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DEPLETED URANIUM IRRADIATION
SMALLER REACTORS

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PRODUCTION TEST IP-669-AC
DEPLETED URANIUM IRRADIATION - SMALLER REACTORS

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PRODUCTION TEST IP-669-AC
DEPLETED URANIUM IRRADIATION - SMALLER REACTORS

INTRODUCTION

The AEC has indicated a need for plutonium with a high concentration of the Pu-240 isotope.¹ Concentrations up to 25 W/o Pu-240 have been requested with a firm commitment given for 25 kilograms of plutonium with at least 18 W/o Pu-240. To meet this production demand, irradiation of depleted uranium, 0.22 W/o U-235, will be undertaken. This test authorizes half of the irradiation in a smaller Hanford reactor, outlines the general plans, and presents the details of the irradiation.

OBJECTIVE

The objective of this test is to authorize irradiation of approximately 10 tons of depleted uranium, 0.22 W/o U-235, in a smaller Hanford reactor. The depleted uranium will be irradiated to exposures which will yield plutonium with at least 18 W/o Pu-240, an average exposure of approximately 1400 MWD/T.

TEST SUMMARY

About 100 columns of depleted uranium will be irradiated in central zone process tubes of the B Reactor. The initial loading of enriched uranium, 0.947 W/o U-235, support for the depleted metal, will involve approximately 330 additional process tubes. At the time of discharge of the depleted uranium, about 130 columns of enriched elements will be required to maintain the same reactivity conditions as for a natural uranium central zone loading. The depleted fuel columns will be irradiated to an average exposure of at least 1400 MWD/T, requiring about 320 reactor-operating days. Maximum exposure of the depleted fuel will be limited to about 1600 MWD/T. Twenty-four weighed and measured monitor columns are included in the test, 12 of which will be discharged at average tube exposures of 800 MWD/T to monitor dimensional behavior. All depleted fuel elements of the test will be numbered to permit segregation after discharge, if desired, of specific portions of each fuel column and to make available complete data on each fuel element for potential fuel performance studies.

DISCUSSION

The AEC has authorized HAP0 to produce 25 kilograms of plutonium containing at least 18 W/o Pu-240.¹ Authorization to irradiate and process depleted uranium fuel cores was granted and a delivery date of the plutonium corresponding to 18 months from receipt of the cores was accepted.² The request for the product provides an opportunity to demonstrate the feasibility of Hanford producing high Pu-240 concentration material. Consistent with the feasibility aspect of the

¹HAN-86317, AT Gifford to AB Greninger, "Depleted Uranium Irradiation Pilot Program," dated October 2, 1963

²AB Greninger to AT Gifford, "Depleted Uranium Irradiation," dated October 16, 1963

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order, this capability will be tested in both the smaller and K reactor types.³ The production will be divided about equally between the reactor types with about ten tons of depleted uranium irradiated to 1400 MWD/T in the smaller reactor and about 12 tons irradiated to about 1600 MWD/T in the K reactor to satisfy the total yield and product concentration requirements. The 25 kilogram-18 W/o Pu-240 are minimum requirements, and every reasonable effort will be made to exceed both minimums although no economic value has been placed on any "overage."

Successful demonstration of this type of irradiation is important to Hanford's over-all plant diversification efforts. Although the program is under the direction of Research and Engineering within IPD, it is not a new test program. Due to fuel performance limitations previous irradiations of depleted uranium at Hanford were not successful; however, as a result of fuel canning improvements made as a result of the earlier experience and in subsequent years, the stated goal exposures are considered reasonable at this time.

The depleted irradiation will require fairly large quantities of compensating 0.947 W/o U-235 enriched uranium elements. The enriched-depleted (E-D) fuel column ratio will change quite rapidly with exposure buildup in the depleted fuel. The initial E-D ratio is to be about 3.1 to 1, three enriched columns for every depleted column; the expected ratio near the end of the depleted exposure period is about 1.4 to 1 (figure 8). During the irradiation, therefore, a total of about 190 of the enriched fuel column locations within the E-D loading arrangement will be changed to natural uranium fuel columns. Figure 1 shows the locations for these enriched-to-natural loading changes. The approximate enriched uranium fuel tonnage requirements and schedule are shown in table I near the end of this document.

The number of E-columns required as support for the depleted uranium as a function of irradiation time is shown in figure 12. The reactivity increases of the block will be compensated by splining between E-metal discharges, with the most severe changes occurring initially. The initial maximum rate of reactivity gain corresponds to about 1.5 splines per day. This drops to a small fraction after the first few months of operation. Normal long-term gains in the natural load require two splines per day for reactivity compensation; thus it will be only towards the end of the first natural uranium cycle, when normal long-term gains requirements will be augmented by the additional requirements of the block, that splining should be somewhat more severe than for normal operation. An accumulated total of 200 extra splines will be required for the test block; corresponding incremental personnel exposures of up to 5r for this insertion may be expected. Spline caps will not be necessary on depleted charges, thus adequate spline coverage between 19 and 35 rows should be available by using caps shown in figure 4. Speed-of-control limits will be somewhat more severe during startups than for a natural uranium loaded pile (see figure 13); however, with the block loaded in the top half of the reactor, speed-of-control requirements should not be limiting using present startup procedures.

Total control may be handled at low exposures (less than 400 MWD/T in the depleted metal) by assuming the block to be natural uranium. This means that any E-metal in the block in addition to that required for support of the depleted metal must be considered as central zone spike and may be compensated by splining in the

³HW-80208, "Depleted Uranium Program," TW Ambrose, December 31, 1963 (Secret)

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block (one spline per two and one-half enriched charges until the enriched to depleted ratio in the block is that required at the given exposure in the depleted metal). For exposure greater than 400 MWD/T in the depleted metal, special Total Control curves to be supplied to the reactor physicist will apply. At extremely high D-metal exposures toward the end of the irradiation it may be necessary to discharge some high exposure E-metal in the block during the first 20 hours of certain outages to obtain an average exposure for E-metal in the block of less than 500 MWD/T by 20 hours down.

The block will initially have a local metal coefficient about one-tenth less than in natural uranium. Since the block will comprise about one-fourth of the pile's reactivity weighting, the full pile effect should be about a 2-3 per cent relative decrease in the metal (doppler) reactivity effect. As exposure increases in the depleted metal the doppler effect approaches that of natural uranium; when the depleted metal exposure is above 400 MWD/T there will be no detectable differences.

The graphite reactivity effect, initially similar to that of natural uranium, climbs rapidly with exposure from 24.0 mk (locally) at 400 MWD/T to 36.6 mk (locally) at 1600 MWD/T exposure in the E-D block.⁴

Correspondingly, full reactor effects (based on a 24.5 mk graphite coefficient contribution at average exposures outside the block) would be from 24.3 mk (full pile) at 400 MWD/T in the depleted to 27 mk (full pile) at 1600 MWD/T in the depleted.

Xenon and samarium effects will be approximately the same as for natural uranium.

The criticality potential for this type of loading pattern is inherently greater than that for a staggered charge such as the E-N charge. If a column of the latter is accidentally flushed, the supporting E-metal is flushed as well as the poison in the column. If, however, a column of poison in the E-D block is discharged (or even worse, mischarged with enriched metal) the supporting E-metal in the block is still in the reactor. As a result, proposals have been made⁵ to guard against such incidents. A block of about 80-0.947 W/o U-235 E-columns with no control poisons present has the potential of going critical by itself upon complete rod withdrawal from the block. Also, in a reactor which would otherwise be just critical with all horizontal control rods in, only about 80 adjacent columns of enriched (0.947) uranium would be required to override the combined inserted VSR and HCR systems and attain criticality in the water-cooled reactor.

Therefore, while charging in the block and when doing maintenance or testing within the block certain special procedures will be specified to assure adequate controls are present to avoid the unplanned occurrence of criticality (see Hazards section and Test Details sections 6A, E, and F).

The fuel used in the previous depleted uranium irradiation at Hanford apparently had two major shortcomings - 1) a core-to-cladding bond problem, and 2) poor end-closure welds.⁶ To minimize the possibility of similar problems during this

⁴Personal communication, J. P. Hamric, 5-26-64

⁵HW-82796, "Proposals for Standards - Prevention of Charging Through Critical," G. C. Fullmer, 6-15-64

⁶HW-62232, "Irradiation Summary Report - PT IP-231-A, Irradiation of Depleted Uranium to High Exposure," R. E. Hall, 10-7-59

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irradiation, several precautions have been taken. To assure a more uniform uranium quality, quality as measured by present ingot-uranium standards, core heat-treatment, and chemistry specifications were made more restrictive for the depleted uranium. Rather than introducing new inspection methods, techniques, or parameters, the specifications were generally made "tighter," permitting less variance in the cores, than those for normal production ingot uranium. Although this action may have resulted in a decreased yield at the feedsite, this cost was accepted to ensure more uniform quality.

Core chemistry and heat treatment data were obtained from the feedsite and analyzed prior to canning the cores. Results of the analysis and comparison with normal production uranium are shown below:

<u>Core Chemistry</u>					
	<u>Depleted</u>			<u>Normal Production</u>	
	<u>Average</u>	<u>Standard Deviation</u>		<u>Average</u>	<u>Standard Deviation</u>
Density	18.95	0.014		18.92	0.05
Iron	119 ppm	11.8		121 ppm	43
Carbon	445 ppm	67		557 ppm	121
Silicon	89 ppm	7.4		92 ppm	15
Surface Hydrogen	1.78 ppm	0.67		~3.0	~1.0

Heat Treatment

Average heat treatment warp for depleted cores 6.76 mils

Average heat treatment warp for standard
production cores 10 mils

All of the depleted uranium cores were measured for heat treatment warp. Four ingots, approximately 100 cores per ingot, were rejected at Hanford for having significantly different average warp, although all ingots were within current limits. Average warp for the cores of the rejected ingots were: 14.4 mils, 8.1 mils, 9.6 mils, and 8.1 mils.

The core chemistry data indicates much better control than normal. Although there is no significant difference in any of the variables, except surface hydrogen, the standard deviations are much less for the depleted uranium. All of the parameter averages are within current ingot specifications, but are much less variable, indicating that the depleted cores closely resemble "average" ingot uranium. One depleted ingot was rejected at HAPO because of high surface hydrogen, about 4 ppm; although it was still within the modified specifications for the depleted metal, it did differ significantly from the other depleted ingots.

The depleted elements were canned on April 27, 1964 in the 313 Building Al-Si shop. Three canning lines on day shift and two canning lines on swing shift

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were used. A comparison of the depleted and "normal" production fuel element reject rates from various stages of the process are shown below:

<u>Reject Type</u>	<u>Depleted Elements</u>	<u>Standard Production Elements</u>
Assembly rejects	3.7%	1.3%
Braze Layer Contaminant	0.99	1.8
Braze Layer Integrity	0.28	0.8
Thin Wall	0.44	0.6
UT-4	0.90	1.8
Facing	0.09	0.1
Weld Closure	0.51	0.5
Marred Surface	1.36	1.5

With the exception of the assembly rejects, the depleted elements behaved as well as, if not better than, standard production fuel elements during canning. The bonding characteristics of the depleted uranium elements, as measured by the braze layer and UT-4 reject categories, were superior on the depleted uranium elements. The weld closure reject categories indicate that the welders performed equally well on the depleted as on standard production fuel.

The depleted uranium elements, as measured by current quality standards for both uranium cores and finished elements, are at least as good as standard production HAPO fuel elements.

To provide some additional control of the depleted fuel elements during the irradiation, the canned elements were separated into 12 groups, each group having a distinct canning line, shift, and range of bond count*. Three canning lines on day shift, two canning lines on swing shift, and the elements unidentifiable as to canning lines form six major categories of the elements. Each of these categories is divided into two groups, one group formed with elements having total bond counts, either in the internal braze layer or in the external layer, less than ten, and the other group formed from elements having total bond counts ranging from 11 to 100. The groups, with the quantity of elements in each:

<u>Canning Line</u>	<u>Shift</u>	<u>Elements with bond count</u>	
		<u>0-10</u>	<u>11-100</u>
1	Day	456	127
1	Swing	606	259
2	Day	514	161
2	Swing	256	69
3	Day	602	94
Unknown	Unknown	450	147
Total		2884	857
		77%	23%

*Bond count is a relative measure of the quality of the Al-Si bonding layer of the elements. A count generally indicates porosity or area of unbondedness. The higher the bond count, the larger the area of unbondedness. Current fuel element specifications demand rejection of fuel elements with a bond count higher than 100.

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Each group of elements will be formed into separate charges; in other words, every depleted fuel charge will contain elements from only one of the above mentioned groups.

Some provisions have been made for testing purposes in the tonnage of depleted uranium available. One part of the testing facet will be that of comparing the irradiation behavior of the elements during the irradiation. Although the main interest of the comparison could well be that of the depleted uranium and standard production elements, a second comparison, that of the variation in behavior of the depleted elements resulting from canning line and shift differences, might be equally important. To monitor the irradiation behavior of the depleted uranium elements, 24 columns of weighed and measured elements were formed. Each of the groups of elements previously mentioned are equally represented in the monitor columns.

The monitor columns will be measured and examined after irradiation for indication of any significant difference among any of the 12 treatments or of any significant difference from current ingot uranium behavior. To provide an indication of the dimensional behavior of the elements, 12 of the monitor columns will be discharged at average exposures of 800 MWD/T. The data obtained from these columns will provide information on which to evaluate the performance of the depleted uranium elements and thus permit either downward adjustment of the goal exposure of the test or of specific groups if abnormal dimensional behavior is observed, or provide added assurance of a successful irradiation.

The 12 remaining monitor columns will be discharged with the test block and will provide data to evaluate performance of depleted uranium for future irradiations.

All of the depleted uranium elements of this test will be numbered with a fuel column number and an element position number, and 48 specially numbered spare elements will be provided. The elements will be charged into the process tubes in numerical order. Upon discharge the elements may then be separated into various column position groupings, corresponding to relative exposure levels of the elements. As the exposure of the higher powered elements is greater than those from other positions, the Pu-240 concentration is also higher. The fuel column position numbers of the elements will permit separation of the elements with ultra-high Pu-240 concentrations. This numbering technique also could, if necessary, permit a reduction in the minimum exposure to obtain the desired yield - from about 1400 MWD/T down to about 1200 MWD/T, about one month in operating time.

This irradiation is not without some sacrifice in reactor operating efficiency. The higher powered fuel columns of this test will reduce the effective serviceable life of the affected process tubes. A comparison of tube corrosion of the 43-piece enriched columns of this test and natural uranium columns in a normal loading shows that for the test the corrosion rate of the tubes loaded with enriched uranium support would reduce, under maximum operating conditions, the effective tube life by about 4 per cent. The effect of this increased corrosion rate, over a natural uranium loading, is shown in the following table:

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<u>Approx. Number of Tubes</u>	<u>Additional Corrosion</u>
16	0.3 mils
25	1.2
20	1.9
45	2.6
30	3.8
25	5.2
10	6.5
30	7.8
130	10.4

Use of enriched fuel columns operating at higher tube powers and to greater exposures will increase the rupture potential of the reactor. Within the test loading an increase by a factor of 3.43 is calculated. Two fuel failures would otherwise be expected from these block columns under normal conditions over the duration of the test; thus during the test up to seven enriched uranium fuel failures may be expected within the block.

HAZARDS

With a reactor loading involving a mixed enriched fuel-target column pattern, a potential exists for increases in reactor neutron activity through inadvertent discharge of the target elements. A block of about 80 adjacent 0.947% U-235 enriched uranium columns has the potential of going supercritical when all poison and control and safety rods have been withdrawn from the local area. Also, in a reactor which would otherwise be just critical with all horizontal control rods inserted, a block of about 80 adjacent 0.947% U-235 enriched uranium columns would have the potential of overriding the inserted vertical control rods and achieving a state of supercriticality with all rods in the water-cooled reactor.

To prevent the occurrence of such an incident, the following procedures and controls will be mandatory during the charging of the block.

At least one subcritical monitor shall be in service at all times during fuel charging operations. Procedural arrangements on the subcritical monitor must assure that the system is reading pile neutron activity, not some test or off position. The subcritical monitor annunciator trip will be set at a factor of 25 or less above the precharging background level. The chart level reading of the operable subcritical monitor must be read and permanently recorded at least once every hour during the charging operation. If the chart reading at any time exceeds a factor of two (2) above the precharging background, the assigned reactor physicist should be notified immediately. Should the level increase a factor of four (4) above normal background (adjusted for D-column loading) the charging is to be stopped and the assigned reactor physicist notified immediately.** The front and rear nozzle caps of process tubes containing depleted uranium shall be marked for prominent visual identification, with seals* on rear caps before charging of the supporting enriched uranium is to take place. It is further required that special tools be necessary for removal of the rear nozzle caps of tubes containing depleted uranium.

* A pin will be used for this purpose; the action necessary for its removal will preclude its reuse.

** See Appendix I, Control Procedures.

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Charging rates of the enriched uranium fuel to be used in the irradiation are limited to 60 columns per hour. This rate would result in a factor of two increase in neutron flux above the precharging background in one hour if the D-metal had not been previously charged as specified; thus ample indication of charging errors would be noted on the subcritical monitor and charging could be stopped before criticality would be achieved. The depleted uranium charges are not to be discharged until after all of the supporting enrichment is discharged.

TEST DETAILS

1. General

The test involves the irradiation of depleted (0.22% U-235) uranium. Since this material is less reactive than natural uranium it is necessary that enriched uranium also be charged to provide reactivity compensation.

The initial ratio of enriched uranium charges to depleted uranium charges has been calculated⁴ to be 3.05 to 1.0. As the depleted uranium gains exposure, the enriched uranium requirement drops until a ratio of about 1.4 enriched to 1.0 depleted columns is reached at a depleted uranium exposure of 1400 MWD/T.

This reactivity increase with irradiation will be compensated by inserting poison splines into the block and discharging all "excess" enriched metal at each reactor outage. The initial power generation rates in the depleted uranium columns will be about 30 per cent of those in the surrounding columns. This percentage will rise with the buildup of plutonium to about 70 per cent at 1400 MWD/T (see figure 11).

2. Reactor

This test will be carried out in B Reactor.

3. Target Elements

The target elements, D-metal, will be hollow (I&E) right cylinders with canned dimensions of 7.965 inches in length and 1.444 inches in outside diameter. Length of the depleted uranium core will be 7.378 inches. They have the same radial dimensions as those of OIIIIN fuel. The depleted elements may be handled with the same procedures that apply to natural uranium.

The depleted elements will be arranged into charges after fabrication, each charge consisting of 36 elements. The elements of each charge will be numbered consecutively from one through 36, and this number will be stamped on the base end of each piece. The elements will be shipped as charges with each intact charge easily identifiable within the shipping container.

4. Fuel Elements

All driver fuel elements authorized by this test are of the OIIIE model containing enriched uranium (0.947% W/o U-235) fuel cores. Approximately 12,500

⁴Personal communication, J.P. Hamric, 5-26-64

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bumpered and 550 smooth OIIIE fuel elements will be required for the initial loading. Water-mix fuel elements (containing natural uranium) will be utilized in the enriched uranium fuel columns, as the seventh element from the downstream end of each 34-piece enriched uranium charge and as the 15th element from the downstream end of each 43-piece enriched uranium charge. No special identification of the enriched elements is required. Each column of bumpered enriched fuel will contain 43 elements and a downstream dummy pattern of the same length as that used for standard OIIIN charges (133 inches). Each column of unbumpered enriched fuel will contain 34 elements and the standard downstream dummy pattern for OIIIE central zone charges (162 inches).

5. Process Channels

Four hundred and twenty-one process channels located in the central zone, as shown in figure 1, will be used in this test. One will contain a graphite stringer (2662 B), 104 will be charged with the depleted uranium, and the remaining 316 tubes will initially be charged with enriched uranium. Some of these will be recharged with natural uranium following their discharge later in the irradiation.

6. Irradiation

A. Loading

In the interest of reducing metal losses from premature discharge, the block will be loaded in two successive outages, with approximately 73 per cent of the block being charged on the first outage (see figures 2 and 3). The depleted uranium target elements will be charged into the specified process tubes in numerical sequence, number one piece being downstream. Thirty-six depleted elements will be charged into each process tube with the standard downstream dummy length (133 inches).

The rear nozzle inserts to be used on tubes containing depleted uranium are 19 inches long. When in place, three eight-inch spacers will have to be removed from the downstream dummy pattern of these tubes and one five-inch spacer inserted.

The first part of the block consists of 76 depleted uranium charges and 233 supporting enriched uranium charges. Sixteen of the enriched uranium charges will be 34-piece nonbumpered charges with a standard downstream dummy for OIIIE charges (162 inches). These charges are shown in figure 2. The depleted uranium charges and the remaining 217 enriched fuel charges (containing 43 pieces of bumpered OIIIE elements) will have a downstream dummy pattern of the same length as that used for a standard OIIIN charge (133 inches). None of the enriched fuel charges will require special charge makeup or piece identification. Should the initial ratio of enriched uranium to depleted uranium be too low, up to 16 additional columns of enriched uranium may be charged to obtain enough reactivity to start up (figure 2). These will be charged only if the initial startup rod configuration indicates

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an unreasonably low excess reactivity for equilibrium operation.

The depleted uranium must be charged into the process tubes before loading the enriched uranium support. Experience with nonheat-producing charges indicates that unusual stresses may be placed in Vanstone flanges within the test block, leading to possible failures. One hundred four special rear nozzle inserts for Vanstone seals will be provided for the low-heat-producing depleted uranium charges⁷ to allow for movement from the expansion of the hot tubes on each header containing cooler depleted columns.

Procedures and special techniques are required to prevent inadvertent discharge of a depleted uranium column during reactor shutdown. The depleted uranium is to be charged at a rate less than 60 columns per hour. All depleted uranium is to be charged before any supporting enriched uranium may be charged. Before supporting enriched uranium is charged, the depleted columns must have the rear nozzle caps in place, be seated, and have the front nozzle caps in place. Any deviation of depleted uranium seating length which would indicate mischarging of the column, such as a lack of downstream spacer pattern, must be investigated and corrected before enriched metal may be charged. Both the front and rear nozzle caps of the tubes containing depleted uranium elements are to be marked for prominent visual identification (painted a bright distinctive color). It is also required that special tools be necessary to remove nozzle caps of the depleted uranium charges. For further protection, it is advised that these nozzle caps be tagged to indicate processing supervisory approval to be required before removal.

The maximum enriched uranium fuel charging rate is limited to 60 columns per hour after the depleted uranium has been charged.

During the charging of the block, Horizontal Control Rods 2 and 8 must be positioned at 260 inches and available for immediate insertion, under normal power, into or adjacent to the test block. Alternate rods may be selected with concurrence of the assigned pile physicist so long as two such rods are available during the charging of the test block.

A representative of Research and Engineering will monitor charge makeup of the depleted uranium and charging of the test block.

A representative of Operational Physics will be present in the control room during the charging of the depleted uranium and during the initial startup with the test block in the pile, from first indication through turnaround and initial power level raising following turnaround, and until flux distributions and excess reactivity conditions can be adequately projected to equilibrium operation.

⁷Drawing H-1-14302 - Vanstone Seal Inserts - Model 3

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B. Supplemental Control

Since there is a continuing gain in reactivity with exposure in the depleted uranium, to maintain a local $k_{\text{effective}} = 1$ in the test block compensating poison must be added. The most rapid changes occur in the early part of the irradiation; at this time a maximum of approximately 30 c-mk/day increases in reactivity occur which must be compensated by poison splines. The corresponding maximum rate of full black spline insertion would be one and one-half splines per day at the beginning of the run. Toward the end of the irradiation the reactivity gains in the block will be quite small (effectively almost zero).

Figure 1 shows the block at the beginning of the run, and the enriched metal supporting the block at 1400 MWD/T exposure. The blank columns within the block are enriched uranium columns that will be discharged during the irradiation to keep the reactivity constant. Enriched uranium will be discharged from the block during most outages in a manner corresponding to the curve in figure 12. The columns to be discharged will be selected by the B pile physicist, and a listing of these columns will be kept up to date on a weekly basis by the Production Computing Operation.

C. Data

Daily flow and temperature for selected process tubes of the test block will be required; these data will be recorded on sheets provided by the test authors.

At least one set of six to eight nonpoisonous spline flux traverses of process tubes located within the block will be required every two months. Such traverses should be taken during equilibrium operation.

A temperature map and tape must be sent to Production Computing Operation each day operated at equilibrium. This will allow constant updating of depleted uranium exposures since the tube power increases with operation.

D. Goal Exposure

The depleted uranium charges will be irradiated to an exposure of about 1400 MWD/Ton. The maximum exposure authorized by this test is 1600 MWD/Ton.

Supporting enriched uranium will be irradiated to normal enriched uranium goal exposure with the exception of the columns to be discharged below goal exposure for reactivity matching purposes and for any possibly discharged early near the end of the block run for total control requirements. The enriched uranium fuel of this test will be discharged according to current practice with regard to rupture-phone lot classification. Abnormal operating conditions may also dictate a change in goal exposure.

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Any modifications to this goal exposure plan may be specified with the concurrence of the Manager, Process and Reactor Development Sub-section; Manager, Production; and Manager, B Processing.

E. Operating Conditions and Limits

At the end of the scheduled irradiation period the depleted uranium charges will have their maximum heat generation rate of about 70 per cent of that of surrounding columns. A plot of power generation versus irradiation time is shown in figure 11.

A 43-piece enriched uranium fuel column has the potential to operate up to 16 per cent higher in power and temperature than an equivalent length natural uranium column in the same flux region. Since the maximum tube outlet temperatures are approximately 115 C, use of full-length (43-piece) enriched uranium charges could result in approaching the trip-after-instability limits. However, there will be a depleted uranium charge adjacent to every enriched charge so that in actual operation the expected increase will be of the order of 8-10 per cent. This means maximum anticipated tube outlet temperatures of 123-126 C with balanced flux, but unbalanced heat generation rates between the bottom and top of the reactor. Although the possibility exists of being limited by TAI limits, this is not expected. Nonequilibrium losses may increase as a result of generally higher individual tube outlet temperatures at equilibrium; this will necessitate a slower approach to equilibrium than is normal following startup. Should a worst case flux distribution occur, the maximum loss of production due to decreased reactor power level during the test is calculated to be six per cent.

The operating limits that apply to the OIIIE fuel element models will be applicable for the fuel elements authorized by this test. No relaxation of TAI limits is authorized by this test.

Speed-of-control limitations are plotted in figure 13⁴. These are slightly more restrictive than normal speed-of-control requirements but would not be limiting under present modes of operation. This curve, or those in Process Standards C-060, whichever are more restrictive, shall apply as speed-of-control criteria.

At exposures above 400 MWD/T in the depleted uranium, total control requirements become more demanding than for normal operation. Applicable curves have been prepared and provided to the B Reactor pile physicist. At exposures over about 1000 MWD/T in the depleted uranium it may become necessary to discharge some high exposure enriched uranium in the test block to reduce the average enriched uranium exposure to 500 MWD/T before the first 20 hours of an outage have elapsed in order to satisfy total control criteria. As a result, Production Computing Operation or the assigned pile physicist will provide B Reactor Processing personnel with a list of the enriched uranium columns to be

⁴Personal Communication, J.P. Hamric, 5-26-64

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discharged for those times during which E-metal discharge would be required before 20 hours of outage time had elapsed.

Should it be necessary to stinger test within the block for tube leaks, up to five front and rear caps of tubes containing depleted uranium on any one row (but only on one row at a time) may be removed at any one time provided that all remaining caps on that row are in place. Only when all depleted uranium nozzle caps are back in place on a row may caps be removed from a nondepleted charge. This will assure no mixup of the special caps identifying depleted uranium columns.

Water shutoff times for the depleted columns of this test will be the same as those for natural uranium fuel columns. Water shutoff times for the 43 element enriched uranium fuel columns will be the same as specified in the Process Standards for enriched uranium fuel.

F. Discharge

At the end of the irradiation all enriched metal supporting the depleted uranium must be discharged before the depleted uranium itself is discharged.

Any time during the irradiation that depleted uranium columns are to be discharged, the adjacent supporting enriched uranium columns must be discharged before the depleted uranium itself is discharged.

The depleted uranium elements may be discharged and picked up in any convenient manner. No special pickup or identification of the depleted uranium charge is required. All Process Standards that apply to the handling and pickup of natural uranium also apply to irradiated depleted uranium.

Three groups of eight columns each of the enriched fuel elements from the first E-metal cycle will be specially picked up and stored for special shipment to allow analysis for plutonium yields. Three additional groups of eight columns each of enriched fuel elements charged when the depleted uranium has reached an exposure of about 800 MWD/T will likewise be specially picked up and stored for special shipment following their discharge. Each group may be stored in a single storage bucket (according to Process Standard H-020). The specific columns for special pickup will be designated prior to their scheduled discharge by the Operational Physics Subsection representative.

Twelve depleted uranium monitor columns will be discharged for examination when the average exposure in the depleted uranium has reached 800 MWD/T. The remaining twelve depleted uranium monitor columns will be specially picked up when they are discharged at the end of the irradiation.

The depleted columns for discharge at 800 MWD/T will be specified by Process and Reactor Development Subsection.

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7. Schedule

An approximate schedule of the charging and discharging of the test elements is shown, along with estimates of Pu-240 concentration, in Table I at the end of the document.

8. Costs

The initial charging of test material will result in discharge of approximately 100 fuel columns below goal exposure. Incremental spline usage, amounting to approximately 200 splines (as well as a corresponding total personnel exposure dose of up to 5 r), may be assigned to the test. Process tube replacement costs for about eight tubes and all fuel failures resulting directly from the test loading may also be charged against the test. Approximately 10⁴ additional hours of outage time will be required by this test. All outage time and similar costs as a direct result of this test may be assigned to cost code xxxx-5R23-xxx.7H.

9. Duration

Authorization for the test expires August 1, 1966.

RESPONSIBILITIES

Research and Engineering Section

Process Technology Subsection shall be responsible for specifying operating limits, auditing for adherence to charge-discharge criteria, providing assistance in scheduling, and forwarding operating data to the test authors.

Process and Reactor Development Subsection shall be responsible for selection and monitoring of the charge make-up, for monitoring test charging, recommending exposures of the test material, providing bases for reactor shutdown control and speed-of-control, obtaining production formation data, over-all coordination of the test, and analyzing and issuing test results.

Testing Subsection will be responsible for post-irradiation fuel element examination and measurement.

Operational Physics Subsection shall be responsible for providing calculational parameters and plans for assuring that operation will be within shutdown control and speed-of-control criteria, for planning loading patterns, for monitoring depleted column charging, for providing reactivity monitoring data and critical control procedures for block E-metal charging, for obtaining enriched uranium product formation data, for determining the front-to-rear flux distribution in the test block, for determining the reactivity effects of the loading, for selecting enriched uranium columns to be discharged, and for issuing results of operational physics aspects and plutonium buildup measurements.

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Manufacturing Section

B Processing Operation shall be responsible for assuming over-all reactor safety and operating continuity, for scheduling of the test activities during the reactor outages, for adherence to the special charge-discharge criteria, for charging test material, for providing prominent visual identification of nozzle caps as required by the test, for supplying special nozzle caps, for collecting routine operating data requested, and for discharge and special pick up of test elements.

Production Subsection shall be responsible for maintaining accurate records of material charged under this program, providing sufficient quantities of enriched uranium fuel elements, for scheduling shipment of unirradiated depleted uranium elements, for supplying weekly updated listings of exposures in the test block and enriched uranium columns to be discharged from the block during unscheduled outages, and for scheduling discharge of the test elements.

P. D. Gross

Engineer, Process Physics
Operational Physics Subsection
Research and Engineering Section

K. L. Hladik / PAE

Engineer, Reactor Engineering
Process and Reactor Development
Research and Engineering Section

PD Gross:KL Hladik:gs

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A P P R O V A L S

T. W. Ambrose for

T. W. Ambrose, Manager
Process and Reactor Development
Research and Engineering Section

R. C. Haynes

R. C. Haynes, Manager, B Processing
B-C Reactor Subsection
Manufacturing Section

R. W. Reid

R. W. Reid, Manager
Process Technology Subsection
Research and Engineering Section

W. J. Ferguson

W. J. Ferguson, Manager
B-C Reactor Subsection
Manufacturing Section

G. C. Fullmer

G. C. Fullmer, Manager
Operational Physics Subsection
Research and Engineering Section

E. R. Astley

E. R. Astley, Manager
Applied Reactor Engineering
Manufacturing Section

C. G. Lewis

C. G. Lewis, Manager
Testing Subsection
Research and Engineering Section

R. E. Dunn

R. E. Dunn, Manager
Production Subsection
Manufacturing Section

O. H. Greager acting for 7-17-64

O. H. Greager, Manager
RESEARCH AND ENGINEERING SECTION

A. R. Maguire

R. S. Bell, Manager
MANUFACTURING SECTION

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FIGURE 1

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TEST BLOCK AND END-OF-CYCLE E-METAL

D Depleted uranium charge

X Enriched uranium charge at end of irradiation

G Graphite stringer or graphite sample channel

Q ORNL charge

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FIGURE 2 - FIRST DEPLETED CHARGE

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- D Depleted uranium charge
- X 34-piece smooth enriched charge
- o 43-piece bumpered enriched charge
- G Graphite stringer or graphite sample channel
- Q ORNL charge
- + 16 additional 43-piece enriched charges (if required for initial startup excess reactivity)

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FIGURE 3 - SECOND DEPLETED CHARGE

- D Depleted uranium charge
 + Standard natural uranium charge
 o 43-piece bumpered enriched charge
 G Graphite stringer or graphite sample channel
 Q ORNL charge
 * 34-piece smooth enriched uranium to be discharged and recharged as standard material uranium charges

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FIGURE 4

DESIGNATED SPLINE CAP PATTERN BETWEEN 19 AND 35 ROWS

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FIGURE 5 - PER CENT PU-240 VS. DEPLETED URANIUM EXPOSURE

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FIGURE 6 - YIELD OF PLUTONIUM VS. DEPLETED URANIUM EXPOSURE

FIGURE 7 - YIELD OF PU-240 VS. DEPLETED URANIUM EXPOSURE

FIGURE 8 - ENRICHED TO DEPLETED RATIOS AS A FUNCTION OF DEPLETED URANIUM EXPOSURE

FIGURE 9

NUMBER OF ENRICHED COLUMNS REQUIRED AS A FUNCTION OF DEPLETED URANIUM EXPOSURE

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FIGURE 10

FIGURE 11 - DEPLETED URANIUM RELATIVE POWER AS A FUNCTION OF EXPOSURE

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FIGURE 12

NUMBER OF ENRICHED URANIUM COLUMNS REQUIRED AS A FUNCTION OF OPERATING DAYS

SPEED-OF-CONTROL LIMITATIONS FOR B REACTOR E-D LOAD

Table I

DEPLETED URANIUM IRRADIATION SCHEDULE

<u>Approximate Date</u>	<u>% 240</u>	<u>Total Tonnage of Enriched Uranium (Accumulated)</u>	<u>Charge-Discharge</u>	<u>Outage Time</u>
7-15-64	0	26.8	Charge 76 depleted Charge 217 enriched Charge 16 short (34-pc) enr.	19.9 hours
8-15-64	2.2	37.3	Charge 28 depleted Discharge 16 short (34-pc) enr. Charge 73 enriched	11.0 "
9-15-64	5.2		Discharge 40 enriched	5.0 "
10-15-64	7.6	63.2	Discharge 260 enriched Charge 225 enriched	32.5 "
12-1-64	10.7		Discharge 45 enriched	5.6 "
1-15-65	12.0	82.8	Discharge 180 enriched Charge 170 enriched	22.5 "
3-1-65	14.2		Discharge 27 enriched Discharge 12 depleted	6.2 "
4-15-65	15.7	97.8	Discharge 133 enriched Charge 130 enriched	16.6 "
6-15-65	18.0			
7-15-65	19.2	112.8	Discharge 130 enriched Charge 130 enriched	16.2 "
End of Test			Discharge 92 depleted Discharge 130 enriched	27.7 "

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APPENDIX ICRITICALITY CONTROL PROCEDURES

Should a factor of four or more increase in background count rate occur while charging in the block, charging is to be stopped and the physicist notified. In the event that the background count rate continues to increase (due, say, to xenon decay) after charging is discontinued, the following steps are to be taken. (The sequence of steps 1-3 to be completed only as required to bring the background back to the level at which charging was stopped or less.)

1. Any HCR's held out for control purposes should be utilized. All HCR's should be positioned at their position of maximum reactivity worth (and yet remain effective for total control). This would require half rods at 120 inches and full rods completely inserted (zero inches).
2. Additional splines should be inserted uniformly in the block. Alternatively, poison columns may be uniformly used to replace some of the E-metal columns charged. This type of poison insertion should be started in the center of the block and continued toward the edges.
3. If the necessary reduction in count level has still not taken place, Ball 3X channels in the center of the block are to be unlocked and balls in those channels dropped.

Assuming the reactor is just critical (background has increased more than a factor of 25 above the pre-charging level) under present operating conditions, the insertion of two half rods worth 100 cmk or more will hold the water-cooled reactor subcritical from xenon decay for the extended times shown below:

<u>Hours Already Down</u>	<u>Time* (hours) Held Subcritical</u>
40	1
60	4.5
80	-

Each two poison columns or each six splines inserted will have an equivalent effect provided they are inserted in a uniform manner.

* This time was calculated assuming no discharge outside the block. If discharging has occurred outside the block, the amount of residual xenon will be reduced and the time held subcritical will increase.

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7/7/94

END