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WANL-TME-687

JUNE 4, 1964

MASTER

**NUCLEAR SAFETY DESIGN
OF THE ASTROFUEL VAULT
USING BORAL SPACERS**

(Title Unclassified)

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June 18, 1964

*Mr. R. W. Schroeder
Space Nuclear Propulsion Office
NASA Lewis Research Center
21000 Brookpark Road
Cleveland 35, Ohio

Subject: WANL-TME-687, "Nuclear Safety Design of the Astrofuel Vault Using
Boral Spacers," dated June 4, 1964

Dear Mr. Schroeder:

Transmitted herewith are three (3) copies of the subject report. This
report is transmitted for your information.

Respectfully,

H. F. Faught
amw

H. F. Faught
Program Manager
NERVA Nuclear Subsystem

Enclosures - 3

cc: Mr. R. Wilke, SNPO-C Resident Office at WANL
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June 4, 1964

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NUCLEAR SAFETY DESIGN OF THE ASTROFUEL

VAULT USING BORAL SPACERS

(Title Unclassified)

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1.0 INTRODUCTION

The Astrofuel vault arrangement described in WANL-TME-621 for the in-process fuel elements will not provide the storage capacity required for anticipated production levels. The nuclear safety design of a storage configuration utilizing nuclear poison is presented herein that will permit a substantial increase in storage capability while maintaining protection against criticality under various conditions of flooding.

2.0 METHOD

2.1 Assumptions

The following assumptions were made in this study:

1. The effective dimensions of the fuel tray are 4.75" wide x 3.75" high x 60" long; the length corresponds to the maximum dimension of in-process fuel elements while the height results from the stacking arrangement in the fuel tray. Vertical boral spacers between each fuel tray form a 5.60" wide storage compartment for handling convenience; spacers are not used between shelves.
2. The storage array is comprised of five (5) shelves with a 20 inch edge-edge spacing between fuel; each shelf consists of relatively close-packed fuel trays with individual boral spacers.
3. The boral spacer consists of an aluminum-clad plate having the overall dimensions: 0.25" thick x 6" high x 60" long. The thickness of the boral is 0.1667 inches which contains 31.5 w/o B_4C and has a bulk density of 2.525 gm/cm^3 ; the resultant atom density of boron in this material is $N = 0.0345 \times 10^{24} \text{ atoms/cc}$.
4. The fuel tray contains a maximum of 20 NRX fuel elements having a loading of 500 mg - U/cc with a U-235 enrichment of 93%. For the purpose of estimating maximum reactivity effects, smaller quantities of elements are considered; by virtue of the stacking arrangement in the fuel trays, fuel is homogeneously distributed over the tray volume regardless of the number of elements in the tray.

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5. For interaction calculations it is assumed that the fuel bead array consists of fifty 12 inch diameter spheres having a 24 inch center-center spacing.
6. Conditions that need be considered in the nuclear safety design of the vault include: a flooded condition where all void spaces are filled with water, a drained condition where only the coolant channels in the fuel elements are occupied by water (resulting from the practice of placing protective caps over the ends of the elements), and a partially-flooded condition where the water level is located at any height in the storage array. The completely dry condition was not analyzed because the results of this study, particularly the evaluation of the drained condition, demonstrated that the reactivity of a dry array was very small. Three 1/2-inch holes are located on both sides of the tray (flush with the bottom) to prevent retention of water in the tray following a flood.

2.2 Reactivity Calculations

Reactivity calculations were performed with DTK transport code in one-dimensional slab geometry using the 16 group Hansen-Roach cross sections and isotropic hydrogen scattering. Although subsequent studies have shown that anisotropic hydrogen scattering should be used in highly moderated systems, the effect is not significant here where the H/U-235 atomic ratio does not exceed 125. (The analytical model underestimates reactivity by less than 2%).

The geometric model used to represent the fuel storage array was a slab, four region cell. The first region consisted of a homogeneous distribution of fuel material contained within the tray; the structural material comprising the tray itself was ignored. The second region represented the space between the fuel tray and the boral spacer; water occupied this space under flooded conditions whereas an actual void was used for the drained condition. The aluminum cladding over the boral material comprised the third region while the boral material itself constituted the outermost region of the cell.

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In order to account for the finite values of the two transverse dimensions of the slab, an effective dimension is used by the code $H = H + \lambda + d$ where H is the actual slab dimension, λ is a reflector savings used when a reflector material is present and d is the extrapolation distance computed internally by the DTK program. A reflector savings of $\lambda = 5$ cm was used for water which compares with a value of 7 cm that is frequently employed for the combination of extrapolation distance and reflector savings of a water reflector.

2.3 Interaction Calculations

2.3.1 Identical Units

Interaction calculations for an array of identical containers were based on a method devised at ORNL and described in K-1478⁽¹⁾. The basic equations involved in this method are:

$$K = k/(1-V)$$

$$V = (1-U_f) \sum_{qi} \bar{\Omega}_i$$

where K = multiplication factor of array.

k = multiplication factor of single isolated unit.

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V = neutron interaction probability.

$(1-U_f)$ = fast neutron leakage probability.

Ω_i = fractional solid angle subtended by the
i'th unit on the most central unit in the
storage array.

q_i = flux weighting factor dependent on the
geometry of the storage array; this value
is conservatively assumed to be unity in
these calculations.

A test of the analytical model by ORNL on arrays of U-235 solutions as well as metal spheres testify to the validity of the method for both thermal and fast systems.

2.3.2 Dissimilar Units

Interaction between two dissimilar units or arrays in the vault was evaluated by means of the following expression:

$$K = \frac{k_1 + k_2 + \sqrt{(k_1 - k_2)^2 + 4 k_1 k_2 V_1 V_2}}{2}$$

$$V = \bar{\Omega} (1-U_f)$$

where K = multiplication factor of system
 V = neutron interaction probability
 r = ratio of lateral buckling (interacting surface)
to the total buckling
 $\bar{\Omega}$ = average fractional solid angle between units
 $(1-U_f)$ = fast neutron leakage probability

In these expressions, k_1 and k_2 are the respective multiplication factors of units 1 and 2 while V_1 is the fraction of neutrons escaping from unit 1 to strike unit 2, and V_2 the fraction from container 2 striking containing 1. The value of r used in the present study was conservatively assumed to be unity. This analytical model is described in K-1309⁽²⁾ where it is tested against numerous critical interacting systems; the results indicate that a maximum error of 3% can be anticipated in the evaluation of neutron interaction between the two arrays.

3.0 RESULTS

The maximum multiplication factor of a single, unpoisoned shelf of close-packed fuel trays that is moderated and reflected was determined to be $k_e = 1.08$. This occurs with a water volume fraction equivalent to thirteen fuel elements per tray. The multiplication factor for a full tray loading of twenty elements is $k_e = 1.03$. It is obvious that some modification must be made to this configuration to prevent criticality under flooded conditions. For this reason the effectiveness of vertical boral spacers between adjacent fuel trays was analyzed.

3.1 Flooded Array

When boral spacers are used the maximum multiplication factor reported above is lowered to $k = 0.84$. However, when five (5) such shelves are stacked together, the array is supercritical ($k > 1.0$). A minimum spacing of twelve (12) inches must therefore be provided between each shelf to ensure nuclear isolation of adjacent shelves under flooded conditions. The reactivity of the array then corresponds to the multiplication factor of a

single shelf, viz. $k = 0.84$.

3.2 Drained Array

Under drained conditions when water is present only in the coolant channels of the fuel elements, the maximum multiplication factor of a single shelf poisoned with boron spacers is $k = 0.07$. The reactivity of the drained array was evaluated by means of the interaction model for identical units described in Section 2.3.1. The value of the fractional solid angle for two 5' x 18.5' slabs with a 20" edge-edge separation is $\Omega = 0.23$. The maximum fractional solid angle in a 5-shelf array, assuming self-shielding of shelves, is therefore $\Omega = 0.46$. Neutron leakage by region and by energy group was obtained by subtracting the absorption cross-section from the effective cross-section used by the one-dimensional computer code: $\sum a \text{ (effective)} = \sum a + DB^2$. The total transverse leakage yielded the following value: $\int -DB^2 d\phi = (1 - U_f) = 0.946$. Substitution of these values in the appropriate equations yields the multiplication factor of the array, $K = 0.13$.

3.3 Partially-Flooded Array

The most reactive configuration for this condition is considered to be a water level located at the top of the lowest fuel shelf. The first step in evaluating the reactivity of this array is to transform the bare, drained shelves located above this half-reflected shelf into a single shelf with an equivalent multiplication factor. Using the interaction model of Section 2.3.1 with allowance for self-shielding between shelves, this equivalent shelf was determined to have a leakage probability $(1 - U_f) = 0.946$ and a multiplication factor $k = 0.09$.

The calculated multiplication factor associated with a fully moderated shelf that is reflected on one side is $k = 0.66$. A reflector savings of $\lambda = 5$ cm was used here instead of the value of 2λ normally used for a reflected slab. Despite the presence of a reflector material, the leakage probability for a moderated, unreflected slab, $(1 - U_f)$ is used since it most closely represents the neutron leakage from this shelf into the array.

The reactivity of a partially-flooded array is determined by evaluating the interaction between the equivalent drained shelf and the half-reflected shelf using the scheme described in Section 2.3.2. Using the following parameters:

Equivalent Drained Shelf:	k_1	=	0.09
	$\bar{\Omega}_f$	=	0.023
	$1-U_f$	=	0.946
	V_1	=	0.2176
Half-reflected Shelf:	k_2	=	0.66
	$\bar{\Omega}_f$	=	0.23
	$1-U_f$	=	0.75
	V_2	=	0.1725

the multiplication factor of the partially flooded array is $K = 0.66$. A similar analysis corresponding to a water level located at the bottom of the lowest fuel shelf yielded a multiplication factor of $K = 0.16$.

3.4 Vault Reactivity

In order to complete the nuclear design of the Astrofuel vault, the neutron interaction between the fuel element array and the fuel bead array must be evaluated. Calculations for a dry, unreflected sphere of UC_2 beads in 10 kg units provided the following parameters:

$$\begin{aligned}k &= 0.20 \\ \Omega &= 0.14 \\ (1-U_f) &= 0.912\end{aligned}$$

which gave a value of $K = 0.22$ for the 50-unit bead array. Since a flood level that would add significant reflection to these units would simultaneously lower the neutron interaction between them, a dry array was assumed to be the most reactive condition from the point of view of neutron interaction. Using the interaction model description in Section 2.3.2 and the following parameters characteristic of each array:

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Bead Array:	k_1	=	0.22
	Ω	=	0.082
	$(1-U_f)$	=	0.912
	V_1	=	.075
Element Array:	k_2	=	0.66
	Ω	=	.050
	$(1-U_f)$	=	.946
	V_2	=	.047

the multiplication factor of the vault for the highest level of neutron interaction is $K = 0.66$ which indicates that no significant interaction exists between arrays.

4.0 SUMMARY AND CONCLUSIONS

The above analysis has shown that an array of five shelves containing close-packed fuel trays is safe under all conditions of flooding with boral spacers located between each tray and with the 20 inch edge-edge spacing provided between the fuel. Furthermore, it has been determined that neutron interaction between the two arrays in the Astrofuel vault is acceptable.

The capacity of the storage array in the Astrofuel vault for in-process fuel elements may therefore be safely increased providing the assumptions used in this analysis are not compromised by the required modifications in procedures and/or structural design.

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Attachment (1)

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REFERENCES

1. H. F. Henry et.al., Extensions of Neutron Interaction Criteria, K-1478, July 1961.
2. H. F. et.al., General Application of a Theory of Neutron Interaction, K-1309, November 1956.

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