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STORAGE OF UNIRRADIATED FUEL IN BORATED CONCRETE AT THE SAVANNAH RIVER PLANT

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INTRODUCTION

At the Savannah River Plant (SRP), we can store more than 3,000 enriched uranium fuel elements in horizontal holes in borated concrete racks. This method of storage was selected because:

- These borated concrete racks are virtually indestructible even for natural disasters such as earthquakes and tornadoes.
- The boron in the concrete precludes criticality for all credible accidents.
- The racks cost only one-third as much as racks that space elements to provide the same degree of nuclear criticality safety.

The purpose of this paper is to describe the largest of these racks and the reactivity calculations and measurements which confirmed that SRP fuel may be safely stored in them.

DISCUSSION

The cross section of the aluminum-enriched uranium fuel assemblies now produced at SRP is shown on slide 1. It consists of three concentric fuel tubes and one concentric target tube. Each fuel tube contains an aluminum-enriched uranium alloy core clad with aluminum. The alloy contains 20 to 30 wt % uranium enriched to between 60 and 93 wt % ^{235}U. The target tube contains 1 wt % ^{6}Li in the aluminum-lithium alloy core and is also clad in aluminum.

Alloy in the tubes is 3.8 m long, thus giving a lineal concentration of 800 g of ^{235}U per meter of length for the normal 3 kg assembly. Special assemblies containing 1,300 g ^{235}U per meter of length were fabricated for a test program.

During the fabrication of these fuel assemblies, we are required to store the individual tube and the three concentric fuel tubes away from the target tube. The target tube is not usually added until the assembly is ready to go into the reactor.

The largest and first rack is shown in slide 2. It measures 12 m long by 2 m long by 2 m high by 4 m deep and contains 910 storage positions. At the time this photograph was taken, the operator was removing an outer fuel tube. You can also see the smaller diameter fuel tubes. A 50-cm-long aluminum end fitting is attached when the three concentric fuel tubes are assembled; these end fittings can be seen protruding from the rack. In the background, you can see a second smaller rack.

A closeup of one of the seven sections of the rack containing a 10 × 13 array of holes is shown in slide 3. At the lower far right are the three different size fuel tubes.

During the design of the rack, it was recognized that it would be difficult, if not impossible, to cast the entire rack at one time. Therefore, it was decided to cast a row of 10 holes into a slab and then stack 13 slabs to construct the section shown here.

The individual slabs are shown in slide 4. They contain 0.35 wt % boron in the form of boron frit that replaces some of the sand in a normal mix. Boron frit is a glass containing 50 wt % B_2O_3 that is quenched while molten to form pieces no larger than 5 mm. With this amount of boron in the concrete and a normal 800 g ^{235}U/meter assembly in each hole, the boron-to-^{235}U atom ratio is 3:4; a 1:0 ratio is generally accepted as assuring the subcriticality of an aqueous solution. Before stacking a slab into the rack, its boron content was confirmed by neutron transmission measurements. A neutron source and a BF_3 detector were placed in the adjacent holes and the transmission of neutrons through the intervening concrete was measured. Measurements were made at five positions diagonally across each slab. This instrument was calibrated with standard slabs with accurately known boron contents. Based on this calibration, the average boron content for all slabs in the rack was 0.35 wt %; the minimum boron content was 0.27 wt % and the maximum was 0.5 wt %.

The nuclear safety of this rack for storage of SRP fuel was confirmed by reactivity calculations and measurements. The reactivity of the rack loaded with fuel was first calculated using the MGBS and TGAN codes developed at the Savannah River Laboratory. MGBS is a 12-group code that generates parameters for use by the TGAN diffusion code. This pair of codes will subsequently be referred to as the multigroup code. A few of these calculations were repeated using KENO-II with Hansen Roach cross sections. Results of these calculations are on slide 5, which gives the effective multiplication constant of the rack as a function of the ^{235}U content of the fuel filling the rack. The calculations were made for the normal condition of no water in the storage holes and for an extremely unlikely accident in which the building and all storage holes are filled with water. The maximum ^{235}U content of a single tube is 475 g/m; therefore, all calculations used single tubes up to this value. Above 475 g ^{235}U/m, the calculations used the three concentric fuel tubes in each position.

These calculations indicate that with a rack full of normal 800 g ^{235}U/m assemblies, the rack would be subcritical by a very large margin and with flooding the rack would still be subcritical by about 20%. With the special 1,300 g ^{235}U/m assemblies, k_{eff} would be a maximum of 0.95 with full flooding. Correlation with experiments of aluminum-uranium fuel tubes in water performed at SRL showed that at similar H/^{235}U atom ratios, the MULTIGROUP code overestimates the reactivity by 7% k. On the other hand, KENO calculations agree within ±1% with nearly critical configurations derived from these same experiments.

The reactivity of the rack was measured during the initial loading of a rack section with fuel tubes containing 380 g ^{235}U/m. A neutron source was placed in a central hole and two BF_3 detectors were placed one on either side of the source. The neutron multiplication, defined as the ratio of average counts on the detectors after fuel is loaded to the average count with no fuel, was monitored continuously to assure that the next loading step would not result in criticality. The neutron multiplication of the rack section loaded with tubes (M) was used to calculate the effective multiplication constant using the relationship:

$$k = \frac{M - 1}{M}$$

This measured value is lower than the values calculated by the MULTIGROUP and KENO. However, it has an uncertainty at the 2σ confidence level of ±50% due primarily to the poor counting statistics at these low neutron multiplications. These measurements were repeated for fuel tubes with slightly higher ^{235}U contents and for assemblies. In all cases, the measured reactivities were less than calculated. Based on these calculations and measurements, the rack was authorized for storage of fuel containing up to 1,300 g $^{235}U/m$.

The reactivity effects of two other parameters, boron and water content of the concrete, were evaluated using the MULTIGROUP code. Slide 6 shows the effective multiplication constant of the rack as a function of the weight percent boron in the concrete. The calculations were made for the highest content tube stored in the rack (475 g $^{235}U/m$) and for the estimated equilibrium water content of the concrete, 7.2 wt %. As expected, the effects of boron content are pronounced and indicate that the rack would be critical if the boron content was reduced to 0.04 wt %. With the maximum authorized ^{235}U content of 1,300 g/m, the rack would be critical with about 0.15 wt % boron, 40% of the actual content. Although the vendor claims less than 7% of the boron can be leached from the boron frit, our procedures required an annual check to confirm the presence of the boron. After three checks showed no decrease in boron content, the interval was increased to every 5 years.

Variations in water content of the concrete have a minor effect on reactivity. Slide 7 shows that the effective multiplication constant increases only 0.05 as the water content decreases from 10 wt %, the initial value. Therefore, we do not have any program to measure the water content of the concrete.

This rack costs $113,000. A rack without built-in neutron poison cost about $400,000 because it would require widely spaced positions to provide the same protection from accidental criticality with interspersed moderation and so would require six times as much floor area. The rack described in this paper was installed in 1966. Subsequently, five additional racks have been installed at different locations at SRP, so that we now have a total of 3,300 storage positions.

REFERENCES

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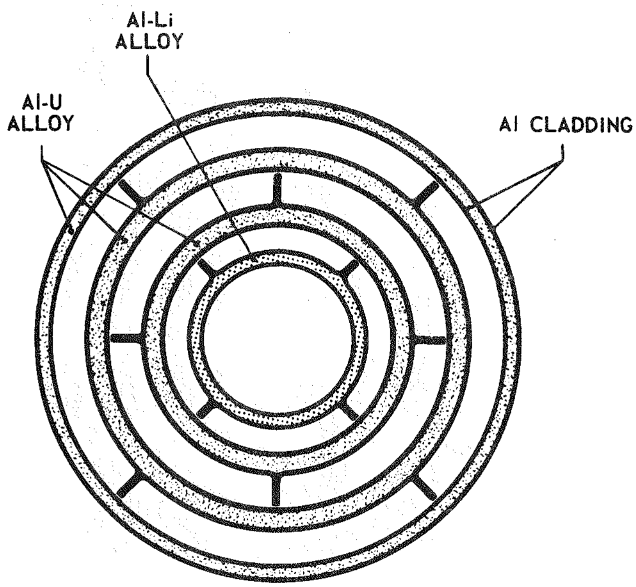
3. Hansen, E. G. and W. H. Roach, Six and Sixteen Group Cross Sections For Fast And Intermediate Critical Assemblies, LAMS-24-43. December 6, 1961.

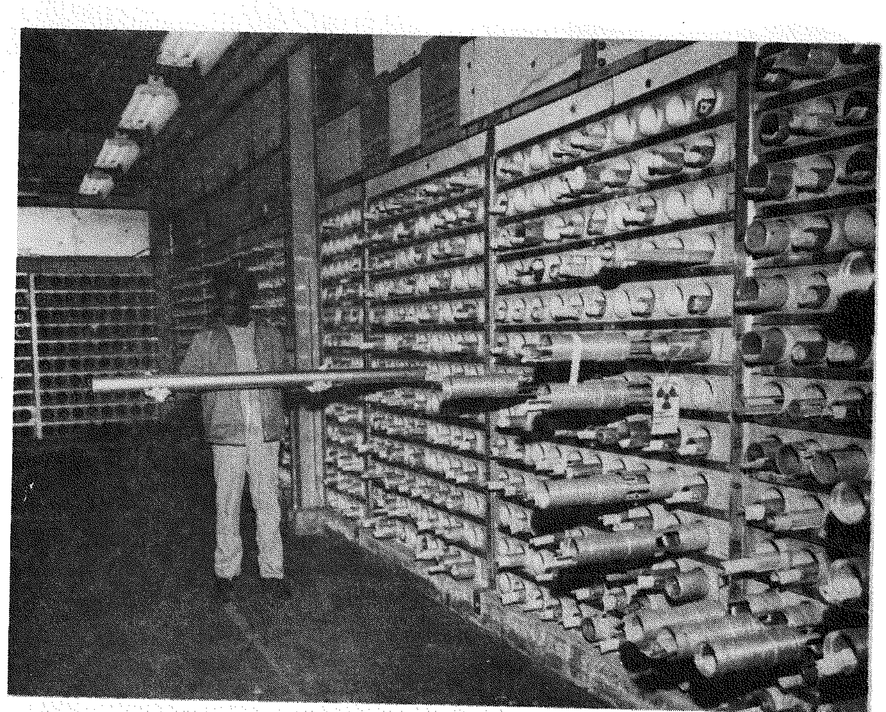
CROSS SECTION OF REACTOR FUEL ASSEMBLY

(3 FUEL TUBES + 1 TARGET TUBE)

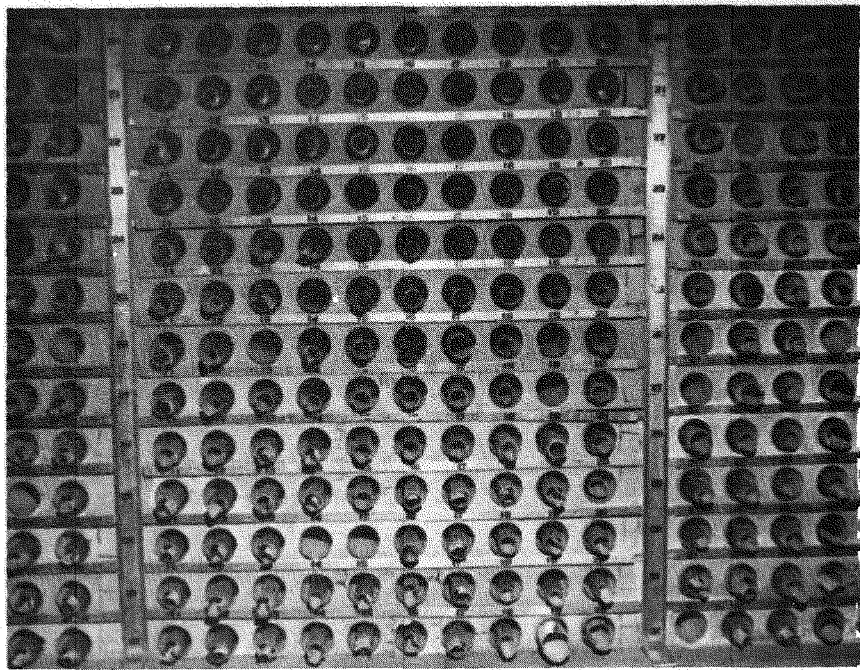


ASSEMBLY LENGTH	4.2 m
ASSEMBLY OD	9.4 cm
TOTAL ^{235}U	3,000 g

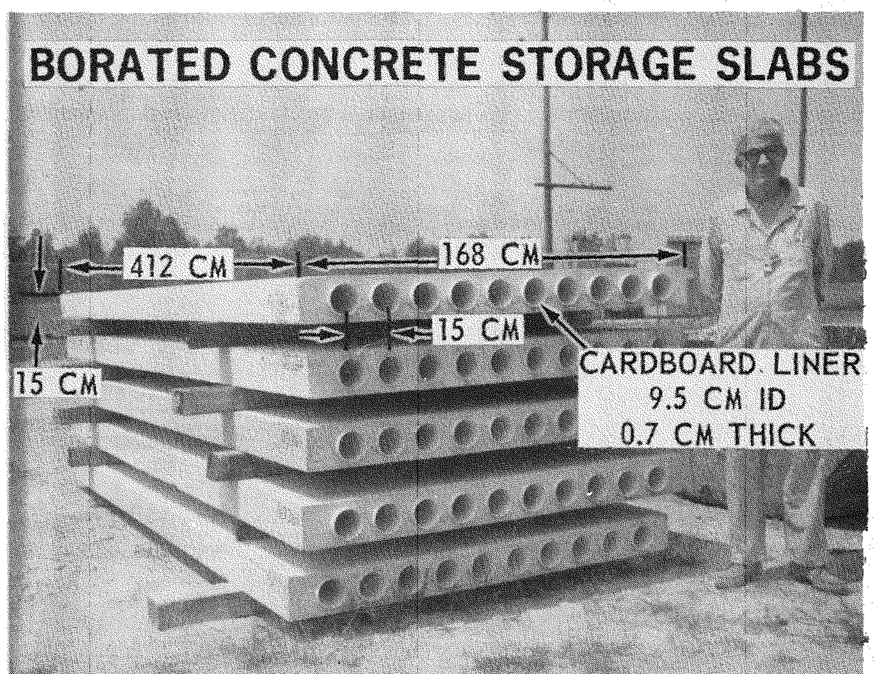
SLIDE 1



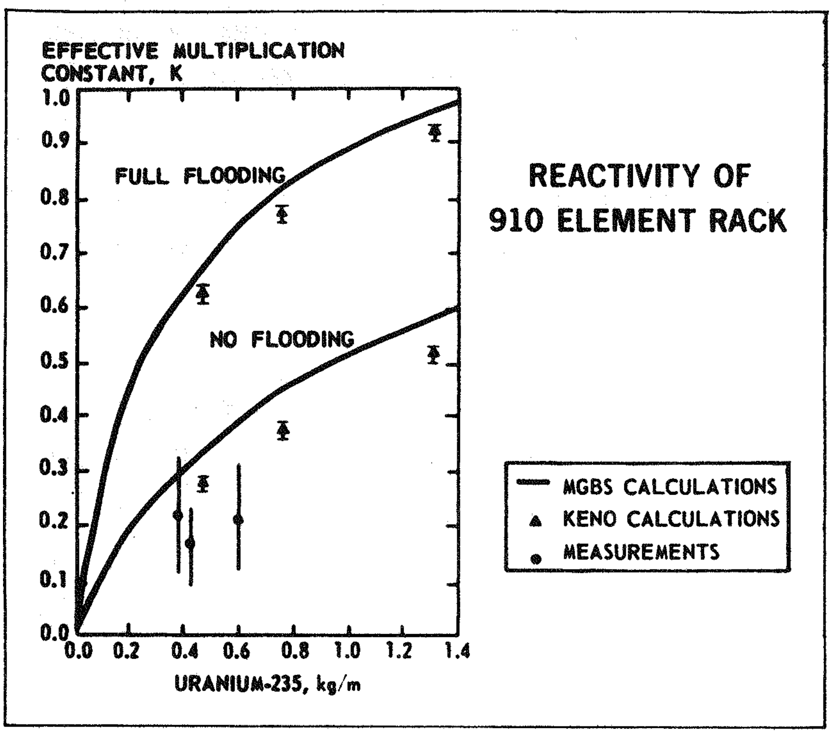
SLIDE 2



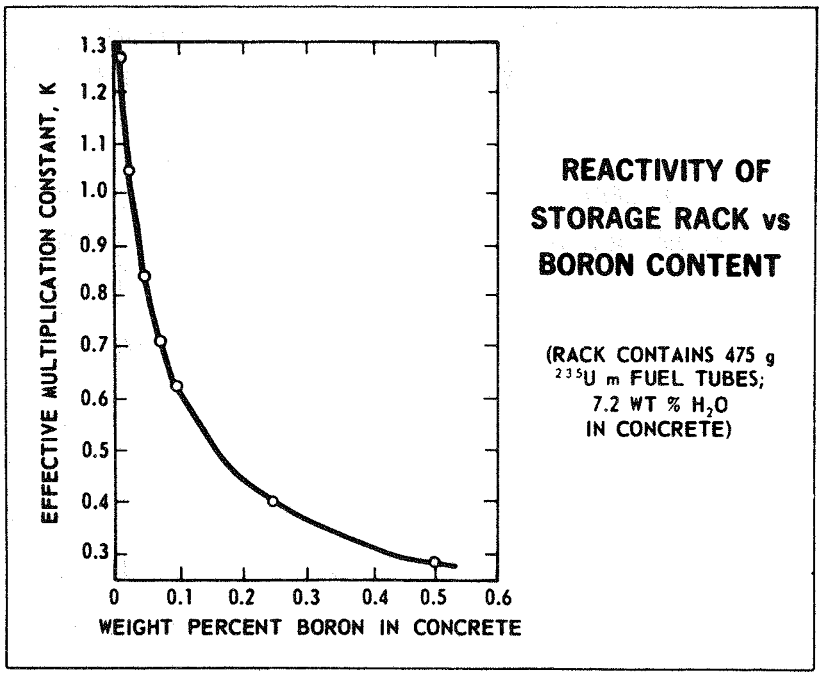
SLIDE 3



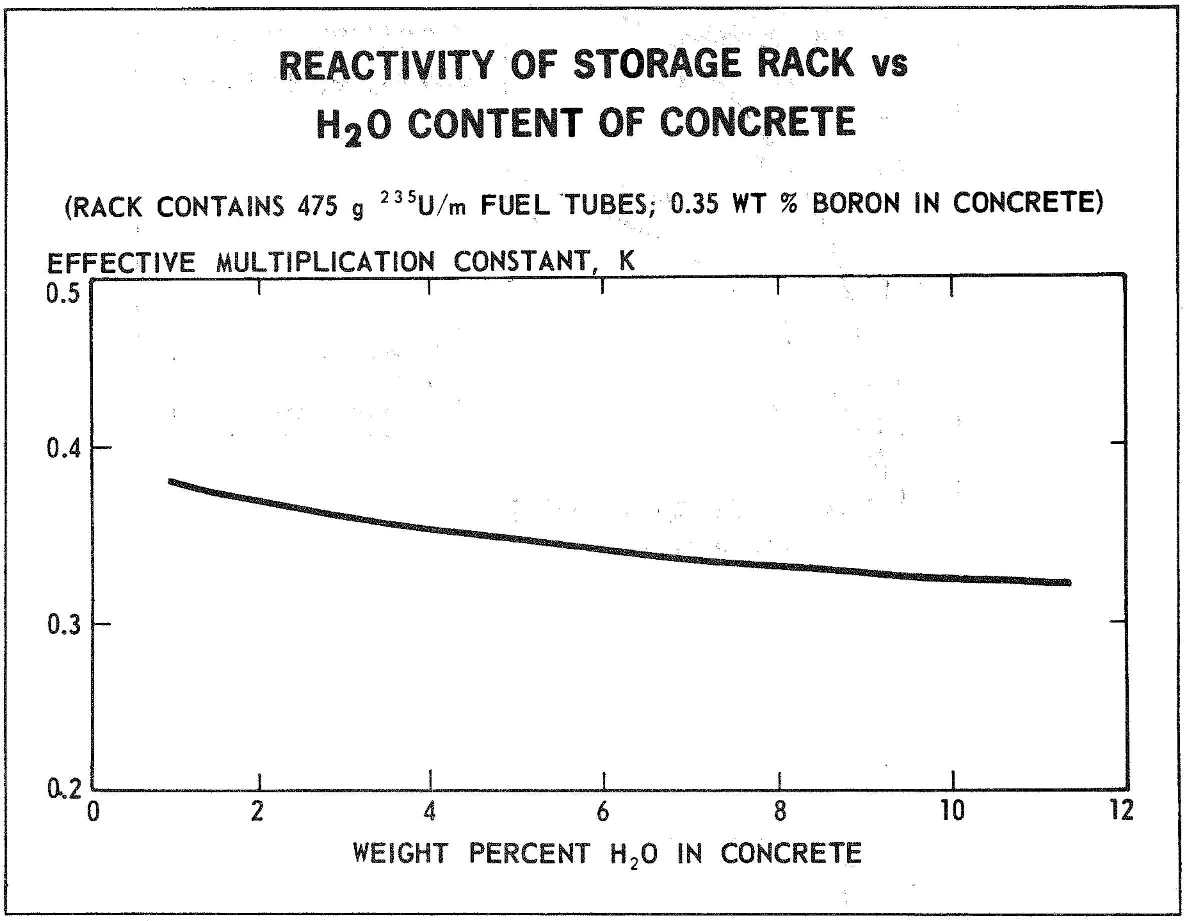
SLIDE 4



SLIDE 5



SLIDE 6


REACTIVITY OF STORAGE RACK vs
H2O CONTENT OF CONCRETE
(RACK CONTAINS 475 g 235U/m FUEL TUBES; 0.35 WT % BORON IN CONCRETE)
EFFECTIVE MULTIPLICATION CONSTANT, K
0.5
0.4
0.3
0.2
0
2
4
6
8
10
12
WEIGHT PERCENT H2O IN CONCRETE

SLIDE 7