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TITLE

DESIGN OF PRODUCTION TEST IP-423-A-FP EVALUATION OF URANIUM FUEL CORES HAVING VARIOUS HEAT TREATMENTS

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DESIGN OF PRODUCTION TEST IP-423-A-FP

EVALUATION OF URANIUM FUEL CORES HAVING VARIOUS HEAT TREATMENTS

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W. H. HODGSON

and

M. A. CLINTON

January 5, 1962

SYNOPSIS

Fuel element dimensional stability may be affected by several variables associated with core quench following beta heat treatment. The purpose of this test is two-fold: 1) to evaluate the dimensional stability and fuel performance of uranium fuel cores produced by a proposed heat treating process employing an oil quench from the beta phase and 2) to evaluate the effects of selected heat treatment parameters on uranium fuel core performance in order to establish an optimum core heat treatment process. The irradiation test program will be conducted at F Reactor and will consist of the following three phases:

PHASE I - Fourteen measured monitor charges containing alternated oil quenched and standard water quenched uranium fuel cores will be irradiated to an 800 MWD/T goal exposure.

PHASE II - Concurrently up to five tons per month of OIIIN ingot uranium oil quenched fuel cores will be irradiated to normal variable goal, followed by 25 tons per month for a period of four months. Performance will be monitored by quality certification monitor charges.

PHASE III - Essentially in accordance with details listed in the appendix to this report, a test which has been statistically designed to evaluate selected heat treatment parameters including up to 24 charges will be irradiated to establish optimum core heat treatment. Selection of the optimum condition will be based on measured changes in fuel length, outer and inner diameter, warp, and ellipticity.

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EVALUATION OF URANIUM FUEL CORES HAVING VARIOUS HEAT TREATMENTS

INTRODUCTION

Fuel element warp occurring during the irradiation period is consided to be one of the major fuel element dimensional stability problems. Warp has been shown to correlate with accelerated corrosion attack(1,2,3) and also can contribute to stuck fuel charges, particularly in bumpered or self-supported charges where the annular clearances are reduced due to the presence of the projection rails. Thus, any process which offers a potential for reducing the average warp should be evaluated.

Preliminary tests offsite(4) have indicated that the use of a commercially available oil for a quench medium following beta heat treatment produces a fuel core with less residual stresses and a slightly finer and more uniform grain size than that produced by the present HAPO method of water quench. Thus, adoption of an oil quench may offer a means whereby warp can be reduced without incurring costly revisions to equipment or fabrication processes. This report presents an irradiation testing program to evaluate the performance of oil quenched cores and to determine the optimum core heat treatment.

OBJECTIVE

The objectives of this test are two-fold: 1) to evaluate the dimensional stability and fuel performance of uranium fuel cores produced by a proposed heat treatment process employing oil quench from the beta phase and 2) to evaluate the effects of selected heat treatment parameters on uranium fuel core performance in order to establish an optimum core heat treatment process.

TEST SUMMARY

This irradiation test program will be conducted at F Reactor and will consist of the following three phases:

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(1) HW-60150, "Determination of Fuel Element Warp and Hot Spot Orientation". T. L. Deobald. 6/10/59.

(2) HW-57645 F, "Final Report on Comparison of Bond Quality with Reactor Performance of Enriched I&E Fuel Elements - Production Test IP-210-A-1-FP". W. H. Hodgson. 1/15/60.

(3) HW-67120, "Analysis of Quality Certification Data - Effect on Warp on the Incidents of Hot Spots". L. T. Hagie and J. L. Jaech. 10/14/61.

(4) DP-550, "Irradiation of Tubular Uranium Fuel Elements with Various Heat Treatments". J. R. Seabach and W. R. McDonell. March, 1961.

[redacted]

Phase I

Fourteen measured monitor charges containing alternated oil-quenched and standard water quenched uranium fuel cores will be irradiated to an 800 MWD/T goal exposure. Fuel element geometry will be OIIIN non-bumpered.

Phase II

Concurrently, up to five tons per month of OIIIN ingot uranium, oil-quenched fuel cores will be irradiated to normal variable goal. If after five months or 25 tons charged, no unusual experience occurrs; the maximum quantity may be increased to 25 tons per month for a period of four months. Performance of lot charged material will be monitored under authorization of the Quality Certification Program.(5,6)

Phase III

As soon as details can be completed, HAPO will receive uranium fuel cores for a test which has been statistically designed to evaluate selected heat treatment parameters to establish the optimum core heat treatment. In addition to re-evaluating the quench mediums of oil and water (sometimes referred to as brine), the effects of core geometry (hollow versus solid), air delay between the beta heat treatment and quench media, quench temperature, core chemistry, and core fabrication will be evaluated. The intent will be to eliminate the obviously undesirable candidates by ex-reactor tests and to complete the evaluation with a small-scale in-reactor test comprised of about 24 monitor tubes.

BASIS AND JUSTIFICATION

The justification for evaluating oil as an uranium core quenching medium following the beta heat treatment can be summarized by the following statements:

A. Irradiation induced warp and general dimensional instability are major fuel element problems.

B. These effects are directly related to the types and degree of preferred orientation in the uranium and are affected by heat treatment.

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(5) HW-58271, "Production Test IP-216-A, Evaluation of Performance of Normal Production I&E Fuel Elements". R. E. Hall and R. R. Bloomstrand, 1/6/59.

(6) HW-59271 A, "Supplement A to PT-IP-216-A, Evaluation of Performance of Normal Production I&E Fuel Elements". M. A. Clinton, 8/20/60.

C. Heat treatment can minimize such instability by randomizing the uranium grain orientation; however, the relative efficiency of the randomization varies with variations in the heat treatment parameters.

D. Oil quench is a heat treatment parameter which has indicated a potential for reducing the average warp;(7,8) therefore, it is proposed to evaluate this heat treatment parameter in the reactors.

Alternate core blanks from the same ingot rods will be fabricated and heat treated as follows:

Parameter	Water Quench	Oil Quench
1. Core Geometry	Solid blank	Hollow blank
2. Chloride Salt Bath at 730 C (1346 F)	12 minutes (min.)	6 minutes (min.)
3. Transfer time to Quench	43 seconds	10 seconds
4. Quench Medium at 55 C (130 F)	Water (brine)	Houghto-K oil
5. Post Quench Dry	Air	Spray wash and forced air dry

Based upon the assumption that the oil-quenched fuel core will have better dimensional stability than our present fuel core, supplementary irradiations of tonnage quantities will be authorized to augment and accelerate the testing program. Tonnage quantities will be lot charged and will be monitored by quality certification charges. Currently, about five tons of OIIIN ingot I&E oil-quenched cores have been canned and are to be charged concurrently with Phase I. Lot charging of five tons per month for five months will be authorized and if the fuel performance is not unfavorable the quantities will be increased to 25 tons per month for a four month

(7) HW-70359, "Oil Quench Cores for PT-IP-423-A-FP". E. A. Weakley, 7/12/61.

(8) HW-71036, "Report of the Working Committee of the Fuel Element Development Committee". September 12-14, 1961. pp. 27-31.

period. The next step will be to larger scale usage (90 tons/month for six months) and will be authorized by a Process Improvement Transition Authorization (PITA) or a supplement to this production test.

The third phase of this program will be to conduct a statistically designed test to determine the optimum heat treating process for uranium fuel cores. In addition to the quench media, there are several other parameters which affect the uranium core grain size, orientation, and residual stresses during the heat treatment process; and, in brief, the test will be a relatively complete study of the following variables:

A. Uranium cores heat treated in solid and hollow form.

B. Air delay times (three times for each quench media).

C. Quench media (oil vs. brine).

D. Quench temperature (three temperatures for each medium).

E. Uranium chemistry and fabrication (Iron and Silicon, Outgassed and Non-Outgassed).

Present estimates indicate that about twenty-four (24) charges will be required for the irradiation phase of the test and that it will be delayed several months as the final test design and material fabrication details have not been completed. The test will probably be ready during either the last quarter of CY-62 or the first quarter of CY-63.

TEST DETAILS

A. Fuel Elements

1. Cores

Cores for the first phase will be obtained from the same ingot rods. Alternate core blanks from the rods are to be oil-quenched and water-quenched as follows:

a. Oil Quench

1. Hollow core blanks
2. Chloride salt bath at 730°C (1346°F) for 6 minutes
3. Transfer time to quench - 10 seconds
4. Oil quench in Houghto-K at 55°C (130°F)
5. Spray washed with a detergent solution to remove excess oil and salt and forced air dried.

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b. Water Quench

1. Solid core blanks
2. Chloride salt bath at 730°C (1346°F)
3. Transfer time to quench - 43 seconds
4. Water (brine) quench at 55°C (130°F)
5. Air dry

The ingot, rod and core position numbers will be stamped on each core.

Cores for the second phase, for lot charging, will all be oil-quenched by the above procedure. Currently, approximately 6 tons of OIIIN I&E oil-quenched cores are on site.

The third phase of the process will incorporate oil-quenched cores with brine-quenched cores in a statistically designed test to determine the optimum heat-treating conditions for HAPO cores (see index for details).

2. COMPONENTS - Jacketing components will be X-8001 aluminum alloy of the standard OIIIN geometry.

3. ASSEMBLY - All fuel elements will be fabricated by the "F" process.(9)

4. QUALITY - All elements shall pass the normal process specifications in effect at the time this material is prepared.

5. QUANTITY - Approximately 462 acceptable fuel elements are required for 14 measured charges. These include 231 oil-quenched test pieces and 231 standard controls. About 1200 pieces are currently available for lot charging. Additional quantities up to 90 tons per month will be charged for irradiation to normal goal exposure on a gradually increasing schedule based on performance.

6. WATER MIXERS - Each column will require a water mixer element located in the No. 10 position from downstream.

7. QUALITY CERTIFICATION - Quality certification charges will be required on lot charged material for Phase II.

8. MATERIAL HANDLING - Phase II lot charged oil quench material will follow normal process channels. Identification of oil quench virgin lots will be retained in lot records. Reprocess oil quench material may be combined with standard material in reprocess lots. Quality Control will retain identity of reprocess lots containing oil quench. Recovered oil quench cores may be combined in recovered lots and thus lose their identity.

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(9) HW-47029, "Process Specifications, Fuel Element Manufacturing Processes". Fuels Preparation Department.

[redacted]

B. TESTING

Pre-Irradiation Tests and Measurements

The following data are being collected on each oil-quenched and water-quenched core in this P.T.:

1. Ingot number
2. Ingot chemistry
3. UT-2 readings, including large grain readings
4. SORT frequencies and ratios

In addition, the elements for the alternately charged tubes will have the following data:

1. Bare core and canned fuel element dimensions. OD 1, 2, and 3; ID 1, 2, and 3; length; warp
2. Total external and internal bond count
3. Canned element weight (1-15)
4. Each piece will have a fuel identification number (position number and series) in addition to piece number and lot number.
5. Column Make-Up - FPD will make up the monitor charges and will place them in specially identified shipping pallets in charging order.

C. IRRADIATION

A. Charging

All monitor columns will be serially numbered and will be charged in numerical order with piece number one downstream. Each column shall have the fuel identification number (series and/or lot number) recorded opposite the tube number on the front face sequence sheet. Charging of the Phase I and Phase III material will be followed by a representative of Research and Engineering. Monitor columns charged under Phase II will receive the same handling treatment as columns charged under authorization of PT-IP-216 - Quality Certification Production Test.

Monitor columns for Phase I and III will be charged into locations which will provide similar irradiation conditions for all the tubes. Locations will be selected by the assigned Process Engineer and Physicist with the concurrence of the test author and will be selected from those available as a result of scheduled discharge.

[redacted]

B. Goal Exposure

1. Goal exposures for material charged under Phases I and III will be 800 MWD/T.
2. Goal exposure for material charged under Phase II will be established by the goal plan in effect for normal production material of the same geometry.
3. Goal exposure changes may be made by request from the test author with the concurrence of reactor processing manager.

C. Discharge

All monitor columns charged under Phase I may be discharged prior to reaching goal discharge exposures after two failures have occurred, providing all columns can be specially picked up. The same conditions will hold for Phase III material.

If a failure occurrs in the lot charged material, the material will be treated as if it were normal production fuel.

D. Operating Conditions and Limits

The operating limits and conditions which are in use for normal production OIIIN fuel will apply toward this material.

E. General

1. Schedule

Fuel elements for Phase I are ready for reactor charging. Approximately six tons of oil-quenched material (identified as KZ-055) are also ready for lot charging. Reactor loading of the above material is requested for the first outage following approval of this test. Phase III material will probably not be ready for reactor charging before September, 1962.

2. Duration

Irradiation of the Phase I material will require about four months. Phase II will extend over a period of about nine months and Phase III will require about four months irradiation time. This test authorization will terminate on December 1, 1963.

3. Post-Irradiation Examinations (105-C - MEF)

All pre-measured fuel elements will

1. Be weaseled and visually inspected for surface conditions,
2. Be measured for length, warp, and diameter changes (OD_1, OD_2, OD_3, ID_5, ID_6, and ID_7),
3. Have weight recorded (downstream 15 pieces)
4. Be bond tested for total count, if equipment is available.

5. Selected pieces may be set aside for stripping and bare core measurements depending on either the preliminary visual examination results or a later analysis of the measured data. Also, selected elements may be sent to Radiometallurgy for destructive examination.

F. Test Audit

Notebook HW-70223 will be utilized to store pre-irradiation data pertinent to this test. The appendix to this report contains a list of items to be recorded in the notebook. Any incidents which occur, whether they seem important or not, must be recorded in the notebook.

HAZARDS

No unusual hazards are associated with this test.

M. A. Clinton, Engineer
Research and Engineering Section
IRRADIATION PROCESSING DEPARTMENT

W. H. Hodgson, Engineer
Engineering Section
FUELS PREPARATION DEPARTMENT

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APPENDIX A

Data to be recorded in Production Test Notebook:

I. Fuel Element Core

   A. Lot Numbers

      1. Ingot Numbers and Chemical Analysis

      2. Unusual Treatment

   B. Finished Dimensions (Pre-Assembly)

II. Aluminum Components

   A. Lot Numbers

      1. Alloy Type

      2. Unusual Treatment

   B. Finished Dimensions (Pre-Assembly)

   C. Pre-Assembly Treatment (Cutoff, Sizing, Inspection) [illegible] -vendor, [illegible]

III. Pre-Assembly Treatment of Cores (All Pieces for Measured Columns)

   A. UT-2 Record Data

   B. SORT Record Data

   C. Surface Tester-Record Data

   D. Measure Length, OD, ID, and Warp of Cores

IV. Assembly Process

   A. Process Used

   B. Brief Explanation of Each Process

   C. Attendant Conditions

   D. Total Bond Count (All Pieces for Measured Columns)

V. Post-Assembly Treatment

A. Autoclaving

B. Other Treatment

C. Inspection

VI. Pre-Irradiation Examination and Measurements (All Pieces for Measured (Monitor) Columns)

A. Dimensions, Length, OD, ID

B. Warp

C. Weight (1-15)

VII. Irradiation

A. Coolant Temperature

1. Inlet

2. Outlet

B. Panellit and Crossheader Pressures

C. Number of Shutdowns (Controlled and Scram)

D. Other

VIII. Post-Irradiation Examination

A. Visual

B. Warp (And Other Profilometer Data)

C. Bond Count - If Possible

IX. Log - running account with dates recording the progress of the PT, unusual incidents (such as slight change in process during assembly), and other deviations whether or not they seem pertinent at the time of occurrence.

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APPENDIX B

TENTATIVE TEST DESIGN
EVALUATION OF HEAT TREATING VARIABLES

Description of Test

The test will consist of 648 fuel elements selected from 12 ingots and 12 dingot bars irradiated in prescribed charging order in 24 tubes, each containing 31 elements plus a water mixer. The following table defines the characteristics of interest.

TABLE I

DEFINITION OF VARIABLES

A:	Heat treating form		(H)	Hollow
			(S)	Solid
B:	Core blank size		(d_1)	1.437" OD
			(d_2)	1.458" OD
			(d_3)	1.479" OD
C:	Air delay time	(Brine quench)	(t_1)	17 seconds
		(Brine quench)	(t_2)	30 seconds
		(Brine quench)	(t_3)	43 seconds
		(Oil quench)	(t_1)	6 seconds
		(Oil quench)	(t_2)	10 seconds
		(Oil quench)	(t_3)	14 seconds
D:	Quench media (Oil vs. brine)			
		(Oil)	(O)	Houghto-K
		(Brine)	(B)	(approx. 25 g/l)

D:	Quench temperature	(Brine)	(q_1)	70 F
			(q_2)	120 F
			(q_3)	170 F
		(Oil)	(q_1)	125 F
			(q_2)	145 F
			(q_3)	165 F
E:	Chemistry & fabrication	(Ingot)	(C_1)	High Fe plus Si
			(C_2)	Low Fe plus Si
		(Dingot)	(C_1)	Non-outgassed
			(C_2)	Vacuum outgassed
				Constant Aluminum

The test consists of three (3) integral blocks, each containing groups of nine (9) cores. The irradiation charges will consist of 27 pieces selected from each of 6 ingots or dingot bars, plus a water mixer and sufficient cores upstream to fill the charges. For each block of ingots or dingots, the selection will be made as shown in Table II.

TABLE II

SELECTION OF "TUBE CHARGE" FROM THE THREE BLOCKS

Treatment #	Core Blank Size	Form	Medium	Delay Time	Quench Temp
1	d_3	S	B	t_2	q_2
2	d_3	H	B	t_2	q_2
3	d_1	S	B	t_2	q_2
4	d_1	H	B	t_2	q_2
5	d_2	H	O	t_3	q_3
6	d_2	H	O	t_3	q_1
7	d_2	H	O	t_1	q_3
8	d_2	H	O	t_1	q_1
9	d_2	H	O	t_2	q_2
10	d_3	H	O	t_2	q_3
11	d_3	H	O	t_2	q_1
12	d_1	H	O	t_2	q_3
13	d_1	H	O	t_2	q_1
14	d_2	S	B	t_3	q_2
15	d_2	S	B	t_1	q_2
16	d_2	H	B	t_3	q_2
17	d_2	H	B	t_1	q_2
18	d_2	H	O	t_2	q_2

Treatment #	Core Blank Size	Form	Medium	Delay Time	Quench Temp.
19	d_3	H	O	t_3	q_2
20	d_3	H	O	t_1	q_2
21	d_1	H	O	t_3	q_2
22	d_1	H	O	t_1	q_2
23	d_2	S	B	t_2	q_3
24	d_2	S	B	t_2	q_1
25	d_2	H	B	t_2	q_3
26	d_2	H	B	t_2	q_1
27	d_2	H	O	t_2	q_2