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REPORT TITLE **Experimental Study of Intrinsic Core Subcriticality by Neutron Spectral Changes (title unclassified)**

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NAA-SR-MEMO **11574**

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TECHNICAL DATA RECORD		PAGE 1 OF 11	
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TITLE (title unclassified) EXPERIMENTAL STUDY OF INTRINSIC CORE SUBCRITICALITY BY NEUTRON SPECTRAL CHANGES		S/A NO 2311	TWR
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Ashley, R. 2 Brehm, R. 2 Buttrey, K. 5 Castle, W. 5 Cockeram, D. 5 Colston, B. 2 Crouter, D. 38 Detterman, R. 5 Eggleston, R. 2 Hawley, J. 5 Heneveld, W. 373 Hench, W. 5 Johnson, C. 5 Keshishian, V. 2 Maki, L. 5 McGoff, D. 5 Mims, L. 5 Morgan, W. 2 Moss, L. 5 Oakes, T. 12 Oliver, D. 5 Ottewitte, E. 5 Roberts, W. J. 2 Saur, A. 4 Scott, W. W. 5 Soske, P. 37 Steen, G. 5 Sturtevant, W. 38 Susnir, J. 5 Thiele, A. 38 Tobler, R. 5 Verna, B. 3 Vollmer, R. 5 Williams, R. O. 5 Yee, S. 373	STATEMENT OF PROBLEM Determine the effectiveness of a distributed neutron poison in a water-flooded SNAP 10A core due to spectral differences between the operational and water immersed configurations.		
		ABSTRACT <p>The SCA-4C and SCA-4B critical assemblies were used to measure the worth of gadolinium in and around the SCA-4 core in the operational and water-flooded configurations respectively. Gadolinium applied to the outer wall of the core vessel decreased the reactivity of the operational system by \$2.44 while causing a \$9.12 decrease in the fresh water immersion case. The maximum gadolinium concentration was $\Sigma_{a.t} = 10.2$ with 90% of the worth being achieved with $\Sigma_{a.t}$ of 2.5 in water and 6.0 dry.</p> <p>Gadolinium applied to the fuel claddings resulted in -\$8.75 for $\Sigma_{a.t} = 0.3$ in the operational configuration and -\$10.65 for $\Sigma_{a.t} = 0.2$ in fresh water.</p> <p>Substitution of sea water for fresh water resulted in a \$2.05 reactivity loss and decreased the worth of $\Sigma_{a.t} = 4.0$ on the core vessel from \$8.57 to \$6.79.</p>	

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INTRODUCTION

A major consideration in the safety of an operational SNAP reactor is the potentially large reactivity effect associated with submersion of the reactor in water. The increased moderation associated with the introduction of water into and around the system results in a significant increase in system reactivity and a shifting of the thermal neutron spectrum, with the peak shifting from about 0.1 ev to lower energies. These effects may be used to advantage by introducing a thermal absorber into the system whose energy dependence makes it more effective in a water immersed core than in the operational system. These experiments were designed to measure the relative worth of gadolinium as applied to the core vessel and to the fuel claddings in both the operational (SCA-4C) and water immersed (SCA-4B) configurations. The poison was measured incrementally to define worth curves as a function of poison concentration in each application. Reference 1 compares gadolinium to other likely thermal absorbers, all of which are more effective in a water-flooded core. Gadolinium is seen to be more effective when the shift in thermal neutron spectrum is considered together with the increase in thermal neutron population.

DESCRIPTION

The chosen method of application of the gadolinium to the system entails the use of coated mylar tape (similar to that used on magnetic tape recorders) applied with an adhesive to the various surfaces. The mylar was furnished by a vendor with gadolinium oxide coatings varying from $\Sigma_{a,t}$ of 0.1 to $\Sigma_{a,t}$ of 2.0, with the mylar base thickness varying from 0.001 to .005 inches. The tape was cut in strips the same length as the core (12.25"), the width matching the circumference of the fuel elements.

The oxide coating on the mylar is composed of iron oxide replaced by gadolinium oxide to the desired $\Sigma_{a,t}$ concentration. The base point is taken with tape coated only with iron oxide so the following measurements of gadolinium oxide are with respect to iron oxide.

In the operational system (SCA-4A) the experimental procedure⁽²⁾ consisted simply of applying a layer of unpoisoned tape, or more if necessary, to the core vessel and determining the critical configuration on the control drums. Boron splines were added and measured individually to decrease the reactivity of the system by the amount expected from the gadolinium. Then by removing the splines as the gadolinium was applied to the core vessel, the worth of the gadolinium was determined with a minimum of drum movement (whose control worth may vary as the poison is added to the core vessel).

A similar procedure was followed in applying the poison to the fuel elements only in this case more faith could be placed in the drum control worths as calibrated earlier. In applying the poison to the

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NO. NAA-SR-Memo-TDR-11574

ATOMICS INTERNATIONAL

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DATE 8-16-65

PAGE 3 OF 11

fuel it was found that more excess reactivity was needed than was available in the SNAP 10A type system (about \$5.25). In order to increase the range of the measurement, the reflector thickness was increased to 3.25" for a system excess of about \$10.50.

Application of the poison in the water immersed system was identical,⁽³⁾ only more boron splines were needed to contain the excess of the unpoisoned, totally immersed system, measured to be \$11.60. For safety reasons, steel straps were affixed to the core vessel after applying the mylar to decrease the chances of the tape coming off while the reactor was critical and inserting a large reactivity step. Each of the critical machines are described in detail in their respective hazards reports, references 4 and 5.

RESULTS AND CONCLUSIONS

The SCA-4A assembly was first utilized to mock-up the operational configuration. Unpoisoned mylar was attached to the core vessel in a series of three 5 mil layers, resulting in a total reactivity effect of +15 cents. Poisoned mylar was then affixed in concentrations of $\Sigma_a \cdot t = 0.1, 0.2, 2.0, 6.0$ and 10.0 . The two smallest values were measured directly, with the value of 2.0 measured by the poison spline substitution method. The two largest values were measured by the period-bump technique with respect to the $\Sigma_a \cdot t = 2.0$ case. In every case the effect of the mylar and adhesive was accounted for by using the equivalent thickness of unpoisoned mylar as the base point. Period measurements were used in lieu of drum calibration curves to eliminate interaction effects between drums and mylar film.

The results of the operational measurements on the core vessel are tabulated in Table 1 below:

TABLE 1

$\Sigma_a \cdot t$ of Gd_2O_3	Negative Reactivity Worth, \$
0.1	.27
0.2	.69
2.0	1.51
6.0	2.19
10.0	2.44

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ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. NAA-SR-Memo-TDR-11574DATE 8-16-65PAGE 4 OF 11

The operational measurements of gadolinium on the fuel cladding were conducted with poison concentrations corresponding to $\Sigma_a.t$ values of 0, 0.1, 0.2, and 0.3. Initially the reflector was set at 2.0" thickness inches high to mock-up the SNAP 10A flight configuration. The reflector thickness was increased by 0.5" to 2.5" in order to measure the $\Sigma_a.t = 0.2$ case, and another 0.5" out to 3.0" was required to measure the $\Sigma_a.t = 0.3$ case.

The results of the operational measurements of gadolinium on the fuel cladding are tabulated below in Table 2:

TABLE 2

$\Sigma_a.t$ of Gd_2O_3	Negative Worth \$
0.0	.05 "
0.1	3.80 ² "
0.2	6.40 ^{2.5} "
0.3	8.75 ³ "

not thickness

Following the operational measurements, the SCA-4B water immersion assembly was activated for the remaining tests. The assembly was loaded to critical and subsequently to full core with the same SCA-4 fuel used for the operational experiments. A large number of boron splines were necessary to control the excess reactivity of the system since the core itself was flooded, as well as having effectively infinite water surrounding the core. Preliminary studies of spline worths were necessary because of the large number used.

The amount of reactivity controlled by a boron spline is most dependent on its radial position with the worths varying from 23 cents in a peripheral position to about 50 cents adjacent to the center element. Any inconsistencies in the spline concentrations are more pronounced with the splines positioned toward the center of the core. At the initial full core loading, 46 splines were utilized and were loaded away from the center of the core to minimize any differences in the individual spline compositions. A redistribution of the splines was effected to gain a compromise between spline worth uncertainties and central flux peaking. The new spline loading consisted of 40 splines and the fission flux distribution was mapped with U-235 pins. Figure 1 illustrates the radial flux through the core and reflector region and Figure 2 shows the axial distribution along the central fuel element.

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NO. NAA-SR-Memo-TDR-11574

DATE 8-16-65

PAGE 5 OF 11

Due to the high peaking with 40 splines, some were moved in adjacent to the center rod and a new spline loading of 37 splines was adopted for the reference case. Each spline was separately identified and measured individually. Figure 5 shows the spline worths by location. Figures 1 and 2 also show the flux distribution with the final 37 spline loading. As a result of measuring each spline, the excess reactivity of the wet core water reflected assembly was found to be $\$11.60 \pm .35$.

The initial measurements in the mylar phase of the experiment were of the reactivity worth of unpoisoned mylar affixed to the core vessel. It was found that 8.0 mils (2 layers) was worth -13% and an additional 12.0 mils added (negatively) another 3% for a total negative worth of 16% with respect to water. These numbers were utilized in calculating the worth of the following Gd measurements.

After removing the unpoisoned mylar, a series of measurements were made on poisoned mylar attached to the core vessel. The results are tabulated below and plotted in Figure 3 along with the operational data. A flux mapping performed with $\Sigma_a.t = 10.2$ is included in Figures 1 and 2.

TABLE 3

$\Sigma_a.t$ of Gd_2O_3 Attached to Core Vessel	Negative Reactivity Worth, %
0.2	3.68
2.2	7.82
4.2	8.56
6.2	8.72
10.2	9.12

Following the core vessel measurements, the reference configuration with 37 splines and no mylar was re-established and was found to have changed less than 4% . The fuel elements were then clad with $\Sigma_a.t$ of 0.1 mylar and in two steps exhausted the excess reactivity of the system.

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NO. NAA-SR-Memo-TDR-11574

DATE 8-16-65

PAGE 6 OF 11

TABLE 4

$\Sigma_{a.t}$ of Gd_2O_3 Attached to the Fuel Elements	Negative Reactivity Worth, %
0.1	5.41
0.2	10.65

The points are plotted in Figure 4, accompanied by the corresponding data from the operational measurement.

After re-establishing the base point, the fresh distilled water used in the system was replaced with sea water and the reactivity effect measured. The sea water was found to be 2.06 less reactive. With the sea water system, a mylar film with a $\Sigma_{a.t}$ of 4.0 was attached to the core vessel. The worth of the Gd was found to have decreased to 6.79 as opposed to 8.57 for the fresh water measurement. The point is plotted in Figure 3. Thus, from the original fresh water base point, addition of $\Sigma_{a.t}$ of 4.0 decreased the reactivity of the system by 8.57. Addition of sea water then changes the reactivity by only 1.28, more negative. Thus, the additive effect of the Gd in sea water slightly surpasses the Gd in fresh water, although the worth of the Gadolinium is reduced in sea water.

Referring back to Figure 2 it may be noticed that the flux is weighted toward the bottom of the core. This effect may possibly be due to the presence of the upper grid plate and cover plate used to separate the top tank water from the core water. Difficulties in positioning the base tank caused the full limit to be restricted such that an air gap may have been present between the upper grid plate and the cover plate.

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~~CONFIDENTIAL~~
NO. NAA-SR-Memo-TDR-11574

DATE 8-16-65

PAGE 7 OF 11

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8/16/65

9 of 11

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Fig. 2

FIGURE 3 REACTIVITY WORTH OF GADOLINIUM ON
THE SCA-4 CORE VESSEL WALL

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8/16/65

11 of 11

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FIGURE 3 REACTIVITY WORTH OF GADOLINIUM
ON THE SEA-A FUEL CLADDING

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