DOCKET NO. 70-133
File Cy.

CLEVITE CORPORATION

MECHANICAL RESEARCH DIVISION

540 EAST 105TH STREET · CLEVELAND 8, OHIO

May 8, 1959

METALLURGICAL PRODUCTS DEPARTMENT

TELEPHONE: ULSTER 1-5500
CABLE ADDRESS: CLESEARCH

U. S. Atomic Energy Commission
Materials Sec., Licensing Branch
Div. of Licensing & Regulation
Washington 25, D. C.

DOCKETED USAEC Division of Licensing & Regulation MAY 11 1959 Docket Officer

Attention: Mr. C. P. McCallum, Jr.

Reference: Docket No. 70-133, SNM 183

Subject: Shipment of Fuel elements

Gentlemen:

In our letter of November 14, 1958, we requested authorization of a shipping procedure covering the shipping of 41 fuel elements in a single shipment. Your reply of December 5, 1958 requested calculations which would permit a determination that the shipment would not go critical. The calculations you requested have been prepared by our consultant and are attached to this letter.

These calculations show that a quantity of 42 of these fuel elements assembled in optimum array, spaced as in the shipping containers, and completely flooded with water would be subcritical. The K_{eff} is 0.723 or 0.651 depending upon whether the system is assumed to be homogeneous or heterogeneous.

Part II of the calculations analyzes an array of 42 of these elements close packed and completely flooded with water. As would be expected, since this shipment consists of a core loading, the calculations indicate that such an array would be critical with a K_{eff} of 1.05.

Part III examines the poisoning effect of cadmium strip in each element and the use of cadmium sheets in the shipping boxes. We plan to use sheets of cadmium approximately 12" wide x 24" long and 0.0020" in thickness mounted in the top and bottom of each box. As shown in the calculations, this quantity of cadmium would reduce the thermal utilization to 0.351 and K_{eff} to 0.465. This indicates that with the cadmium present, this shipment would be in no danger of going critical even though the elements were crushed into a close packed array and completely flooded with water.

We request that approval be granted to transport these elements either via Railway Express-Armed Surveillance or in a private vehicle driven

NH6'/1

or accompanied by a qualified Clevite employee. The construction of the shipping container as shown in DWG. D-346 attached to our November 14th letter will be in accordance with ICC Spec. 15A or 15B. Labeling will be in accordance with ICC specifications.

We trust that the enclosed information will enable you to complete your evaluation of this shipping procedure.

Very truly yours,

D. J. Berger

D. J. Berger
Executive Assistant

DJB/sj

Att:

①

DOCKET NO. 70-133

I Criticality of "as shipped elements" in optimum array

Assumptions: 6 x 7 array (= 42 elements)
Lattice = 6" x 6" x 23.5" per element
Complete water flooding
} ∴ core is 36" x 42" x 23.5"

Volume:

$V_{core} = 36" \times 42" \times 23.5" = 35,500 \text{ in}^3 = 582,000 \text{ cm}^3$

$V_{element} = 2.996" \times 3.164" \times 23.5" = 218.4 \text{ in}^3$

$V_{al} \quad \frac{5145^{gm} - 1274 \text{ gm}}{2.7 \text{ gm/cc} \times 16.4 \text{ cm}^3/\text{in}^3} = 87.4 \text{ in}^3/\text{element}$

42 elements give $42 \times 87.4 = 3,670 \text{ in}^3/\text{core}$

$V_{H_2O/element} = 218.4 - 87.4 = 131.0 \text{ in}^3/\text{element}$

$V_{H_2O/core} = 35,500 - 3670 = 31,830 \text{ in}^3/\text{core}$

$V_{al}/V_{H_2O} = \frac{3670}{31,830} = 0.115$

$f_{H_2O} = \frac{31,830}{35,500} = .897$

$f_{al} = \frac{3670}{35,500} = .103$

$f_u = .0005$

Cross sections (Natural Density – M. B. Distribution)

$\Sigma_a^U = 29.1 \text{ cm}^{-1}$

$\Sigma_a^{H_2O} = .0228 \text{ cm}^{-1}$

$\Sigma^{al} = 0.0123 \text{ cm}^{-1}$

(2)

In the Core:

$$\Sigma_a^U = 29.1\ \text{cm}^{-1} \times \left(\overbrace{\frac{5435\ \text{gm}^{25}}{18.7\ \text{gm/cm}^3} \Big/ 582{,}000\ \text{cm}^3/\text{core}}^{f_U = .0005}\right) = 0.0145\ \text{cm}^{-1}$$

or

$$\Sigma_a^U = \frac{5435\ \text{gm}^{25}/\text{core} \times \left(\frac{.602 \times 10^{24}}{235}\right) \frac{\text{atoms}^{25}}{\text{gm}^{25}} \times 607 \times 10^{-24} \frac{\text{cm}^2}{\text{atom}^{25}}}{582{,}000\ \text{cm}^3/\text{core}}$$

$$= 0.0145$$

$$\Sigma_a^{H_2O} = 0.0228 \times \overbrace{0.897}^{f_{H_2O}} = 0.02045\ \text{cm}^{-1}$$

$$\Sigma_a^{al} = 0.0123 \times \overbrace{0.103}^{f_{al}} = 0.00127\ \text{cm}^{-1}$$

For η: $\quad \eta = \frac{\nu \Sigma_f^{fuel}}{\Sigma_a^{fuel}} \cong \frac{\nu \sigma_f^{25}}{\sigma_a^{25}}$ (full enrichment) $= 2.09$

For f: $\quad$ Homogenized $\quad f = \frac{\Sigma_a^{fuel}}{\Sigma_a^{fuel} + \Sigma_a^{H_2O} + \Sigma_a^{al}} = \frac{0.0145}{.0145 + .02045 + .00127}$

$$= 0.399$$

Thus, on a conservative basis (neglecting the reduced multiplication due to a reduced f as a result of lumping),

$$k_\infty = \eta f^* = 2.09 \times 0.399 = 0.836$$

* Assume $p\epsilon = 1$, which is valid for a highly thermal system such as this.

Lumped: To bring in the effect of the water lattice surrounding the Aluminum + Uranium + water element.

$$f = \frac{(\Sigma V \bar{\Phi})_{element}}{(\Sigma V \bar{\Phi})_{element} + (\Sigma V \bar{\Phi})_{core}} = \frac{1}{1 + \left(\frac{\Sigma^{H_2O}}{\Sigma^{element}}\right)\left(\frac{V^{H_2O}}{V^{element}}\right)\left(\frac{\bar{\Phi}_{H_2O}}{\bar{\Phi}_{element}}\right)}$$

$$\frac{\Sigma^{water}}{\Sigma^{element}} = \frac{\Sigma^{H_2O}}{(\Sigma^{U} f^{U} + \Sigma^{al} f^{al} + \Sigma^{H_2O} f^{H_2O})_{\text{in the element}}}$$

$$= \frac{0.0228}{(24.1 \times .0045) + \left(.0123 \times \frac{87.4}{218.4}\right) + \left(.0228 \times \frac{131.0}{218.4}\right)}$$

$$= \frac{.0228}{.0145 + .0492 + .0137} = \frac{.0228}{.0774} = 0.295$$

$$\frac{V^{water}}{V^{element}} = \frac{(\text{Area})_{cell} - (\text{Area})_{element}}{(\text{Area})_{element}} = \frac{(\sim 6)^2 - (\sim 3)^2}{(\sim 3)^2} = 3$$

$\frac{\bar{\Phi}_{water}}{\bar{\Phi}_{element}} \simeq 2$ As an assumption (conservative), Referring for example to Foster Wheeler Calculations for a central flux trap

$$\therefore f = \frac{1}{1 + (.295)(3)(2)} = 0.361$$

thus,

$$k_\infty = 2.09 \times 0.361 = 0.755$$

For k_{eff}:

τ: $$\frac{1}{\sqrt{\tau}} = 0.176(\overset{f_{H_2O}}{.893}) + 0.057(\overset{f_{al}}{.103})$$

$$= .157 + .006 = .163$$

$$\therefore \tau = 37.6$$

B^2: taking an extrapolation distance of 9 cm in each direction (see ORNL-963)

$$\tilde{a} = 36'' + 2d = 83.4 \text{ cm} + 2(4) \text{ cm} = 101.4 \text{ cm}$$
$$\tilde{b} = 42'' + 2d = 106.8 \text{ cm} + 2(4) \text{ cm} = 124.8 \text{ cm}$$
$$\tilde{c} = 23.5'' + 2d = 59.8 \text{ cm} + 2(4) \text{ cm} = 77.8 \text{ cm}$$

$$\therefore B^2 = \pi^2\left(\frac{1}{\tilde{a}^2} + \frac{1}{\tilde{b}^2} + \frac{1}{\tilde{c}^2}\right)$$
$$= 9.87(.0000971 + .0000643 + .000166)$$
$$= 9.87(.000327) = 0.00323$$

L^2: take $(L^2)_{core} \simeq (L^2)_{H_2O}$ as a good approximation.

then,
$$e^{-B^2\tau} = e^{-(0.00323)(37.6)} = e^{-0.121} = 0.886$$

$$\frac{1}{L^2+B^2} = \frac{1}{1+(2.88)^2(0.00323)} = \frac{1}{1+.0268} = 0.973$$

and

$$(K_{eff})_{Homogeneous} = 2.09 \times 0.399 \times 0.886 \times 0.973 = \underline{\underline{0.723}}$$

$$(K_{eff})_{Heterogeneous} = 2.09 \times 0.361 \times 0.886 \times 0.973 = \underline{\underline{0.651}}$$

Both cases show the system to be subcritical with complete flooding and elements in original position.

II Criticality of "Closed-Packed" elements

Assumptions: 6 x 7 array (42 elements)
Core is 18" x 21" x 23.5"
complete water flooding

Volumes:

$V_{core} = 18'' \times 21'' \times 23.5'' = 8,890\ in^3 = 145,500\ cm^3$

$V_{metal} = 3,670\ in^3$

$V_{H_2O} = 8,890 - 3,670 = 5,220\ in^3$

$$\frac{V_{metal}}{V_{H_2O}} = \frac{3670}{5220} = 0.703$$

$$f_{H_2O} = \frac{5220}{8890} = 0.588$$

$$f_{metal} = \frac{3670}{8890} = 0.412$$

Cross sections in the core:

$$\Sigma_a^U = \frac{5,435\ \text{gm}^{25}/\text{core} \times \left(\frac{.602\times10^{24}}{235}\right)\frac{\text{atoms}}{\text{gm}^{25}} \times 607\times10^{-24}\ \text{cm}^2/\text{atom}^{25}}{145,500\ \text{cm}^3/\text{core}}$$

$$= 0.0584\ \text{cm}^{-1}$$

$$\Sigma_a^{H_2O} = 0.0228 \times 0.588 = 0.0134\ \text{cm}^{-1}$$

$$\Sigma_a^{al} = 0.0123 \times 0.412 = 0.00508\ \text{cm}^{-1}$$

For K_{eff}:

as before, $\eta = 2.09$

$pe = 1.00$

now,

$$f = \frac{\Sigma_a^{fuel}}{\Sigma_a^{fuel} + \Sigma_a^{H_2O} + \Sigma_a^{al}} = \frac{0.0584}{0.0584 + 0.0134 + 0.00508} =$$

$$= \frac{.0584}{.0769}$$

$$= 0.760$$

Using the previous formula for τ,

$$\frac{1}{\sqrt{\tau}} = 0.176(0.588) + .057(0.412)$$

$$= 0.1035 + 0.0235 = 0.127$$

$$\tau = 62 \text{ cm}$$

Note: (an alternative value of $\tau = 60$ cm is obtained by extrapolating from data in ORNL-294)

To obtain B^2, using the same extrapolation length as before,

$$\tilde{a} = 18'' + 2d = 59.7 \text{ cm}$$
$$\tilde{b} = 21'' + 2d = 71.4 \text{ cm}$$
$$\tilde{c} = 23.5'' + 2d = 77.8 \text{ cm}$$

$$\therefore B^2 = \pi^2\left(\frac{1}{\tilde{a}^2} + \frac{1}{\tilde{b}^2} + \frac{1}{\tilde{c}^2}\right)$$

$$= 9.87(.000281 + .000196 + .000166)$$

$$= 9.87 \times .000643 = 0.00635$$

L^2. For L^2 we could use $L^2 = \frac{D_{core}}{\Sigma_a^{core}}$, but as an approximate value we can use $L^2 = 3.64$ (see ORNL-963) with little error since k is so insensitive to it thus,

$$e^{-B^2\tau} = e^{-(0.00635)(62)} = e^{-0.394}$$

$$= 0.675$$

$$\frac{1}{1+L^2B^2} = \frac{1}{1+(3.64)(0.00635)} = 0.978$$

and so

$$K_{eff} = (2.09)(0.760)(1)(0.675)(0.978)$$

$$= \underline{\underline{1.05}}$$

Note (use of the value of $\tau = 60\ cm^2$ would give $K_{eff} = 1.06$)

III Reducing criticality by adding a poison

this can be done only if the poison remains in intimate with fuel in case of an accident. thus, strips of cadmium can be inserted between plates of all elements and fastned in place in some way. One might recommend 1 strip of .020" cadmium, 1/2" wide, in each element. Calculations below show that this method will reduce K_{eff} to <1.

Cadmium Poison:

Cadmium .020" thick is black to thermal neutrons. Hence, its absorption area is $\frac{1}{4} \times$ (surface area).

$\therefore$ Absorption area $= (23.5" \times .5") \times 2$ sides $\times \frac{1}{4} = 5.88 \frac{in^2}{strip}$

for 42 strips $= 42 \times 5.88 \times 6.45 \frac{cm^2}{in^2} = 1592 cm^2$

$$\therefore \Sigma^{cd} = \frac{\text{Absorption area}}{\text{Core Volume}} = \frac{1592\ cm^2}{145,500\ cm^3}$$

$$= 0.01095$$

the only significant change produced is in the thermal utilization:

$$f = \frac{\Sigma_a^{fuel}}{\Sigma_a^{fuel} + \Sigma_a^{H_2O} + \Sigma_a^{al} + \Sigma_a^{cd}} = \frac{0.0584}{.0584 + .0134 + .0051 + .01095}$$

$$= 0.667$$

Hence

$$K_{eff} = 2.09 \times (0.667) \times 1 \times (0.675) \times (0.978)$$

$$= 0.92$$

$\therefore$ It is now subcritical.

(10)

Using Cadmium sheets 12" wide x 24" long and 0.020" thick in the top and bottom of the shipping container.

Absorption Area = (12" x 24") x 2 sides x 1/4 = 144 in²/strip

For 14 strips = $14 \times 144 \times 6.45 \frac{cm^2}{in^2} = 13{,}000\ cm^2$

$$\Sigma_a^{cd} = \frac{\text{Absorption Area}}{\text{Core Volume}} = \frac{13{,}000\ cm^2}{145{,}500\ cm^3}$$

$= 0.0894$

$$f = \frac{\Sigma_a^{fuel}}{\Sigma_a^{fuel} + \Sigma_a^{H_2O} + \Sigma_a^{Al} + \Sigma_a^{cd}} = \frac{0.0584}{.0584 + .0134 + .0051 + .0894}$$

$= 0.351$

$K_{eff} = 2.09 \times (0.351) \times 1 \times (0.675) \times (0.978)$

$= 0.465$

OVERSIZE DOCUMENT PAGE PULLED

SEE APERTURE CARDS

NUMBER OF OVERSIZE PAGES FILMED ON APERTURE CARDS 1

9402250150-01

APERTURE CARD/HARD COPY AVAILABLE FROM

RECORDS AND REPORTS MANAGEMENT BRANCH