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By Authority of CG-PR-2
DS Revis, 2-4-94

By Jerry Males 4-21-94
Verified by DK Hanson 4-21-94

- 1 - C. E. J. Wende
- 2 - A. B. Greeninger
- 3 - J. E. Haider - E. P. Lee -
700 File
- 4 - P. F. Gast
- 5 - U. H. Stambler
- 6 - J. H. West
- 7 - Pink Copy
- 8 - Yellow Copy

June 18, 1947

TO: C. E. J. Wende

FROM: P. F. Gast

REACTIVITY OF NEW PILES

Summary

This memorandum lists the effect upon reactivity which would result from certain changes of material or design which might be considered for the new piles. Some of the information, published previously, is repeated here for convenience.

The following table gives the reactivity loss due to 1% impurity of the given material in all the aluminum of the pile:

<u>Material</u>	<u>Loss due to 1% in all aluminum</u>
Pb	50 lb
Zn	246 lb
Cu	61 lb

The gain in reactivity resulting from a reduction of the thickness of the end caps from 0.350 inches is given in the following table for two cap thickness and under the assumption 1) that the same number of slugs per tube is used, or 2) that the total length of active column is approximately the same as now 33 slugs with 0.175-inch caps, 24 slugs with 0.100-inch caps)

<u>New thickness</u>	<u>Same number slugs</u>	<u>Same approximate length of column</u>
0.175 "	150 lb	175 lb
0.100 "	194 lb	239 lb

The gain resulting from adding more slugs per tube is tabulated below ("Increase in K from More Slugs per Tube", L. Marshall, 11/17/44, Document Number 3-1064)

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Slugs per column

Gain over 32 slug column

32	00 ih
33	16
34	27
35	35
36	42
37	49
38	56

The use of graphite purified by a new process which greatly reduces the boron content ("High Purity Graphite", J. G. Beekley, 5/23/47, Document Number GE-R-10,822) will result in the following gains:

Whole pile	456 ih
Central 1/2 of pile volume	434 ih
Central 1/8 of pile volume	242 ih

The effect of graphite density upon reactivity is 18.7 ih per 1% change in density.

Details

Aluminum Impurities

An extensive table of the reactivity loss arising from impurities in the uranium metal has been prepared ("Effect of Metal Impurities", P. F. Gent and J. H. West, 12/18/46, Document Number 7-5225). The effect of impurities in the aluminum of the pile may be obtained from that table by use of the following formula:

$$\text{Loss in Al} = (\text{Loss in U}) \times \frac{(\text{Am't Al})}{(\text{Am't U})} \times 1.38$$

where the factor 1.38 gives the ratio of neutron flux in the aluminum to the average flux in the Uranium. The net conversion factor, including slug cans, process tubes, and end caps is:

$$(\text{Loss in Al}) = .041 (\text{Loss in U})$$

The table given in the summary is computed on this basis.

End Cap Thickness

A change in end cap thickness affects the pile reactivity in two ways: it changes the effective density of uranium and it changes the amount of aluminum in the pile. If the reduction in column length is not made up by the addition of more slugs this also affects the reactivity. The change in effective metal density is computed by use of the formula

$$R = r \sqrt{\frac{1}{1-g}}$$

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in which R is the "effective" radius of the slug.
r is the actual radius of the slug.
l is the length of the uranium in the slug.
g is the gap between the uranium pieces in the column.

Thus for 0.350 inch end caps,

$$R = r \sqrt{\frac{8}{8.7}} = .999 r$$

for 0.175 inch caps

$$R = r \sqrt{\frac{8}{8.33}} = .977 r$$

for 0.100 inch caps

$$R = r \sqrt{\frac{8}{8.20}} = .988 r$$

The difference in reactivity for different values of R may be read from a curve constructed from data given in EOC-SKA-298, 11/1/43. This curve indicates the following gains:

Cap thickness	Delta k	Increase
.175"	0.200	83
.100"	0.232	97

The reduction of aluminum absorption may be computed from the same formula used to compute the effect of aluminum impurities noting that for the end caps

$$\frac{A_{\text{eff}} - A_0}{A_{\text{eff}} A_0} = \frac{7 \times 2.7}{8 \times 18} = .0131$$

For reduction to 0.175 inches this leads to a gain of 100 ih and for 0.100 inches to 142 ih. Shorter end caps lead to a reduction in column length which reduces the effective size of the pile and therefore decreases the reactivity. The longitudinal buckling is computed from the formula $B = (\pi/L)^2$ where L is the effective column length. The results of column shortening are presented in the table below.

Cap thickness	L	B	delta B	Increase
0.350"	775	16.23×10^{-6}	0	0
0.175"	747	17.43	1.32×10^{-6}	33
0.100"	736	18.22	1.79	45

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The addition of one slug to the column of 0.175 inch end caps will increase the length to 768 cm and result in a net loss of 8 ih as compared to 33 ih when no additional slugs are used. The addition of two slugs to the column of 0.100 inch end caps will restore the column to its original length and recover all lost reactivity. The table presented in the summary gives the net gains arising from the three effects listed above.

Purified Graphite

The graphite purification process discussed in the reference mentioned in the summary reduces the neutron absorption crosssection of the graphite from 4.9 millibarns to 4.4 millibarns principally by the removal of boron. The gain in reactivity arising from this source is due to an increase in the thermal utilization f of the lattice. Mathematically

$$\frac{dk}{k} = \frac{df}{f}$$

But in this case $df = \frac{4.9 - 4.4}{4.9}$ (fraction of neutrons absorbed in moderator.)

$$= \frac{0.5}{4.9} \approx 0.095$$

Where the value 0.095 is taken from the Project Handbook, IV E, page 15.

$$\text{Thus } dk\% = \frac{0.095}{.865} \times 100 = 1.1\%$$

or in inhours the gain is 45 ih.

The loss in density associated with the process is 0.12%. The effect of graphite density on the reactivity of the pile is given by (Project Handbook, IV E, page 25)

$$dk\% = .045 \text{ (percent change in density)}$$

$$\text{or } d\text{ ih} = 10.7 \text{ ih (percent change in density)}$$

This indicates a reduction of 2 ih due to loss of density in the purifying process. The above figure for the effect of density is obtained from calculation. A smaller figure derived from an experiment conducted in the Test Pile is sometimes found in the literature. The interpretation of this experiment to obtain the effect in a power pile is however not straight forward. It appears advisable to use the larger and more conservative figure in calculations of loss of reactivity due to decreased graphite density.

A central core consisting of one-half the pile volume and similar in shape to the pile will have linear dimensions 0.794 of those of the whole pile.

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From a reactivity standpoint such a core will have a weight factor of 0.95 ("Principles of Nuclear Power", Chapter 22, page 28) and the gain to be expected from use of purified graphite in this core is $0.95 \times 456 = 434$ ih.

A core consisting of 1/8 of the pile will have linear dimensions 0.5 those of the pile and a weighting factor of 0.53. Gains from use of purified graphite in such a core will be 242 ih.

Paul F. Gast
Paul F. Gast
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8/9/94

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