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ENGINEERING SPECIFICATIONS
THORIUM OXIDE TARGET ELEMENTS

Issued By:

Advanced Process Engineering Unit
Fuels Engineering Subsection
Production Fuels Section
Irradiation Processing Department

FEB 03 1992

June 15, 1965

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ENGINEERING SPECIFICATIONS
THORIUM OXIDE TARGET ELEMENTS

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ENGINEERING SPECIFICATIONS
THORIUM OXIDE TARGET ELEMENTS

References:

- (1) HW-83599 Rev. 1, "Provisional Product Specifications for Thorium Oxide Target Elements," F. E. Panisko and H. G. Powers, September 8, 1964. (Confidential)
- (2) HW-80289, "Production of Clean U-233 - Process Parameters and Limits," L. W. Lang, J. W. McCurry, R. H. Meichle, H. C. Rathbun, January 6, 1964. (Secret)
- (3) HW-80996, "Developmental Requirements for Canning a Low Density Thoria Demonstration Load," G. A. Huff, F. W. Knight, E. V. Padgett, H. G. Powers, February 25, 1964. (Secret)
- (4) HW-76847, "Production of U-233 and Program Proposal," L. W. Lang, R. H. Meichle, H. C. Rathbun, March 21, 1963. (Secret)
- (5) RL-SEP-180, "Tentative U-233 and Thorium Nitrate Specifications," R. E. Tomlinson, December 18, 1964. (Secret)
- (6) AT(40-1)-3297, "Thoria Contract with Nuclear Fuels Services, Inc.," October 23, 1964. (Unclassified)
- (7) "The Sol-Gel Process for the Remote Preparation and Fabrication of Recycle Fuels," D. E. Ferguson, O. C. Dean, D. A. Douglas, Oak Ridge National Laboratory, Oak Ridge, Tennessee, May 1964. (Unclassified)

F-O-R-W-A-R-D

The isotope, Uranium-233, is formed by the nuclear reaction $\text{Th-232} (n, \beta) \rightarrow \text{Th-233} (\beta) \rightarrow \text{Pa-233} (\beta) \rightarrow \text{U-233}$.⁽²⁾ This reaction, which takes place during the irradiation of thorium in either a metallic or oxide form, along with a target element fabrication process and a chemical process for the separation and recovery of U-233, forms the basis for U-233 production at Hanford. Studies and process development and optimization are continuing in the three major areas of target fabrication, target irradiation, and U-233 separation and recovery.

In mid-1964, process development work and preliminary fabrication of thoria target elements was performed by Hanford Laboratories (Battelle Northwest Laboratories). Preliminary irradiation experience was obtained by the charging of about two tons of target elements fabricated by the Laboratories. In September 1964, the Production Fuels Section assumed responsibility for thoria target element production and fabrication facilities were designed and installed.^(1,3)

The thorium-oxide used up to 1967 in the thoria target elements has been prepared by the processing of thorium ores, selected from national inventories, by the Sol-Gel process.⁽⁷⁾ However, thorium oxide produced by the Sol-Gel process is no longer available. As

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a result, two alternate processes have been approved, viz., Light Thoria (steam denitrated) and the Precipitation process. Only limited product capability is available with the Light Thoria process. Therefore, until further supply capabilities are developed the Precipitation process shall be employed in the preparation of thorium oxide.

In the precipitation process the thorium nitrate is treated with aqueous ammonia, nitric acid and CO₂ gas in such a manner as to produce a thorium precipitate. After the precipitate is allowed to settle and the solution decanted, the addition of aqueous ammonia followed by vigorous agitation results in some hydrolysis and peptization of the solution. At this point ammonia sulfate is added to enhance dissolution characteristics. The slurry is then filtered to form a wet filter cake. This cake may be placed in a tray and oven dried or kneaded with nitric acid to yield a thixotropic gel and then oven dried.

In the Sol-Gel process, the ores are treated to form a thorium nitrate, which undergoes denitration to an oxide. The oxide is then dispersed in a hydrosol which is subsequently converted to a gel by evaporation of the water. The gel is densified by drying and calcination of the gel. The properties and behavior of the product thorium-oxide are highly sensitive to changes in the Sol-Gel process. Loss-on-ignition and tap density properties of the incoming thorium-oxide have had the greatest influence on the variation which has been experienced in the product.

Light thoria is formed by the conversion of thorium nitrate to thorium oxide by steam denitration.

Thorium-oxide requires a supply of neutrons for the conversion of Th-232 to U-233, the source of which in the Hanford reactors is 0.95 w/o U-235 enriched uranium metal fuel elements charged in adjacent reactor tubes. Five columns of enriched uranium fuel elements are required for each column of thoria elements in the central zones of the reactors, whereas the fringe zones of the reactors require two columns of enriched uranium for each column of thoria elements. Depending upon the specific location within the central and fringe zones, the target elements are irradiated from four to six weeks in the central zones and six to nine months in the fringe zones. Such irradiation times assure that the level of contamination in the U-233 product will meet the current U-232 contamination limits.* Time of irradiation is an important factor in the conversion reaction since the level of U-232 contamination, which is formed by fast (n, 2n) reactions, is dependent upon irradiation time.(4)

Certain specifications for incoming thorium-oxide⁽⁶⁾ are not reflected in the Engineering Specifications since the characteristics do not carry over directly to the finished target elements. Limits on particle size distribution and tap density requirements of the

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incoming thorium-oxide influence compaction capability of the thoria and are reflected in the bulk density specification of the target elements. The loss-on-ignition specification for the incoming thorium-oxide differs from that of the target elements to compensate for the in-process changes in this property, caused by hygroscopic behavior of thoria during target element fabrication.

The Engineering Specifications have been established with the purpose of defining the properties of thoria target elements which meet the requirements of the U-233 production program. Insofar as possible, the Specifications define characteristics and dimensions of the product target elements. Where a quality characteristic cannot be satisfactorily defined in the product, control is exercised by limits imposed on the processing conditions. As experience is gained in the U-233 production process, refinement of the process requirements will be reflected in revisions to the Engineering Specifications.

* U-232 contamination level in the product U-233 is a controllable variable. The customer specifications set the U-232 levels that are to be produced. Current commitments require less than eight ppm U-232 in the final product.

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THORIUM OXIDE TARGET ELEMENTS

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FLOW SHEET

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Thorium Oxide from
Producer Site

Acceptance Sampling

Blending

Weighing

Wafer Compaction

"Core" Compacting

Capping

Closure

Inspection and Stamping

Cleaning

He Leak Test

Radiograph

Final Inspection

Storage

Aluminum Components

Acceptance Sampling

Component Cleaning

Deoxidization

Washer Swaging

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SPECIFICATION THORIUM OXIDE		DATE EFFECTIVE September 17, 1965	

- References: (1) HW-83559 Rev. 1, "Provisional Product Specifications for Thorium Oxide Target Elements," F. E. Panisko and H. G. Powers, September 8, 1964. (Confidential)
- (2) HW-76847, "Production of U-233 and Program Proposal, L. W. Lang, R. H. Meichle, R. Nilson, March 21, 1963. (Secret)
- (3) HW-80289 Rev., "Production of Clean U-233 Process Parameters and Limits," L. W. Lang, T. W. McCurry, R. H. Meichle, H. C. Rathvon, January 31, 1964. (Secret)
- (4) HW-83835, Trip report meeting at Germantown, Maryland, to discuss thorium specifications, August 14, 1964, L. H. Rice, A. G. Blasewitz, G. F. Owsley. (Unclassified)

BASIS

In the production of U-233, prior studies have indicated that the fabrication and irradiation of thorium-oxide target elements has economic advantages over the use of thorium metal.⁽²⁾ The current U-233 process is therefore based upon the irradiation of high bulk density thorium oxide followed by the chemical separation and recovery of the resulting U-233.

The physical properties and behavior of the thorium oxide markedly influences target element fabrication and irradiation as well as the chemical processing for U-233 recovery. For this reason, certain characteristics and properties of the thorium-oxide must be controlled to provide efficient and economical production of U-233.

Bulk density of the thorium-oxide in the target elements has a direct effect on the economics of the process since the density determines the amount of thorium in a unit volume in reactor. Bulk density of the thorium oxide is influenced by particle density, particle size, and level of impurities, which requires that these properties be specified. The particle density is not specified, but bulk density, which is directly related, is specified in the incoming thorium-oxide specification. There appears to be a balance between particle density and dissolution rate but not enough is known about the relationship nor the control of the particle density during preparation of the oxide to make a specification at this time. Bulk density of the elements and thorium dissolution rate must again be considered in the particle size specification.

Irradiation behavior of the thorium requires control of a number of properties of the thorium-oxide. The Th-230 content is the major source of U-232 contamination in the U-233 product made during short-term irradiations (< 60 days). The Th-230 is therefore responsible for much of the radioactivity associated with the U-233 and is considered the major contributor when more than 1.0 ppm is present. Control of the U-232 contamination contributed by the oxide is attained by control of the ratio of Th-230 to Th-232 in the feed thorium.⁽²⁾

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Basis (cont'd)

The uranium specification, which is intended to control the level of the isotope U-238, is necessary because of the carry-over of this element in the process to cause an isotopic contamination of the U-233. The original specification, which required less than 20 ppm uranium in the thorium oxide, was revised downward to provide a higher purity product to meet the customer requirements.

Boron, lithium, cadmium, samarium, gadolinium, dysprosium, and europium are high cross-section impurities which absorb neutrons and reduce the reactivity of the thorium and therefore the conversion of U-233. These impurities further influence the process by acting to dilute the Th-232 in the incoming thorium.

The loss-on-ignition specification requires better definition to determine its effect on density, irradiation behavior, off-gas quality, and dissolution rate. It is thought to be related to particle density and chemical inertness of the thorium. The specification for this property was initially established at 0.04 percent maximum since it was recognized that some control was required and thorium prepared for prior studies met this limit. It was subsequently found that process capability would not meet this specification under routine production conditions. The specification has undergone changes as more knowledge has been gained and currently includes limits on the condensable and non-condensable loss-on-ignition. Further, this requirement is imposed on the thorium contained in finished target elements. Control is maintained at this process point to provide control of the amount of moisture being absorbed by the thorium during fabrication of the elements. Basic work is continuing to define this property and to characterize thorium in terms of irradiation behavior and chemical properties.

Limits on the amounts of chloride and silicon are directly related to the chemical processing operations. High chloride ion concentration could cause severe corrosion in the stainless-steel equipment used in chemical processing.⁽⁴⁾ The presence of silicon in excessive amounts interferes with dissolution and other separations operations by tending to emulsify solutions. The specification on dissolution rate is based on economics. Thorium is unreactive chemically and is therefore difficult to dissolve. Under these conditions, the dissolution step becomes limiting in the chemical processing and U-233 recovery. The rate of dissolution specification is intended to balance the needs of chemical processing against the need of the target fabrication and irradiation for an unreactive thorium.

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SPECIFICATIONS

T-100.1 Ionium Content:

Th-230: Th-232

1:1 x 10⁶ max.

T-100.2 Thorium Content:

87.5% min.

T-100.3 Specific Impurities:

Uranium

Campaign average not to exceed 3.0 ppm (thorium basis). Lot or shipment maximum not to exceed 5.0 ppm (thorium basis).

Boron

TNT* content plus 3 ppm max.

Chloride

50 ppm max.

Silicon

TNT content plus 50 ppm max.

Lithium, Cadmium, Samarium, Gadolinium, Dysprosium, and Europium

TNT content plus 2 ppm total maximum.

Total Impurities

TNT content plus 500 ppm max.

*Thorium nitrate tetrahydrate

To determine total impurities, analyses shall be performed for the following elements:

Al	Cd	Eu	Na	Sm
B	Cl	Fe	Ni	U
Be	Co	K	P	Zn
Bi	Cr	Li	Pb	
C	Cu	Mg	Si	
Ca	Dy	Mn	Sn	

The above specifications for purity are on thorium oxide basis.

T-100.4 Loss-on-ignition of thoria in the finished target elements shall not exceed 0.10% on a ThO₂ basis.

T-100.5 Dissolution: A dissolution test shall be performed on the material in the manner prescribed as follows:

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Specifications (cont'd)

- T-200.5.a The product sample shall be a representative sample from which all material that would pass a standard six-mesh screen (U.S. Standard) has been removed. The sample weight shall be at least five grams.
- T-100.5.b The dissolvent shall be 12.3 ± 0.1 molar nitric and $0.025 \pm .001$ molar fluoride ion. The source being hydrofluoric acid, $0.1 \pm .002$ molar aluminum nitrate.
- T-100.5.c An amount of thorium-oxide product sample and an amount of dissolvent shall be used such that complete dissolution of the thorium-oxide would result in a solution one molar in thorium.
- T-100.5d The thorium-oxide sample and the dissolvent shall be combined under conditions as follows:
- T-100.5.d (1) The dissolvent shall be boiling under reflux at atmospheric pressure.
- (2) Following the addition of the thorium-oxide, the mixture shall be agitated violently.
- T-100.5.e Under these conditions, at least 95 percent of the thorium-oxide shall be dissolved within six (6) hours from the start of the test. (That is, the solution shall come to at least 0.95 molar thorium within six hours.)

Revision 1 dated September 17, 1965

- T-100 Basis expanded to include justification for all specifications.
- T-100.4 Changed from: Loss-on-ignition - 0.10% maximum at 1050C for better definition of this property.
- T-100.5 Deleted nitrogen specification.

Revision 2 dated April 22, 1968

- T-100.3 and Basis changed to reflect U-238 contamination limits required to meet customer specifications. T-100.4, changed LOI from 0.15% condensable and 0.05% non-condensable to 0.10% maximum.

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		DATE EFFECTIVE	
		September 17, 1965	

- References:
- (1) HW-40000, "Fuel Element Technical Manual," H. H. Burley, August 1, 1965. (Secret)
 - (2) Aluminum Association Bulletin on Alloy Designation and Composition, November 1, 1956.
 - (3) RL-REA-665, "Revision of Thoria Loss-on-Ignition Specification," W. K. Alexander, February 15, 1965. (Confidential - to be issued)
 - (4) HW-80289, "Production of Clean U-233 - Process Parameters and Limits," L. W. Lang, J. W. McCurry, R. H. Meichle, H. C. Rathbun, January 6, 1964. (Secret)

BASIS

The thorium-oxide to be irradiated in Hanford production reactors must be contained because it is a loose, dry material and would not remain in the reactors in this form. The principle requirements of the containing or jacketing material are corrosion resistance, low neutron absorption cross-section, formability and freedom from defects that might lead to penetration by reactor coolant water. The material must also be compatible with reactor operations and separations techniques so that the product may be recovered in the desired form and purity. The design of the jacket is critical to fulfill dimensional and strength requirements.

There are few materials which meet the aforementioned requirements other than aluminum, beryllium, and zirconium when used in the thickness required to protect and contain thorium. Aluminum was selected because of its abundance, ease of fabrication, suitable properties of strength, heat transfer, and resistance to thermal stress and strain. This selection was made years prior to the thorium program when uranium was first jacketed and prepared as fuel elements at Hanford.

Many alloys of aluminum have been tested and evaluated to provide the optimum alloy for fuel element cladding which would resist thermogalvanic corrosion, pitting attack, intergranular attack, and uniform corrosion. The 8001 alloy presently used in fuel element production is more resistive to high temperature corrosion and intergranular attack than other alloys which were evaluated because of the nickel content. These properties, however, were not required for the thorium elements since the temperature of the cladding was calculated to be about 70 C rather than the temperatures in excess of 100 C to which fuel element cladding is subjected. Further, in the co-dissolution process for the recovery of U-233, the dissolution rate of thorium-oxide, which is the limiting operation in chemical processing, tends to be depressed by the presence of nickel. For these reasons, C-64, a nuclear-grade aluminum alloy having lower levels of high cross-section impurities than commercial aluminum, was selected for the cladding material. Self-supports used on the K3T target element are fabricated from 8001 alloy since the support design and collapsibility characteristics have been established for this alloy. The very small amount of nickel being introduced into the system in these supports is not expected to have a significant effect on the chemical processing.

Aluminum possesses excellent conductivity for heat transfer and therefore can dissipate the heat produced during irradiation to the coolant and maintain relatively low

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Basis (Cont.)

surface temperature on the elements. Calculations have indicated that internal cooling of the thorium target elements is not required under present irradiation conditions.⁽⁴⁾ The target elements were therefore designed with a solid cylinder configuration. Although the maximum heat generation rates for thorium are about ten per cent of those of natural metallic uranium, the maximum central core temperature of a 75 per cent theoretical density thorium target element is calculated to be about 1200 C. The very poor heat transfer characteristics of thorium results in a surface temperature of about 70 C on the target elements, while the average core temperatures are about 600 C. Since surface temperatures are low, contouring of the ends of the elements to prevent misalignment in the reactor tubes is not required. Misalignment of a target element would not increase the surface temperature sufficiently to cause a significant increase in cladding corrosion rates during the period of irradiation.

The dimensions and geometry of the aluminum components are critical since they determine the final dimensions of the target element. The components remain essentially unaltered during the canning of thorium-oxide except for cleaning and closure of the can-to-cap junction to prevent water entry in the finished target element.

In addition to the final dimensions of the target element, aluminum component dimensions must also consider environment and forces acting upon the elements during charging, irradiation, and discharging. Reactor charging machines are set to exert a maximum force of 1100 pounds on a column of thorium element during the charging and discharging operations. The target elements must therefore be capable of withstanding such a force applied longitudinally to the ends of the elements. Calculations indicate that internal pressures generated in the thorium target elements should not exceed 100 psi during irradiation provided that control of condensable and non-condensable gases is maintained.⁽³⁾ Thus it is required that the target elements maintain their dimensions without significant distortion when subjected to irradiation-induced internal pressure.

Thorium element cladding with 0.045 inch wall cans has been demonstrated to be acceptable. No undue distortion of this cladding has been experienced during irradiation except in the elements which have failed due to water entry. Compression and pressure tests indicate that these cans are capable of withstanding charge-discharge forces and normal internal pressures. Target element closures with 0.090 inch wall cans were demonstrated satisfactorily in terms of radiation performance of the elements. The heavier wall cans were used in an attempt to improve the closure by providing two sequential welds in the closure zone; however, these attempts were not successful. The increased cost of the aluminum components and the reduced volume of thorium in each element caused the thicker wall cans to be discarded. In addition to these factors, any consideration of heavier wall cans must recognize, too, that an increase in the aluminum-thorium ratio will have an impact on chemical processing since aluminum tends to reduce the thorium dissolution rate in the co-dissolution process.

SPECIFICATIONS

T-200.1 Aluminum caps and cans will be fabricated from C-64 alloy. Aluminum washers will be fabricated from a nuclear-grade 6061-T-6 alloy. Chemical composition limits of the approved alloys are shown below:

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TARGET ELEMENT JACKETING MATERIAL

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Specifications (Cont.)

Caps and Cans C-64 Alloy		Washer 6061-T-6 Alloy	
Element	Composition Limit (%)	Element	Composition Limit (%)
Aluminum	99.30 min.	Aluminum	Remainder
Iron	0.35-0.50	Iron	.8 max.
Silicon	.17 max.	Silicon	.4 - .8
Titanium	.05 "	Titanium	.15 max.
Copper	.04 "	Copper	.15 - .40
Manganese	.03 "	Manganese	.15 max.
Chromium	.03 "	Chromium	.15 - .35
Zinc	.03 "	Zinc	.25 max.
Magnesium	.01 "	Magnesium	.8 -1.2
Tin	.01 "	Lithium	.008 max.
Lead	.01 "	Cadmium	.003 "
Bismuth	.01 "	Cobalt	.001 "
Nickel	.01 "	Boron	.001 "
Lithium	.008 "	Others Each	.05 "
Cadmium	.003 "	Others Total	.15 "
Cobalt	.001 "		
Boron	.001 "		

T-200.2 The self-supports shall be fabricated of aluminum alloy 8001-H16 with the following chemical composition:

Element	Composition Limit (%)
Aluminum	97.51 min.
Nickel	0.90-1.30
Iron	0.45-0.70
Silicon	0.17 max.
Copper	0.15 "
Lithium	0.008 "
Cadmium	0.003 "
Cobalt	0.001 "
Boron	0.001 "
Others Each	0.05 "
Others Total	0.15 "

T-200.3 Aluminum component dimensions shall permit conformance of the finished target elements to the dimensional requirements shown in Table T-305.

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Specifications (Cont.)

T-200.4 As-Received Properties

T-200.4.a Finished components shall be free of fabrication defects such as laps, seams, folds, separations, galls (other than minor surface conditions), and embedded foreign material.

T-200.4.b Excessive numbers of component pieces exhibiting marring and mechanical damage shall be cause for rejection of a component lot.

Revision 1 dated September 17, 1965

T-200 Basis changed to include justification for all specifications.

T-200.2 Added to include specification for self-supports.

T-200.4.c Deleted because requirements covered by T-200.4.a.

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SPECIFICATION

TARGET ELEMENT SELF-SUPPORTS

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BASIS

Target elements that are charged in ribless process tubes require alignment and support. This is necessary to maintain a uniform annulus between process tube and target element providing a space for uniform coolant flow. The design and physical attributes of the support are important for assurance of a high quality element. The support must therefore meet the following criteria:

- (1) The support to cladding bond strength must be sufficient to withstand the frictional forces of charging and discharging.
- (2) Strength to support the weight of the target element.
- (3) Strength to resist deformation under normal handling conditions.
- (4) Collapsibility (lack of mechanical strength) in event the target element swells or distorts during irradiation.
- (5) Adequate corrosion resistance and compatibility with adjacent materials in the reactor environment.
- (6) Minimum resistance to reactor coolant flows.
- (7) Sufficient members in the proper location to meet functional requirements and be amenable to well-developed processes for attachment.

The self-supports used presently are known as the "arch" bumper support. They are attached by ultrasonically spot welding the support to the cladding lateral surface.

Unlike fuel element self-supports, the target element supports are attached to the can component prior to filling the component with thorium since the finished target element does not have sufficient strength to withstand the pressures required for attachment. Mandrels of hardened steel are placed in the can component to provide structural support during attachment and testing of the weld strength.

SPECIFICATIONS

- T-201.1 The self-support design and location shall conform with the major dimensions shown in Table T-305 and Figure T-305.
- T-201.2 Self-supports shall be fabricated of aluminum alloy 8001-H-16 as outlined in specification T-200.2.
- T-201.3 The self-support shall be attached to the K3T can component by ultrasonic spot welding.
- T-201.4 The maximum projected rail row width shall be 0.280 mils.

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T-201

SPECIFICATION

TARGET ELEMENT SELF-SUPPORTS

DATE EFFECTIVE

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Specifications (Cont.)

- T-201.5 The support to can component weld for each weld tab of the arch rail shall withstand a minimum shear force of 120 pounds, applied tangential to the target element.
- T-201.6 The minimum weld tensile peel strength for the combined welds shall be 35 pounds for the self-support arch rail.
- T-201.7 The self-support target elements shall have four (4) rows of two (2) supports each spaced at 90 ± 1.5 degree intervals.

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THORIUM OXIDE TARGET ELEMENTS

SPEC. NO.

T-300

SPECIFICATION

TARGET ELEMENT CORE DENSITY

DATE EFFECTIVE

References: (1) HW-76847, "Production of U-233 and Program Proposal,"
L. W. Lang, R. H. Meichle, H. C. Rathbun,
March 21, 1963. (Secret)
(2) Thoria Contract with Nuclear Fuels Services, Inc.,
AT(40-1)-3279, October 7, 1964.

BASIS

The irradiation of thorium-oxide has a marked economic advantage over the irradiation of metallic thorium. In an economic analysis of metallic thorium vs. thorium-oxide irradiation, full cycle costs of U-233 production, including target element fabrication, irradiation, and U-233 separation and recovery, reflect a reduction of approximately 35 per cent in unit cost for U-233 produced by irradiation of thorium-oxide.⁽¹⁾ On this basis, the irradiation of thorium-oxide target elements was selected for the current Hanford U-233 program.

Bulk density of the target elements is dependent upon both the inherent particle density and compactibility of the thorium-oxide. Particle density of the thoria affects not only the bulk density, but also the dissolution rate of the thoria. Optimum particle density is therefore determined by balancing the needs for high bulk density target elements and thoria dissolution rates which are acceptable to the chemical processing operations.

Compactability of the thorium-oxide is dependent upon particle size distribution and affects basically the bulk density of the target elements.⁽²⁾ Higher bulk density of the target elements provides the inherent economy of having more thorium in the reactor per unit of volume. Uniformity in density of the elements is required to reduce variations in reactivity and improve reactor control.

Greater efficiency and neutron economy results from higher bulk density targets in the central zone of the reactor. In the fringe loadings, bulk density has a lesser impact since fewer neutrons are available in that zone for the conversion reaction.

Some blending of the thoria has been found necessary to reduce variability in the target loading. The objective of such blending is to improve in-lot and between-lot homogeneity of the thorium-oxide. Such calculated lot blending results in improvements in conformance to the thorium-oxide specifications.

SPECIFICATIONS

- T-300.1 The thorium-oxide target element core shall be vibrationally compacted to a bulk density of 7.5 ± 0.30 g/cc.
- T-300.2 The target element model, as listed in Table T-300, shall contain amounts of thorium-oxide within the limits shown.
- T-300.3 The thoria target elements may contain one compacted thoria wafer whose specifications and physical properties conform to those detailed in Specification T-100 and Table T-300, respectively.

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TARGET ELEMENT CORE DENSITY

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Specifications (cont'd)TABLE T-300

<u>Model</u>	<u>Nominal Vol. (cc)</u>	<u>Wt. of Thoria Powder Element (Grams)</u>		<u>Thoria Wafer Dimensions</u>		
		<u>Max.</u>	<u>Min.</u>	<u>Diameter in $\pm$ 0.012</u>	<u>Thickness in $\pm$ 0.025</u>	<u>Wt Grams $\pm$ 6</u>
C4T	190.05	1,482	1,368	1.330	0.370	66
K6T	200.01	1,560	1,440	1.365	0.370	71
K3T	236.10	1,842	1,700	1.485	0.370	84
K7T	174.03	1,357	1,253	1.275	0.370	62

Revision 1 dated September 17, 1965

T-300 Basis expanded to include justification for all specifications.
 T-300.1 Changed from 7.0 ± 0.2 g/cc to provide higher bulk density core.
 Table T-300 New model, volumes and weight limits of thoria for the new density requirements.

Revision 2 dated December 10, 1965

T-300.1 Changed from $7.2 \pm$ g/cc to provide higher bulk density core.
 Table T-300 - weights changed to coincide with density change.

Revision 3 dated January 24, 1966

T-300.1 Changed from $7.3 \pm .2$ g/cc to provide higher bulk density over a wider range.
 Table T-300 - weights changed to coincide with density change.

Revision 4 dated October 21, 1966

T-300.3 Added to permit use of a thoria wafer. Table T-300 revised to provide dimensional specifications for thoria wafers.

Revision 5 dated April 22, 1968

Table T-300 - Model designation changed from 010T to C4T; C1T to K6T; and added K7T. Nominal powder volume and powder weight per element changed to reflect use of thoria wafer.

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SPECIFICATION TARGET ELEMENT CLOSURE		DATE EFFECTIVE April 22, 1968	

- References: (1) HW-83559 Rev.1, "Provisional Product Specifications for Thorium-Oxide Target Elements," F. E. Pansiko and H. G. Powers, September 8, 1964. (Confidential)
- (2) RL-REA-665, "Revision of Thoria Loss-on-Ignition Specification," W. K. Alexander, February 15, 1965. (Confidential)
- (3) DUN-2409, "Thoria Target Element Fabrication and Irradiation Experience."

BASIS

The closure area of the thoria target elements is considered to be the most critical area in terms of cladding integrity since it is a zone of discontinuity in the cladding. It is therefore of the utmost importance that the junction between the cap and the can be sealed with a high-integrity barrier between the reactor coolant and the thorium-oxide core material.

Prior irradiation experience has shown that penetration of the cladding by reactor coolant water causes a swelling of the target element when the water reacts with the thorium-oxide. Such swelling has been severe enough to cause failure of the closure weld or the can wall and contamination of the reactor coolant by thoria no longer contained by the cladding. Excessive swelling of the target elements has caused the element to stick in the reactor process tubes, which necessitated removal and replacement of the tubes. In every case of water penetration of the cladding thus far, swelling of the element has occurred. In cases where the swelling has not been severe enough to cause failure of the cladding, the swelling has caused restrictions in the coolant flow which, in turn, has caused a temperature imbalance. Cladding corrosion is not a problem under normal conditions, but could become severe if high target element temperatures were experienced.

Closure of the junction between the cap and the can is currently achieved by a fusion weld, using a tungsten-inert gas shielded arc weld process. (1) In the use of such a closure process, or in any closure method using high temperatures, provisions must be made to remove excess heat from the element in order to minimize expansion of the entrapped gas in the element, which may lead to defective welds by "blowout" of the molten metal. One technique that is employed in the fusion closure welding of thoria elements to minimize internal gas expansion, is to place a thoria wafer (T-300) directly below the aluminum end cap. This procedure has an inherent advantage over an external heat sinking system in that the primary modes of heat transfer (convection and radiation) are disrupted. Weld integrity is also affected by the presence of finely divided thoria in the weld zone. The welding cover requirements are intended to provide sufficient contamination-free weld thickness to withstand the anticipated corrosion and handling and charging forces which may be experienced by the target elements.

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Basis (cont'd)

The molten weld metal has a tendency to flow out and overhang the edge of the can component. The overhang is characteristic of this type weld on a thin material if sufficient cover is to be guaranteed. The amount of overhang must be controlled so that the reactor coolant flow is not restricted. The restriction could reduce the amount of coolant and bring imbalance to the coolant system.

The thoria target elements are required to withstand certain externally-applied forces during handling and charging, as well as irradiation and/or heat-induced internal forces while in reactor. The target element generally and the closure zone specifically must be capable of withstanding external charge-discharge forces applied longitudinally to the column of elements. Such forces are arbitrarily controlled in the reactors at a maximum of 1100 pounds.

Studies and calculations of gas pressure generation in the thoria target elements during irradiation indicate that internal pressure of the elements is not expected to exceed 100 psi. (2) These pressures are dependent upon adequate control of condensable and non-condensable off-gas. Water entry to the thoria by failure of the cladding has resulted in severe distortion and rupture of the cladding by expansion of the thoria. Neither the cans nor the closures can reasonably be designed to restrain such distortion. Control of this behavior is achieved by assuring high integrity closure and cladding.

SPECIFICATIONS

- T-301.1 The minimum target element closure shall be one weld, applied by the TIG process, which shall have a minimum of 0.025 inch of defect-free weld metal cover at the cap-to-can junction.
- T-301.2 The weld bead shall not exceed the maximum specified can OD. (T-305) by more than 0.010 inch.
- T-301.3 The target element cap and closure zone shall be capable of withstanding an external force of 1500 pounds applied longitudinally to the element by a one-inch diameter ram.
 - T-301.3.a Diameter increase caused by the application of such a force shall not exceed 0.010 inches.
 - T-301.3.b There shall be no evidence of weld damage caused by the application of such a force.
- T-301.4 The target element cladding and closure zone shall be capable of withstanding an internal gas pressure of 300 psig.
 - T-301.4.a Diameter increase caused by the generation of such pressure shall not exceed 0.010 inches.

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Specifications (cont'd)

T-301.4.b There shall be no evidence of weld damage caused by such internal pressure.

Revision 1 dated July 23, 1965

T-301 Basis changed to include better definition of aluminum wafers used in capping.

Revision 2 dated September 17, 1965

T-301 Basis modified to include component end cap instead of aluminum wafers for closure. Basis expanded to include justification for all specifications.

T-301.3 Additional specification covering capability to withstand charge-discharge forces.

T-301.4 Additional specification covering capability to withstand internal gas pressure.

Revision 3 dated April 22, 1968

Basis: Added reference 3 and statement on thoria wafers in paragraph 3 of basis.

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SPEC. NO.

T-302

SPECIFICATION

TARGET ELEMENT IDENTIFICATION

DATE EFFECTIVE

September 17, 1965

BASIS

Record of materials and processing methods used in thorium preparation and target element fabrication is necessary for proper evaluation of fabrication variables, irradiation behavior, and chemical process and recovery variables. Adequate marking and identification of the fabricated elements are necessary for the maintenance of such records.

The target elements should be grouped according to a consistent system such as thorium-oxide lots, a single day's fabrication, or similarity of material so that the history of all target elements in a lot is similar as near as practicable.

The identification mark normally used at Hanford is made by stamping. The maximum stamping depth must be specified to insure that the minimum residual can-base thickness is adequate to withstand reactor conditions. Minimum stamp depth is required to assure legibility.

SPECIFICATIONS

T-302.1 An identification mark shall be stamped in the base of each target element and shall indicate by code letter and number designations the core material, the model, the core lot number, the bulk density of the thorium-oxide, and the aluminum supplier. This code can be used to trace the history of the target element.

T-302.2 The maximum stamp depth shall be 0.035 inch.

T-302.3 Minimum depth of stamp shall be 0.010 inch to assure legibility.

Revision 1 dated September 17, 1965

T-302 Basis expanded to include justification for all specifications

T-302.3 Added minimum stamp depth.

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SPECIFICATION

TARGET ELEMENT CLEANLINESS

DATE EFFECTIVE

September 17, 1965

- References: (1) HW-80289 Rev., "Production of Clean U-233--Process Parameters and Limits," L. W. Lang, J. W. McCurry, R. H. Meichle, H. C. Rathbun, January 6, 1964. (Secret)
- (2) HW-76847, "Production of U-233 and Program Proposal," L. W. Lang, R. H. Meichle, R. Nilson, March 21, 1963. (Secret)

BASIS

Thorium oxide, which is low (<1.0 ppm) in Th-230 has little radioactivity from this source: the Th-230 becomes a major contributor when more than 1.0 ppm is present.. The Th-232, however, has similar decay products as U-232, which is formed from irradiation of thorium-oxide. Both of the isotopes decay to Th-228, and it is the daughters of this isotope which contribute the high-energy gamma radiation to make thorium-oxide more radioactive than uranium metal. If a zone is contaminated with both uranium and thorium-oxide, it must be considered the latter until decontaminated.

The thorium-oxide received at Hanford often contains extreme fines which allow the material to become airborne readily. Such airborne material presents a health hazard since it may be inhaled or ingested. A large percentage of thorium-oxide which is inhaled is retained in the lungs. Although no chemical toxicity is involved, the lungs may be damaged by radiation from the thorium-oxide deposited in them. A portion of any inhaled thorium will be transported by the blood from the lungs and may eventually become fixed in the bone structure, which could result in radiation damage to the blood-forming tissue. Ingested thorium-oxide tends to settle in tissue and bone marrow, which subjects both areas to radiation.

To eliminate radiation hazards from thorium contamination, it is necessary that the target elements and storage pallets be cleaned of all loose or smearable contamination before removal from the controlled areas of the target element fabrication facility.

SPECIFICATIONS

T-303.1 Thorium-oxide target elements shall be cleaned to remove all traces of smearable contamination on the surface of the elements.

Revision 1 dated September 17, 1965

T-303 Basis expanded to include justification for all specifications.

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SPECIFICATION	TARGET ELEMENT CLOSURE TESTING		DATE EFFECTIVE September 17, 1965

- References: (1) RL-REA-N-40, Personal Notes, D. W. Peterson, Page 55.
(Unclassified)
(2) 992249-0009, "Leak Detection Manual," Consolidated
Electrodynamics Corporation, Monrovia,
California. (Unclassified)

BASIS

The irradiation performance of the target element is largely dependent on the integrity of the closure weld at the cap-can junction of the elements. A defective closure could permit entry of reactor coolant to the thorium-oxide. There has been evidence in failed elements that the coolant has reacted with the thorium-oxide causing it to swell, thus causing a distortion or rupture of the target element cladding. The closure integrity must therefore be assured by extensive testing designed to measure the closure quality in order to eliminate those elements with defective closures.

The weld metal thickness or cover is specified to assure sufficient metal thickness to withstand corrosion effects and penetration due to handling damage. This minimum of weld cover must be assured by adequate testing as necessary. X-ray photographs provide a visual record of the extent of the cover of weld metal by revealing both the number and size of voids and any inclusions of foreign material.

Pinholes which penetrate the weld are often microscopic in nature and not readily discernible on visual examination. Calculations indicate that an opening slightly less than 0.0001 inches in diameter would permit water entry during a six-month reactor residence at 50 F and 300 psi pressure differential such that ten per cent of the void space in the element would be filled with water. On this basis, a helium leak testing level was established which would define such a hole.

Helium leak testing was selected for testing integrity of the target elements because of its wide application and high sensitivity in such tests. Although other techniques may be used, in prior campaigns helium has been added to the elements by an evacuation and helium backfill operation. Some helium has also been trapped in the element from the argon-helium inert gas blanket used during the closure welding. Tests have indicated that the concentration of helium in the element in previous campaigns has ranged from 0.1 to 3.0 per cent of the void volume. It is necessary that the concentration of helium in the elements to be tested be known and assured at the time of testing.

Definition of a defect 0.0001 inches in diameter was initially based upon a calculated leak rate of a helium atmosphere at 100 per cent concentration. Calculations based upon literature sources⁽²⁾ indicate that under conditions of molecular flow, a concentrating effect takes place when dilute helium is used. The concentrating effect is directly related to the ratio of the densities of helium and the carrier gas. On this basis, the helium leak rates for different concentrations of helium in the target elements have been calculated. Some refinement of these calculations may be required as actual experience is gained in this leak testing technique.

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SPECIFICATION

TARGET ELEMENT CLOSURE TESTING

DATE EFFECTIVE

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SPECIFICATIONS

- T-304.1 The weld cover shall be measured to insure the minimum requirement as defined in T-300.1 and T-300.2 are being met.
- T-304.2 The thorium target elements shall be tested for penetrations in the cladding or weld closure area by means of a helium leak detector.
- T-304.3 The target element void space shall contain helium sufficient to permit detection of a leak as defined in T-304.4
- T-304.4 The helium leak rate shall not exceed the rates defined by the curve in Figure T-304 for the corresponding helium concentrations.
- T-304.5 The helium weld area shall be radiographed and those welds not meeting the following requirements shall be rejected:

Weld Cover 0.025 minimum

Thorium-Oxide Contamination or
Other Defects 0.025 minimum between
defects

No Pinhole Defects

Revision 1 dated September 17, 1965

- T-304.4 Helium leak rate changed to provide specifications for varying helium concentrations in target elements.

LOGARITHMIC 358-120
MILITARY LOGAR CO. BOSTON, U.S.A.
3 X 3 CYCLES

FIGURE T-304

PER CENT HELIUM IN TARGET ELEMENTS

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		T-305	
		DATE EFFECTIVE	
		December 10, 1965	

BASIS

It is essential to inspect the finished target element to assure conformance to specifications with respect to dimensional and surface characteristics of the final product. The finished dimensions of the target element must be controlled to provide a uniform product that will not restrict reactor coolant flow. Warped or oversized elements could restrict water flow whereas undersize elements would allow additional water in the process tubes, all of which would affect reactor coolant balance. Weld overhang, if excessive, could also affect reactor coolant balance.

The can wall minimum thickness has been reduced to allow use of existing components. The can is fabricated with a 0.040 minimum can wall and is reduced slightly by etching during component preparation. The external column strength and internal pressure strength are well within the limits of Specification T-301.

Surface mars that are too deep, material imbedded in the surface of the element, and raised pieces of aluminum on the surface of the element could all promote localized corrosion during irradiation. This could cause penetration of the cladding and eventual failure of the target element resulting in reactor shutdown. The limits of the depth of mars on the base are less restrictive because of greater thickness of the material. This also allows for stamping identification in the base that will remain identifiable after handling and irradiation.

Reactivity of the target elements is the basis upon which the reactor loading is designed. Efficiency and safety in the reactor operation require uniformity in the reactivity properties of the target elements. It is therefore necessary that the reactivity measurements of each target model be made in the Hanford Test Reactor on a routine audit basis.

SPECIFICATIONS

T-305.1 Dimensions

T-305.1.a See Table T-305 and Figure T-305 appended to this specification for required physical dimensions.

T-305.2 Surface

T-305.2.a All surfaces shall be free of foreign contaminants.

T-305.2.b The finished target element surface, including the weld, shall have no evidence of seams, cracks, laminations, pinholes, or perforations, inhomogeneity, corrosive attack, or other abnormalities not subject to ready and conclusive evaluation as to their acceptability.

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Specifications (cont'd)

T-305.3 Reactivity

T-305.3.a A sample, one finished element, will be drawn randomly from each homogeneous thorium-oxide target element lot and tested in the Hanford Test Reactor for reactivity.

T-305.3.b Reactivity measurements for the thoria target elements shall not exceed the following maximum "blackness" dih values:

Target Modeldih

C4T

-15.50

K3T

-19.00

K6T

-16.00

K7T

Not yet available

Measured values shall be forwarded, by lot, to the Supv., Process Physics prior to shipment of the elements to the reactor.

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TARGET ELEMENT FINAL INSPECTION

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TABLE T-305

PHYSICAL DIMENSIONS OF
FINISHED THORIUM OXIDE TARGET ELEMENTS

	<u>Maximum*</u>	<u>Minimum*</u>
1. Effective Outside Diameter		
C4T	1.448	1.441
K6T	1.483	1.476
K3T	1.603	1.596
K7T	1.483	1.476
2. Length		
C4T	8.985	8.785
K6T	8.985	8.785
K3T	8.985	8.785
K7T	8.985	8.785
3. Can Base Thickness	.195	.155
4. Cap Thickness	- Excluding K7T	.120
	- K7T	.095
5. Can Wall Thickness	- All models ex-	.260
	cluding K7T	.235
	- K7T	.038
	.050	.083
6. Thickness of Defect-Free Weld Metal		.025
7. Weld Overhang	.010	
8. Depth of Surface Mar		
Base	.035	
Can Wall or Cap	.010	
Weld Bead	.004	
9. Indentation		
Washer Swaging	.020	
Other	.010	

* All dimensions in inches

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Revision 1 dated July 23, 1965

Table T-305

4. Changed from

	<u>Maximum</u>	<u>Minimum</u>
Cap Thickness	<u>.240</u>	<u>.180</u>

to give clear definition of cap and includes provisions for etching of outer wafer.

5. Changed from

	<u>Maximum</u>
Cap or Base	<u>.035</u>

to include only base because of thickness of outer wafer.

Revision 2 dated September 17, 1965

Table T-305

1&2 Changed all model numbers because of change in can wall thickness from 0.090 inch to 0.045 inch.

4. Inner cap specification deleted.

5. Changed from

	<u>Maximum</u>	<u>Minimum</u>
Can Wall Thickness	<u>.095</u>	<u>.085</u>

to show change in can wall thickness

T-305 Basis expanded to include justification for all specifications.

T-305.3 Reactivity values listed for new models.

Revision 3 dated December 10, 1965

Table T-305

5. Changed from

	<u>Maximum</u>	<u>Minimum</u>
Can Wall Thickness	<u>.050</u>	<u>.040</u>

to allow etch of component in component preparation.

Basis changed to include reasons for minimum can wall thickness change.

Revision 4 dated April 22, 1968

T-305.3b and Table T-305 - Changed model designation from 010T to C4T, C1T to K6T, and added K7T. Changed radiation limits to maximum "blackness" only. Added requirement to send data on elements to the Supervisor, Process Physics.

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FIGURE T-305

LOCATION OF SELF-SUPPORTS ON K3T THORIA TARGET ELEMENT

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SPEC. NO.

T-306

SPECIFICATION

TARGET ELEMENT PACKAGING AND HANDLING

DATE EFFECTIVE

September 17, 1965

BASIS

Proper handling and storage of finished target elements is necessary to maintain the quality of the target element. They should not be stored under conditions that could promote corrosion of the cladding. They should be stored, if possible, where there is shielding that will reduce the radiation hazard. Normal uranium provides a very adequate shield.

The target element or storage pallet needs easily recognizable identification so as not to become mixed with uranium fuel elements or other target elements. This will also alert passers-by to the presence of this radioactive material.

The target elements must be handled in a manner that will not degrade their quality by marring or denting.

SPECIFICATIONS

T-306.1 Thorium-oxide target elements shall be stored in such a manner that their condition at the time of shipment will meet the requirements of all previous specifications.

T-306.2 The target elements shall be stored such that they can readily be identified by casual observation of shipping pallets.

Revision 1 dated September 17, 1965

T-306 Basis expanded to include justification for all specifications.

UNCLASSIFIED

END

**DATE
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