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DOUGLAS UNITED NUCLEAR, INC.

REPORT TO THE WORKING COMMITTEE OF

THE FUEL ELEMENT DEVELOPMENT COMMITTEE

by:

J. T. Stringer
Fuels Engineering Subsection
Production Fuels Section
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SMALL AND K REACTOR PRODUCTION FUELS

Uranium Core Production Data

Inspection of Virgin Cores

The combined UT-2 and visual bare-core reject rate was 0.15 percent for the period December 1, 1965 through March 31, 1966.

Grain Size

The average grain size of cores received during the period October 15, 1965 through March 3, 1966, was between A-6 and A-7 on salt-water heat treated cores, and between A-5 and A-6 on induction-oil and salt-oil heat treated cores.

Uranium Specifications

Since June 1963, certain types of substandard fuel elements have been charged into the upstream five positions in the reactor process tubes. To date, this upstream charging program has been limited to fuels with canning defects such as end-facing rejects, marred-surface rejects, high bond count rejects, and other similar categories. The number of elements charged under this program was 55,000 in CY 1965, and is expected, due to recent revisions in the authorized reject categories, to average 89,000 elements per year. The upstream charging is practical because the failure potential in the upstream five positions is far less than in the downstream positions. Currently, approximately five percent of the fuel charged is classed as "upstream fuel," and the reactors have the capacity to charge approximately 12 percent as upstream fuel. No failures have been sustained in the upstream charging program, and the success has prompted extension of the program to include cores that are rejected at the feed site.

National Lead Company of Ohio has proposed establishing a Class II core category for upstream charging which will include cores rejected for seven types of defects. The seven reject types are:

- (1) Acceptable cores from ingots in which the core metal quality reject rate is greater than 25 percent.
- (2) Cores rejected by the UT-2 tester for fine grains, but which can be distinguished from unheat-treated cores.
- (3) Cores with a machining defect on the radius.
- (4) Cores with tightly closed seams.
- (5) Cores with reduced dimensions comparable to the dimensions on recovered cores.
- (6) Cores produced from ingots that are within 20 percent of the chemical composition limits (carbon and density excepted).

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- (7) Cores produced from ingots which have deviated from the process specifications but which comply with all product specifications.

No problems are anticipated in irradiating any of the above cores except for Item (4), tightly closed seams, which will have to be carefully evaluated in order to establish acceptance standards. The Class II category will probably comprise two to three percent of the cores received by Douglas United Nuclear.

Fuel Performance

Fuel performance has been very good for the past four months. Two enriched and one natural AlSi-bonded fuel elements and one hot-die-sized overbore element failed during the period December 16 through April 27, 1966. These failures are summarized in Table I.

TABLE I

<u>Fuel Element Type</u>	<u>Reactor</u>	<u>Exposure</u>	<u>Classification</u>	<u>Rupture Date</u>
Natural Nonbumpered- AlSi	C	88	Side Hot Spot	12/23/65
Natural Overbore- HDS	C	93	Side Groove Corrosion	12/28/65
Enriched Self-Support- AlSi	KW	51	Side Mechani- cal Damage	1/12/66
Enriched Bumpered- AlSi	D	34	Core Split	2/14/66

The improved fuel performance can be attributed largely to the increased use of bumpered fuel in B, C, and D Reactors. However, control chart calculations indicate an improvement in intrinsic fuel quality. Bumbers are being used on approximately 67 percent of all non-self-support fuel in C Reactor and on approximately 50 percent of the fuel in B and D Reactors. When used, the bumpered fuel is generally charged into the downstream 65 percent of a process tube.

Future Planning - Five Year R&D Program

Several of the five-year Research and Development programs heavily involve the fuels business. A brief synopsis of the plans for FY 1967 and FY 1968 on these programs is presented below.

Basic Plutonium Production

The development effort in this program will be directed principally toward cost reduction, and the main fuels cost reduction item is the hot-die-sizing process. The schedule for conversion to hot-die-sizing calls for the procurement and installation of equipment starting in July 1968, and full conversion being accomplished in January 1969.

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The evaluation of longer, 10-inch and 12-inch, fuel elements will continue, and it is anticipated that feed site fabrication costs on longer fuel can be reduced sufficiently to realize a net reduction in AEC operating costs by their use.

High Power Density Fuel

The objective of this program is to develop a fuel element that will provide satisfactory service at twice the current tube power. Such an element would make 50 percent of the reactor space available for target loadings. In this operation, the maximum core temperature would be 460 C, the maximum cladding temperature would be 155 C, and the average exposure could be as high as 2400 MWD/T. The basic fuel problems are cladding corrosion and core stability. The program is directed first toward achieving a 50 percent increase in tube power and later toward a 100 percent increase. The scheduled tests in this program are listed in Table II.

Co-Product

A demonstration load of 2.1 percent enriched fuel, lithium-aluminum and lithium-aluminate targets will be irradiated in a K Reactor. The loading will consist of 21 tubes of driver elements operating at 130 percent of present tube power and six to eight columns of target elements. The load will be reactor charged in November 1966.

Reactor Modernization

This program is directed toward increasing the flexibility of the Richland reactors to support non-defense needs by enlarging the process channels approximately one inch. The enlargement of the channels makes additional volume available for target elements, coolant, and fuel. The fuel used in a modernized reactor will be a rod-in-tube geometry with finished fuel dimensions of approximately 2.4 inch O.D. and 1.3 inch I.D. on the tube, and one-inch diameter on the rod. Approximately 450 sets of rod-in-tube fuel cores have been received from the FMPC for process development and for testing in the KER facility. A multi-tube test facility will be installed in one of the reactors within the next two years. This facility will probably involve 40 to 50 enlarged process tubes.

Thoria Development

The possibility of specifying surface area rather than loss-on-ignition to control the amount of volatiles present in thoria is being investigated. Samples of Mallinckrodt sol-gel thoria with various surface areas were heated under vacuum to 500 C and held at that temperature for twelve hours to remove moisture and adsorbed gases. A portion of each sample was then spread in a thin layer and exposed to an air stream of 52.9 percent relative humidity at 25 C for 96 to 120 hours. Samples of both the exposed and the unexposed thoria were analyzed for moisture and non-condensable gases. The results of the experiment are shown in Figure 1. A mass spectrometer analysis showed the non-condensable gas on one sample to be approximately 80 percent CO₂, 1.7 percent N₂, 5.3 percent CO, 3.6 percent H₂, 1.8 percent CH₄, 6 percent NO₂, and 1.1 percent H₂O.

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TABLE II

TESTING SCHEDULE FOR HIGH POWER DENSITY PROGRAM

Test	Purpose	Number of Tubes	Reactor	Charge Date
1.25 percent enriched AlSi fuel, standard alloy	Preliminary test at increased tube power.	5	KW	May 1966
Initial evaluation of high-silicon clad HDS fuel	Determine corrosion characteristics of HDA-4 (Al-10 w/o Si - 1 w/o Ni) cladding. 0.97 enriched fuel.	29	D	May 1966
1.25 percent enriched uranium alloy and heat treatment test	Evaluate effect of alloying and heat treatment on core stability during operation at 50 percent increase in tube power. AlSi and HDS clad, salt-oil and induction-oil heat treatments, uranium alloys: 150 Fe-100 Si, 350 Fe-800 Al, 350 Fe-350 Si-800 Al, 350 Si.	18	K	July 1966
High-silicon clad HDS fuel	Further evaluation of HDA-4 cladding alloy, 0.947 enriched.	18	K	August 1966
Nickel-plated 8001 alloy clad HDS fuel	Evaluate the use of nickel plating to improve corrosion characteristics. 0.947 enriched fuel.	18	K	September 1966
Demonstration of 50 percent increase in tube power	Demonstration test, 1.25 percent enriched.	25-100	K	February 1967
Preliminary evaluation of fuel at 100 percent increase in tube power.	Evaluate stability and corrosion problems of fuel operating at 100 percent increase in tube power, 2.1 percent enriched.	5	K	September 1967

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Heat Treating

A test has been prepared to determine the irradiation performance of hot-die-sized fuel with four core heat treatments; hollow salt-oil, solid salt-oil, hollow induction-oil, and solid induction-oil. X-ray diffraction data for the four heat treatments are shown in Figure 2.

UO₂ Irradiations

Three partial columns of aluminum-clad I&E geometry UO₂ elements were charged in KW reactor on November 14, 1965. On February 11, 1966, a failure was sustained in one column, and the test was discharged at an average exposure of 1490 MWD/T. The elements contained uranium enriched to 1.3 percent U-235, and two columns were fabricated by vibrational compaction and the third with sintered pellets. The core densities on the two types of fuel were 87 and 93 percent of theoretical, respectively. Tubes 1582 and 1580 contained the vibrationally compacted UO₂ and operated at maximum specific powers of 60 to 69 KW/ft.; tube 1584 contained sintered UO₂ and operated at a maximum specific power of 82 to 100 KW/ft. After discharge, two, possibly four, failed elements were found in tube 1584. Figures 3 and 4 show the external appearance of two failures which occurred in positions 7 and 8. The other two failures were not recognized when the fuel was first examined and may have occurred after discharge. They are characterized by small cracks in the cladding.

Figure 5 is a cross-section of the element from position 8 in tube 1584. A void area of about 12 percent is observed, and the structure indicates that approximately 70 percent of the core operated in the molten stage. A region about 90 mils thick on the O.D. and 40 mils thick on the I.D. did not become molten. The two failures in positions 7 and 8 occurred on adjacent ends of the elements in the region of maximum specific power. The apparent cause of the failures was localized overheating which melted the aluminum cladding.

Alternate Process Development

Ledge and Groove Corrosion

Localized corrosion of aluminum-clad fuel elements, defined as ledge and groove corrosion, is observed in some of the downstream fuel positions in all Hanford production reactors. The frequency and the magnitude of the corrosion problem have varied with complete randomness.

Early experience seemed to indicate that hot-die-sized fuel might be more subject to ledge and groove corrosion than AlSi fuels. A number of studies were begun to evaluate this. The run-to-rupture test, PT-781, was used to try to determine any apparent differences in the two fuel types. Table III is a compilation of the test data from PT-781.

Although the test data indicates specific differences in the fuels, there is no firm basis for predicting differences in performance of the fuels. Test data have been computer processed, and histograms prepared relating uniform and non-uniform corrosion to several environmental conditions

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FIGURE 2
G-2 DATA FOR HDS CORE HEAT TREATMENTS

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FIGURE 3

UO₂ Element - Tube 1584 KW
Position 7

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FIGURE 4

UO₂ Element - Tube 1584 KW
Position 8

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-12-

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FIGURE 5

UO₂ Element - Tube 1584 KW
Position 8

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TABLE III

RUN-TO-RUPTURE TEST DATA
(PT-781)

BASIS:

10 Columns AlSi to Goal (~ 335 elements)
10 Columns HDS to Goal (~ 335 elements)

	<u>HDS</u>	<u>AlSi</u>
Average Warp	1.6 mils	2.1 mils
TFC	2.6 mils	3.7 mils
Hot-Spot Corrosion	22 pcs.	86 pcs.
Primary Ledge and Groove Corrosion	130 pcs.	110 pcs.
Severe Corrosion (External)		
< 10 mils	--no difference--	
> 10 mils	57 pcs.	78 pcs.
Severe Corrosion (Internal)	49 pcs.	19 pcs.
Weight Loss	1.5 gm.	2.3 gm.
Δ O.D. ₂	3.3 mils (-6 +12 mils)	6.1 mils (-20 +22 mils)

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including power, water temperature, exposure, tube age, calculated local water temperature, and surface temperature. Data are not yet evaluated.

Radiometallurgy work on a single HDS non-failed fuel element from PT-781 included examination of the core-jacket bonding layers at twelve points on the external (O.D.) and internal (I.D.) surfaces. Bonding as indicated by absence of separation, and presence of thin, continuous diffusion layers, was uniformly excellent. Efforts to produce a micro-etch on the HDS fuel to reveal aluminum grain size were unsuccessful, and this work is continuing.

High velocity water corrosion tests, aimed at defining differences between fuel jacketing that may be indicative of groove corrosion behavior, have to date included a series of tests under the following conditions.

Water temperature	105 - 110 C
Water velocity (metal)	80 - 85 ft./sec.
Duration	16 - 70 hours
Water quality	Variable
Test material	Variable

Initial tests were carried out using 300 Area process water, and corrosion penetration up to 23 mils deep was achieved in hot-die-sized jacketing. Further comparative tests indicated AlSi jacketed fuel to be less severely attacked than HDS jacketing, with three to four mils penetration in the former and up to 12 mils in the latter. In the later tests, both the observed differences and the total amount of corrosion were reduced in 300 Area process water with evidence of scale formation in the test area. In seeking to standardize the water quality, both reactor process water and deionized water were tested with additions of diatomaceous earth up to 50 ppm. The most reproducible behavior was achieved with deionized water with 50 ppm diatomaceous earth. Tests in this media have included:

- HDS 8001 alloy - bare metal*
- HDS high silicon (10 w/o) alloy
- HDS C-64 alloy - bare metal
- HDS 8001 alloy with autoclave film intact

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*Autoclave film removed by abrasion with emery cloth

These were compared to an AlSi-brazed 8001 alloy jacketing, without autoclave film for the first three and with the film intact for the fourth test. Testing was carried out 22 to 24 hours except for the autoclave material, which was tested for 50 hours. Corrosion was generally in the range of one to three mils, with no apparent difference between the test material and the AlSi dip-canned standard. The tests were then repeated using process water obtained from 100-K Area. Again there was no apparent difference between the test material and the standard. However, this work is being carried further to evaluate the galvanic properties of the fuels-coolant system.

Paralleling the comparison of hot-die-sized and AlSi process fuel corrosion behavior was a test to reproduce pitting or groove corrosion. Electrolytic tests of hot-die-sized fuel elements included preliminary experiments in

300 Area process water, deionized water, and a saline electrolyte (.01 molar) buffered to pH 5.0 to 5.5 with sodium acetate and acetic acid. Tests in 300 Area process water and in deionized water were not considered successful, with only minor scattered pitting or no corrosion produced after an approximately six-hour test. Initial experiments with the saline buffered solution were carried out with a D.C. current of five amps/fuel element, and a solution temperature of 75 to 80 C. Gross pitting and discoloration were induced after only one hour of testing. Based on preliminary evaluation, the corrosion appears to be somewhat characteristic of in-reactor corrosion. Further evaluation of the corrosion experience and the test variables is underway. The second test was based on both the known galvanic potential and the fact that there is some in-reactor vibration. A similar setup was used as for the first test except that an ultrasonic generator was used to simulate vibration. In this case, both pits and grooves were formed, indicating that vibration may be a contributor to the forming of grooves from pits. Again, both types of fuels seemed to be attacked equally.

Since silicon-bearing aluminum alloys are being studied as a possible future replacement for the X-8001 alloy, a fuel clad with high-silicon alloy (10 w/o silicon-aluminum) was subjected to the galvanic-vibration test conditions. This material had no apparent pitting, but did show signs of uniform corrosion.

As a part of the study of ledge and groove corrosion, a study was made of the known cases of corrosion for each reactor for the years 1963 through 1965. The results of this study are shown in Figures 6 through 8. A study of these results shows that there is no predictable pattern to corrosion in general, but that on the gross basis it might be said to worsen toward late summer. However, there is not enough data for the surrounding months to verify this. More work is being carried out to extend this study and also to evaluate water quality and how it varied over the same interval. The objective of this work is to establish correlation between water properties and corrosion frequency and severity.

Aimed at further defining physical differences between the aluminum jacketing of HDS and ALSi dip-canned fuel elements, measurements of residual stress were made, using unirradiated fuel elements from the PT-781 (run-to-rupture test) material. No consistent difference between the types of fuels or between locations on the fuel is indicated by the stress measurements which generally range from 1100 psi tensile to 9000 psi tensile, with two values for HDS fuels as low as 2300 psi compressive. Estimated accuracy on the values is ± 2500 psi; values are not absolute since no comparable standards were available. A qualitative appraisal is that HDS exhibited more variability than the ALSi.

A second method of qualitative measurement yielded anomalous results, in that the jacket of both types of fuels appeared to be in compression. The diameter of transverse sections of the fuel elements were measured. The uranium was then removed by dissolution of the nickel in hot nitric acid. A blank aluminum piece was included to estimate the aluminum dissolution. Finally, the resulting rings of aluminum were measured and corrected for aluminum dissolution. It was found that the jacketing grew in diameter, ranging from 16 to 20 mils for ALSi fuels and 8 to 20 mils for HDS fuels,

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FIGURE 6

PERCENT OF FUEL ELEMENTS EXHIBITING PRIMARY GROOVE CORROSION

FIGURE 7

PERCENT OF FUEL ELEMENTS EXHIBITING PRIMARY LEDGE CORROSION

FIGURE 8

PERCENT OF FUEL ELEMENTS EXHIBITING PRIMARY LEDGE OR GROOVE CORROSION

indicating the jacketing on the fuel elements was under compressive stress. Measurements were made on each of two HDS and two AlSi fuels at three points. Again, results indicate only higher variability in the HDS jacketing compared to AlSi.

High Silicon-Aluminum Alloy Test

An irradiation test of enriched fuels clad in high silicon-aluminum alloy (10 w/o silicon) was prepared and is scheduled to be charged in a small reactor during May. The design of the irradiation test provides for comparison of the corrosion behavior of hot-die-sized high-silicon alloy, hot-die-sized 8001 alloy, and AlSi dip-canned 8001 alloy. It includes five charges of each type and five "striped" charges of high silicon and hot-die-sized 8001 alloy. The test is designed to ascertain a factor of two difference in weight loss at a 95 percent confidence level (approximately two-fold difference in weight loss between high silicon and 8001 alloy was indicated by laboratory corrosion tests). The fuel cores are small reactor 0.947 enriched uranium. Cores having different cladding treatment were selected from adjacent positions in the fuel rod at the producer site to minimize any difference in corrosion behavior due to core quality.

Nickel Plating

1. Uranium

Autoclave tests of nickel-plated uranium specimens indicated that a significant improvement in resistance to attack by water can be achieved by alterations of uranium etching and plating conditions. A single sample having approximately 2.4 mils-thick nickel plate showed no evidence of failure after 388 hours (16.2 days) exposure to 175 C steam. This is an approximately 35-fold improvement over plate 2.1 to 2.5 mils thick, etched and plated by the present pilot plant process. Results of testing three samples are as follows:

<u>Electrolytic Etch Solution</u>	<u>Type Etch</u>	<u>Plating Bath</u>	<u>Plate Thickness, Mils</u>	<u>Behavior in 175 C Steam</u>
H ₂ SO ₄ -HCl	"Smooth"	Sulfamate with approximately .02 M Cl ⁻	2.4	No evidence of failure after 388 hours (16.2 days)
H ₂ SO ₄ -HCl	"Smooth"	Sulfamate with approximately .15 M Cl ⁻	2.1	Failed after 106 ± 8 hours
H ₂ SO ₄ -HCl	"Smooth"	Std. Watts	2.1	(1) Failed after 33 hours (2) Not failed after 25 hours

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<u>Electrolytic Etch Solution</u>	<u>Type Etch</u>	<u>Plating Bath</u>	<u>Plate Thickness, Mils</u>	<u>Behavior in 175 C Steam</u>
H ₃ PO ₄ -HCl	"Rough"	Std. Watts	2.2	Failed after 11 hours

All samples were rotated at 750 RPM during plating.

Exploratory experiments in electrodeposition of nickel by pulse plating included increasing the cathode current density up to approximately 1900 amp/sq. ft. Visual appraisal of the samples indicated that the higher current density reduced porosity as well as altered the grain structure of the plate, manifested by an increase in brightness. These observations are based on four cylindrical uranium samples plated as follows in a nickel sulfamate bath, leaving approximately 0.15 M Cl.

<u>Sample No.</u>	<u>Current Density Amp/Sq. Ft.</u>	<u>D.C. "ON" Time, Microsecond</u>	<u>D.C. "OFF" Time, Microsecond</u>
1	1000	400	2800
2	1700	400	2800
3	1900	400	4600
4	1000	400	4600

Samples #1 and #4 exhibited visible pores in the plate. Samples #2 and #3 were notably brighter than #1 and #4.

Preliminary metallographic evaluation of nickel plate deposited by pulse plating revealed a difference in grain size produced by varying the "ON" time and the "OFF" time for the direct current. Approximately two-mil thick plates deposited at 600 amp/sq. ft. by the following D.C. pulse techniques were evaluated:

<u>Sample Number</u>	<u>"ON Time, Micro-Sec.</u>	<u>"OFF" Time Micro-Sec.</u>
(1)	400	800
(2)	1,000	1,000
(3)	2,000	2,000

Sample (1) exhibited the finest grains and most random orientation, with the maximum grain size of approximately 0.4 mils diameter. Sample (2) exhibited larger grains, and sample (3) still larger, with single grains extending completely through the plate. Further evaluation of the grain-refining effects of pulse plating included metallographic study of plates deposited by non-pulsed current for comparison to pulsed-current plate. The non-pulsed plate deposited from a chloride-Watts bath; a bromide-Watts bath, and a chloride-sulfate bath appeared to be similar in that all three exhibited columnar grains oriented normal to the substrate surface with some single grains one mil and more in length.

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A single sample of uranium plated with triplex coating of approximately 0.3 mils Ni, 0.1 mils Cr, and 0.8 mils Ni failed after six hours' exposure in 175 C steam. Nickel was plated in a standard Watts-chloride bath employing the "rough" (H_3PO_4 -HCl) preplate etch.

2. Aluminum

Investigation of nickel deposition on aluminum to increase corrosion resistance of the fuel element jacketing surface included preliminary tests of chemical reduction of nickel ion employing hydrazine as a reducing agent. It is believed chemical ("electroless") reduction may possess some advantages over electrodeposition, including thickness control and freedom from porosity. Use of hydrazine (N_2H_4) as a reducing agent eliminates the phosphorous constituent of the plate, found in "electroless nickel" employing a sodium hypophosphite reducing agent. Uniform-appearing deposits were achieved with a deposition of 0.2 to 0.3 mils/hour. The plate was deposited both on bare aluminum and on aluminum coated with a galvanically-deposited zinc ("zincated"). Tests in hot caustic solution indicated the plates were porous and poorly adherent, with penetration and some detachment of the plate after 40 to 80 seconds immersion. Efforts to improve plate porosity and adhesion thus far have not been successful, including (1) heating the plated metal at 450 C for one hour and at 400 C for 16 hours, (2) applying D.C. at 15 to 20 amp/sq. ft. (aluminum cathodes) for five minutes after immersion to aid in starting the chemical deposition reaction.

Zirconium Plating

Zirconium coatings were successfully electrodeposited from a fused fluoride salt bath at temperatures of 700 and 800 C. At 700 C, a sound-appearing plate approximately 1/32 inch thick was deposited in 48 hours at a current density of approximately 10 amp/sq. ft. At 800 C, 50 amp/sq. ft. current density was employed, depositing an approximately 1/64 inch thick plate in 10 hours. This plate appeared larger grained than the 700 C deposit.

The tests cited above were part of a series employing an Li-K-Na fluoride eutectic bath and the following range of process variables:

Temperature	- 550 - 800 C
Current Density	- 10 - 50 amp/sq. ft.
Composition	- 6 - 16 weight percent ZrF_4

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At temperatures less than 650 C, powdery deposits were obtained at less than 10 weight percent ZrF_4 and at 10 weight percent and above the deposits were nodular or dendritic.

A series of fused chloride-salt baths and modified fluoride-salt baths were employed in an effort to obtain satisfactory plates in the region of 600 C. Three different chloride systems were:

Lithium-potassium eutectic
Cesium (40 mol percent)-Lithium (60 mol percent)
Cesium (65 mol percent)-Sodium (35 mol percent)

Plating carried out at 500 to 600 C was not successful in that in addition to zirconium, a crystalline material was deposited, tentatively identified as a zirconium-alkali metal compound. Additional work included use of a borium-lithium-potassium fluoride eutectic with a melting point of 452 C.

Experience essentially duplicated that using a sodium-lithium-potassium-fluoride eutectic. Studies of electrodeposition of zirconium from a fused salt bath included tests of plating directly on uranium at bath temperatures of 650 C and 700 C. A sodium-lithium-potassium-fluoride eutectic bath was used since several chloride baths, including other cations (barium, cesium), offered no improvement. Uranium pre-plating treatment consisted of degreasing followed by pickling in 10 M HNO_3 , 65 C, until the surface was visibly free of oxides. In the plating bath, two methods of pretreatment included:

- 1) A five-minute soak to dissolve the remaining oxide.
- 2) A five-minute anodic treatment at 100 ma/sq. cm.

At 650 C, only 1/4 to 1/2 mils thick of plate could be deposited. The cause(s) for the cessation of deposition are not known. Process variations included a ZrF_4 content in the bath of 10 and 15 weight percent and both "soak cleaning" and anodizing of the uranium in the plating bath. Plating was carried out at approximately 15 amp/sq. ft. At 700 C, employing the "soak cleaning" in the plating bath and 20 amp/sq. ft. current density, a plate 1/2 to one mil thick was deposited, but it readily detached as the sample was cooled in ambient air. Experiments to improve adhesion at the 700 C plating temperature are continuing.

Weld and Closure Testing

Hot-die-sizing tests employing ultrasonic vibration of the cap to achieve cap-end bonding during the sizing operation have been successful in reproducibly achieving good bonds between the lateral surface jacketing and the uranium core, but little or no bonding of the cap to the core has been exhibited. Standard HDS "O"-size natural uranium fuel components have been employed, with preheat and sizing conditions closely approximating those for the present pilot-plant process. Ultrasonic vibration of the cap is achieved by clamping the preheated assembly in a vertical position between two rams. The upper ram is coupled to four transducers which apply a torsional ultrasonic vibration. These two clamping rams are stationary during the sizing step. The sizing die encircles the lower ram, and sizing is accomplished by moving the sizing die upward traversing the length of the assembly.

On initial experiments, application of 3,600 kw of electrical energy to the transducers resulted in excessive deformation of the cap, which impeded the upward flow of the can wall above the die, and the sizing step could not be completed because of excessive wrinkling of the can wall. Redesign permitted the caps to be deformed sufficiently during sizing to intimately contact the can wall but not interfere with its upward travel during sizing.

In general, satisfactory bonding between the lateral-surface jacket and the core was achieved under all conditions tested, as evidenced by both

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metallography and stud pull results. Bonding of the base end core and can is achieved, but not consistently. At pre-sizing temperatures ranging from 400 to 550 C, base-end stud pull values range from 200 to 550 pounds ($\geq$ 300 pounds is considered satisfactory). Whether or not the base-end bonding is improved by ultrasonic vibration applied at the cap end is not known. Bonding between the cap and the core with any strength measurable by stud-pulling has not been achieved. Evidence of some Al-Ni diffusion is revealed by metallography. These studies are incomplete. Further tests include use of cores with concentric circular grooves on the end surfaces to induce aluminum displacement at the core-cap interface.

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