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NEUTRON FLUX SUPPRESSION IN APPR CONTROL RODS

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NEUTRON FLUX SUPPRESSION IN APPR CONTROL RODS

I. General.

The detection of flux peaking in the APPR control rods in the water region immediately above the fuel elements resulted in an investigation into the effects of this peak. The existence of the flux peak is important only insofar as it extends into the fuel region and affects the fuel. Referring to Fig. 1 the flux begins to rise from the usual pattern about 3/4-inch from the end of the active fuel. Inasmuch as the cadmium-covered gold activity is relatively constant, the peak is essentially thermal in nature. The net effect of the flux increase at the fuel tip is to increase the fission rate in the upper 3/4-inch of fuel and thereby the temperature with a resulting possibility of regional boiling.

To correct this situation, it was decided to suppress the flux in the region of peaking by the addition of a suitable absorbing material. In order to be satisfactory, the absorbing material should have a relatively high thermal absorption cross section, low corrosion rate and stability under irradiation. It must be available and relatively easy to fabricate.

II. Suppressor Material.

A number of materials were considered as possible flux suppressors, the most important of which are listed in Table 1.

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TABLE 1

<u>Material</u>	<u>Clad Required</u>	<u>Irradiation Stability</u>	<u>Corrosion Resistance(Unclad)</u>
Hafnium	No	Good	Good
Cadmium	Yes	Good	
Boron Steel	Yes	Poor	
B-10 Iron Alloy	Yes	-	
Haynes-25	No	Good	Good
Lindsay Mix (Rare Earth Oxides)	Yes	-	
Ag-In-Cd Alloy	No	Good	Insufficient information.
Silver	Yes	Good	

Of those materials listed, measurements were made on cadmium, boron steel, and Haynes-25 to determine their effectiveness as flux suppressors. Hafnium, which appears to be the most desirable, was eliminated on the basis of lack of availability.

Clad materials were eliminated because of fabrication difficulties and the inability to bring clad absorber sufficiently close to the fuel.

Haynes-25 alloy was chosen despite its relatively low absorption cross section. It is unaffected by radiation, and has adequate mechanical qualities such as welding or brazing characteristics, etc. Corrosion studies were made on the basis of 334.6 cm^2 in area (nine 50 mil plates) of the Haynes-25. Corrosionwise, the most significant component is cobalt which comprises about 50% of the alloy. Calculations indicate that over a three-

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months' period, corrosion products of .05 gm of cobalt will result in an activity of 1.60 curies in the demineralizer bed. Inasmuch as the demineralizer shielding is being revised, adequate protection against this added activity will be provided. Normal recharge cycle for the demineralizer resin is three months. Other corrosion products of Haynes-25 are negligible.

III. Suppressor Design.

APPR fuel elements are fabricated with the fuel (meat) ending $1/2 \pm 1/4$ -inch from the end of the fuel plate. The nominal half-inch of steel plate of low absorption cross-section above the fuel complicates the task of suppression. Unless the suppressing material is brought into this low absorption region, the flux will not be suppressed there and a smaller although undesirable peak will still exist. It is because of this necessity of getting absorber very close to the fuel that clad materials cannot be used. Having absorber plates mounted parallel and above fuel plates would present a problem of keeping fuel and suppressor plates aligned so as not to restrict coolant flow.

In view of these requirements, the suppressor was designed as a series of combs located perpendicular to and extending down between the fuel plates. The shape and dimensions of the suppressor plates are shown in Fig. 2 and the position of these plates in the control rod in Fig. 3. In order to accommodate the suppressor plates, the handle required to remove fuel assembly from control rod box had to be redesigned.

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Inasmuch as coolant flow must be at least equal to that in the fuel region, the amount of suppressor material was restricted to nine 50 mil plates. It is presently intended that the suppressor plates will be brazed into position at the time of fuel element assembly at Oak Ridge.

IV. Zero Power Measurements.

Measurements on various materials were made at the Alco Critical Facility using bare gold and cadmium covered gold foils and with 5 rod bank withdrawn 6.3 inches. This insertion was chosen since it is approximately the maximum shim bank insertion occurring at midlife with no xenon (1). The most adverse power distribution and thereby the limiting power removal occurs under this condition.

Results of axial traverses along the control rod centerline are shown in Figs. 4 and 5. In every case, while the flux is quite strongly depressed in the region of the water hole peak, there is still an undesirable peak at the end of the fuel. This points up the desirability of having the absorbing material extend down between the plates as far as possible, or having very high cross-section material for plates located on top of the fuel plates. As discussed previously, clad materials cannot be used due to the inability of getting absorber close enough to the fuel. In Fig. 4 the cadmium plates were parallel to and on top of the fuel plates; the Haynes-25 combs were perpendicular to and extended down between the fuel plates. It should

(1) AP-Memo-61, Results and Analysis of the APPR-1 Zero Power Experiments-
Nov. 1956

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be noted even a large percentage of peak suppression does not result in an equal percentage of flux reduction at the end of the fuel where suppression is of the greatest importance.

Fig. 5 also shows a comparison of Haynes-25 and boron steel. As pointed out previously, boron steel cannot be used. Also indicated is the fact that the peaks are due essentially to neutrons of energies below 0.4 ev., the cadmium cutoff.

Results of a traverse along the side of the control rod is shown in Fig. 6. This indicates that with no suppressor a lateral picture across the rod would show a high peak in the center of the rod. Addition of the suppressor reduces this peak and effectively levels the flux across the rod in the end of fuel region.

V. Thermal Analysis.

Calculations indicate that without flux suppression, the fuel metal surface temperature at the end of the central control rod fuel plate would be 655° due to the flux peaking. This temperature is based on uniform coolant velocity in all elements and includes all known hot channel factors (2). The effects upon temperature at this hot spot by the addition of suppressors is shown in Fig. 7. It should be noted that the curves are based on the worst possible combinations of manufacturing tolerances and flow velocities anticipated in normal operation of the APPR. With nine 50 mil Haynes-25 combs, the maximum fuel metal surface temperature is 585°F, 18° above saturation temperature.

(2) AP-Memo-17, Hot Channel Factors & Power Distribution for the APPR-1-
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The flow tailoring of the APPR core assures non-boiling at the control rod fuel element tip. Tailoring consists of individual orificing of each stationary fuel element in order to control coolant flow through various parts of the reactor. The curves of Fig. 7 also show the effects of the modified tailoring.

As the reactor core burns out, the flux shape will change from that in the clean core. Investigation indicates that addition of suppressors to all rods plus core tailoring will be adequate to prevent any boiling over the reactor lifetime.

VI. Flux and Power Analysis.

For proper evaluation of the flux peak, it is necessary to correlate the experimental data from bare and cadmium-covered gold foil measurements with the actual fission rate or power. One approach was to try and get a comparison between available catcher foil and gold foil data. Fig. 8 shows the results of intercell measurements made on the APPR critical experiment at ORNL and Fig. 9 shows gross measurements made on the BSR (3). Unfortunately, catcher foil data in water hole regions is too sparse to give conclusive results. A comparison between cadmium-covered gold and dysprosium foil data also failed to give concrete results.

- (3) ORNL 1537, Determination of the Power of the Bulk Shielding Reactor, Part III, G. M. McCammon, L. B. Holland, J. L. Meem, Dec. 1953.

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The second approach involved calculations concerned with the fraction of thermal fissions in the APPR. Consideration of ORNL critical experiment data and calculations in (4) indicate that 83% of the fissions in the APPR are caused by neutrons of energies below 0.4 ev. and that 76% are caused by neutrons of energies below 0.17 ev. For the purposes of calculation of power distribution in the control rod fuel element region away from the peak, 80% of the fissions were assumed to be caused by neutrons having thermal (bare minus cadmium-covered gold) distribution and 20% by neutrons having the epicadmium distribution. The results of these calculations are shown in Figs. 10, 11, and 12.

A third approach was to consider the activation cross-sections of the measuring materials to arrive at an estimate of the power distribution. Realizing that no provision was made for self-shielding in using resonance integrals, foil activity may be expressed as

$$A \propto \bar{\sigma}_{th} \phi_{th} + \int \sigma_{act}(E) \phi(E) dE$$

where the first term describes the energy region below cadmium cutoff, the second the region above cadmium cutoff, and the σ 's are activation cross-sections. Assuming $\phi(E) = \frac{a}{E}$, the ratio of bare gold and cadmium-covered gold foil activities may be obtained and the thermal flux determined as a function of position along the rod axis. If a power ratio is set up for

(4) APAE-7 Reactor Analysis for the APPR - J.G. Gallagher, et al., May 1956

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different positions along the axis relative to an arbitrarily chosen zero point

$$\frac{P_z}{P_{z_0}} = \frac{[\sigma_f \phi_{th} + a \int \sigma_f(E) dE/E]_z}{[\sigma_f \phi_{th} + a \int \sigma_f(E) dE/E]_{z_0}}$$

the power ratio can be calculated. The results of these calculations are shown in Fig. 13. As a check of this method with a rod withdrawal of 6.3 inches, calculated percent fissions below 0.4 ev is 94%; ORNL using bare and cadmium-covered gold foil data from the clean experiment results in a figure of 96.7% fissions below 0.4 ev as compared with 91% as calculated by ORNL using bare and cadmium-covered catcher foils.

As a result of careful consideration of the various theoretical methods, it was felt that the second approach gave the most realistic picture of the actual situations.

Zero power measurements were all made at 68°F and atmospheric pressure. In order to determine the peaking effects at APPR operating temperatures two calculational models were set up. The first was a one group calculation on the peak reduction in a water hole between two black absorbers; the second was a two group multiregion model which fairly closely approximated the actual rod. Both methods indicate a reduction in peak with no suppressor at 450°F. Preliminary calculations indicate the relative flux at the end of the fuel at the rod centerline is about the same at both temperatures.

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FIG 1

RELATIVE ACTIVITY VS. VERTICAL POSITION
AT CENTER OF ROD C
PLATES 7 & 10

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FIG. 2

SUPPRESSOR PLATE DESIGN

MAT'L: HAYNES-25 ALLOY, 0.050 IN. THICK
NO. REQ'D: 9 PER ROD

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FIG. 3
CONTROL ROD FUEL ASSEMBLY
WITH SUPPRESSORS

EUGENE DIETZGEN CO
MADE IN U. S. A.

NO. 340A 10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH

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FIG. 4

BARE GOLD ACTIVATION IN CENTER OF ROD C
 SHOWING
RELATIVE EFFECTS OF COMB & PLATE
TYPE SUPPRESSORS IN THE WATER HOLE

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FIG 5

GOLD ACTIVATION MEASUREMENTS
IN ROD C WITH VARIOUS FLUX
SUPPRESSORS IN WATER HOLE

5 HAYNES COMBS 50 MIL THICK
9 HAYNES COMBS 50 MIL THICK
9 1% NAT'L BORON SS COMBS 40 MIL THICK

EUGENE DIETZGEN CO.
PRINTED IN U. S. A.
NO. 340 M DIETZGEN GRAPH PAPER
MILLIMETER

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FIG. 6
RELATIVE ACTIVITY VS. VERTICAL POSITION
AT EDGE OF ROD C WITH 9 50 MIL HAYNES-25
COMBS

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FIG 8

COMPARISON OF GOLD ACTIVITY AND FISSION
PRODUCT ACTIVITY IN ORNL C.E.

CORE LOADING 20.1 Kg U-235, 255 GM B

o Au ACTIVITY
+ FISSION PRODUCT ACTIVITY

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FIG 9

COMPARISON OF GOLD AND FISSION PRODUCT ACTIVITY
IN BSR

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FIG 10
RATIO OF THERMAL FISSIONS TO
EPITHERMAL FISSIONS IN ROD C WITH
VARIOUS SUPPRESSORS IN THE WATER HOLES

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EUGENE DIETZEN CO.
PRINTED IN U. S. A.
NO. 34014M DIETZEN GRAPH PA-7
MILLIMETER

FIG 11
POWER DISTRIBUTION IN
ROD C WITH VARIOUS
FLUX SUPPRESSORS

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FIG 12

RELATIVE THERMAL FLUX
AND POWER AS A FUNCTION
OF ABSORPTION IN THE WATER
HOLE REGION

RELATIVE ACTIVITY OR POWER

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FIG 7

AXIAL TEMPERATURE DISTRIBUTION
IN CENTRAL CONTROL ROD FUEL
ELEMENT SURFACE METAL

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FIG 13
POWER AND THERMAL FLUX AT END OF
CONTROL ROD FUEL PLATES

(CENTER OF ROD, CURVES NORMALIZED TO
VALVE AT 5" (0.170))

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