APAE-121

AEC Research and
Development Report
UC-81, Reactors, Power
(Special Distribution)

HAZARDS REPORT FOR
PM-2A CORE II

By:
J. R. Coombe
L. D. Stephenson

Approved by:
E. W. Schrader, Acting Project Engineer

Issued: June 21, 1962

Contract No. AT(30-1)-2639
with U.S. Atomic Energy Commission
New York Operations Office

ALCO PRODUCTS, INC.
Nuclear Power Engineering Department
Post Office Box 414
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ABSTRACT

This report describes the changes incurred in the PM-2A by the planned insertion of PM-2A Core II and the replacement of the startup and check sources. PM-2A Core II components were fabricated to specifications very nearly identical to those of PM-2A Core I. The essential difference in the cores is the boron loading which permits PM-2A Core II to meet a "one-stuck rod criteria" at beginning of life. This core has been subjected to a zero power experiment and loading procedures have been developed at the Alco Critical Facility. The nuclear and thermal and hydraulic characteristics are essentially identical to those of Core I and the replacement of the startup and check sources represent no increase in the potential for or magnitude of a hazardous situation.

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HAZARDS REPORT FOR PM-2A CORE II

1.0 INTRODUCTION

This report provides the hazard report for the replacement of PM-2A Core I and operation with the PM-2A Core II. Core II will be compared with Core I and the differences evaluated as related to the PM-2A hazards summary report.⁽¹⁾ The replacement of the startup and check sources which appears advisable to accomplish at the same time will also be discussed. This report was prepared as a part of Subtask 10.2 of the FY-62 Program Plan for Engineering Support and Development of Army PWR Power Plants.

2.0 COMPARISON OF CORE I AND CORE II

The replacement core will consist of Type 2 elements. The Type 1 element and the Type 2 element are described in detail in the hazards summary report,⁽¹⁾ the ten year core development program⁽²⁾ and in the specifications for Core I^(3,4) and Core II.^(5,6) The only differences in the elements are the switch from Geneva oxide to spherical oxide, the boron loadings which are discussed in Section 4.0 of this report, and the clad material. The clad material for the Core I elements is 304L low cobalt stainless steel and for the Core II elements is 347 low cobalt, low tantalum stainless steel.

3.0 QUALIFICATION OF CORE II ⁽⁷⁾

The PM-2A Core II fuel elements were fabricated by the United Nuclear Corporation under Atomic Energy Commission Contract AT(30-1)-2608 following an Alco Products, Inc., specification.^(5,6) The fuel elements were examined for their compliance with proper fabrication by the following methods:

3.1 Stationary Fuel Element

Visual Inspection

The surfaces of 15 plates were visually inspected and found to be acceptable with regard to pitting, surface conditions and finish.

X-ray Examination

Examination of radiographs of the plates revealed satisfactory homogeneity without any voids or external defects.

Surface Contamination

Plates were checked for surface contamination with a gas proportional alpha counter.

Homogeneity

The 15 qualification plates exhibited satisfactory homogeneity. Samples were sent to Lucius Pitkin for total uranium and total boron analyses. The maximum percent deviation of the boron in two plates where five samples were obtained from each plate was $\pm 8.75\%$.

Bond Integrity

Microscopic examination of five transverse samples from each of two plates showed no lack of bonding at the clad frame, core frame or clad core interfaces. Microscopic examination of other plates also showed no evidence of any lack of bonding.

Clad-Core-Clad Thicknesses

Ten transverse samples used in the bond integrity examination were metallographically measured and determined to fall within specified clad-core-clad thicknesses.

Total Plate Loading

Eight plates were completely dissolved for a chemical analysis of total uranium and total boron content. The boron loading was well within the $\pm 12\%$ specified. Difficulty was experienced in the analysis for the uranium but this was believed to be the result of using the sample for boron and uranium analyses. This was eliminated when separate samples were used for the uranium analysis.

End Conditions

Metallographic examination of bond integrity samples showed no evidence of voids at the core-frame-clad or clad-frame interfaces.

3.2 Control Rod Fuel Element

Similar processes were followed for the Core II control rod fuel qualification.

4.0 RESULTS OF THE ZERO POWER EXPERIMENT

The only significant change in the Core II from the Core I is in the boron loading. The original boron loading specification is based on the fact that a known amount will be lost in fabrication. The boron loadings actually in the fuel plates as determined by the zero power experiments on Core I⁽⁸⁾ and Core II⁽⁹⁾ corresponded to the estimates made and are:

	<u>Core I</u>	<u>Core II</u>
B-10 Loading per Stationary Fuel Element	0.424	0.492 gm
B-10 Loading per Control Rod Fuel Element	0.336*	0.390 gm
Total B-10 in Core	15.235	17.7 gm

The increased boron loading in Core II as evidenced by the preceding information has allowed Core II to meet a "one stuck rod" criteria.

In comparison of Core I and Core II, there was a negligible change in the radial power distribution. However, the axial power peak of Core II is decreased slightly, compared to that of Core I.

The loading procedures (TPC 380)⁽¹⁰⁾ have also been developed for PM-2A Core II at Alco's Critical Facility.

5.0 CONTROL ROD MARGIN WITHOUT ABSORBER REPLACEMENT

The maximum core reactivity occurs at start of life when the reactor is at room temperature. (Fig. 5.1) For PM-2A Core II, start of life reactivity at 68°F is \$18.4. This excess reactivity will be controlled by the five rod bank of Eu₂O₃ absorbers in use for the lifetime of PM-2A Core I. The neutron flux distribution and energy spectrum of Core I and Core II are sufficiently alike so that the worth of fresh Eu₂O₃ absorbers in Core II would be essentially the same

* Determined by assuming same percent loss in control rod fuel elements as in stationary fuel elements.

**Figure 5.1. Estimate of Variation of Reactivity with Energy Release
PM-2A Cores I and II, 510°F, Eq. Xenon (10 Mw)
PM-2A Core II ZPE VI**

as in Core I. The worth of the five rod bank in Core II is therefore 21.7%⁽¹⁾ less the decrease in bank worth resulting from the change in the absorber nuclear characteristics during the lifetime of Core I.

The change in the nuclear characteristics of the control rods was calculated by the excess reactivity method.⁽¹¹⁾ Here, "burnup" is defined as the number of absorptions per original europium atom in the core: i.e., $B = \frac{A}{N_0}$ where N_0 is the europium atomic concentration times the volume of the absorber material in the core at the average bank position. In this approach, it is assumed that all the excess neutrons ($K_{eff} - 1$) are absorbed in the control rod absorber material.

$$\text{Absorptions } A = P \delta \nu \bar{K}_{ex} t$$

where: (9)

$$P = 10^7 \text{ watts} = \text{average power output}$$

$$\delta = 3.22 (10^{10}) \frac{\text{Fissions}}{\text{watt-sec}}$$

$$\nu = 2.46 \frac{\text{neutrons}}{\text{fission}}$$

$$\bar{K}_{ex} = 0.036$$

$$t = 0.97 \text{ years}$$

$$A = 8.75 (10^{23}) \text{ absorptions}$$

Appendix A presents an evaluation of boron-10 absorber burnup on the SM-1. This evaluation indicates that the excess reactivity method overestimates the actual burnup by a factor of ~ 1.45. Europium burnup would then be conservative by at least this factor.

The initial europium loading is 151 gm per plate.⁽¹⁾ The absorber plate dimensions are: (12)

Thickness	0.229 cm
Width	5.67 cm
Length	52.80 cm
Volume	68.4 cm ³

The initial europium concentration is:

$$\frac{151 \text{ gm} \times 6.23 (10^{23})}{68.4 \text{ cm}^3 \times 152} = 0.00875 (10^{24}) \frac{\text{atoms}}{\text{cm}^3}$$

The rod bank consists of 5 rods, each made of four plates. The total absorber volume is then 1368 cm³.

The average bank position in PM-2A Core I is 13.95 in. withdrawn for 9.7 MWYR.⁽¹³⁾ Because of the 1.3 in. gap between the absorber and control rod fuel section, the average absorber insertion is:

$$21.75 - 13.95 - 1.3 = 6.50 \text{ in.}$$

The initial number of europium atoms in the core for this insertion is

$$N_0 = 0.00875 (10^{24}) \frac{\text{atoms}}{\text{cm}^3} \times 1368 \text{ cm}^3 \times \frac{6.50}{20.81} = 3.73 (10^{24}) \text{ atoms}$$

Thus, the average burnup in terms of the part of the absorber which is in the core is

$$B = \frac{2.75 (10^{23})}{3.73 (10^{24})} = 0.234$$

Burnup of the B-10 in the SM-1 absorbers after 10.5 MWYR of energy release indicates a burnup of 0.114.⁽¹⁴⁾

The burnup in the center control rod was assumed to be 1.185 times the average burnup as in the case of SM-1.⁽¹⁰⁾

$$B_{\text{center rod}} = 1.185 (23.4\%) = 27.7\%$$

Experimental evidence indicates a flatter burnup distribution.⁽¹⁴⁾

Curves of europium thermal cross section as a function of europium burnout,⁽¹¹⁾ which include fast absorption, indicate a ratio of $\frac{\Sigma_a}{\Sigma_{a0}} = 0.74$, for the center rod. Determinations of the relative change in the fast macroscopic cross sections bracket this number and the number density for the europium isotopes ~ 0.95 for B = 0.234; therefore, 0.74 was selected as a conservative ratio to be used.

The number of europium atoms initially present in one absorber was 2.39 (10²⁴) atoms. The effective number of original europium atoms in terms of the change in macroscopic cross section remaining after 9.7 MWYR is

$$2.39 (10^{24}) \times 0.74 = 1.77 (10^{24})$$

Linear Power Chamber

Log N

BF₃

Safety Chamber-1

Safety Chamber-2

Figure 6.1. PM-2A Core Layout

Here, use is made of the relationship between center rod worth and europium concentration as developed for the SM-1. (11) This is permissible because the relative change in rod worth with absorber concentration will be approximately the same for SM-1 and PM-2A.

The change in center rod excess reactivity based on the initial and "burned up" europium concentrations is 2.73%. The average decrease in excess reactivity for the five rod bank is therefore approximately

$$\left(2.37 + 4 \times \frac{2.37}{1.185} \right) \frac{1}{5} = 2.39\%$$

The five rod bank was initially worth 21.7% ρ . The decrease in bank worth resulting from burnup for 9.7 MWYR is

$$= (21.7\% \rho) (2.39\%) = 0.52\% \rho = \$0.65$$

This value is conservative because the relative change in the thermal macroscopic cross section calculated for the lower 6.5 in. of absorber was applied to the entire absorber section.

The initial worth of the five rod bank in PM-2A Core II is therefore

$$21.7 - 0.52 = 21.18\% \rho \text{ (68°F)}$$

As the maximum excess reactivity of PM-2A Core II is $\$18.4 = 13.35\% \rho$, the minimum shutdown margin of Core II is

$$21.18 - 13.35 = 7.83\% \rho$$

This analysis has been very conservative and it is reported in the literature (15) that "in control rods of typical dimensions, the loss of thermal effectiveness after 3000 hr at 100 Mw is negligible for concentrations of the oxide above 15 volume percent." The concentration of the oxide in the PM-2A is 38 volume %. (12)

6.0 THE ONE STUCK ROD CRITERIA

Stuck rod measurements on Core I demonstrated that criticality could be attained by withdrawing the center rod 17.56 in. or any outside rod 19.56 inches. In Core II with the most reactive rod (4) (Fig. 6.1) full out, the next reactive rod (3) must be removed to 7.714 inches. The shutdown margin with rod 4 fully

withdrawn is estimated to be \$0.90. In Fig. 5.1, it can be seen that maximum core reactivity occurs at start of life. However, without absorber replacement, the decrease in the worth of the remaining four rods is approximately

$$\frac{4}{5} \times \$0.65 = \$0.52$$

as given in Section 5. Therefore, the stuck rod margin without absorber replacement is estimated to be at least

$$\$0.90 - \$0.52 = \$0.38$$

7.0 REPLACEMENT OF THE STARTUP SOURCE AND THE CHECK SOURCE

7.1 The Startup Source

The PM-2A Core I is provided with a polonium-beryllium neutron source and a beryllium photoneutron source which emits neutrons from a (γ , n) reaction with beryllium due to interaction of high energy gamma ray (1.6 Mev or greater) from fission product decay. This fission product decay gamma energy has been determined to be more than adequate in an analysis conducted after a 387 hr power run in the startup testing of the PM-2A. (16)

However, when the core is replaced, the fission product energy for the photoneutron source is not available. The polonium-beryllium source was 31.69 curies with a yield of 8.09×10^7 neutrons/sec on August 17, 1960. Polonium-210 has a half-life of 138.40 days. The polonium has already undergone a decay of at least 4 half-lives. The activity of this source at the time of publication of this report would be less than 2 curies.

7.2 The Check Source

A polonium-beryllium check source was provided in the initial installation for use in calibrating and checking the operation of the BF_3 startup chamber. This check source had a strength of 18.45 curies and a yield of 4.71×10^7 neutrons/sec on August 18, 1960. (16) This check source is located on the inside of the upper shield tank and was placed on the bottom of the upper shield tank resting against the BF_3 housing penetration.

The check source activity at the time of publication of this report is less than 1.2 curies and on installation of Core II will be significantly lower.

8.0 THERMAL AND HYDRAULIC PERFORMANCE

The axial power distribution of Core II will be improved over that of Core I. This results from the heavier loading of boron in Core II with a subsequent shallower penetration of the control rods at startup. The power distribution for Core II will be improved over that of Core I. (Fig. 5.1). The radial power distribution, coolant flow and distribution will be essentially the same as for Core I.

9.0 THE SPENT FUEL RACK

A spent fuel rack test adequately demonstrated the sub-criticality of the PM-2A spent fuel rack, when fully loaded with 36 PM-2A Core I stationary elements and 6 control rod fuel elements.⁽¹⁶⁾ The spent fuel rack should not be supplied with more than this number of fuel elements.

PM-2A Core II has been shipped to the U.S. Army of Fort Belvoir and consists of 30 stationary elements and 5 control rod fuel elements. The loading procedures specify that the spent core be removed to the spent fuel rack before Core II is loaded. These factors should preclude the possibility of supplying a greater fuel loading to the spent fuel rack than that already experienced.

10.0 CONCLUSIONS

1. Core II meets a "one stuck rod criteria."
2. The startup and check sources need to be replaced along with Core I.
3. The thermal and hydraulic behavior of Core II is improved over that of Core I.
4. Core II has been properly qualified for use in the PM-2A.
5. Core II will operate safely in the PM-2A and will not increase the probability or magnitude of any postulated accident.

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APPENDIX A - EVALUATION OF ABSORBER BURNUP IN SM-1

This analysis was originally conducted by B. J. Byrne and published as an internal document by Alco Products, Inc.

A. BURNUP OF B-10 ABSORBER IN 10.5 MWYR's

$$1. A = \rho \delta \nu \Delta K_{ex} t F = \text{No. absorptions in rod}$$

$$= 10.5 \text{ MWYR} \times 3.24 \times \frac{10^{16} \text{ fission}}{\text{MW sec}} \times 3.156 \times \frac{10^7 \text{ sec}}{\text{yr}} \times 2.46 \frac{\text{neutrons}}{\text{fission}} \times 0.045 \text{ Avg } \Delta K$$

$$= 1.19 \times 10^{24} F$$

F = factor account for absorptions in water hole, steel, and lower reflector

$$2. \text{ Avg A per plate} = \frac{1.19 \times 10^{24} F}{20} = 5.95 \times 10^{22} F \text{ absorptions}$$

Say $\bar{C}$ rod sees flux 1.12 x average other rods see flux 0.97 x average (14)

$$\frac{1 \times 1.12 + 4 \times 0.97}{5} = 1.00$$

$$\text{A per plate (}\bar{C}\text{ rod)} = 6.66 \times 10^{22} F$$

$$\text{A per plate (ecc. rods)} = 5.77 \times 10^{22} F$$

$$3. \text{ B-10 atoms per plate} = \frac{14.1 \times 0.6024 \times 10^{24}}{10.0} = 85.0 \times 10^{22}$$

4. Avg. burnup of B-10 atoms

$$\bar{C} \text{ rod} = \frac{6.66 \times 10^{22} F}{85.0 \times 10^{22}} = 0.0783 F$$

$$\text{ecc rod} = \frac{5.77 \times 10^{22} F}{85.0 \times 10^{22}} = 0.0679 F$$

5. Actual Avg. % Burnup of B-10⁽¹⁴⁾

$$\phi_{\text{Rod}} \cong 5.39\%$$

$$\text{ecc Rod} \cong 4.68\%$$

$$F = \frac{.0468}{.0679} = \frac{.0539}{.0783} = 0.69$$

B. BURNUP OF EU ABSORBERS IN 10.5 to 16.5 MWYR (6.0 MWYR).

1. No. absorptions

$$A = \rho \delta \nu \Delta K_{\text{ex}} t F$$

$$A = 6.0 \times 3.24 \times 10^{16} \times 2.46 \times 3.156 \times 10^7 \times 0.03 \times 0.69 = 3.12 \times 10^{23}$$

2. Absorptions per plate

$$\text{Avg. A per plate} = \frac{3.12 \times 10^{23}}{20} = 1.56 \times 10^{22}$$

$$A \text{ per plate } (\phi_{\text{rod}}) = 1.56 \times 10^{22} \times 1.12 = 1.75 \times 10^{22}$$

$$A \text{ per plate (ecc rod)} = 1.56 \times 10^{22} \times 0.97 = 1.51 \times 10^{22}$$

3. Eu atoms per plate

$$N_{\text{Eu}} = \frac{151}{152} \times 0.6024 \times 10^{24} = 59.8 \times 10^{22}$$

4. Avg. burnup per plate

$$\phi_{\text{rod}} = \frac{1.75 \times 10^{22}}{59.8 \times 10^{22}} = 2.93\%$$

$$\text{ecc rod} = \frac{1.51 \times 10^{22}}{59.8 \times 10^{22}} = 2.53\%$$

5. Max. Burnup per plate

$$\phi_{\text{rod}} = 2.93 \times 4.61 = 13.5\%$$

$$\text{ecc rod} = 2.53 \times 4.61 = 11.7\%$$

END