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

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HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

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HW-83029 RD
Page 2

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

INTRODUCTION

Irradiation of thorium for the production of "clean" U-233 at HAPO began in CY 1963. Several small-scale tests, involving from gram-size quantities up to a few elements, were successfully conducted and 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, and 4) provide sufficient irradiated thoria material to permit demonstration of the chemical processing capabilities.

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 formed 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 165 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 to 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.

DECLASSIFIED

HW-83029 RD
Page 3

BASIS AND JUSTIFICATION

Since the initial stages of irradiation of thorium at Hanford, both optimism and skepticism have existed regarding the feasibility of these irradiations. As the thorium irradiation cycle is different than 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 HAPO 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. Extrapolation of experimental results to the K Reactor situation show very good agreement with theoretical predictions. This agreement, however, needs to be confirmed through experimental result. 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 probably then be made before commitments demand use of a K Reactor 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 imperative, therefore, that the problems and difficulties associated with chemical processing be identified as soon as possible. Again, this part of the program is quite different from standard production techniques and theoretical predictions need be evaluated by experimental results.

The total quantity of thorium oxide which would be available for processing is about six tons, close to the lower level of tonnage required for accurate evaluation. Four tons of thorium have already been irradiated in a smaller reactor. The two tons of this test will complete the requirement.

DECLASSIFIED

HW-83029 RD
Page 4

In view of possible 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 element pattern, a potential exists for increases in pile neutron activity through inadvertent discharge of the target elements. At least one subcritical monitor shall be in-service at all times during fuel charging operations. Switching arrangements on the subcritical monitor should be springloaded to assure that the system is reading pile 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 every hour during the charging operation. If the chart reading at any time reaches or exceeds a factor of two (2) above the pre-charging background, the assigned reactor physicist should be notified immediately. Should the level get a factor of four (4) above background due to the charging, the charging is to be stopped and the assigned reactor physicist notified immediately. Charging of thorium oxide columns of this test shall be into previously discharged process tubes which then have the rear nozzle caps securely in place. The front and rear nozzle caps of process tubes containing thorium elements shall be marked for prominent visual identification.

Charging rates of the enriched uranium fuel used in the target irradiation are limited to ninety (90) tubes per hour. Discharging of the thorium columns will be restricted by the depleted uranium charging procedures if that irradiation is undertaken immediately after that of the thorium. Should no additional irradiations involving the enriched uranium support be required, the thorium columns are not to be discharged until after all of the supporting enrichment is discharged.

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

DECLASSIFIED

HW-83029 RD
Page 5

irradiation. In this respect, 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, the irradiation differs from that of natural uranium.

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 element discharge 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 over-all objectives, and although the "block" of tubes in the loading pattern is increased in size as a result, the 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. The elements are 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

DECLASSIFIED

HW-83029 RD
Page 6

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 8400 enriched uranium, 0.947 w/o U-235, fuel elements are required for this test. About 375 of these elements will be of the KIVE model, the remainder being of the KVES fuel model. The fuel charges consisting with KVES fuel of 51 elements each, and with KIVE elements of 46 elements each, will be formed at the reactor. No special identification of the enriched elements is required. The KIVE fuel charges will be loaded into ribbed aluminum process tubes equipped with spline caps and the associated upstream spacer pattern.

5. Process Channels

One hundred ninety-one (191) central zone process channels, as shown in Figure 2, will be used in this test. Included in the pattern are eight ribbed aluminum process tubes equipped with spline caps. All remaining process tubes are smooth-bore Zircaloy-2. Twenty-eight 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 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 elements is not permitted.

The eight ribbed aluminum process tubes within the tube pattern will each be charged with 46 KIVE elements. The smooth Zircaloy-2 process tubes will be charged with 51 elements each. None of the enriched uranium fuel charges will require special charge makeup or piece identification.

DECLASSIFIED

HW-83029 RD
Page 7

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 46-piece KIVE fuel columns in the aluminum tubes will, therefore, not be centered front-to-rear, with respect to the other fuel columns.

Procedures and special techniques are required to prevent inadvertent discharge of a thorium oxide target column during reactor shutdown. The thorium columns, because of the relatively low crushing strength of the elements, cannot be used to displace irradiated fuel elements. The tubes must be discharged, presumably by flush-discharging, prior to loading the thorium columns. To remove the possibility of inadvertent discharge of the thorium columns, the empty process tubes should be verified as being empty and then the outlet nozzle cap placed onto the tube before charging the thorium elements. Immediately upon charging and seating the column against the rear cap, the front nozzle cap should be placed onto the tube. Any deviation of thorium 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 thorium elements are to be marked for prominent visual identification; e.g., painted a bright, distinctive color. For further procedural protection, it is advised that these nozzle caps be tagged so that processing supervisory approval is required before removal.

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

A representative of Research and Engineering will monitor charging of material of this test.

B. Supplemental Control

Supplemental control requirements will not be affected by this test loading.

DECLASSIFIED

HW-83029 RD

Page 8

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 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: 3955 KE, 3979 KE, 3555 KE, 3579 KE.

D. Goal Exposure

The thorium oxide charges will be irradiated for about 35 full-reactor-power operating days. A special reactor shutdown may be required for the discharge should no outages occur during the planned discharge period.

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

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, then 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.

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/ft. A plot of power generation versus irradiation time is shown in Figure 3.

DECLASSIFIED

HW-83029 RD
Page 9

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 the one thorium oxide column at the end of the extended irradiation period will be about 350 kw. The maximum tube outlet temperature will be approximately 50 C. With the full-length charge of thorium 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 Irradiation 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 thorium elements are under irradiation. Upon discharge of the thorium target elements, removal of the extended range and installation of the "standard" Panellit gages is mandatory.

A full-length 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. Tubes containing spline caps and the associated upstream spacer pattern will not be charged with full-length columns. The potential tube outlet temperature increase in these columns will then be about 9 per cent.

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 83 columns are adjacent to the thorium columns, 26 additional are adjacent to horizontal control rods, and eight columns are short-charged. All of the remaining enriched columns are within one lattice unit of a spline cap tube and 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.

DECLASSIFIED

HW-83029 RD
Page 10

The operating limits that apply to the KVE or to the KIVE fuel element models 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, hence graphite oxidation rates, are not increased in this type of loading.

The probability of fuel element failures occurring in the enriched uranium fuel columns of this test is extremely small, as the exposure attained by the columns will be about 250 Mwd/t. The rupture potential of the thorium oxide elements is considered to be zero.

Corrosion rates for the ribbed aluminum process tubes will be increased as a result of using enriched fuel in the tubes. However, the 9 per cent maximum tube outlet temperature increase for about 35 days will not significantly decrease the process tube life.

F. Discharge

If no compensating poison, depleted uranium 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

DECLASSIFIED

HW-83029 RD
Page 11

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 15 depleted columns may be charged before placing the rear nozzle caps on the charged tubes.

Up to fifteen (15) 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.

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 pick up or identification of the thorium columns is required.

Five of the enriched uranium fuel columns adjacent to the thorium charge in tube 4381 KE are required for special processing to determine the conversion ratio. Special pick up of these five columns will be required.

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. Irradiation of the test load will require a reactor shutdown after about 35 full-reactor-power operating days. Advantage will be taken of an outage within the variation permitted, but if this does not occur, then a specially scheduled outage must be made.

Estimates of outage time required for this test:

Flush-discharging of 28 fuel columns =	1 hour
Charging 28 thorium columns @ 15 columns/hr =	1.9 hours
Charging 148 KVE @ approx. 25 tubes/hr =	5.9 hours
Charging machine transfer time =	3 hours
Charging 8 KIVE	0.5 hour
Discharging 28 thorium columns @ 15 columns/hr =	1.9 hours
Discharging 148 KVE @ 9 tubes/hr (if required) =	16.4 hours
Charging machine transfer time	3 hours
Discharging 8 KIVE	<u>0.2 hour</u>
Total	34.5 hours

DECLASSIFIED

HW-83029 RD
Page 12

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

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 of the charge make-up, 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 shutdown control and speed-of-control criteria, loading pattern arrangements, for obtaining enriched uranium product formation data, 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 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 collecting routine operating data requested, for discharge and special pick up of test elements.

DECLASSIFIED

HW-83029 RD
Page 13

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 thorium target elements, and for scheduling discharge of the test elements.

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DECLASSIFIED

HW-83029 RD
Page 14

TARGET ASSEMBLY FOR RADIATION MEASUREMENTS

Thorium Oxide weight 200 lbs.
Cer. Mat. 100 lbs.

FIGURE 1

THORIUM OXIDE TARGET ELEMENT
FOR RADIATION MEASUREMENTS

DECLASSIFIED

HW-83029 RD
Page 15

FIGURE 2

CENTRAL ZONE THORIUM OXIDE LOADING
KE REACTOR
PT-IP-645-A

E - Enriched Uranium Fuel Column
T - Thorium Oxide Target Column
X - Air Channel or KER Loop Channel

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DECLASSIFIED

HW-83029 RD
Page 16

FIGURE 3
RATIO OF POWER LEVELS IN THORIUM OXIDE
COLUMNS AND ADJACENT ENRICHED URANIUM
COLUMNS IN K REACTOR CENTRAL ZONE

FOR PT-IP-695-A
Power Level in Thorium Oxide Column
Power Level in Adjacent Enriched Uranium Column

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