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PRODUCTION TEST IP-694-A

DEPLETED URANIUM IRRADIATION - K REACTORS

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PRODUCTION TEST IP-694-A

DEPLETED URANIUM IRRADIATION - K REACTORS

By

P. D. Gross and K. L. Hladek

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August 17, 1964

HANFORD ATOMIC PRODUCTS OPERATION
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PRODUCTION TEST IP-694-A
DEPLETED URANIUM IRRADIATION - K 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 Hanford K reactor, outlines the general plans, and presents the details of the irradiation.

OBJECTIVE

The objective of this test is to authorize irradiation of approximately 12 tons of depleted uranium, 0.22 W/o U-235, in a Hanford K 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 1600 MWD/T.

TEST SUMMARY

About 90 columns of depleted uranium will be irradiated in central zone process tubes of the KE Reactor. The initial loading of enriched uranium, 0.947 W/o U-235, support for the depleted metal, will involve approximately 380 additional process tubes. At the time of discharge of the depleted uranium, about 140 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 1600 MWD/T, requiring about 250 reactor-operating days. Maximum exposure of the depleted fuel will be limited to about 2000 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.

BASIS AND JUSTIFICATION

The AEC has authorized HAPO 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 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

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

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

³HW-80208, Depleted Uranium Program, TW Ambrose, December 1, 1963 (Secret)

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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 KE Reactor to satisfy the total yield and product concentration requirements. The 25 kilogram-18 W/o Pu-240 specification designates 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, due to 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 4 to 1, four enriched columns for every depleted column; the expected ratio near the end of the depleted exposure period is about 1.8 to 1 (figure 5). During the irradiation, therefore, as many as 240 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 9. The reactivity increases of the block will be compensated by splines between E-metal discharges, with the most severe changes occurring during the first few weeks. The initial maximum rate of reactivity gain corresponds to about 1.5 splines per day. This decreases 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 rates should be somewhat more severe than for normal operation.

Should the majority of the spline caps be filled prior to a scheduled outage, so adequate reactivity compensation cannot be made within the block, an unscheduled outage may be necessary. This is not probable, however, since there will be 37 spline caps present in the block and only 30 of them will be required to compensate the 66 enriched columns to be discharged during the following scheduled outage approximately six weeks after the initial startup. Inordinate changes in operating schedules would be necessary before such a situation could again arise during the remainder of the irradiation.

Speed of control requirements defined in Process Standards C-140 are adequate when the block is in the reactor. An accumulated total of about 150 extra splines will be required for the test block.

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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 excess of that required for support of the depleted metal must be considered as central zone spike and may be compensated by splining in the block (one spline per two and one-half enriched charges). For exposures 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 more restrictive total control requirements towards the end of the irradiation may lengthen minimum outages by an hour or so.

The block will initially have a local metal coefficient about one-tenth less than in natural uranium. Since the block will comprise about one-fifth of the pile's reactivity weighting, the full pile effect should be about 1-2 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.

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 loading. 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 made⁴ to guard against such incidents. A block of about 90 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 90 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.⁵ To minimize the possibility of similar problems during this

*Personal communication, AD Vaughn, 6-24-64

⁴HW-82796, Proposals for Standards - Prevention of Charging Through Critical, GC Fullmer, 6-15-64

⁵HW-62232, Irradiation Summary Report - PT IP-231-A, Irradiation of Depleted Uranium to High Exposure, RE 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, the 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	0.057	18.92	0.05
Iron	138 ppm	14	121 ppm	43
Carbon	436 ppm	63	557 ppm	121
Silicon	93 ppm	8	92 ppm	15
Surface Hydrogen	2.56 ppm	0.55	~3.0 ppm	~1.0

Heat Treatment

Average heat treatment warp for depleted cores 8.3 mils
 Average heat treatment warp for standard production cores 10 mils

Twenty-five depleted uranium cores from each ingot were measured for heat treatment warp. No ingots were rejected at Hanford for having significantly different warp.

The core chemistry data indicates much better control than normal. Although there is no significant difference in any of the variables 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. No depleted uranium ingots were rejected at HAPO for core chemistry abnormalities.

The depleted elements were canned on June 23, 1964 in the 313 Building Al-Si shop. Three canning lines on day shift and two canning lines on swing shift were used. A comparison of the depleted and "normal" production fuel element reject rates from various stages of the process are shown below:

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<u>Reject Type</u>	<u>Depleted Elements</u>	<u>Standard Production Elements</u>
Assembly Rejects	3.1%	1.3%
Braze Layer Contaminant	0.47	1.8
Braze Layer Integrity	0.74	0.8
Thin Wall	1.14	0.6
Facing	0.24	0.1
Welding Closure	0.16	0.5
Marred Surface	1.20	0.5

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>
4	Day	811	150
4	Swing	558	83
5	Day	644	254
5	Swing	344	103
6	Day	749	187
Unknown	Unknown	21	7
Total		3127	784
		80%	20%

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

*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 bond count higher than 100.

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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 76 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 1600 MWD/T down to about 1400 MWD/T, about three weeks in operating time.

Use of enriched fuel columns operating at higher tube powers and to greater exposures than natural uranium fuel will increase the rupture potential of the reactor. Within the test loading an increase by a factor of 5.3 is calculated. About 0.1 fuel failures would otherwise be expected from these block columns under normal conditions over the duration of the test; thus during the test, a 50 per cent probability exists that a fuel failure may be experienced within the block in the supporting enrichment columns.

HAZARDS

With a reactor loading involving a mixed enriched fuel-target column pattern, a potential exists for increases in reactor neutron reactivity through inadvertent discharge of the target elements. A block of about 90 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

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horizontal control rods inserted, a block of about 90 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, and is not incapacitated in some test or off position. The subcritical monitor annunciator trip, if available, 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 indicates an increase of a factor of two or more above the precharging background, the assigned reactor physicist should be notified immediately. Should the level increase by a factor four or more above normal background (adjusted for D-column loading) the charging is to be stopped and the responsible Operational Physics representative notified immediately.

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).
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 precharging level) under present operating conditions, the insertion of two half-rods worth 100 c-mk or more will hold the water-cooled reactor subcritical from xenon decay for the extended times shown below:

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<u>Hours Already Down</u>	<u>Time* (hours) Held Subcritical</u>
40	1
60	3
80	20
90	∞

The front and rear nozzle caps of process tubes containing depleted uranium shall be marked for prominent visual identification, with seals placed on the rear caps before charging of the supporting enriched uranium is to take place. Special tools are required for removal of the rear nozzle caps of tubes containing depleted uranium.

The charging rate of the enriched uranium fuel to be used in the irradiation is limited to 90 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, as compared to an increase to no more than the precharging background if charges were correct. 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 considerably 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 calculated⁶ to be 3.8 to 1.0. The initial loading will be set up with a ratio of 4.1 enriched uranium charges to one depleted charge to allow operation through the samarium dip with adequate reactivity for control purposes within the block. As the depleted uranium gains exposure, the enriched uranium requirement drops until a ratio of about 1.8 enriched to 1.0 depleted columns is reached at a depleted uranium exposure of 1600 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 35 per cent of those in the surrounding columns. This percentage will rise with the buildup of plutonium to about 70 per cent at 1600 MWD/T (see figure 11).

*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.

⁶Personal Communication, JP Hamric, 6-24-

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2. Reactor

This test will be carried out in the KE Reactor.

3. Target Elements

The target elements, D-metal, will be hollow (I&E) right cylinders with canned dimensions of 7.865 inches in length and 1.509 inches in outside diameter for use in the smooth-bore zircaloy-2 process tubes; 7.865 inches in length and 1.459 inches in outside diameter for use in ribbed aluminum process tubes. Length of the depleted uranium cores will be 7.325 inches. The elements have the same radial dimensions as those of KVE and KIVN fuel respectively. The depleted elements may be handled with the same procedures that apply to natural uranium. The depleted elements to be used in the smooth process tubes, identified as the KID model, will be of the self-support type having supports identical with those used on present K self-support fuel models. The maximum circumscribed support circle for the elements of this test will be 1.700 inches. The depleted elements for use in aluminum process tubes are identified as the KIID model.

Reactivity tests of the depleted cores in the 305 Test Reactor indicate that the level of U-235 in the cores is as specified, 0.22 W/o. The reactivity values for the depleted cores ranged from -8.030 ih to -8.319 ih. Specifications for natural and enriched uranium cores dictate ih values from -0.25 to -0.35 and +2.05 to +2.25 respectively.

The depleted elements will be arranged into charges after fabrication, each charge consisting of 43 elements. The elements of each charge will be numbered consecutively from one through 43, 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 KVE and KIVE models containing enriched uranium (0.947% W/o U-235) fuel cores. Approximately 19,200 self-supported KVE and 1150 smooth KIVE fuel elements will be required for the initial loading. Water-mix fuel elements (containing natural uranium) will be utilized in the KIV enriched uranium fuel columns, as the seventh element from the downstream end of each 46-piece enriched uranium charge. No special identification of the enriched elements is required. Each column of self-supported enriched fuel will contain 51 KVE elements and a downstream dummy pattern of the same length as that used for standard KVN charges (112 inches) with the exception of 14 columns around the edges of the block which will contain 46 KVE elements and a downstream dummy pattern of the same length as that used for central zone spike E-metal (128 inches). Each column of nonself-supported enriched fuel will contain 46 KIVE elements and the standard downstream dummy pattern for KIVE central zone charges (128 inches).

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5. Process Channels

Four hundred and eighty-three process channels located in the central zone, as shown in figure 1, will be used in this test. One will contain a graphite stringer (3066 KE), one is an air channel (3565 KE), two are KER loops (3865 and 3674 KE), 12 will be charged KIVN for reactivity matching purposes, 90 will be charged with the depleted uranium, and the remaining 377 tubes will initially be charged with enriched uranium. The 377 enriched charges include 25 columns of KIVE fuel which will be discharged and replaced with KIVN during the first outage following startup with the test block. Some of the KVE fuel will be recharged with natural uranium following their discharge later in the irradiation (see figure 1).

6. Irradiation

A. Loading

In the interest of reducing metal losses, the low exposure enriched uranium left from the thorium irradiation (PT IP-695-AC) will be utilized as part of the driver fuel for this test. The depleted uranium target elements will be charged into the specified process tubes in numerical sequence, number one piece being downstream. Forty-three depleted elements will be charged into each process tube with the standard downstream dummy length (112 inches). Two depleted charges have been prepared for ribbed aluminum tubes and are to go in 3567 KE and 3167 KE. All remaining depleted elements are to be charged into smooth-bore zircaloy-2 tubes. None of the enriched fuel charges will require special charge makeup or piece identification.

The depleted uranium must be charged into the process tubes before loading the enriched uranium support. Since 169 columns of the KVE supporting enriched fuel will be present in the block prior to depleted uranium charging, it will be necessary to ensure that compensating depleted uranium is always charged before discharging thorium columns.

Two depleted uranium columns must be charged for each thorium column to be discharged. One depleted column is to be charged prior to and within three lattice units of the thorium column to be discharged; the second depleted column may be used to charge-discharge the thorium column. No more than seven rear nozzle caps may be removed at one time from tubes containing thorium oxide elements; the depleted uranium may be charged into these tubes, coincident with the discharge of the thorium elements, at a rate not to exceed one tube per three minutes. This again provides a factor of two increase in flux in one hour if the seven tubes are flushed and/or if enriched uranium rather than poison is recharged.

If all of the depleted columns have been charged with the exception of the two smooth columns (KIID) and those displacing thorium columns, up to 14 rear nozzle caps may be removed at one time from the thorium columns for charge-discharge.

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All charged depleted columns must be seated and capped on the rear before nozzle caps are removed from nondepleted columns.

It is suggested that the reactor be shut down for 90 hours before additional supporting enriched uranium is charged.* Before additional 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). Special tools will be necessary to remove the rear 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 90 columns per hour after the depleted uranium has been charged.

During the charging of the block, Horizontal Control Rods 3 and 9 must be out of the reactor and available for immediate insertion, scrammable or under normal power, into or adjacent to the test block. Alternate control rods may be selected from HCR 4, 5, 6, 7, 8, or 10 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 both the depleted and the supporting enriched uranium and during the initial startup with the test block in the reactor, 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.

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 15 c-mk/day increase in reactivity occurs within the block 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).

*See Hazards section

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Figure 1 shows the block at the beginning of the run, and the enriched metal supporting the block at 1600 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 6. The columns to be discharged will be selected by the KE 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 data for selected process tubes for 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 1600 MWD/Ton. The maximum exposure authorized by this test is 2000 MWD/Ton. Fuel performance may dictate changes in goal exposure plans.

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-prone lot classification. Abnormal operating conditions may also dictate a change in goal exposure.

Any modifications to this goal exposure plan may be specified by the test authors with the concurrence of the Manager, Process and Reactor Development Subsection; Manager, Production; and Manager, KE 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 8.

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A 51-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 (51-piece) enriched uranium charges could result in approaching the trip-after-instability limits. However, there will be a depleted uranium charge within two lattice units of 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 120-125 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 5 per cent.

The operating limits that apply to the KVE and KIVE fuel element models will be applicable for the fuel elements authorized by this test. No relaxation of TAI or TOA boiling limits is authorized by this test.

Speed-of-control criteria in Process Standard C-140 are applicable while the block is in the reactor.

At the K Reactors a full-length, 51-element, enriched uranium fuel column will extend into the upstream cored section of the graphite stack. Since graphite temperatures in this part of the stack are already close to Process Standards limitations, it is possible that under present operating conditions excessive graphite temperatures may be encountered in the upstream portion of the test block. Should such a situation arise, a temporary waiver of Reactor Process Standard C-040 to the extent of increasing the graphite temperature limit 50 C may be obtained for the vicinity adjacent to the test block with the concurrence of the Manager, KE Processing; the Manager, Process and Reactor Development; and the Manager, Process Technology.

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 KE 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 KE Reactor Processing personnel with a list of the enriched uranium columns to be discharged for those times during which E-metal discharge would be required before 20 hours of outage time had elapsed.

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Should it be necessary to stinger test within the block for tube leaks, up to eight 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 51-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 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 charges is required. All Process Standards that apply to the handling and pickup of natural uranium also apply to irradiated depleted uranium.

Three groups of six 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 six columns each of enriched fuel elements charged when the depleted uranium has reached an exposure of about 800 MWD/T will also 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 12 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 1 near the end of the document.

COSTS

The initial charging of test material will result in discharge of approximately 70 fuel columns below goal exposure. Incremental spline usage, amounting to approximately 150 splines may be assigned to the test. All fuel failures resulting directly from the test loading may also be charged against the test. Approximately 103 additional hours of outage time will be required by this test. All outage time and similar costs (including any necessary reactor power reduction up to 5 per cent) as a direct result of this test may be assigned to code XXXX-5R23-XXX.7H.

ISSUE AND EXPIRATION DATES

Charging of test material is requested for the first outage following approval of this test document. Authorization for the test expires August 1, 1966.

P. D. Gross

P. D. Gross, Engineer
Operational Physics Subsection
Research and Engineering Section

K. L. Hladek

K. L. Hladek, Engineer
Process and Reactor Development
Research and Engineering Section

PDG/KLH:gs

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RESPONSIBILITIES

1. Research and Engineering Section

- A. 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.

R. M. Reid

- B. Process and Reactor Development 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, analyzing test data, and issuing test results.

A. W. Ambrose

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

C. B. R.

- D. 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 both depleted and supporting enriched 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.

H. C. Fullmer

2. Manufacturing Section

- A. KE 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 pickup of test elements.

R. B. Clough

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- B. 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.

T. P. Smith for R. E. Damm

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Table I

Depleted Uranium Irradiation Schedule

<u>Approx. Date</u>	<u>% 240</u>	<u>Total Tonnage of Enriched Uranium (Accumulated)</u>	<u>Charge-Discharge</u>	<u>Outage Time</u>
9-5-64	0	28.4	Charge 90 depleted Charge 25 KIVE Charge 189 KVE	19.2 hours
10-18-64	4.0	44.5	Discharge 25 KIVE Discharge 160 KVE Charge 115 KVE	25.1
11-22-64	7.5	60.2	Discharge 189 KVE Charge 112 KVE	16.1
1-3-65	11.8	72.5	Discharge 115 KVE Charge 88 KVE	12.7
2-7-65	13.3	82.3	Discharge 12 depleted Discharge 112 KVE Charge 70 KVE	13.5
3-21-65	15.8	93.2	Discharge 88 KVE Charge 78 KVE	9.8
4-25-65	17.7	102.3	Discharge 70 KVE Charge 65 KVE	7.8
6-6-65	End of Test		Discharge 143 KVE Discharge 78 depleted	23.0

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Figure 1
Test Block and End-of-Cycle E-Metal

HW-82744
Page 21

	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0
58	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
57	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
56	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
55	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
54	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
53	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
52	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
51	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
50	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
49	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
48	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
47	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
46	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
45	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
44	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
43	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
42	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
41	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
39	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
38	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
37	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
36	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
35	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
34	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
33	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
32	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
31	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
30	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
29	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
28	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
27	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
26	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
25	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59

D Depleted Uranium Charge Self-Support
 S 51-Piece Enriched Charge at End of Irradiation
 DS Aluminum Tube Initially Containing 46-Piece KIVE Fuel
 E Depleted Uranium Charge in Ribbed Aluminum Tube
 X 51-Piece Enriched Uranium Charge Supporting Thorium
 46 KIVN Natural Uranium Charge
 46 46-Piece KV Enriched Uranium Charge

3 KER Loop-3
 4 KER Loop-4
 AC Air Channel
 GS Graphite Stringer
 T Thorium

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Figure 2
Per Cent Pu-240 as a Function of Depleted Uranium Exposure

Figure 3
Grams/Ton Total Pu as a Function of Depleted Uranium Exposure

HW-82744
Page 23

DECLASSIFIED

Figure 4

HW-82744

Page 24

Grams/Ton Pu-240 as a Function of Depleted Uranium Exposure

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Figure 5
Ratio of Enriched to Depleted Uranium Columns
as a Function of Depleted Uranium Exposure

HW-82744
Page 25

DECLASSIFIED

Figure 6

HW-82744

Number of Enriched Columns Required in Block
as a Function of Depleted Uranium Exposure

Page 26

Figure 7
Number of Equilibrium Operating Days as a
Function of Depleted Uranium Exposure

HW-82744

Page 27

DECLASSIFIED

Depleted Uranium Column Power as a Function of Exposure

Figure 8

Figure 9
Number of Enriched Columns Required as a
Function of Irradiation Time

HW-82744
 Page 29

A P P R O V A L S

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6/16/94

END