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GENERAL ELECTRIC

HANFORD ATOMIC PRODUCTS OPERATION - RICHLAND, WASHINGTON

TITLE

HIGHLIGHT REPORT OF THE WORKING COMMITTEE TO THE FUEL ELEMENT DEVELOPMENT COMMITTEE

AUTHOR

General Electric Co.
HAPO

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HIGHLIGHT REPORT OF THE

WORKING COMMITTEE

TO THE FUEL ELEMENT DEVELOPMENT COMMITTEE

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October 7, 1964

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TO: Fuel Element Development Committee

FROM: Working Committee of the Fuel Element Development Committee

The Working Committee met at Hanford on October 6 - 8, 1964. Because of the proximity of the FEDC meeting on October 22, 1964 to the Working Committee meeting, it was not possible to issue the full Working Committee report in time for the FEDC meeting. In lieu of a full report, a classified sites highlights report is being issued at this time. This will be followed with an unclassified recommendations and comments section. The full Working Committee report will be issued later.

J. T. Stringer, HAP0
Chairman

T. C. Evans, SRP

N. F. Neumann, MCW

C. E. Polson, NLO

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Summary of the Working Committee Site Report From

MALLINCKRODT CHEMICAL WORKS

URANIUM DIVISION

For the Period of April 28, 29, and 30, 1964 to October 6, 7, and 8, 1964

PRODUCTION PROGRAM REVIEW

1. REDUCTION

During the reporting period, the plant has continued to produce the unalloyed 5-segment dingot. Shipping yields (UF_4 to metal) have averaged 92.7%. Since May, 1964, a corner sample slice has been saved from a segment of two random dingots per week for the purpose of monitoring the iron content of the metal. During this period, the iron pickup in reduction has averaged 14 ppm over the incoming green salt levels.

Ground Nelco crowns will soon become the standard magnesium for the MCW reduction process. The adoption of this material was naturally based upon economics, but followed an extensive plant test program.

Chemical impurities of metal produced using ground crowns were compared with those obtained from earlier normal ground ingot magnesium. The elements Al, Cr, Cu, Mu, and Si were statistically higher for metal made with ground crowns, but only Al was "practically" higher.

The Nelco ground crown magnesium tested at MCW was coarser than Reade ground ingot magnesium, but gave no indications of any blending difficulty.

Yields for the test material and standard comparison metal were both 95.77.

Small, but significant increases in firing time were noted.

2. THORIA PRODUCTION

Successful processes for production of dehydrated thoria gel, and for high firing it, have been developed. Over 80 lots of fired thoria (about 950 pounds ThO_2 per lot) have been produced.

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DEVELOPMENT PROGRAM REVIEW

1. ALLOY STUDIES

The equilibrium diagrams for the U-Fe and the U-Al systems have been completed and are presented in this report.

2. CRYSTALLOGRAPHIC ORIENTATION

The textures induced by quenching binary uranium alloys from the beta phase were studied by X-ray diffraction of Jominy end-quenched samples. Similar textures were found for U-Si, U-Fe, U-Cr, U-Al alloys at 100, 250, and 750 ppm concentration. Near the quenched surface, the metal had strong negative irradiation growth potentials. At 20 to 50 mils from this surface, the metal had slightly more negative G_3 values. Between 50 and 150 mils the G_3 became more positive and approached a value of zero growth. These textures produced during quenching result from the alignment of alpha grains in a direction which minimizes the stress that is created at the alpha-beta interface. Near the surface of the metal, some of the beta phase is retained to low temperatures where it transforms to alpha by a shear mechanism. The latter grains are not highly oriented by the transformation; therefore, the surface contains less texture.

3. CENTRIFUGAL CASTING OF FUEL CORES

Laboratory investigation of direct, centrifugal casting of fuel cores is continuing. Cores of Mark VB-0 geometry have been produced. Grain size of the casting is large, but is refined by a standard, salt-oil, beta heat treatment.

4. TTT DIAGRAMS

The time, temperature, transformation diagram for a U-Fe alloy has been investigated. The data indicate that the retention of beta is short-lived for the 750 ppm iron alloy.

5. ELECTROLYTIC REDUCTION

Laboratory work has continued on means of obtaining high current efficiencies. The best result to date was an average current efficiency of 50% which was sustained for seven hours.

The prototype electrolytic cell was started May 6, 1964, and startup had proceeded through melting of the initial salt load and achievement of 1400°F internal temperature when the unipolar D.C. generator failed. Since that time, the machine has been returned to the manufacturer twice for repairs and modifications. It now appears that it will be reinstalled at Mallinckrodt on or before October 1, 1964; startup of the electrolytic cell should begin shortly after that.

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SUMMARY OF THE WORKING COMMITTEE
SITE REPORT FROM
NATIONAL LEAD COMPANY OF OHIO
FOR THE PERIOD OF JUNE, 1964 TO OCTOBER, 1964

PRODUCTION

1. Testing of Cut-Crown Magnesium

Because of the lower cost (4.8 cents per pound) cut-crown magnesium is attractive as a replacement for chipped-ingot magnesium.

Several lots of cut-crown magnesium were tested at National Lead. The results are as follows:

Date	Cut-Crown	Con-trols ¹	Reduction Yield (%)	Derby Grade Distribution (%)			
				Grade 1	Grade 2	Grade 3	Grade 4
11/63	36	0	96.8 ²	19.4	69.5	11.1	0
1/64	189	--	94.9 ²	19.0	28.6	51.3	11.0
	---	63	96.6 ²	54.0	36.5	9.5	0
7/64	32	--	98.8 ³	75.0	9.4	9.4	6.2
	---	36	98.8 ³	88.9	0	8.3	2.8
8/64	32	--	96.8 ³	84.3	9.4	6.3	0
	---	40	98.7 ³	100.0	0	0	0

¹Reductions with Nelco chipped-ingot magnesium.

²Yields "corrected" downwards by derby grade factors.

³Crude yields not adjusted for derby grade.

All tests used normal hydrofluorinated green salt except that of 7/64. It was enriched recycle from a blend of R-O-R and 6 to 4 source.

Ingots which contained all derbies (four) from the November and January tests contained from 33 to 52 ppm aluminum (47 ppm average) and nitrogen from 20 to 62 ppm (39 ppm average).

There will be a gradual replacement of the present chipped-ingot magnesium with the crushed crown for production operations. Nitrogen, aluminum, and carbon will probably increase slightly with crushed crown magnesium. The number of derbies which require cleaning will probably increase. Fuel quality changes will be carefully evaluated.

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2. Remelting of Top Crops

Hanford has authorized up to 15% of the crucible charge of both normal and enriched metal to consist of melted and cast drip crops.

Savannah River is evaluating ingots containing both 10 and 50% remelted top crops in a reactor test.

3. Status of Melt Temperature Control Equipment

Two units for measuring melt temperatures have been installed on production furnaces in Plant 5. Two more are being installed in Plant 9.

Tests will be conducted with the equipment to ascertain the degree of control obtainable under production conditions, and to determine if quality or operational improvements will justify an extensive capital outlay for the remaining furnaces.

4. Production of NPR Billets

Final inspection yields have been good on NPR billets (85 to 90%). Solid castings for both billet sizes are now of the same weight to simplify plant operations and to improve yields on inner billets.

The method of cooling NPR ingots has been changed to reduce the furnace downtime. Instead of furnace cooling completely, the ingots are removed from the furnace, the mold covered, and the unit cooled in a booth. No changes in structure were observed.

The final portion of the 1.25 enriched outer fuel was shipped to HAPO in August. Early in August, the NPR cast metal was changed from "300" to "500" type metal.

Test quantities of 1.95 enriched NPR fuel with alloying additions of 300 Fe and 800 Al are being processed. Companion pieces of standard composition are also included.

5. Conversion from 7 Inch to 8 Inch Diameter Ingots

With the approval of SRP for the use of 8 inch solid ingots for the Mark V-B inner fuel, all rolled metal is now processed from this size. Scheduling, inventory control, and melting operations have been improved through this standardization.

6. Conversion to 9 Inch Ingots for Mark V-B Outer Extrusions

Substantially lower production costs are anticipated as a result of development of a process of producing solid 9 inch ingots,

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drilling, and extruding closer to finished dimensions for the Mark V-B outer fuel. Partial conversion in production has started to permit Reactive Metals to gain further experience with this change.

7. Elimination of Beta Treatment for SRP Ingots

Approval for processing of Mark V-E Ingots without heat treatment prior to extrusion was granted by SRP. Several more campaigns are planned to permit RMI to obtain further experience.

Due to more severe Mark V-B irradiation exposure, a reactor test will be required to ascertain the advisability of eliminating heat treatment of this fuel.

8. Changes in Blank Size - Mark V-E Inner Fuel

Variations in wall thickness, due to extrusion, together with the machining method used, resulted in lower than desirable yields. This combination left defects on the surface which could not be removed.

To eliminate this difficulty, and still hold costs down, it was proposed that more stock (.025 inch) on the outer diameter be left prior to heat treatment. The change was approved by SRP and placed in operation.

DEVELOPMENT

1. University of Florida Contract

NLO has a subcontract at the University of Florida to study the quaternary phase diagram of U-Fe-Si-C and also to investigate deformation mechanisms of U and U-base alloys by straining samples at various rates and temperatures.

Work on the phase system has been started with arc melting and metallographic analyses of several alloys.

Deformation studies have been completed on unalloyed uranium at room temperature, 400°C, 500°C, and 600°C at strain rates of .009, .08, and .75 in./in./minute. The results have shown the following:

1. Twinning accounts for little of the deformation at 600°C.
2. Distribution of inclusions and second phase particles is uniform during all deformations.

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3. At 600°C, the amount of subgrain boundary increases with total specimen extension and with strain rate.
4. The volume fraction of twins remains constant with increasing strain at 600°C.
5. Twinning becomes more important as a mode of deformation below 600°C.
6. Deformation at temperatures below 600°C does not result in well developed subgrains.

2. Electron Microprobe Studies

Identification of pure oxides and hydrides, by fluorescence from impact of the electron beam, has been accomplished on the microprobe.

Useful techniques for identification of (Zr,U)C phases have also been established in working with uranium shot particles. The eutectic composition of the UP network phase was also verified through use of the microprobe.

3. Texture Gradients in Induction Heated-Oil Quenched Cores

Growth index values for induction heated-oil quenched cores were measured in the radial, tangential, and longitudinal direction. Curves showing variations from outside to inside of the hollow cores revealed no differences from standard salt heated-oil quenched cores. Therefore, dimensional stability during irradiation should be equivalent to present production fuel.

4. Electron Microscope Studies of U-C System

Very satisfactory techniques for examining thin sections of uranium have been developed. Good photographs have been obtained of cast uranium containing slight additions of carbon. The high magnification photographs have shown dislocation networks, high angle boundaries, and tilt boundaries of importance in understanding the physical metallurgy of uranium. Fine particles (0.1 to 0.25 microns) of U(C,N,O) have been observed as precipitates on low index planes.

5. Grain Size Charts and Standards

Metal samples and copies of charts and procedures have been sent to all Working Committee Members for comment. This will be discussed at the Working Committee meeting in October.

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SUMMARY OF THE WORKING COMMITTEE SITE REPORT FROM
SAVANNAH RIVER PLANT
FOR THE PERIOD OF MAY 1964 TO SEPTEMBER 1964

Static cast cylinders of Sicral F-2 alloy, and centrifugally cast Mark V-B-OF cores of an Fe-Si-Al alloy were received for metallurgical characterization. Very minor internal porosity, and acceptable surface quality was observed. Following beta heat treatment, which had to be modified from the standard treatment for the Sicral F-2 alloy, the fuel cores had acceptable grain size and grain orientation. Irradiation of both materials is planned.

Process changes adopted at FMPC that should result in lower manufacturing costs for SRP cores are, (1) conversion from 7-3/8-inch in diameter hollow ingots to 9-inch diameter solid ingots, (2) reduction of the amount of overstock on Mark V-B extruded tubing from 0.125-inch on OD and ID to 0.100-inch and 0.075-inch on OD and ID, respectively, (3) machining of Mark V-B inner cores on the Cross Transermatic, (4) modification of the casting cycle for Mark V-E ingots, and (5) elimination of triple beta heat treatment of Mark V-E ingots.

Hot die size bonding was demonstrated as an acceptable cladding process for Mark V-B-OF slugs during July. Current programs are designed to develop similar confidence in our ability to clad Mark V-E-OF and IF slugs by this process.

Post irradiation examination of Mark V-B-OF slugs irradiated during the winter of 1963-1964 revealed that low alloy (150 Fe - 100 Si) and adjusted low alloy (175 Fe - 175 Si) uranium has satisfactory dimensional stability for normal exposures and central metal temperatures. Diameter increases of 0.005 to 0.007-inch, and volume increases of less than 2% were found in slugs irradiated to 1600-1800 MWD/T at central metal temperatures ranging from 300° to 410°C.

An extensive series of irradiation tests of the performance of various alloys in Mark V-B outer fuel slugs were completed. Measurements of the volume changes are now being made. The results to date show the following:

- ° The four alloys with greatest swelling resistance, listed in order of decreasing performance, are:

Composition, ppm			
Fe	Si	Al	Mo
-	350	-	1000
350	350	800	-
350	350	800	1000
250	350	-	-

These alloys appear to be capable of operation to maximum exposures of at least 3000 $\frac{\text{MWD}}{\text{T}}$ at temperatures in the range 475°-500°C with less than

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2% increase in volume.

- ° Considerable anisotropic growth was observed in the Si-Al series of alloys and resulted in premature discharge of five assemblies in one of the tests. Similar behavior was exhibited by an assembly of 350 ppm Si-1000 ppm Mo alloy that was quenched to 500°C during heat treatment.
- ° Additions of Cr to the Fe-Si-Al alloys decreased the resistance to swelling.
- ° No significant difference was observed in the performance of ingot and dingot slugs of alloys of the following compositions:

Nominal Composition, ppm		
<u>Fe</u>	<u>Si</u>	<u>Al</u>
-	250	-
-	250	250
200	250	-
200	250	250

All of these alloys appear to be satisfactory for operation at normal temperatures (420°C Max.) for nearly twice the normal exposure (3500 $\frac{\text{MWD}}{\text{T}}$).

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Summary of the Working Committee Site Report From

GENERAL ELECTRIC COMPANY - HAPO

For the Period of April 1, 1964 to September 1, 1964

IRRADIATION PROCESSING DEPARTMENT

The Hanford specification for the maximum iron content of uranium has been increased from 185 ppm to 200 ppm. Use of remelted top crops in up to 15 per cent of the charge weight was also approved for both normal and enriched ingots.

A test comparing salt-oil and induction-oil heat treated normal uranium cores (O3N) was discharged at 650 MWD/T exposure. No statistical difference was observed in the average warp of the salt and induction heat-treated cores. Pilot-scale testing of up to 20 tons of induction heat-treated cores is expected to be resumed in October 1964.

Approximately 12.5 tons of seven-inch depleted fuel elements were charged in B Reactor during July, and 13.5 tons of self-supported depleted fuel elements were charged in KE Reactor in August to produce high (18 w/o) Pu-240 product. Goal exposures are expected to average 1400 and 1600 MWD/T, respectively.

Thirteen normal and 26 enriched production fuel elements failed in the reactors during the period from April 1, 1964 through August 31, 1964. The higher failure rate is attributed to the use of non-bumper enriched fuel and an apparent decrease in quality as measured by total bond count.

The results of a test comparing the dimensional behavior of salt-water heat treated six and ten-inch enriched cores to 800 MWD/T exposure shows no significant difference in warp. Further tests leading to production transition are planned.

Initial test quantities of twelve-inch natural cores warped excessively during canning. Warp of recovered cores correlated strongly with the heat treat induced warp prior to straightening.

Ex-reactor testing was completed and in-reactor testing is underway on a more economical, stronger "arch" rail design to replace the present collapsible-bridge rail on K Reactor self-supported fuel.

A development facility for the assembly of thorium-oxide target elements was established in June, and is now being used to produce material for U-233 production. Process development is oriented toward improving the current average target element compacted oxide density (7.5 ± 0.2 g/cc).

Over 2500 hot die sized fuel elements have been irradiated or are undergoing irradiation. Except for an unforeseen diameter growth problem (six to eight mils more than AlSi fuel), irradiation of this material has progressed

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satisfactorily. It is expected that this problem will be resolved by process parameter tests in progress. A hot die sizing pilot plant is being equipped to produce 5000 fuel elements per month beginning about January 1965.

N-REACTOR DEPARTMENT

N-REACTOR PRODUCTION FUELS

Fuel Production Status

During the second quarter of CY 1964, 119.2 tons of uranium were coextruded with a uranium utilization of 69.8 per cent. This utilization figure is 2.8 per cent lower than that for the preceding quarter. The decreased yield is largely attributed to the introduction of new fuel models and a change in the amount of permissible length of rework for these models. Major shop problems were warp, external clad thickness variation, and weld rejects, all on inner fuel elements. A study of coextrusion end defects has resulted in a revised tentative cutting schedule in which an additional ten inches of good inner tube and six inches of good outer tube may be recovered.

Billet Development

Progress in three development programs produced the following results: (1) Coextrusion from tipped-mandrel-produced billets showed a 30 per cent decrease in maximum clad thickness variation, a significant improvement. Warp in the billet stock, however, resulted in a poor billet yield, approximately 35 per cent, requiring further development. (2) Metallographic examination of billets extruded from cupped ingots showed improved ID structure over normally-extruded billets. Inner cladding thickness variation of the coextruded fuel from these billets was better than from standard billets, but the small number of ingots tested limits the evaluation. (3) Primary extrusion results were satisfactory for ten billet assemblies in which a highly-worked inner sleeve was used. Coextrusion will be performed at Hanford.

N-Reactor Fuel Development

Alternate Uranium Composition

Fabrication development, material evaluation, and irradiation testing programs are in process for the selection of fuel materials capable of satisfactory performance under the more severe operating conditions required by the coproduct mode of operation in N-Reactor. Three potential billet fabrication routes are being evaluated for fabrication of billets from prospective fuel element alloys.

Fuel compositions known to be amenable to current N-fuel fabrication processes are being prepared for fuel element irradiation tests. These tests are being supplemented by a comprehensive program of capsule irradiations to distinguish the effect of alloying additions upon

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fabrication, corrosion resistance, and swelling performance. Material evaluation and heat treating effects are included in these studies.

TIG-Braze End Closure

The TIG-braze closure is made in a single step by making a conventional tungsten-inert-gas weld with a wire preform between the end cap and the fuel clad. The wire, a zirconium-beryllium alloy, is set in a groove in the cap prior to welding and is melted during the welding operation to form the braze joint underneath the weld and is bonded to the weld.

Tooling problems resulting from the need of an interference fit between the cap and cladding have been solved as well as those existing at the V-shaped uranium-cap juncture. Current studies include means of manufacturing wire preforms. The two most promising techniques include swaging steel clad zirconium-beryllium alloy followed by chemical removal of the steel from the finished wire and coextrusion of a bundle of steel clad zircaloy-beryllium rods in a steel can.

Irradiation Experience

N-Fuel Prototype Tests

Radiometallurgical examination has been completed on an NOE irradiated in a KER loop to 3070 MWD/T and its companion NIE irradiated to 2440 MWD/T. The fuel of the NOE experienced a 3.64 v/o increase and the fuel of the NIE experienced 1.17 v/o increase as a consequence of the KER irradiation. These components appear in excellent condition without indications of warp, clad bumping or rippling, crud deposits or corrosion effects, and the bores appear undistorted. However, the examination of the structure, which is characteristically hashed and swirled, reveals apparent voids in the swirls of the structure. The voids appear to be tearing at boundaries between zones of the uranium fuel that are distorted by the irradiation. Electron microscopy has provided further evidence of this tearing behavior and indicates that this is the major factor contributing to the observed fuel swelling.

Heavy-Wall Driver-Tube Fuel Element Testing

Thirteen 1.25 per cent enriched driver elements (heavy-wall, fuel tube) were discharged from a KER loop after attaining an average exposure of about 1300 MWD/T. Four drivers in the center of the charge swelled in excess of 2 v/o.

A maximum fuel swelling of 3.3 v/o was observed in one of the centrally located drivers which operated with a maximum fuel temperature of approximately 530 C to an exposure of about 1850 MWD/T. A maximum fuel swelling of 3.6 v/o (at 2000 MWD/T) had been predicted on the basis of previous KER fuel irradiation data.

Alternate Composition Fuel Tests

High temperature irradiation tests in KER loops of fuel elements made from uranium with iron-aluminum additions showed them to swell about 60 per cent

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as much as standard uranium fuel in the same loop. Maximum fuel temperatures ranged from 455 C to 585 C and average exposure was 1500 MWD/T in one test and 2500 MWD/T in the other.

N-Fuel Failure

On July 7, 1964, a fuel failure occurred in a fringe tube of N-Reactor while the reactor was operating at 30 per cent of rated power. Examination revealed that the failure was caused by a defect in the end cap. This defect, which extended through the cap at its inner surface, connected with porosity in the weld to permit water entry to the uranium. The thin layer of braze material under the end cap may have delayed the failure so that it did not occur during autoclaving.

HANFORD LABORATORIES

Sixteen single tube fuel elements, half containing standard N composition fuel and half containing nominal 400 ppm Fe and 800 ppm Al additives, have been irradiated at maximum fuel temperatures ranging from 455 to 585 C. Eight were exposed to an average of 1400 MWD/T and eight to 2500 MWD/T. In each case, the Fe-Al additions cut swelling from 2.1 v/o in the standard fuel and 1.2 v/o in the additive fuel.

Destructive examination has been completed on an N-outer component irradiated to 3070 MWD/T and its companion inner component irradiated to 2440 MWD/T. The outer component suffered a 3.64 v/o increase and the inner 1.17 v/o. No evidence of inadequate clad, bond, closure, or support performance has been detected. Void formation in the fuel appears to be primarily of mechanical origin rather than gas porosity.

Thirteen 1.25 per cent enriched driver elements were irradiated to 1300 MWD/T average exposure, 1850 MWD/T peak exposure. A maximum fuel swelling of 3.3 v/o was observed in one of the peak exposure elements. A standard N-fuel composition was employed in these elements.

Fuel elements of a heavy wall single tube design are being developed for exposure to 2200 MWD/T (peak) at peak central metal temperatures of 600 C. Altered goal exposures for the current tube-in-tube design to as high as 4000 MWD/T at 430 C metal temperature are being considered. Both conditions require more swelling resistance than that provided by the current 150 ppm Fe + 100 ppm Si N-fuel composition.

Fuel compositions containing varied levels of Fe, Si, and Al are being procured for irradiation testing in behalf of these objectives. In addition, a number of compositions will be evaluated by capsule irradiations. These will contain compositions of Fe, Si, Al, Zr, P, Nb, and Mo.

A portion of the development work deals with the corrosion characteristics of these fuels. Corrosion behavior is being correlated against the half cell potential of each alloy measured against a platinum-gold anode.

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A developmental end closure utilizing a conventional tungsten-inert gas weld with a Be-Zr wire between the end cap and the fuel clad is being tested.

A modified strengthened N-outer fuel support having a tee-shaped cross section has been designed and successfully hot forged.

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