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TITLE

PRODUCTION TEST IP-695-AC
THORIUM OXIDE IRRADIATION - K REACTORS

AUTHOR

P. D. Gross
and
K. L. Hladek

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PRODUCTION TEST IP-695-AC

THORIUM OXIDE IRRADIATION - K REACTORS

By

P. D. Gross and K. L. Hladek

July 7, 1964

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PRODUCTION TEST IP-695-AC, THORIUM OXIDE IRRADIATION
K REACTORS

INTRODUCTION

Irradiation of thorium for the production of "clean" U-233 at HAP0 began in CY 1963. Several small-scale tests, involving from gram-size quantities up to a few elements, were successfully conducted; the results from these tests, coupled with theoretical predictions, indicated the desirability of further investigation. This test is one of the final steps in the pilot irradiations of ton quantities of thorium oxide target elements.

OBJECTIVES

The objectives of this test are to 1) authorize the irradiation of about two tons of thorium oxide target elements in central zone process tubes of KE Reactor, 2) determine the reactivity effects of an enriched uranium-thorium oxide (E-Q) loading in the K Reactors, 3) demonstrate the feasibility of using the K Reactors in production of "clean" U-233, 4) provide sufficient irradiated thoria material to permit demonstration of the chemical processing capabilities, and 5) obtain data from an extended irradiation of one column of thoria elements.

TEST SUMMARY

Two tons of thorium oxide target elements will be irradiated in central zone process tubes of the KE Reactor. The thoria elements, containing oxide with a density of 7.35 g/cc, will be arranged into 29 columns, each column consisting of 38 elements. All of the thorium oxide elements will be charged into smooth-bore, Zircaloy-2 process tubes. About 169 enriched uranium, 0.947 w/o U-235, fuel columns, consisting of 51 elements per column, will be required to support the irradiation as the E-Q ratio is about 5.8:1. These thorium oxide target elements are scheduled for an irradiation of about 35 full-reactor-power operating days. The exposure of the supporting enriched uranium fuel columns at the time of the thoria discharge is estimated to be 450 Mwd/t.

BASIS AND JUSTIFICATION

As the thoria irradiation cycle is different from the scheme used to produce plutonium, certain different operating characteristics do exist—short irradiation times, enriched uranium support, large-quantity throughput. With the results of each small-scale irradiation and the recent tonnage irradiations in F Reactor, the feasibility of producing clean U-233 is more soundly demonstrated.

Portions of the over-all HAP0 plan for U-233 production need to be completed before final analyses of the proposal can be made. One aspect which needs evaluation is that of demonstrating use of the K Reactors for this program. Old reactor experimental results have shown very good agreement with theoretical predictions.

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Similar agreement for the K Reactors, however, needs to be confirmed through experimental results. The reactivity effects of the loading need to be confirmed before proceeding with large-scale irradiations. Should any discrepancies in the observed and expected conditions occur, the necessary modifications could be made before large-scale use of a K Reactor is necessary for this program.

Although the irradiation facets of the U-233 production appear quite favorable, and economic studies of various production levels have been presented, HAPO has not demonstrated the capability to chemically process irradiated thorium oxide on a production scale. It is necessary, therefore, that unforeseen problems and difficulties associated with chemical processing be identified as soon as possible. The total quantity of thorium oxide which has been authorized for the program is six tons, close to the lower level of tonnage required for accurate chemical processing evaluation. Four tons of thoria have already been irradiated in a smaller reactor. Irradiation of the two tons of this test will complete the requirement.

In view of impending U-233 commitments for large quantities of clean product, early answers to the questions at hand are essential.

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. Should such a discharge occur during operation, the increase of reactivity anticipated is 13-14 cmk per column of thoria replaced by water. This is equivalent to the instantaneous withdrawal of 1 1/2 to 2 splines; it may be compared to flushing a partial column of poison in a Poison Column Control Facility at a smaller reactor.

Approximately 90 adjacent enriched, 0.947 w/o U-235, uranium columns with no compensating poison or control or safety rods present has the potential of achieving criticality in a K-Reactor lattice. With a K Reactor that is just critical with all HCRs in the reactor and all VSRs out, addition of about 110 columns of uncompensated enriched uranium would override the inserted VSR system and achieve criticality with all rods in the reactor. For this reason, the following mechanical and procedural steps are taken.

All thorium oxide elements of this test must be charged into the process tubes before loading the enriched uranium support. At least one subcritical monitor shall be in-service at all times during fuel charging operations. Switching arrangements on the subcritical monitor should assure that the system is reading reactor neutron activity, not in some test or off position. The chart level reading of the operable subcritical monitor must be read and permanently recorded at least once

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every hour during the charging operation. Should the level increase by a factor of four (4) above normal background (prior to poison column loading) due to the charging, the charging is to be stopped. Charging of thorium oxide columns of this test shall be into empty process tubes which have the rear nozzle caps securely in place. The front and rear nozzle caps of process tubes containing thoria elements shall be marked for prominent visual identification and shall require special tools for removal from the nozzles.

Charging rates of the enriched uranium fuel used in the target irradiation are limited to ninety (90) tubes per hour, to allow detection of a factor-of-two increase in neutron flux over background during any one-hour charging period, before critical is reached. This applies whether or not thoria has been previously charged. Should no additional irradiations involving the enriched uranium support be required, the thoria columns are not to be discharged until after all of the supporting enrichment is discharged. Discharging of the thoria columns will be restricted by the depleted uranium charging procedures if that irradiation is undertaken immediately after that of the thorium.

Fission product release to the effluent system of the reactor—piping, river and atmosphere—after a cladding failure and subsequent complete release of the contents of one of the thorium oxide elements would be no more hazardous than a failure of one uranium fuel element.

Personnel exposure rates resulting from activities associated with irradiated thorium oxide elements of this test will be much less than the rates encountered in dealing with uranium fuel under the same circumstances.

TEST DETAILS

1. General

Thorium oxide is a target material. It has very low heat generation rates and contributes insignificantly to reactor power. To compensate for this target element, enriched uranium, 0.947 w/o U-235, is required to support the irradiation. To maintain total reactivity values equal to a natural uranium fuel loading about six enriched uranium fuel columns are required for every thorium oxide column.

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A second irradiation program involving usage of the target-enriched uranium support concept is that of depleted uranium irradiation to produce plutonium with high concentrations of the Pu-240 isotope. The depleted uranium irradiation has been divided between the smaller and K-Reactor types. The approximate fuel loading schedule for the K-Reactor depleted uranium irradiation roughly corresponds to the time that the thorium oxide would be discharged. To minimize low-exposure discharge of natural uranium fuel elements and to conserve enriched uranium fuel usage, a "back-to-back" irradiation scheme has been worked out for the two programs. The depleted uranium irradiation will involve a larger number of process tubes than the thorium. Consequently, the thorium loading plan has been established which is consistent with the subsequent depleted production test. Although the "block" of tubes in the loading pattern is increased in size as a result, a total number of process tubes directly associated with the thorium irradiation is the same. The block is still designed to have the same reactivity worth as a natural uranium loading.

2. Reactor

This irradiation will take place in the KE Reactor.

3. Target Elements

For this test, 1102 thorium oxide target elements are required; about 1170 elements will be shipped as S. S. Accountability material. There will be no additional special handling or storage requirements of the unirradiated thorium pieces. At the conclusion of the test irradiation, any unused thorium elements shall be returned to Production Fuels. The elements are solid right cylinders, 8.8 inches in length and 1.516 inches in diameter. A drawing of the element is shown in Figure 1. All target elements used in this test will contain thorium oxide with a density of 7.35 g/cc canned with 8001-F aluminum alloy. Total weight of the finished element will be about 3.6 pounds. The elements will be self-supported, using an "arch-rail" support 0.089 inch in height, with a maximum circumscribed circle of 1.683 inches.

The thorium oxide elements will be arranged into charges after fabrication, a charge consisting of 38 elements. The elements of each charge will be numbered consecutively from one through 38, and this number will be stamped on the base end of each piece. The target elements will be shipped as charges with each intact charge easily identified within the shipping container.

4. Fuel Elements

Approximately 8620 enriched uranium, 0.947 w/o U-235, KVE fuel elements are required for this test. The 169 fuel charges consisting of 51 elements each will be formed at the reactor. No special identification of the enriched elements is required.

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5. Process Channels

One hundred ninety-eight (198) smooth-bore, Zircaloy-2, central zone process channels, as shown in Figure 2, will be used in this test. Twenty-nine of the smooth-bore process tubes will contain self-supported thorium oxide elements.

6. Irradiation

A. Loading

The thorium oxide target elements of this test will be charged into the specified process tubes, shown in Figure 2, in numerical sequence, number one piece being downstream. Thirty-eight (38) thorium oxide target elements will be charged into each process tube. The thorium oxide target elements must be charged into the process tubes before loading the enriched uranium support. Machine charging of the thorium oxide elements is permitted; displacement of uranium fuel elements with thorium oxide elements is not permitted. While charging the thorium oxide elements, the maximum pushing force exerted by the charging machine shall be limited to 1000 pounds.

The smooth-bore, Zircaloy-2 process tubes will be charged with 51 elements each. None of the enriched uranium fuel charges will require special charge make-up or piece identification.

Each fuel column and each thorium oxide column of this test will be positioned within the process tube using the standard downstream aluminum spacer pattern, 112 inches in length. The downstream aluminum spacer pattern for the tubes containing thorium oxide elements shall contain only perforated spacers, to minimize the probability of mistaking tubular spacers for the thoria elements during pickup after discharge. Lead cadmium anchor pieces may be used at either end of the thoria charge to prevent chattering and/or flushing of the light elements during operation and subsequent discharge.

Procedures and special techniques are required to prevent inadvertent discharge of a thorium oxide target column during reactor shutdown. The thoria columns, because of the relatively low crushing strength of the elements, approximately 1800 pounds, cannot be used to displace irradiated fuel elements. The tubes must be discharged, presumably by flush discharging, prior to loading the thoria columns. To remove the possibility of inadvertent discharge of the thoria columns, the empty process tubes should be verified as being empty and then the outlet nozzle cap placed onto the tube before charging the thoria elements. The thorium oxide elements will be seated against the rear cap by hand; "ram seaters" may not be used. Immediately upon charging and seating the column against the rear cap, the front nozzle cap should be placed onto the tube.

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Any deviation of thoria column seating length which would indicate mischarging of the column, such as a lack of downstream spacer pattern, must be investigated and corrected before proceeding with additional charging. Both the front and the rear nozzle caps of the tubes containing thoria elements are to be marked for prominent visual identification (painted a bright, distinctive color). It is required that special tools be necessary to remove the nozzle caps from the tubes containing thoria elements. For further procedural protection, it is advised that these nozzle caps be tagged to indicate processing supervisory approval is required before removal.

The maximum enriched uranium fuel charging rate is limited to ninety (90) columns per hour.

During charging of the test blocks, horizontal control rods 3 and 9 should be out of the reactor and available for immediate insertion. Their combined poison worth of approximately 130 cmk will thus be available for immediate insertion into the test block. Alternate control rods may be selected from HCR 4, 5, 6, 7, 8 or 10, with the concurrence of the assigned reactor physicist, so long as two such rods are available during charging of the test block.

A representative of Research and Engineering must monitor loading of the test elements into the charge magazines and the charging of the elements, both thoria and enriched, of this test. A representative of Operational Physics will be present both the data monitoring during the charging of the block and for the initial startup with the test block in the reactor.

B. Supplemental Control

Supplemental control requirements for handling reactivity transients will not be affected by this test loading.

C. Data

Daily flow and temperature data 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 test block will be required. The traverses should be taken during equilibrium operation, with at least two of the following tubes having traverses taken in them: 3955KE, 3979KE, 3555KE, 3579KE.

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D. Goal Exposure

The thorium oxide charges will be irradiated for about 35 full-reactor-power operating days. Twenty-eight of the thorium oxide columns are to be discharged during the first scheduled outage following 30 full-reactor-power operating days with the test block. The thoria elements may be irradiated up to 50 full-reactor-power operating days before discharge of the 28 columns becomes mandatory.

The maximum exposure authorized by this test for the thorium oxide column 4381KE is 150 full-reactor-power operating days.

No fuel element or target element failures are anticipated in this test. Should two target element failures occur, however, the test shall be terminated.

The enriched uranium fuel columns are scheduled for use as support for a depleted uranium irradiation, as authorized by a separate test. Should authorization for the depleted uranium not be obtained, discharge of the enriched uranium fuel columns of this test will take place during the same outage as the discharge of the thorium occurs; with regard to criteria established for discharge of the target elements, see section 6.F.

Any modifications to this goal exposure plan will be specified by Process and Reactor Development Subsection, with the concurrence of the Manager, KE Processing and the Manager, Production Operation.

E. Operating Conditions and Limits

At the end of the scheduled irradiation period, the thorium oxide columns will have their maximum heat generation rate, estimated to be about 30 kw. A plot of power generation versus irradiation time is shown in Figure 3.

Coolant flow rates in the tubes containing thorium oxide elements are estimated to be about 48 gpm, giving a maximum tube outlet temperature of 25 C. The maximum heat generation of thorium oxide column 4381KE at the end of the extended irradiation period will be about 300 kw. The maximum tube outlet temperature will be approximately 50 C. With the full-length charge of thoria elements, Panellit pressures of about 380 psi are anticipated. Extended range Panellit gages, mid-scaling at 380 ± 60 psi, are therefore necessary. These gages will be certified by Testing Subsection and appropriately identified as being extended range gages. The trip settings of these gages will remain at 25 and 75. Use of these gages is limited to the short period of time the thoria elements are under irradiation. Upon discharge of the thoria target elements, removal of the extended range and installation of the "standard" Panellit gages is mandatory.

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A 51-element enriched uranium fuel column may operate as much as 16 per cent higher in power and temperature than a full-length natural uranium column in the same region. Since maximum tube outlet temperatures are approximately 105 C, use of the full-length enriched uranium charges could result in approaching the Trip-After-Instability Limits.

With the high tube powers in the central zone being about 1750 kw, a worst-case consideration for the enriched uranium full-length columns would increase the tube ΔT from about 95 C to about 110 C. Tube outlet temperatures would therefore be approaching the TAI limits. A majority of the enriched fuel columns will be operating under conditions much less severe than those used in the above case, as 87 columns are adjacent to the thorium columns, 26 additional are adjacent to horizontal control rods. All of the remaining enriched columns, about fifty-five (55) tubes, are within one lattice unit of a spline cap tube; the local effects of a poisonous spline should more than compensate for the potential increase in tube outlet temperatures. Although the possibility exists for being limited by TAI limits, this is not expected.

Should a worst-case situation occur, either excessively hot or excessively cold within the test block, the maximum reduction of reactor power level due to the test is calculated to be 5 per cent.

The operating limits that apply to the KVE fuel element model will be applicable for the fuel elements authorized by this test.

Process Standard A-050.03, restricting the acceptable operating range of the Panellit gage, will be waived for the process tubes of this test which contain thorium oxide elements. Operation of these gages, with the mid-range at 380 psi and with the standard trip settings of 25 and 75, will not compromise reactor safety.

Results of in-reactor tests with graphite samples and graphite thermocouples from the central zone thorium loading at F Reactor indicated that graphite temperatures, and hence graphite oxidation rates, are not increased in this type of loading. At the K Reactors, however, 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 Standard 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.

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The probability of fuel element failures occurring in the enriched uranium fuel columns during this test is extremely small, as the exposure attained by the columns will be about 450 Mwd/t at the time of thorium discharge. The rupture potential of the thorium oxide elements is considered to be zero.

Water shut off times for the thorium columns of this test are less restrictive than for natural uranium fuel columns. Actual water shut off times for these columns will be provided by Process and Reactor Development Subsection.

Water shut off times for the 51-element enriched uranium fuel columns will be the same as specified in the Reactor Process Standards for enriched uranium fuel.

F. Discharge

If no compensating poison (depleted uranium is effectively a poison material) is to be charged into the reactor, all enriched uranium fuel columns used for support of the thorium irradiation must be discharged before discharge of the thorium oxide target elements.

Should the depleted uranium irradiation test be approved and that irradiation is to follow directly after the thorium test, definite procedures will be required for the depleted charging, the thorium discharging, and the enriched uranium charging. The details of these procedures will be given in the authorization document, but are also outlined below:

Prior to discharging any of the irradiated thorium columns, all other tubes to contain depleted uranium columns shall be charged, the columns seated, and the front and rear nozzle caps installed. No more than 7 depleted columns may be charged before placing the rear nozzle caps on the charged tubes.

Up to seven (7) rear nozzle caps may be removed from the tubes containing thorium oxide elements and the depleted columns may be charged into these tubes, coincident with the discharge of the thorium elements, at a rate not to exceed one tube per three (3) minutes. This again allows a factor of two increase in flux in one hour if the 7 tubes are flushed and/or if enriched uranium rather than poison is recharged.

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The thorium oxide elements may be discharged and picked up in any convenient manner, with due regard to the enriched uranium discharge schedule; no special pickup or identification of particular thoria columns is required. Storage of the irradiated thoria elements in the basin will permit access for shipping at any given time after discharge. As no specific "holding" period has been established for these pieces, shipment may be required at any time after discharge, to meet the test schedules.

The storage locations of the thoria elements shall be prominently identified to minimize inadvertent shipment of the pieces. Transfer of the irradiated thoria elements from KE Reactor will require the prior approval of the test authors.

The six initial enriched uranium fuel columns adjacent to the thoria charge in 4381KE are required for special processing to determine the conversion ratio. Special pickup of these six columns will be required.

Storage and shipment of the irradiated thoria elements will require no special procedures beyond those required for irradiated natural uranium fuel elements.

7. Costs

Charging of the block of tubes with the test loading will result in discharge of approximately 60 fuel columns below normal goal exposure.

Estimates of outage time required for this test:

	<u>Hours</u>
Flush-discharging of 29 fuel columns	2.0
Charging 29 thoria columns @ 15 columns/hr	1.9
Charging 169 KVE @ approximately 15 tubes/hr	11.3
Discharging 29 thoria columns @ 15 columns/hr	1.9
Discharging 169 KVE @ 9 tubes/hr (if required)	<u>18.8</u>
Total	35.9 hours

The outage time lost as a direct result of this test may be assigned to cost code XXX-5R23-XXX.5E.

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.

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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.

Operational Physics Subsection shall be responsible for providing calculational parameters and plans for assuring that operation will be within shutdown and speed-of-control criteria, for planning loading patterns, for data monitoring during block 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, and for issuing results of operational physics aspects and plutonium buildup measurements.

Testing Subsection shall be responsible for certifying the reliability of the special Panellit gages used in this test.

Manufacturing Section

KE-KW Reactor Subsection shall be responsible for scheduling of the test activities during the reactor outages, for adherence to the special charge-discharge criteria, for installation, identification and removal of the special Panellit gages, 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, for discharge and special pickup 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 thoria target elements, and for scheduling discharge of the test elements.

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

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

PD Gross:KL Hladek:go

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Thorium Oxide Weight = 3.63 lbs.
Can Wall fabricated from 8001-F Alloy

FIGURE 1
THORIUM OXIDE TARGET ELEMENT
PT-IP-695-A

CENTRAL ZONE THORIUM OXIDE LOADING
KE REACTOR
PI-CP-6961A

LEGEND

3-KER Loop three flow tube
4-Ker Loop four flow tube
AC-Air Channel

E-Enriched Uranium Fuel Column
T-Thorium Oxide Target Column

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FIGURE 3

RATIO OF POWER LEVELS IN THORIUM OXIDE
COLUMNS TO ADJACENT ENRICHED URANIUM
COLUMN POWER LEVELS VERSUS IRRADIATION
TIME IN K REACTOR CENTRAL ZONE FOR
PT-IP-695-A.

Power Level In Thorium Oxide Column

Power Level in Adjacent Enriched Uranium Column

0.18

0.16

0.14

0.12

0.10

0.08

0.06

0.04

0.02

0

0 20 40 60 80 100 120 140 160

Irradiation Time, Days

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APPROVALS

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

R. G. Clough, Manager - KE Processing
KE-KW Processing Subsection
Manufacturing Section

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

A. R. Maguire, Manager
KE-KW Processing Subsection
Manufacturing Section

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

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

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

R. E. Dunn, Manager
Production Subsection
Manufacturing Section

O. H. Greager, Manager
RESEARCH AND ENGINEERING SECTION

R. S. Bell, Manager
MANUFACTURING SECTION

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