.175	1.499	1.588	1.924	2.013	3.188	3.280	3.837	4.002	4.035	0.864	1.10	1.869	4.159	8.00	0.311	0.336	0.553	3.71	12.36	16.07	0.077*

Aluminum runners are included in the outer can instead of the process tube.

* Polyethylene spacers are used to center the fuel and are considered part of the water volume for the wet case.

TABLE 5ATUBE IN TUBE ELEMENTS: URANIUM GEOMETRY

	<u>Case 1</u>
Inner Tube Diameter (inches)	1.66 x 1.12
Outer Tube Diameter (inches)	2.50 x 2.00
Enrichment	N. U.
Inner Tube IR (cm)	1.422
OR (cm)	2.108
Outer Tube IR (cm)	2.54
OR (cm)	3.175
Inner Tube Area (cm ²)	7.609
Outer Tube Area (cm ²)	11.401
Total Area (cm ²)	19.01
Inner Tube Length (cm)	10.16
Outer Tube Length (cm)	20.32
Inner Tube ρ (grams/cm ³)	18.60
Outer Tube ρ (grams/cm ³)	18.95
ρ Average (grams/cm ³)	18.81
Double End Cap	None
S/M (cm ² /grams)	0.0555

Surface-to-mass ratio was determined from the outer surface of the outer tube and the masses of both tubes.

TABLE 5B

TUBE IN TUBE ELEMENTS: RADII AND AREAS

	<u>Case 1</u>
<u>Radii (cm)</u>	
Uranium Inner Tube, IR	1.422
OR	2.108
Uranium Outer Tube, IR	2.54
OR	3.175
Inner Tube, Inner Can, IR	1.257
OR	1.397
Inner Tube, Outer Can, IR	2.13
OR	2.20
Outer Tube, Inner Can, IR	2.438
OR	2.527
Outer Tube, Outer Can, IR	3.188
OR (corrected for runners)	3.280
Process Tube, IR	3.837
OR	4.002
Graphite, IR	4.035
<u>Aluminum</u>	
Inner Tube, Inner Can, Area	1.168
Inner Tube, Outer Can, Area	0.952
Outer Tube, Inner Can, Area	1.388
Outer Tube, Outer Can, Area	1.869
Process Tube Area	4.159
Total Aluminum Area	9.536
V-Al/U	0.502
<u>Coolant</u>	
Core Radius (cm)	1.257
Inner Annulus Thickness (cm)	0.238
Outer Annulus Thickness (cm)	0.553
Area (core)	4.96
(inner annulus)	3.47
(outer annulus)	12.36
Total Area	20.79
Polyethylene	0.072*

* Polyethylene spacers used to center the fuel. Spacers are considered part of the water volume for wet case.

TABLE 6
EQUIVALENT CELL RADII
FOR ALL LATTICE SPACINGS

<u>Lattice Spacing</u> <u>(inches)</u>	<u>Equivalent</u> <u>Cell Radius</u> <u>(cm)</u>
4-3/16	6.001
5-3/16	7.434
6-3/16	8.867
7	10.031
7-3/16	10.300
7-1/2	10.748
7-11/16	11.016
8	11.464
8-3/8	12.001
9-3/8	13.434
10-3/8	14.868
12-3/8	17.734
14	20.063
14-9/16	20.876
15	21.496
4-3/16 x 8-3/8	8.486

DATA SECTION II

MATERIAL BUCKLING TABLES

TABLE 1
CASE 1. 0.925-INCH RODS, N. U.
a. 8-Foot Pile

L.S. (in.)	B ₁₁		V-A1/U	A-A1/U	V-H ₂ O/U	A-H ₂ O/U	V-C/U	A-C/U	CR		B ²		Date		Ref.	N.B.
	W	D							W	D	W	D	W	D		
5-3/16	63.87	63.58	0.427	0.537	0.436	0.305	39.31	68.2	25.0	19.6	68	66	5/55	5/55	7, 18	21, 26
6-3/16	66.48	71.84	0.427	0.537	0.436	0.305	57.11	99.0	34.8	27.7	89	122	3/54	2/54	7	9, 26
7	67.59	76.19	0.427	0.537	0.436	0.305	73.88	127.4	41.5	34.9	67	113	5/55	5/55	7, 18	22, 26
7-1/2	64.96	73.51	0.427	0.537	0.436	0.305	85.23	147.1	48.6	40.6	51	103	2/54	2/54	7	8, 26
5-3/16	64.72	63.91	0.545	0.686	0.249	0.174	40.25	69.9	23.7	20.6	75	69	4/55	4/55	7, 18	21, 26
6-3/16	67.86	70.64	0.545	0.686	0.249	0.174	58.06	100.7	33.1	29.6	98	115	4/53	4/53	7, 18	9, 26
7	70.44	75.28	0.545	0.686	0.249	0.174	74.83	129.0	41.2	37.8	84	109	4/55	4/55	7, 18	22, 26
7-1/2	67.12	71.90	0.545	0.686	0.249	0.174	86.18	148.7	47.4	43.4	66	95	6/53	5/53	7, 18	8, 26
5-3/16	56.24	61.53	0.639	0.805	1.130	0.790	39.31	68.2	32.0	19.6	-3	49	5/55	4/55	7, 18	21, 26
6-3/16	55.19	68.59	0.639	0.805	1.130	0.790	57.11	99.0	42.4	27.9	-13	103	2/54	1/54	7	9, 26
7	56.31	72.96	0.639	0.805	1.130	0.790	73.88	127.4	48.5	37.2	-30	98	5/55	4/55	7, 18	22, 26
7-1/2	54.44	71.07	0.639	0.805	1.130	0.790	85.23	147.1	55.5	41.0	-49	90	2/54	1/54	7	8, 26
7	64.83	---	0.757	0.953	0.249	0.174	73.88	127.4	38.04	--	48	-	8/55	-	---	22, 26
5-3/16	58.07	57.79	0.968	1.219	0.249	0.174	39.31	68.2	22.3	19.4	17	14	6/55	6/55	18	21, 26
6-3/16 ^a	67.10	69.32	0.545	0.686	0.249	0.174	58.06	100.7	31.8	28.6	93	107	12/53	12/53	12	15
6-3/16 ^b	68.03	69.96	0.545	0.686	0.249	0.174	58.06	100.7	32.5	28.9	99	111	4/53	12/53	12	15, 9
6-3/16 ^c	67.91	70.62	0.545	0.686	0.249	0.174	58.06	100.7	32.8	29.4	98	115	12/53	12/53	12	15

a, b, c: Core loadings of 0.925-inch rods surrounded by 1.17-inch rods to study precision of core measurements.
The numbers of tubes of 0.925-inch fuel for a, b, and c, are 4 x 7, 6 x 7, and 8 x 7, respectively.

TABLE 1
CASE 1. 0.925-INCH RODS, N. U.*
b. 4-Foot Pile

7-1/2	---	30.20	---	---	---	---	---	---	---	---	---	101	---	4/56	-	43, 26
8-3/8	28.64	28.92	0.545	0.686	0.249	0.174	---	186.8	53.9	--	39	63	10/56	10/56	-	43, 24, 26

* Clustered sources were used and the extrapolation length was assumed to be 1.15 inches.

TABLE 1

CASE 2. 0.925-INCH RODS, 1.007 PER CENT ENRICHMENT

a. 4-Foot Pile

L.S. (in.)	B ₁₁		V-Al/U	A-Al/U	V-H ₂ O/U	A-H ₂ O/U	V-C/U	A-C/U	CR		B ²		Date		Ref.	N.B.
	W	D							W	D	W	D	W	D		
6-3/16	34.07	34.14	0.424	0.534	0.465	0.326	56.8	98.7	--	--	356	360	4/56	4/56	6, 22	36, 39
7	32.18	32.94	0.424	0.534	0.465	0.326	73.6	127.1	33.6	28.8	309	352	6/56	6/56	6, 22	37, 36
7-1/2	32.97	33.97	0.424	0.534	0.465	0.326	84.9	146.6	--	--	278	331	4/56	3/56	6, 22	36, 43
8-3/8	30.89	31.66	0.424	0.534	0.465	0.326	106.5	185.1	48.7	42.0	211	261	6/56	5/56	22	24, 36
6-3/16	33.93	34.07	0.542	0.683	0.248	0.174	57.7	100.4	--	--	349	356	3/56	2/55	6, 22, 21	36, 39
7	32.48	32.90	0.542	0.683	0.248	0.174	74.5	128.7	33.7	29.8	326	350	6/56	6/56	6, 22	36, 37
7-1/2	33.32	33.82	0.542	0.683	0.248	0.174	85.9	148.2	--	--	297	313	3/56	3/56	6, 22	36, 43
8-3/8	31.09	---	0.542	0.683	0.248	0.174	107.5	186.8	46.2	--	224	-	6/56	--	6, 22	24, 36
6-3/16	32.48	33.67	0.636	0.801	1.111	0.786	56.8	98.7	--	--	270	335	4/56	4/56	6, 22	36, 39
7	31.04	32.61	0.636	0.801	1.111	0.786	73.6	127.1	42.6	29.2	236	334	6/56	6/56	6, 22	36, 37
7-1/2	31.53	33.57	0.636	0.801	1.111	0.786	84.9	146.6	46.0	--	192	310	5/56	4/56	6, 22, 21	36, 43
8-3/8	---	31.48	0.636	0.801	1.111	0.786	106.5	185.1	--	41.7	-	249	--	10/56	6, 22	24, 36
6-3/16	30.75	33.14	0.771	0.971	1.889	1.326	55.8	97.1	--	--	160	307	5/56	5/56	6, 22	36, 39
7	29.20	32.38	0.771	0.971	1.889	1.326	72.7	125.5	--	28.4	102	320	5/56	5/56	6, 22	36, 37
7-1/2	29.74	33.22	0.771	0.971	1.889	1.326	84.0	145.0	--	--	67	292	5/56	5/56	6, 22	36, 43
8-3/8	28.65	31.41	0.771	0.971	1.889	1.326	105.5	183.5	--	--	40	245*	5/56	5/56	22	36, 24
6-3/16§	---	34.30	0.470	0.592	---	---	55.0	95.6	--	--	367	--	2/56	--	21	36, 39

Clustered sources were used and the extrapolation distance was assumed to be 1.15 inches.

* A second measurement in October, 1956, gave B² = 249.

§ Case 2A: no spacers between fuel.

TABLE 1

CASE 3. 1.17-INCH RODS, N.U.

a. 8-Foot Pile

L.S. (in.)	B ₁₁		V-A1/U	A-A1/U	V-H ₂ O/U	A-H ₂ O/U	V-C/U	A-C/U	CR		B ²		Date		Ref.	N.B.
	W	D							W	D	W	D	W	D		
5-3/16	55.49	50.68	0.438	0.551	0.258	0.180	23.98	41.7	17.6	14.1	-11	-76	6/55	6/55	7, 19	21, 30
6-3/16	65.74	64.79	0.438	0.551	0.258	0.180	35.08	61.0	24.5	20.3	84	77	12/55	7/53	12, 19	12, 30
7	73.41	76.70	0.438	0.551	0.258	0.180	45.45	78.5	29.8	26.2	100	116	7/55	8/55	7, 19	22, 30
7-1/2	72.59	77.47	0.438	0.551	0.258	0.180	52.46	90.6	34.8	28.5	99	122	11/53	11/53	7, 19	14, 30
10-3/8	57.92	62.39	0.438	0.551	0.258	0.180	102.76	178.7	60.5	55.0	15	57	7/55	7/55	7, 19	20, 30

TABLE 1

CASE 4. 1.336-INCH RODS, N.U.

a. 4-Foot Pile

8-3/8	34.00	34.96	0.491	0.618	0.286	0.200	52.15	90.1	38.2	32.0	79	126	3/57	3/57	--	44

TABLE 1

CASE 5. 1.336-INCH RODS, 0.94 PER CENT ENRICHMENT

a. 4-Foot Pile

5-3/16	27.18	26.10	0.481	0.61	0.283	0.198	18.57	32.3	13.6	9.7	226	112	11/56	11/56	6, 24	42, 34
6-3/16	30.12	29.83	0.481	0.61	0.283	0.198	27.15	47.2	19.0	14.6	308	286	8/56	7/56	6, 23	39, 34
7-3/16	33.75	33.67	0.481	0.61	0.283	0.198	37.21	64.7	25.0	20.4	326	321	9/56	9/56	6, 23	33, 34
8-3/8	32.32	32.63	0.481	0.61	0.283	0.198	51.59	89.1	33.5	28.2	301	320	8/56	7/56	6, 23	24, 34
10-3/8	30.61	31.43	0.481	0.61	0.283	0.198	80.54	138.5	47.4	41.6	201	256	12/56	12/56	6, 24	32, 34

TABLE 1

CASE 6. 1.343-INCH RODS, 4.46 PER CENT ENRICHED U-Al ALLOY

a. 4-Foot Pile

4-3/16	66.49	41.69	---	--	---	---	---	--	13.1	8.5	1572	1222	12/55	12/55	6	35, 45
5-3/16	52.42	110.82	---	--	---	---	---	--	19.0	13.1	1323	1134	12/55	12/55	6	35, 45
6-3/16	84.5	69.46	---	--	---	---	---	--	23.2	18.0	1078	1010	11/55	12/55	6	39, 45
7-3/16	55.82	54.10	---	--	---	---	---	--	29.3	24.5	897	877	10/55	10/55	6	23, 45
8-3/8	44.77	46.04	---	--	---	---	---	--	37.7	33.3	709	736	9/55	9/55	6	35, 45
10-3/8	36.63	37.92	---	--	---	---	---	--	52.4	37.1	470	519	11/55	11/55	6	35, 45

Clustered sources were used and the extrapolation distance assumed was 1.15 inches for Cases 4, 5, and 6, except that Case 6 used three sources in line, one at (0, 0) and two at (0, ±b/4).

TABLE 1
CASE 7. 1.343-INCH RODS, 7.5 PER CENT ENRICHED U-Al ALLOY
a. 4-Foot Pile

L.S. (in.)	B ₁₁		CR		B ²		Date		Ref.	N.B.
	W	D	W	D	W	D	W	D		
4-3/16	63.37	51.35	--	--	1886	1419	1/56	1/56	6	35, 45
5-3/16	116.08	56.69	--	10.3	1612	1375	1/56	1/56	6	35
6-3/16	---	---	18.8	14.1	1368	1258	6/55	6/55	6	45
7-3/16	134.79	102.3	23.4	18.6	1163	1122	7/55	7/55	-	23, 45
8-3/8	64.23	65.06	30.4	25.7	965	972	9/55	9/55	6	35, 45
10-3/8	43.28	45.07	41.1	36.4	678	719	8/55	8/55	6	35, 45
4-3/16 x 8-3/8§	---	89.48	15.3	12.4	1166	1041	5/54	5/54	-	18, 45
7-3/16*	---	97.68	--	19.0	--	1114	--	6/55	-	23, 45

* Upper source position. All others used lower source position.

§ Clustered sources were used and λ was assumed to be 1.6 inches. Three sources were used for all others, one at (0, 0) and two at (0, $\pm b/4$), and the extrapolation distance was 1.15 inches.

TABLE 1

CASE 8. 1.36-INCH RODS, N.U.

a. 8-Foot Pile

L.S. (in.)	B_{11}		V-A1/U	A-A1/U	V-H ₂ O/U	A-H ₂ O/U	V-C/U	A-C/U	CR		B^2		Date		Ref.	N.B.
	W	D							W	D	W	D	W	D		
6-3/16	62.13	58.31	0.323	0.410	0.436	0.305	26.99	46.9	24.5	17.5	56	21	6/54	5/54	7	19, 38
7-1/2	69.99	76.33	0.323	0.410	0.436	0.305	40.50	69.9	33.8	26.6	84	117	6/54	6/54	7	19
12-3/8	51.88	57.39	0.323	0.410	0.436	0.305	113.30	196.9	82.8	69.8	-56	12	6/54	5/54	7	19, 38
5-3/16	48.35	43.08	0.480	0.609	0.272	0.191	18.44	32.1	15.3	11.8	-114	-225	3/55	1/55	7	21, 38
6-3/16	59.22	56.48	0.480	0.609	0.272	0.191	26.99	46.9	21.5	17.2	31	2	3/53	10/52	7	38
7	69.49	69.85	0.480	0.609	0.272	0.191	35.05	60.5	27.3	22.3	78	81	2/55	1/55	7	22, 38
7-1/2	70.22	72.98	0.480	0.609	0.272	0.191	40.50	69.9	31.4	20.2	85	101	8/52	8/52	7	38
8	68.53	73.88	0.480	0.609	0.272	0.191	46.32	80.0	35.0	29.6	84	113	7/51	5/51	7	38
8-3/8	65.31	70.66	0.480	0.609	0.272	0.191	50.94	88.6	38.2	33.0	84	118	11/50	11/50	7	38
10-3/8		64.24	0.480	0.609	0.272	0.191	79.14	137.6		48.8	26	71	10/54	12/54	7	20
5-3/16	49.35	45.00	No data available.		---	---	---	--	16.7	12.4	-97	-180	3/55	4/55	-	21, 38

TABLE 1

CASE 8. 1.36-INCH RODS, N.U.*

a. 4-Foot Pile

6-3/16	28.64	0.480	0.609	---	---	26.99	46.9	--	-2	3/56	12, 11	38, 39
7-1/2	30.25	0.480	0.609	---	---	40.50	69.9	26.6	105	3/56	11	43, 38
8-3/8	30.89	0.480	0.609	---	---	50.94	88.6	31.3	117	4/54	11	16, 38
10-3/8	29.62	0.480	0.609	---	---	79.14	137.6	45.5	74	7/55	11	38, 32

* Clustered sources were used and the extrapolation distance was assumed to be 1.15 inches.
except for the 8-3/8-inch lattice where λ was assumed to be 1.6 inches.

TABLE 1

CASE 9. 1.66-INCH RODS, N. U.

a. 8-Foot Pile

L. S. (in.)	B ₁₁	V-A1/U	A-A1/U	V-H ₂ O/U	A-H ₂ O/U	V-C/U	A-C/U	CR D	B ² D	Date D	Ref.	N. B.
6-3/16	46.26	0.0695	0.0882	---	---	16.59	29.0	12.6	-153	6/53	7, 26	10, 27
7-1/2	68.15	0.0695	0.0882	---	---	24.85	43.3	19.3	73	6/53	7, 26	11, 27
10-3/8	71.80	0.0695	0.0882	---	---	48.55	85.2	39.4	120	8/54	26	20, 27
12-3/8	64.63	0.0695	0.0882	---	---	69.54	121.9	53.8	76	8/53	7, 26	10
15	58.46	0.0695	0.0882	---	---	102.69	179.0	76.2	-4	8/53	7, 26	11

TABLE 1

CASE 9. 1.66-INCH RODS, N. U. *

b. 4-Foot Pile

									B ²			Date			
									W	D	M	W	D		
5-3/16	---	0.264	0.335	0.362**	0.255	10.76	18.87	-	-657	-253		10/57	11/57	28	44
6-3/16	---	0.264	0.335	0.362	0.255	16.01	28.05	-72	-203	-107		8/57	8/57	28	44
7-3/16	---	0.264	0.335	0.362	0.255	22.18	38.86	32	1	26		9/57	9/57	28	44
8-3/8	---	0.264	0.335	0.362	0.255	30.70	53.79	67	86	82		7/57	6/57	28	44
9-3/8	---	0.264	0.335	0.362	0.255	38.89	68.14	61	108	81		9/57	9/57	28	44
10-3/8	---	0.264	0.335	0.362	0.255	48.00	84.19	39	107	-		7/57	7/57	28	44

* Clustered sources were used and the extrapolation distance was assumed to be 1.66 inches.

** Volume of either H₂O or MIPB. The molecule ratio for MIPB is not given.

TABLE 1

CASE 10. 1.66-INCH RODS, 1.007 PER CENT ENRICHMENT*

a. 4-Foot Pile

		B ₁₁							CR		B ²				
		W	D						W	D	W	D			
5-3/16	---	23.33	0.069	0.087	---	---	11.31	19.8	-	---	---	-157	2/56	6, 21	42, 29
6-3/16	---	30.67	0.069	0.087	---	---	16.56	29.0	-	---	---	154	2/56	6, 21	39, 29
7	---	32.45	0.069	0.087	---	---	21.50	37.5	-	---	---	325	2/56	6, 21	37, 29
7-1/2	---	34.70	0.069	0.087	---	---	24.85	43.4	-	16.2	---	367	2/56	6, 21	42, 43, 29
8-3/8	---	34.23	0.069	0.087	---	---	31.25	54.9	-	---	---	405	2/56	6, 21	24, 29
10-3/8	---	33.36	0.069	0.087	---	---	48.55	85.2	-	31.2	---	368	2/56	6, 21	29, 32
12-3/8	---	32.46	0.069	0.087	---	---	69.54	121.9	-	45.5	---	268	2/56	6, 21	29, 44

* Clustered sources were used and the extrapolation distance was assumed to be 1.15 inches.

TABLE 1

CASE 11. 1.92-INCH RODS, N.U.**

a. 4-Foot Pile

L.S. (in.)	B_{11}		V-Al/U	A-Al/U	V-H ₂ O/U	A-H ₂ O/U	V-C/U	A-C/U	CR		B^2	
	W	D							W	D	W	D
6-3/16	26.72	24.63	0.264	0.332	0.288	0.201	11.64	20.25	14.2	8.9	-186	-400
8-3/8	33.42	33.41	0.264	0.332	0.288	0.201	22.65	39.41	24.2	18.2	65	67
10-3/8	33.78	34.89	0.264	0.332	0.288	0.201	35.60	61.94	36.6	29.8	70	127
12-3/8	34.88	36.43	0.264	0.332	0.288	0.201	51.31	89.28	49.1	40.9	34	102

	N_B		L_λ		N_λ		$\lambda_\perp$		$\lambda_{ }^*$		$\sigma(\lambda)^*$	$\sigma(B^2)$		Date		Ref.
	W	D	W	D	W	D	W	D	W	D		W	D	W	D	
6-3/16	6	6	4	4	4	4	1.34	1.20	1.03	1.03	0.25	13	15	4/59	4/59	35
8-3/8	6	6	4	4	4	4	1.37	1.39	1.06	1.06	0.25	6	6	11/58	12/58	35
10-3/8	6	6	1 + 2	1 + 2	11	11	1.56	1.50	1.03	1.03	0.25	5	5	5/59	6/59	35
12-3/8	6	6	3	3	5	5	2.11	2.25	1.03	1.03	0.25	6	4	4/59	4/59	35

* Assumed values based on later measurements.

** Clustered sources were used.

TABLE 1

CASE 12. 2.5-INCH RODS, N.U. §§

a. 4-Foot Pile

L.S. (in.)	B_{11}		V-Al/U	A-Al/U	V-H ₂ O/U	A-H ₂ O/U	V-C/U	A-C/U	CR		B^2	
	W	D							W	D	W	D
8-3/8	31.59	29.54	0.188	0.237	0.393	0.275	12.67	22.07	--	12.1	-60	-199
10-3/8	32.78	33.50	0.188	0.237	0.393	0.275	20.31	35.38	31.9	20.6	49	88
12-3/8	34.15	36.41	0.188	0.237	0.393	0.275	29.58	51.53	41.7	30.9	28	108
14-9/16	32.68	35.46	0.188	0.237	0.393	0.275	41.58	72.43	58.1	38.4	-29	98**

	N_B		L_λ		N_λ		$\lambda_\perp$		$\lambda_{ }^*$	$\sigma(\lambda)^*$	$\sigma(B^2)$		Date		Ref.
	W	D	W	D	W	D	W	D			W	D	W	D	
8-3/8	5	5	1 + 2	4	8	4	1.6	1.3	1.03	0.25	8	10	1/59	2/59	35
10-3/8	5	6	1§	1§	3	3	1.4	1.6	1.03	0.25	7	6	2/59	2/59	35
12-3/8	5	5	1	1	3	3	2.0	1.7	1.03	0.25	6	5	3/59	3/59	35
14-9/16	4	4	3	3	5	5	1.3	1.4	1.03	0.25	5	5	3/59	4/59	35

* Assumed values based on later measurements

** Average of two experiments

§ Taken 1-inch above position 1.

§§ Clustered sources were used.

TABLE 2

CASE 1. 0.50-INCH 7-ROD CLUSTERS, N.U.

a. 4-Foot Pile

L.S. (in.)	B ₁₁			V-A1/U	A-A1/U	V-H ₂ O/U*	A-H ₂ O/U	V-C/U	A-C/U	CR		
	W	D	M							W	D	M
5-3/16	26.87	25.24	---	0.711	0.897	0.864	0.605	16.97	29.5	18.2	9.9	--
6-3/16	28.55	28.00	28.45	0.711	0.897	0.864	0.605	25.24	43.9	22.0	13.8	20.4
7-3/16	32.67	33.29	---	0.711	0.897	0.864	0.605	34.98	60.9	27.4	19.1	--
8-3/8	32.90	34.40	33.21	0.711	0.897	0.864	0.605	48.42	84.3	34.7	26.0	33.5
10-3/8	32.16	34.09	---	0.711	0.897	0.864	0.605	75.70	131.8	49.3	39.4	--

	B ²			N _B			L _λ		N _λ	λ	λ _⊥	Date			Ref.
	W	D	M	W	D	M	W	D				W	D	M	
5-3/16	-152	-337	-	6	7	-	1	1	4	1.25§	1.25§	10/58	10/58	--	32
6-3/16	-15	-64	-23	6	7	7	4	4	4	1.25	1.25	5/58	7/58	6/58	32
7-3/16	2	36	-	6	6	-	5	5	4	1.25	1.25	3/58	3/58	--	32
8-3/8	14	93	31	6	6	6	4	4	4	1.25	1.25	7/58	7/58	8/58	32
10-3/8	-26	81	-	5	6	-	4	4	3	1.25	1.25	6/58	6/58	--	32

* Dry case included polyethylene spacers with an equivalent V-H₂O/U of 0.011.

§ Measurements of λ were made for several of the lattices but not all. Thus the values were averaged to give 1.25 inches instead of being quoted as individual values. Clustered sources were used.

TABLE 2

CASES 2 through 5. 0.925-INCH CLUSTERS, 5-, 6-, OR 7-RODS, N.U.

a. 8-Foot Pile

L.S. (in.)	Rods	B ₁₁		V-Al/U	A-Al/U	V-H ₂ O/U	a. 8-foot Pipe				CR		B ²		Date		Ref.	N.B.	
		W	D				W	D	W	D	W	D							
Separated																			
7	7	35.86	28.78	0.379	0.477	0.664	0.463	8.44	14.6	15.6	6.9	-290	-720	--	--	21, 30	--		
10-3/8	7	40.51	41.21	0.379	0.477	0.664	0.463	21.23	36.9	28.9	18.0	2	23	--	--	21, 30	--		
14	7	43.84	49.98	0.379	0.477	0.664	0.463	41.42	71.4	44.3	31.1	-33	87	--	--	21, 30	--		
10-3/8	5	40.05	42.66	0.427	0.537	1.004	0.701	29.95	52.0	31.5	22.2	-12	62	5/56	3/56	21	40, 26		
14	5	53.11	70.25	0.427	0.537	1.004	0.701	57.94	100.0	57.9	39.6	-69	83	1/56	1/56	21	41, 26		
Unseparated																			
7	7	33.43	28.93	0.367	0.477	0.362	0.253	8.44	14.6	12.5		-407	-708	---	--	30	--		
10-3/8	7	41.30	40.89	0.367	0.477	0.362	0.253	21.40	37.2	25.8	18.7	25	13	---	6/56	30	40, 26		
14	7	61.21	71.44	0.367	0.477	0.362	0.253	41.39	71.3	47.9	38.5	19	90	10/55	12/55	21, 30	41, 26		
14	6	59.99	71.03	0.394	0.496	0.631	0.440	48.30	83.4	50.3	40.6	8	87	10/55	9/55	21	41, 26		

TABLE 3

CASE 1. 1.36 x 0.50-INCH HOLLOW, N.U.

a. 8-Foot Pile (E Only)

L.S. (in.)	B ₁₁		V-Al/U	A-Al/U	V-H ₂ O/U	A-H ₂ O/U	V-C/U	A-C/U	CR		B ²		Date		Ref.	N.B.
	W	D							W	D	W	D	W	D		
5-3/16	48.97	45.65	0.554	0.703	0.314	0.221	21.85	38.3	16.5	12.4	-103	-166	4/55	3/55	18	21, 38
7	68.79	70.40	0.554	0.703	0.314	0.221	41.08	71.5	28.7	23.6	74	84	3/55	2/55	17	22, 38
10-3/8	57.59	62.60	0.554	0.703	0.314	0.221	92.12	161.5	58.7	51.8	12	58	11/54	11/54	16	20, 38

TABLE 3

CASE 1. 1.36 x 0.50-INCH HOLLOW, N.U.

b. 4-Foot Pile (E Only)

8-3/8	30.41	---	0.554	0.703	0.314	0.221	59.47	104.25	38.2	--	84	--	6/54	--	--	16, 38

TABLE 3

CASE 2. 1.37 x 0.48-INCH HOLLOW, N.U.

a. 4-Foot Pile

8-3/8	33.89	34.98	0.473	0.600	0.501	0.350	56.6	98.2	40.4	33.1	74	127	4/57	4/57	*	44
7-11/16	30.40	31.04	0.473	0.600	0.501	0.350	47.3	82.2	33.5	26.8	77	125	4/57	4/57	*	28

TABLE 3

CASE 3. 1.37 x 0.48-INCH HOLLOW, 1.44 PER CENT ENRICHMENT

a. 4-Foot Pile

5-3/16	34.49	30.06	0.473	0.600	0.501	0.350	20.4	35.5	12.7	8.4	739	473	11/56	11/56	6	42, 31
6-3/16	44.44	39.18	0.473	0.600	0.501	0.350	29.9	52.0	17.4	12.6	711	566	4/57	4/57	6	39
7-3/16	42.99	41.18	0.473	0.600	0.501	0.350	41.1	71.4	22.9	17.6	663	614	1/57	1/57	6	33
7-11/16	43.46	42.60	0.473	0.600	0.501	0.350	47.3	82.2	25.6	20.4	630	609	1/57	1/57	6	28
8-3/8	38.53	38.60	0.473	0.600	0.501	0.350	56.6	98.2	30.5	25.0	585	588	11/56	11/56	6	24
9-3/8	47.19	49.31	0.473	0.600	0.501	0.350	71.2	123.9	35.5	29.9	499	537	1/57	1/57	6	25
10-3/8	34.33	35.58	0.473	0.600	0.501	0.350	87.7	152.5	42.6	35.8	420	478	11/56	11/56	6	31, 32
8-3/8	51.81	52.39	0.654	0.823	0.447	0.312	56.5	98.0	28.6	24.5	572	580	4/57	4/57	*	44

* HW-49752 B

Extrapolation distance used was 1 inch for Case 1-a, 1.6 inches for Case 1-b, and 1.15 inches for Cases 2 and 3.

Clustered sources were used for Cases 1-b, 2, and 3.

TABLE 3

CASE 4. 1.66 x 0.81-INCH HOLLOW, N.U.

a. 8-Foot Pile (I Only)

L.S. (in.)	B ₁₁		V-Al/U	A-Al/U	V-H ₂ O/U	A-H ₂ O/U	V-C/U	A-C/U	CR		B ²		Date		Ref.	N.B.
	W	D							W	D	W	D	W	D		
6-3/16	52.11	51.17	0.175	0.222	0.224	0.158	21.78	38.16	15.5	14.3	-53	-66	9/53	9/53	4	10, 27
7-1/2	71.48	72.45	0.175	0.222	0.224	0.158	32.68	56.96	23.2	21.9	93	98	10/53	9/53	4	11, 27
10-3/8	66.57	69.98	0.175	0.222	0.224	0.158	63.86	111.94	43.1	42.7	88	109	9/54	9/54	-	20, 27
12-3/8	59.74	61.51	0.175	0.222	0.224	0.158	91.46	160.24	58.6	57.1	35	51	10/53	5/54	4	10, 27
15	54.81	56.07	0.175	0.222	0.224	0.158	135.06	235.41	81.8	80.7	-41	-30	10/53	11/53	4	11, 27

TABLE 3

CASE 5. 1.66 x 0.94-INCH HOLLOW, 1.007 PER CENT ENRICHMENT *

a. 4-Foot Pile (I Only)

6-3/16	33.12	32.20	0.196	0.247	0.251	0.175	24.43	42.48	--	--	306	253	3/56	3/56	6	39, 29
7-1/2	35.60	34.86	0.196	0.247	0.251	0.175	36.65	63.29	--	--	409	375	2/56	2/56	6	43, 29
8-3/8	---	33.75	0.196	0.247	0.251	---	46.11	80.19	--	24.8	-	380	---	7/56	6	24, 29
10-3/8	32.56	32.72	0.196	0.247	0.251	0.175	71.62	124.45	37.2	36.0	324	333	7/56	6/56	6	29, 32
12-3/8	31.76	31.70	0.196	0.247	0.251	0.175	102.59	178.40	--	--	226	222	3/56	3/56	6	44, 29
10-3/8§	---	---	0.163	0.21	0.397	0.279	71.62	124.45	--	--	331	332	7/56	6/56	-	--
7-1/2**	35.60	34.93	0.102	0.128	---	---	36.65	63.29	19.69	--	409	378	2/56	2/56	-	43

* Extrapolation distance used was 1.15 inches. Clustered sources were used.

** No inner can used.

§ Measurement with slightly-changed volumes of water and aluminum. No information available on geometry of cans and water.

TABLE 3

CASE 6. 1.66 x 1.12-INCH HOLLOW, N.U.

a. 8-Foot Pile (I Only)

6-3/16	56.21	56.57	0.283	0.362	0.652	0.463	30.43	53.77	20.6	16.7	-1	3	5/54	1/54	4	10, 27
7-1/2	68.19	73.51	0.283	0.362	0.652	0.463	45.66	80.68	28.7	26.1	73	103	4/54	3/54	4	11, 27
10-3/8	59.36	64.54	0.283	0.362	0.652	0.463	89.24	157.69	51.2	48.6	29	73	10/54	9/54	4	20, 27
12-3/8	54.15	57.64	0.283	0.362	0.652	0.463	127.90	226.00	71.0	65.8	-26	14	5/54	1/54	4	10, 27
15	51.01	53.47	0.283	0.362	0.652	0.463	188.74	333.50	98.2	96.9	-96	-61	3/54	3/54	4	11, 27

TABLE 3

CASE 7. 2.5 x 1.6-INCH HOLLOW, N.U.

a. 4-Foot Pile (I & E)

L.S. (in.)	B ₁₁		V-Al/U	A-Al/U	V-H ₂ O/U	A-H ₂ O/U	V-C/U	A-C/U	CR		B ²	
	W	D							W	D	W	D
8-3/8	31.45	31.58	0.381	0.494	1.283	0.907	21.47	37.74	30.3	17.1	-68	-65
10-3/8	33.03	35.92	0.381	0.494	1.283	0.907	34.41	60.49	37.4	22.9	-34	100
12-3/8	33.33	36.63	0.381	0.494	1.283	0.907	50.11	88.09	57.9	36.8	-43	111
14-9/16	31.44	35.03	0.381	0.494	1.283	0.907	70.44	123.83	--	46.0	-129	70
12-3/8S	33.37	36.37	0.381	0.494	1.283	0.907	50.11	88.09	56.9	35.8	-32	114

	Coolant	N _B	L _λ	N _λ	λ ₁	λ ₁₁	σ(λ)	σ(B ²)	Date	Ref.
8-3/8	D	5	3	14	1.5	1.03	0.084	6	1/60	37
8-3/8	W	6	3	14	1.5	1.03	0.99	4	11/59	37
10-3/8	D	6	1 + 2	7	1.6	1.03	0.74	7	3/60	37
10-3/8	W	5	1 + 2	7	1.8	1.03	0.35	7	3/60	37
12-3/8	D	5	3	10	2.4	1.03	0.34	3	2/61	41
12-3/8	W	4	3	12	0.7	1.03	0.13	4	11/60	41
14-9/16	D	4	3*	8	1.9	1.03	0.18	5	8/59	37
14-9/16	W	4	3*	8	2.1	1.03	0.22	6	11/59	37
12-3/8S	D	5	3	10	1.7	1.2	0.18	3	12/60	41
12-3/8S	W	4	3	10	1.6	1.03	0.15	3	12/60	41

* Taken 1 inch above position 3.

Clustered sources were used except for cases labeled "S" which were rerun with split sources.

TABLE 3(a)

CASES 1 AND 2. 1.356 x 0.414-INCH HOLLOW, N. U.

a. Comparison with 1.336-Inch Solid, 4-Foot Pile

Case	L. S. (in.)	V-A1/U	A-A1/U	V-H ₂ O/U	A-H ₂ O/U	V-C/U	A-C/U	B ²		Differences	ΔB^2
								W	D		
1 (Hollow)	8-3/8	0.605	0.762	0.319	0.223	55.56	96.62	42	82	Dry (Solid) - Wet (Solid)	33.3 $\pm$ 2.2
2 (Solid)	8-3/8	0.522	0.657	0.273	0.200	51.88	90.22	54	87	Dry (I & E) - Wet (I & E)	40.0 $\pm$ 2.2
										Dry (Solid) - Dry (I & E)	5.0 $\pm$ 2.5
										Wet (Solid) - Wet (I & E)	11.7 $\pm$ 1.9

TABLE 3(a)

CASES 3 AND 4. 1.37 x 0.48-INCH HOLLOW, N. U.

a. Comparison with 1.336-Inch Solid, 4-Foot Pile

3 (Hollow)	8-3/8	0.622	0.783	0.398	0.287	56.15	97.64			Dry (Solid) - Dry (I & E)	11.4 $\pm$ 3.0
4 (Solid)	8-3/8	0.523	0.658	0.334	0.233	51.78	90.04			(Dry-Wet) Solid - (Dry-Wet) I&E	-6.1 $\pm$ 2.7
										Dry (Solid) - Wet (Solid)	47.1 $\pm$ 1.8
										Dry (I & E) - Wet (I & E)	53.2 $\pm$ 2.0

References HW-49752 B, HW-57772, and undocumented letter, "Reactivity Changes with I & E Fuel Elements", E. Z. Block to J. H. Brown, 5-27-57.

Extrapolation distance used was 1.66 inches for this series. No attempt was made to determine accurate β 's since the study was intended to measure differences, not the absolute values of the buckling.

Clustered sources were used for all four cases.

TABLE 4

CASE 1. 2.5 x 1.6-INCH TUBE WITH 0.5-INCH ROD, N.U. **

a. 4-Foot Pile

L.S. (in.)	B ₁₁		V-Al/U	A-Al/U	V-H ₂ O/U	A-H ₂ O/U	V-C/U	A-C/U	CR		B ²	
	W	D							W	D	W	D
14-9/16	31.71	34.87	0.382	0.484	1.11	0.781	65.98	114.94	69.3	48.0	-111	63

	Coolant	N _B	L _λ	N _λ	λ _⊥	λ	σ(λ)	σ(B ²)	Date	Ref.
14-9/16	D	4	3*	8	1.9	1.03	--	4	8/59	37
14-9/16	W	4	3*	8	2.0	1.03	--	4	9/59	37

* Taken 1 inch above position 3.

** Clustered sources were used.

TABLE 4

CASE 2. 2.5 x 1.6-INCH TUBE WITH 1.175-INCH ROD, N.U. **

a. 4-Foot Pile

L.S. (in.)	B ₁₁		V-Al/U	A-Al/U	V-H ₂ O/U	A-H ₂ O/U	V-C/U	A-C/U	CR		B ²	
	W	D							W	D	W	D
8-3/8	31.66	30.75	0.311	0.393	0.626	0.439	15.62	27.15	25.2	--	-51	-111
10-3/8	33.96	35.59	0.311	0.393	0.626	0.439	25.03	43.52	36.3	21.0	7	87
12-3/8	33.76	36.95	0.311	0.393	0.626	0.439	36.46	63.40	49.3	33.2	-21	126
14-9/16	32.27	35.07	0.311	0.393	0.626	0.439	51.25	89.12	61.0	--	-68	65
12-3/8S	33.10	---	0.311	0.393	0.626	0.439	36.46	63.40	49.1	--	-31	-

	Coolant	N _B	L _λ	N _λ	λ _⊥	λ	σ(λ)	σ(B ²)	Date	Ref.
8-3/8	D	6	3	14	1.5	1.03	0.11	7	12/59	37
8-3/8	W	5	3	14	1.5	1.03	0.085	6	12/59	37
10-3/8	D	6	1 + 2	7	1.5	1.03	0.63	7	2/60	37
10-3/8	W	5	1 + 2	7	1.7	1.03	0.27	7	3/60	37
12-3/8	D	4	3	10	2.4	1.03	0.24	3	2/61	41
12-3/8	W	6	3	10	2.4	1.03	0.23	2	2/61	41
14-9/16	D	4	3	8	2.2	1.03	0.70	6	7/59	37
14-9/16	W	4	2*	8	1.5	1.03	0.22	5	9/59	37
12-3/8S	W	5	3	10	1.1	0.87	0.28	5	1/61	41

* Taken 1 inch above position 2.

** Clustered sources were used except for case labeled "S".

TABLE 5

CASE 1. 2.5 x 2.0-INCH TUBE WITH 1.66 x 1.12-INCH TUBE, N.U.**

a. 4-Foot Pile

L.S. (in.)	B ₁₁		V-A1/U	A-A1/U	V-H ₂ O/U	A-H ₂ O/U	V-C/U	A-C/U	CR		B ²	
	W	D							W	D	W	D
7-3/16	30.59	28.88	0.502	0.634	1.094	0.770	14.85	25.82	23.00	10.09	-123	-259
8-3/8	31.44	31.74	0.502	0.634	1.094	0.770	21.12	36.73	28.27	14.45	-64	-50
10-3/8	31.73	34.02	0.502	0.634	1.094	0.770	33.86	58.88	38.24	25.00	-45	76
12-3/8	32.70	36.24	0.502	0.634	1.094	0.770	49.31	85.75	56.16	36.86	-72	104
14-9/16	31.52	34.67	0.502	0.634	1.094	0.770	69.32	120.55	65.32	---	-127	55

	Coolant	N _B	L _λ	N _λ	λ _⊥	λ	σ(λ)	σ(B ²)	Date	Ref.
7-3/16	W	5	4	8	1.4	1.03	0.13	10	10/59	35
7-3/16	D	4	1	8	1.6	1.03	0.11	10	11/59	35
8-3/8	W	6	3	7	1.3	1.03	0.15	6	11/59	35
8-3/8	D	6	3	14	1.5	1.03	0.09	6	12/59	35
10-3/8	W	5	1 + 2	11	1.4	1.03	0.14	6	9/59	35
10-3/8	D	5	1 + 2	10	1.8	1.03	0.25	7	7/59	35
12-3/8	W	5	1 + 2	11	1.5	1.03	0.14	3	6/59	35
12-3/8	D	5	1 + 2	11	1.5	1.03	0.15	5	6/59	35
14-9/16	W	4	3*	4	2.2	1.03	--	4	5/59	35
14-9/16	D	4	3*	4	1.8	1.03	--	5	4/59	35

* Taken 3 inches above position 3.

** Clustered sources were used.

TABLE 5

CASE 1. 2.5 x 2.0-INCH TUBE WITH 1.66 x 1.12-INCH TUBE, N.U.

b. 8-Foot Pile

L.S. (in.)	Pile Size (feet)	Source Position	λ _⊥	λ	B ² W	Ref.
8-3/8	6 x 8	Clustered	1.6	1.9	-63	39
8-3/8	8 x 8	Clustered	2.0	2.1	-63	39
14-9/16	10 x 8	Clustered	3.7	1.5	-123	39
8-3/8	6 x 8	Split	1.0	1.1	-72	39
8-3/8	8 x 8	Split	0.8	1.2	-87	39
14-9/16	10 x 8	Split	0.7	0.7	-128	39

Position

- 1 - Cell corner, between columns of tubes.
- 2 - Cell edge, under columns of tubes.
- 3 - Cell edge, radius of equivalent cylindrical cell (approximate).
- 4 - Between tubes, tube row.
- 5 - Corresponding positions, tube row.

FIGURE II-1
Cell Position for Horizontal Traverses

DATA SECTION III

EXPONENTIAL PILE CONSTRUCTION DIAGRAMS

TABLE 1
LATTICE SPACINGS USED FOR BUCKLING MEASUREMENTS

Fuel	Lattice Spacing (inches)													
	4-3/16	5-3/16	6-3/16	7	7-3/16	7-1/2	7-11/16	8	8-3/8	9-3/8	10-3/8	12-3/8	14	14-9/16
1. Solid Rods														
Size (in.)														
Enrichment														
0.925 N.U.		X	X	X		X		X						
0.925 1,007 per cent			X	X		X		X						
1.17 N.U.		X	X	X		X					X			
1.36 N.U.		X	X	X		X		X			X			
1.36 0.94 per cent		X	X		X			X			X			
1.336 N.U.								X						
1.336 0.94 per cent		X	X		X			X			X			
1.343 4.46 per cent U-Al	X	X	X		X			X			X			
1.343 7.5 per cent U-Al	X	X	X		X			X			X			
1.66 N.U.		X	X		X		X		X		X		X	
1.66 1,007 per cent		X	X	X		X		X		X	X			
1.92 N.U.								X		X	X			
2.5 N.U.			X					X		X	X			
2.5 N.U.								X		X	X		X	
2. 5 N.U.														
2. Clustered Rods														
No. of Rods														
Size (in.)														
Enrichment														
7S 0.500 N.U.		X	X		X			X		X				
7S 0.925 N.U.				X						X			X	
7U 0.925 N.U.				X						X			X	
6U 0.925 N.U.										X			X	
5S 0.925 N.U.										X			X	
3. Hollow Fuel Rods														
Size (in.)														
Enrichment														
Coolant Location														
1.36 x 0.50 N.U.		X		X				X		X				
1.37 x 0.48 1.44 per cent		X	X		X		X	X	X	X				
1.37 x 0.48 N.U.							X	X						
1.66 x 0.81 N.U.								X		X		X		
1.66 x 0.94 1,007 per cent								X		X		X		X
1.66 x 1.12 N.U.								X		X		X		X
2.50 x 1.60 N.U.								X		X		X		X
2.50 x 1.60 N.U.														
4. Tube-in-Rod														
Size (in.)														
Enrichment														
2.50 x 1.60 + 0.50 N.U.														X
2.50 x 1.60 + 1.17 N.U.									X		X			X
5. Tube-in-Tube,									X		X		X	X
N.U.														

Fuel Element:

1.343", 4.46%U-Al Alloy

The 1.343", 7.5% rod has the same construction except for two less rows at the top.

		Slot	Z (cm)
15		2	58.34
14		3	68.98
13		4	79.61
12		5	90.25
11		6	100.88
10		7	111.52
9		8	122.16
8		9	132.79
7		10	143.43
6		11	154.06
5		12	164.70
4		13	175.34
3		14	185.97
2			
1			

a = 85.09 cm

b = 121.92 cm

Δ = 0.00 cm

P = 46.43 cm

Q = 95.73 cm

X = -1.27 cm

Y = 0

Row 1:8 - (4-3/16")² tube bars.

FIGURE III-1

4-3/16-Inch Lattice, 4-Foot Pile

FIGURE III-2
5-3/16-Inch Lattice, 8-Foot Pile

TABLE 2

DATA FOR 5-3/16-INCH LATTICE, 8-FOOT PILE

Fuel Elements

	Slot	Z* (cm)
0.925", N.U.	12	81.58
1.17", N.U.	14	94.75
1.36", N.U.	16	107.93
1.36" x 0.5", N.U.	18	121.11
	20	134.28
	22	147.46
	24	160.64
a = 247.809 cm	26	173.81
b = 243.840 cm	28	186.99
Δ = -1.27 cm	30	200.16
P = 2.54 cm	X = 3.988 cm	
Q = 50.80 cm	Y = 0.0	

Row 1: 19 - (4-3/16")² tube bars;
18 - (1" x 4-3/16")

* Z distances are measured to the bottom of the count bar position.

Row 2: 1" fill layer

□: Probable count bar positions

FUEL ELEMENT ARRANGEMENTS

0.925":

1. Complete loading
2. 172 tubes 0.925" in crimped cans buffered by 0.925" in 0.925" PT.

1.17":

1. Complete loading

1.36" x 0.5":

1. 210 tubes of 4" rods through center buffered on sides by 151 tubes of 8" rods on sides of pile.
2. 45 tubes of 1.36" x 0.5" hollow rods in core of pile with a sandwich loading. (See diagram below.)

1.36" solids 8" long	1.36" solids 4" long	1.36" solids 8" long
1.36" solids with 0.04" spacers	1.36" x 0.5" hollow rods	1.36" solids with 0.04" spacers
1.36" solids 8" long	1.36" solid 4" long	1.36" solids 8" long

TABLE 2 (contd)

3. 24 tubes 1.34" x 0.5" hollow rods in core of pile in sandwich loading. (See diagram below.)

1.36" solids 8" long	1.36" solids 4" long			1.36" solids 8" long
1.36" x 0.5" hollow	1.36" solids 4" long	1.36" x 0.5" hollow	1.36" solids 4" long	1.36" x 0.5" hollow
1.36" solids 8" long	1.36" solids 4" long			1.36" solids 8" long

1.36"

1. 184 tubes of 4" long rods through center of pile, with 151 tubes of 8" long rods buffering the sides.
2. 210 tubes of 4" solid rods with 151 tubes of 8" rods for buffer region on sides.

The complex core loadings were used due to lack of sufficient fuel for a complete load. Different loadings were used to evaluate the precision of the results for partial loadings.

FIGURE III-3

5-3/16-Inch Lattice, 4-Foot Pile

FIGURE III-3A

5-3/16-Inch Lattice, 4-Foot Pile
0.5-Inch Rod Clusters

058 1089-4

AEC GE RICHLAND WASH

Fuel Elements:

- *1. 343" - 7.5 % U-Al Alloy
- 1. 343" - 4.46% U-Al Alloy
- 1. 36" - 0.94% Enrichment
- 1. 66" - 1.007% Enrichment
- 1. 37" x 0.48" - 1.44% Enrichment

		Slot	Z (cm)
25	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	4	71.51
24			
23	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	6	84.69
22			
21	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	8	97.87
20			
19	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	10	111.04
18			
17	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	12	124.22
16			
15	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	14	137.39
14			
13	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	16	150.57
12			
11	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	18	163.75
10			
9	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	20	176.92
8			
7	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	22	190.10
6			
5	○ ○ ○ ○ ○ ○ ○ ○ ○ ○		X = 0
4			
3	○ ○ ○ ○ ○ ○ ○ ○ ○ ○		Y = 0
2			
1	○ ○ ○ ○ ○ ○ ○ ○ ○ ○		

Subtract 42.54 cm for Z values with upper source position.

a=116.05 cm   Row 1: 9-(4-3/16")² tube bars; 8-(1" x 4-3/16")
 b=121.92 cm   Row 2: 1" fill layer
 Δ=-1.27 cm
 P=46.43 cm
 Q=95.73 cm

*Also used upper source position: P = 3.89 cm

FIGURE III-4
 5-3/16-Inch Lattice, 4-Foot Pile

Fuel Elements (All N. U.):

0.925"   1.66" x 0.81"
 1.17"   1.66" x 1.12"
 1.36"
 1.66"

Row 1: 16 - (4-3/16")² tube bars,
 15 - (2" x 4-3/16")
 Row 2: 2" fill layer

Outside edge of 0.925" solid lattice had 0.925" rods in different aluminum cans.

FIGURE III-5
 6-3/16-Inch Lattice, 8-Foot Pile

Fuel Elements:

0.5" - 7-rod clusters, N. U.

		<u>Slot</u>	<u>Z (cm)</u>	<u>X (cm)</u>
25		1	40.64	0
24		3	56.35	"
23		5	72.07	"
22		7	87.79	"
21		9	103.50	"
20		11	119.22	"
19		13	134.93	"
18		15	150.65	"
17		17	166.37	"
16		19	182.08	"
15		21	197.80	"
14		23	213.52	"
13		25	229.23	"
12		9-L1	103.50	15.72
11		9-L2	"	31.73
10		9-L3	"	47.15
9		9-R1	"	-15.72
8		9-R2	"	-31.73
7		9-R3	"	-47.15
6				
5				
4				
3				
2				
1				

Y = 0

a = 120.65 cm

b = 121.92 cm

Δ = -2.54 cm

P = 35.32 cm

Q = 85.09 cm

- Row 1: 8-(4-3/16")² tube bars;
 6-(2" x 4-3/16");
 1-(2" x 4-3/16") count bar
- Row 2: 8-(2" x 4-3/16");
 4-(3-1/2" x 2");
- Row 9: 8-(4-3/16")² tube bars;
 7-(2" x 4-3/16") count bars.

For the 1.92" fuel, the top two layers contained
 1.66" solid fuel.

FIGURE III-6

6-3/16-Inch Lattice, 4-Foot Pile

Fuel Elements:

0.925" - 1.007% Enrichment

1.17" N. U.

1.343" - 4.46% U-Al Alloy

1.343" - 7.5%U-Al Alloy

1.36" N. U.

1.336" - 0.94% Enrichment

1.66" - 1.007% Enrichment

1.37" x 0.48" - 1.44% Enrichment

1.66" x 0.94" - 1.007% Enrichment

		Slot	Z (cm)
23	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	7	103.98
		9	119.69
22		11	135.41
21	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	13	151.13
20		15	166.84
19	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	17	182.56
18			
17	○ ○ ○ ○ ○ ○ ○ ○ ○ ○	X = 0	
16		Y = 0	
15	○ ○ ○ ○ ○ ○ ○ ○ ○ ○		
14		a = 121.92 cm	
13	○ ○ ○ ○ ○ ○ ○ ○ ○ ○		
12		b = 121.06 cm	
11	○ ○ ○ ○ ○ ○ ○ ○ ○ ○		
10		Δ = -2.54 cm	
9	○ ○ ○ ○ ○ ○ ○ ○ ○ ○		
8		P = 46.43 cm	
7	○ ○ ○ ○ ○ ○ ○ ○ ○ ○		
6		Q = 95.73 cm	
5	○ ○ ○ ○ ○ ○ ○ ○ ○ ○		
4			
3	○ ○ ○ ○ ○ ○ ○ ○ ○ ○		
2			
1	○ ○ ○ ○ ○ ○ ○ ○ ○ ○		

Row 1: 8-(4-3/16")² tube bars;
7-(2" x 4-3/16")

Row 2: 2" fill layer

FIGURE III-7

6-3/16-Inch Lattice, 4-Foot Pile

1.66" - 1.007% Enrichment
0.925" - 1.007% Enrichment

Row 1: $7 - (3 - 1/2'')^2$ tube bars;
 $6 - (3 - 1/2'')^2$
Row 4: $12 - (3 - 1/2'')^2$
 $1 - (3 - 1/2'')^2$ count bar

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FIGURE III-9
7-Inch Lattice, 8-Foot Pile

TABLE 3
DATA FOR 7-INCH LATTICE, 8-FOOT PILE

Fuel Elements:

	Slot	Z (cm)
0.925", N.U.	8	69.22
1.17", N.U.	10	87.00
1.36", N.U.	12	104.78
1.36" x 0.50", N.U.	14	122.56
	16	140.34
a = 257.81 cm	18	158.12
b = 243.84 cm	20	175.90
Δ = -4.44 cm	22	193.68
P = 254 cm	24	211.46
Q = 50.80 cm	26	229.24
	X = 0	
	Y = 0	

Row 1: 15 - $(3-1/2'')^2$ tube bars;
14 - $(3-1/2'')^2$

Row 2: 29 - $(3-1/2'')^2$

FUEL ELEMENT ARRANGEMENTS

0.925":

1. Complete loading
2. 172 tubes 0.925" rods in crimped cans buffered by 53 tubes of 0.925" rods in 0.925 PT

1.17":

1. Complete loading

1.36":

1. Complete loading of 1.36" rods, 4" long.
2. 173 tubes 1.36" rods, 4" long buffered by 1.36" rods 8" long on sides of pile.
3. 111 tubes 1.36" rods, 4" long, through center of pile buffered by 114 tubes 1.36" rods, 8" long, on sides of pile.

1.36" x 0.50":

1. 111 tubes 1.36" x 0.50" rods, 4" long, buffered on sides of pile by 1.36" x 0.50" rods, 8" long.
2. 45 tubes 1.36" x 0.50" rods, 4" long, buffered by 108 tubes of 1.36" x 0.50" rods, 8" long and 70 tubes of 1.36" rods, 4" long.

7-rod clusters of 0.925" rods

Row 1: $9-(3-1/2'')^2$ tube voids; $10-(3-1/2'')^2$
 Row 2: $19-(3-1/2'')^2$
 Rows 17, 20 and 23: $9-(4-3/16'')^2$ tube bars; $8-(2'' \times 4 \times 3/16'')$;
 $8-(1/2'' \times 4 \times 3/16'')$; $2-(4-3/16'')^2$
 Rows 18, 21, and 24: $2''$ fill layer.
 Rows 19, 22, and 25: $1/2''$ fill layer.

FIGURE III-10
7-Inch Lattice, 8-Foot Pile

FIGURE III-10A

7-Inch Lattice, 8-Foot Pile
0.925-Inch Rod Clusters

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Fuel Elements:

0.5" - 7-rod clusters

2.5" x 2.0" + 1.66" x 1.12"

1.66"

Slot	Z*(cm)	X (cm)
4	69.53	9.13
7	87.78	"
10	106.04	"
13	124.30	"
16	142.55	"
19	160.81	"
22	179.07	"
25	197.32	"
28	215.58	"
9	96.91	0.0
9-L1	"	9.13
9-L2	"	27.38
9-L3	"	45.64
9-L4	"	63.90
12	115.17	0.0
12-L1	"	18.26
12-L2	"	36.51
12-L3	"	54.77
12-L4	"	73.02

Y = 0

a = 164.41 cm

b = 121.92 cm

Δ = 0.00 cm

Q = 95.73 cm

P = 48.14 for the tube-in-tube.

P = 45.96 for clusters and 1.66" solid

*For 7-rod clusters and 1.66" solid add 2.18 cm to get the corresponding Z values for the tube-in-tube.

Row 1: 9-(4-3/16")² tube bars; 8-(2" x 4-3/16"); 9-(1" x 4-3/16"); 4-(1/2" x 4-3/16")

Row 2: 13-(2" x 4-3/16"); 12-(1/2" x 3")

Row 3: 13-(1" x 4-3/16"); 6-(1/2" x 3")

Row 9: 8-(2" x 4-3/16") count bars; 7-(2" x 3"); 2-(2" x 4-3/16")

Row 10: 9-(4-3/16")² tube bars; 8-(2" x 4-3/16") count bars; 18-(1/2" x 4-3/16"); 2-(1" x 4-3/16")

Rows 8 and 11: 1/2" fill layers

Row 12: 9-(2" x 4-3/16") count bars; 8-(2" x 3"); 2-(1-1/2" x 2")

The tube-in-tube lattice was lacking Rows 27 and 28.

FIGURE III-11

7-3/16-Inch Lattice, 4-Foot Pile

FIGURE III-11A
7-3/16-Inch Lattice, 4-Foot Pile
1.66-Inch Solid Fuel

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Fuel Elements:

1. 343" - 7.5% U-Al Alloy
1. 343" - 4.46% U-Al Alloy

Slot Z*(cm)

4	36.59
6	54.84
8	73.10
10	91.36
12	109.61
14	127.87
16	146.13
18	164.38
20	182.64

X = 0

Y = 0

*Upper source position.

Add 45.54 cm for Z values
with lower source position.

1. 343" - 7.5% taken with sources
in upper and lower positions.

1. 343" - 4.46% taken with lower
source position only.

Upper source plane

Lower source plane

a = 212.13 cm
b = 121.92 cm
Δ = -3.81 cm
P: lower = 46.43 cm
P: upper = 3.89 cm
Q = 95.73 cm

Row 1: 7-(4-3/16")² tube bars; 6-(4-3/16" x 3")
Row 2: 16-(4-3/16" x 3")

FIGURE III-12

7-3/16-Inch Lattice, 4-Foot Pile

FIGURE III-13
7-1/2-Inch Lattice, 8-Foot Pile

TABLE 4

DATA FOR 7-1/2-INCH LATTICE, 8-FOOT PILE

Fuel Elements:

	Slot	Z (cm)
0.925", N.U.	11	73.02
1.17", N.U.	14	92.08
1.36", N.U.	17	111.12
1.66", N.U.	20	130.18
1.66" x 0.81", N.U.	23	149.22
1.66" x 1.12", N.U.	26	168.28
	29	187.32
	32	206.38
a = 256.54 cm	Y = -6.35 cm for the 1.17" rod	
b = 243.84 cm	Y = 0 for all others	
Δ = -5.08 cm	X = -9.52 cm	
P = 2.54 cm		
Q = 50.80 cm		

Row 1: 14 - (3-1/2")² tube bars;
           13 - (3-1/2")²
           13 - (1/2" x 3-1/2")

Row 2: 3-1/2" fill layer

Row 3: 1/2" fill layer

Fuel Elements:

0.925" N.U.

0.925" - 1.007% Enrichment

1.36" N.U.

1.66" - 1.007% Enrichment

1.66" x 0.94" - 1.007% Enrichment

		Slot	Z (cm)
31		3	60.56
30		6	79.61
29		9	98.66
28		12	117.71
27		15	136.76
26		18	155.81
25		21	174.86
24		24	193.91
23		27	212.96
22		30	232.01
21			
20			
19			
18			
17			
16			
15			
14			
13			
12			
11			
10			
9			
8			
7			
6			
5			
4			
3			
2			
1			

X = 0

Y = 0

a = 123.19 cm

b = 121.92 cm

Δ = -5.08 cm

P = 45.96 cm

Q = 95.73 cm

Row 1: 7-(3-1/2")² tube bars; 6-(3-1/2")²;
6-(1/2" x 3-1/2")

Row 2: 1/2" fill layer

Row 3: 1-(3-1/2")² count bar; 15-(3-1/2")²

FIGURE III-14

7-1/2-Inch Lattice, 4-Foot Pile

Fuel Elements:

1. 37" x 0.48" - 1.44% Enrichment

1. 37" x 0.48" N. U.

21	○		○		○		○		○		○		○		○		○		○
20					○														
19	○		○		○		○		○		○		○		○		○		○
18					○														
17	○		○		○		○		○		○		○		○		○		○
16					○														
15	○		○		○		○		○		○		○		○		○		○
14					○														
13	○		○		○		○		○		○		○		○		○		○
12					○														
11	○		○		○		○		○		○		○		○		○		○
10					○														
9	○		○		○		○		○		○		○		○		○		○
8					○														
7	○		○		○		○		○		○		○		○		○		○
6					○														
5	○		○		○		○		○		○		○		○		○		○
4					○														
3	○		○		○		○		○		○		○		○		○		○
2					○														
1	○		○		○		○		○		○		○		○		○		○

Slot	Z (cm)
2	61.04
4	80.56
6	100.09
8	119.62
10	139.14
12	158.67
14	178.19
16	197.72
18	217.25
20	236.77

X = 0

Y = 0

a = 127.48 cm

b = 121.92 cm

Δ = -4.45 cm

P = 45.96 cm

Q = 95.73 cm

Row 1: 7-(4-3/16")² tube bars;
6-(3-1/2" x 4-3/16")

Row 2: 10-(3-1/2" x 4-3/16");
4-(1" x 3-1/2"); 1-(3-1/2" x 4-3/16"); count bar.

FIGURE III-15

7-11/16-Inch Lattice, 4-Foot Pile

FIGURE III-16
8-Inch Lattice, 8-Foot Pile

FIGURE III-17
 8-3/8-Inch Lattice, 8-Foot Pile

Fuel Elements (All N.U.):

- 1. 92"
- 2. 50"
- 2. 5" x 2. 0" with 1. 66" x 1. 12"
- 2. 5" x 1. 6"
- 2. 5" x 1. 6" with 1. 17"

1. 92" and 2. 5" solid

Row 1: $8 - (4 - 3/16")^2$ tube bars; $6 - (4 - 3/16")^2$;
 $1 - (4 - 3/16")^2$ count bar

Rows 2 and 6: $10 - (4 - 3/16")^2$; $10 - (2" \times 4 - 3/16")$;
 $2 - (1/2" \times 4 - 3/16")$

2. 5" Hollow Fuel Elements

Same as 1. 92" fuel, plus $2 - (1" \times 4 - 3/16")$ solids in each layer

Slot	X (cm)	Z* (cm)
1	0.0	51.27
3	"	72.55
5	"	93.89
7	"	115.09
9	"	136.36
11	"	157.64
13	"	178.91
15	"	200.18
17	"	221.45
19	"	242.73
6-L1	5.32	104.45
L2	15.95	"
L3	26.59	"
L4	37.23	"
L5	47.86	"
L6	58.50	"
L7	69.14	"
8	0	125.73
8-L1	10.64	"
L2	21.27	"
L3	31.91	"
L4	42.54	"
L5	53.18	"
L6	63.82	"
L7	74.45	"

Y = 0

*For 1. 92" x 2. 50" solid fuel, add 2.18 cm to each corresponding slot to get the Z values of the 2. 5" hollow fuel elements.

	1. 92"	2. 50"	2. 5" hollow
a	159.62	159.62	164.70
b	121.92	121.92	121.92
Δ	-5.32	-5.32	-2.78
P	45.96	45.96	48.14
Q	95.73	95.73	95.73

FIGURE III-18

8-3/8-Inch Lattice, 4-Foot Pile

FIGURE III-18A

8-3/8-Inch Lattice, 4-Foot Pile
2.5-Inch Solid Fuel

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FIGURE III-19

8-3/8-Inch Lattice, 4-Foot Pile

Fuel Element: 2.5" x 2.0" with 1.66" x 1.2" N. U.

FIGURE III-20

8-3/8-Inch Lattice, 8-Foot Pile

Fuel Element: 2.5" x 2.0" with 1.66" x 1.12" N. U.

Add 10.636 cm increments to obtain corresponding X values in Row 6.
Z of Row 6 is 92.0 cm.
Bottom row and two top rows are 2.5" x 1.6" fuel (wet) used as buffers.
Both the buckling and cadmium ratio of the buffer layer are matched to the tube-in-tube lattice.

FIGURE III-21
8-3/8-Inch Lattice, 8-Foot Pile

Fuel Elements:

1.66" N.U.

1.37" x 0.48" - 1.44% Enrichment

FIGURE III-22

9-3/8-Inch Lattice, 4-Foot Pile

FIGURE III-23
10-3/8-Inch Lattice, 8-Foot Pile

TABLE 5
DATA FOR 10-3/8-INCH LATTICE, 8-FOOT PILE

Fuel Elements:

	Slot	Z (cm)
1.17", N.U.	9	60.55
1.36", N.U.	11	73.72
1.66", N.U.	13	86.90
1.36" x 0.50", N.U.	15	100.07
1.66" x 0.81", N.U.	17	113.25
1.66" x 1.11", N.U.	19	126.43
	21	139.60
	23	152.78
a = 247.81 cm	25	165.96
b = 243.84 cm	27	179.13
Δ = -7.86 cm	29	192.31
P = 2.54 cm	X = 0	
Q = 50.80 cm	Y = 0	

Row 1: 19 - (4-3/16")² tube bars;
18 - (1" x 4-3/16")

Row 2: 1" fill layer

- Usual fuel arrangement
- ⊗ Count bar positions

FUEL ELEMENT ARRANGEMENTS

1.17":

1. Complete loading

1.36":

1. 60 tubes 1.36" rods in core buffered by 40 tubes of 1.36" x 0.50" rods.
2. 1.36" rods in a complete loading.

1.66":

1. 42 tubes 1.66" buffered by 58 tubes of 1.66" x 1.12" with 0.925" rods in the center

1.36" x 0.50":

1. 1.36" x 0.50" rods buffered by 1.66" x 1.12" with 0.925" rods.
2. 1.36" x 0.50" in core of pile buffered by 1.36" solid rods.
3. 1.36" x 0.50" rods in sandwich loading similar to 5-3/16" lattice.

1.66" x 0.81":

1. 41 tubes of 1.66" x 0.81" rods (dry) buffered by 59 tubes of 1.66" x 1.12" with 0.925" rods.
2. 41 tubes 1.66" x 0.81" wet buffered by 55 tubes of 1.36" rods.

1.66 x 1.12": Complete loading

Fuel Elements:

- 1.36" N.U.
- 1.336" - 0.94% Enrichment
- 1.37" x 0.48" - 1.44% Enrichment
- 1.343" - 4.46%U - Al Alloy
- 1.343" - 7.5%U - Al Alloy
- 1.66" - 1.007% Enrichment
- 1.66" x 0.94" - 1.007% Enrichment

		Slot	Z (cm)
22		6	96.60
21		9	122.95
20		12	149.30
19		15	175.66
18		18	202.01
17		X = 0	
16		Y = 0	
15			
14		a = 121.71 cm	
13		b = 121.92 cm	
12		Δ = -5.32 cm	
11		P = 46.43 cm	
10		Q = 95.73 cm	
9			
8			
7			
6			
5			
4			
3			
2			
1			

Row 1: 5-(4-3/16")² tube bars; 4-(2" x 4-3/16");
2-(1" x 4-3/16")

Row 2: (4-3/16")² Fill Layer

Row 3: 11-(2" x 4-3/16"); 2-(1" x 2")

FIGURE III-24

10-3/8-Inch Lattice, 4-Foot Pile

Fuel Element:

0.925" clusters, N. U.

Row 1: 11-(4-3/16")²; 10-(1" x 4-3/16")
 Row 2: 1" fill layer
 Row 3: 6-(4-3/16")²; 10-(1" x 4-3/16");
 5-(1/2" x 4-3/16"); 10-(1/2" x 3-1/2")
 The (1/2" x 4-3/16") and the (1/2" x 3-1/2")
 are used to fill the tube voids.

FIGURE III-25

10-3/8-Inch Lattice, 8-Foot Pile

FIGURE III-25A

10-3/8-Inch Lattice, 8-Foot Pile
0.926-Inch Rod Clusters

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Fuel Elements (All N. U.):

0.5" - 7-rod clusters

1.92"

2.5"

2.5" x 1.6"

2.5" x 2.0"

2.5" x 1.6" and 1.17"

2.5" x 2.0" and 1.66" x 1.12"

Slot	Z*(cm)	X (cm)
4	77.58	0.0
7	103.93	"
10	130.28	"
13	156.64	"
16	182.99	"
19	209.24	"
22	235.69	"
25	262.05	"
6	90.75	"
6-L1	"	13.18
L2	"	26.35
L3	"	39.53
L4	"	52.70
L5	"	65.88
8	117.11	0.0

Y = 0

a = 163.56 cm

b = 121.92 cm

Δ = 2.78 cm

P = 45.91 cm for cluster
and solids.

P = 48.09 cm for all others

Q = 95.73 cm

*For cluster and solid rods.
Add 2.18 cm for all others.

1.92" solids, 2.5" x 2.0" and 1.66" x 1.12"

Row 1: 7-(4-3/16")²; 6-(4-3/16")² tube bars; 4-(2" x 4-3/16");
2-(1" x 4-3/16")

Row 2: 13-(4-3/16"); 5-(2" x 4-3/16")

Row 3: 7-(2" x 4-3/16"); 40-(1/2" x 3-1/2")

Row 5: 1" layer

Row 6: 11-(4-3/16")² count bars; 2-(4-3/16")²; 10-(1" x 4-3/16")

Row 7: 6-(4-3/16")² tube bars; 5-(4-3/16")² count bars; 10-(1" x 4-3/16");
2-(4-3/16")²

2.5" solid

Same as 1.92" except Row 5 exchanged for Row 8, and no count bars in Row 7.

0.5" Clusters

Same as 1.92" fuel except no count bars in Row 6.

2.5" x 1.6", 2.5" x 1.6" with 1.17"

Same as 1.92" fuel except Row 6 taken from left side of pile, and Row 8 from
right side.

Row 8 is same cell position as Row 6 from the opposite side. (5-3/16" increments
taken from sides to the center. 7 positions used.)

FIGURE III-26

10-3/8-Inch Lattice, 4-Foot Pile

Fuel Elements:

1.92" N. U.
 2.50" N. U.
 2.5" x 2.0" with 1.66" x 1.12" N. U.
 1.66" - 1.007% Enrichment
 2.5" x 1.6" N. U.
 2.5" x 1.6" with 1.17" N. U.
 1.66" x 0.94" - 1.007% Enrichment

Row 1: $7-(4-3/16'')^2$; $6-(4-3/16'')^2$ tube bars; $10-(2'' \times 4-3/16'')$
 Row 2: $12-(4-3/16'')^2$; $11-2'' \times 4-3/16''$; $4-1/2'' \times 4-3/16''$
 Row 3: $17-4'' \times 4-3/16''$; $8-1/2'' \times 3-1/2''$
 Row 6: $2-(4-3/16'')^2$; $10-2'' \times 4-3/16''$; $11-(4-3/16'')^2$ count bars
 Row 7: $2-(4-3/16'')^2$; $6-(4-3/16'')^2$ tube bars; $5-(4-3/16'')^2$ count bars;
 $10-2'' \times 4-3/16''$

Slot	Z* (cm)	X (cm)
4	83.18	0.0
7	114.62	"
10	146.05	"
13	177.48	"
16	208.91	"
19	240.35	"
22	271.78	"
6	98.90	"
6-L1	"	15.72
L2	"	31.43
L3	"	47.15
L4	"	62.86
L5	"	78.58
R1	"	-15.72
R2	"	-31.43
R3	"	-47.15
R4	"	-62.86
R5	"	-78.58

Y = 0

*For 1.92" and 2.5" solid.
 Add 2.18 cm for all others.

a = 189.12 cm
 b = 121.92 cm
 $\Delta = -0.24$ cm

	1.92"	2.50"	All others
P	45.96	45.96	48.14
Q	95.73	95.73	95.73

The z values for the 2.50" x 2.00" -
 1.66" x 1.12" fuel have an additional
 increment of 2.18 cm per slot.

FIGURE III-27

12-3/8-Inch Lattice, 4-Foot Pile

Fuel Element (All N. U.):

1.66"
1.66" x 0.81"
1.66" x 1.12"
1.36"

FIGURE III-28

12-3/8-Inch Lattice, 8-Foot Pile

Fuel Elements:

0.925" clusters N.U.

FIGURE III-29

14-Inch Lattice, 8-Foot Pile

Fuel Elements (All N. U.):

2.50"
 2.5" x 2.0" with 1.66" x 1.12"
 2.5" x 1.6"
 2.5" x 1.6" with 1.17"
 2.5" x 1.6" with 0.5"

Slot	Z*(cm)	X (cm)
5	88.26	10.64
9	125.25	"
13	162.24	"
17	199.23	"
21	236.22	"
25	273.21	"
29	310.20	"
7	109.54**	0.0
8	114.62	0.0
8-L1	"	10.64
L2	"	18.50
L3	"	26.35
L4	"	36.99
L5	"	47.62
L6	"	55.48
L7	"	63.34
L8	"	73.98
L9	"	84.61
R1	"	-10.64
R2	"	-18.49
R3	"	-26.35
R4	"	-36.99
R5	"	-47.62
R6	"	-55.48
R7	"	-63.34
R8	"	-73.98
R9	"	-84.61

Y = 0

*Add 2.18 cm for all except 2.50".

**For Rows 7 and 8 interchanged.

a = 179.60 cm

b = 121.92 cm

Δ = -2.54 cm

P = 48.14 cm for all except 2.50"

P = 45.96 cm for 2.50"

Q = 95.72 cm

The 2.5" x 1.6", 2.5" x 1.6" with 1.17", and the 2.5" x 1.6" with 0.5" fuel elements have Rows 7 and 8 interchanged such that the counting positions are still in the $(4-3/16)^2$ count bars.

Row 1: $10-(4-3/16'')^2$; $5-(4-3/16'')^2$ tube bars; $4(2'' \times 4-3/16'')$

Row 2: $4-(4-3/16'')^2$; $1(4'' \times 4-3/16'')$; $1(2'' \times 4-3/16'')$ parallel to tubes; $9(4'' \times 4-3/16'')$; $1-(4-3/16'')^2$; $2-(3-1/2'' \times 4-3/16'')$; $1(1/2'' \times 4-3/16'')$ perpendicular to tubes.

Row 3: $11(2'' \times 4-3/16'')$; $7(2'' \times 3-1/2'')$

Row 8: $15-(4-3/16'')^2$ count bars; $4(2'' \times 4-3/16'')$ count bars.

Row 9: $10-(4-3/16'')^2$ count bars; $5-(4-3/16'')^2$ tube bars; $4(2'' \times 4-3/16'')$ count bars.

FIGURE III-30

14-9/16-Inch Lattice, 4-Foot Pile

FIGURE III-30A

14-9/16-Inch Lattice, 4-Foot Pile

059387-2

AEC GE RICHLAND WASH

Fuel Element: 2.5" x 2.0" with 1.66" x 1.12" N. U.

	Slot	X (cm)	Z (cm)
31	6	0.0	87.78
30	10	"	124.77
29	14	"	161.76
28	18	"	198.75
27	22	"	235.74
26	26	"	272.73
25	6-L1	7.86	87.78
24	6-L2	29.13	"
23	6-L3	36.99	"
22	6-L4	44.85	"
21	6-L5	66.12	"
20	6-L6	73.98	"
19	6-L7	81.84	"
18	6-L8	103.11	"
17	6-L9	110.97	"
16	6-L10	118.82	"
15	9	0.0	114.14
14	9-L1	7.86	"
13	9-L2	18.49	"
12	9-L3	29.13	"
11	9-L4	36.99	"
10	9-L5	44.85	"
9	9-L6	55.48	"
8	9-L7	66.12	"
7	9-L8	73.98	"
6	9-L9	81.84	"
5	9-L10	92.47	"
4	9-L11	103.11	"
3	9-L12	110.97	"
2	9-L13	118.82	"
1	9-L14	129.46	"

Y = 121.92 cm

a = 274.64 cm
b = 243.84 cm
Δ = -10.64 cm
P = 34.84 cm
Q = 81.76 cm

Row 1: $26-(3 \times 1/2")^2$
Row 2: $8-(4 \times 3/16")^2$ tube bars; $14-(4 \times 3/16")^2$; $7-(2" \times 4 \times 3/16")$ and $2-(1" \times 4 \times 3/16")$
Row 4: 2" fill layer
Row 6: $8-(4 \times 3/16")^2$ tube bars; $14-(4 \times 3/16")^2$ count bars; $7-(2" \times 4 \times 3/16")$ count bars and $2-(1" \times 4 \times 3/16")$
Row 9: $22-(4 \times 3/16")^2$ count bars; $7-(2" \times 4 \times 3/16")$ count bars and $2-(1" \times 4 \times 3/16")$
Row 8: $22-(2" \times 4 \times 3/16")$ count bars; $7-(2")^2$ count bars.

*X values in Row 8 are same X values as in Row 9.
Z (cm) of Row 8 is 106.28 cm.

This is the basic pile used in a study of the effect of adding graphite to the sides.
The measurements reported in Section II were made with 4" of graphite added to each side of the pile, so that Δ = -0.476 cm.

FIGURE III-31

14-9/16-Inch Lattice, 8-Foot Pile

FIGURE III-31A

14-9/16-Inch Lattice, 10 x 8-Foot Pile
Tube-in-Tube Fuel

0601138-1

Fuel Elements:

1.66" N.U.
1.66" x 0.81" N.U.
1.66" x 1.12" N.U.

Closed circles are fuel positions; open circles are hole bars plugged with graphite.

FIGURE III-32

15-Inch Lattice, 8-Foot Pile

Row 1: 11-(4-3/16")² tube bars
Row 2: 10-(4-3/16")²; 1-(4-3/16")² count bar
The tube rows alternate starting in the second row for the pile with sources in the lower position.

FIGURE III-33

4-3/16- x 8-3/8-Inch Lattice, 4-Foot Pile

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