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THE FABRICATION OF THE FUEL ELEMENTS FOR THE TRANSIENT REACTOR TEST

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The Transient Reactor Test Facility was designed and constructed to operate with a large transient thermal flux for brief time intervals in order to permit meltdown studies on mockups of fast reactor fuel elements and for certain other reactor safety studies.⁽¹⁾ The core for this reactor contains highly enriched uranium oxide fuel particles dispersed in a graphite moderator. Due to the combination of high thermal conductivity of the graphite and wide dispersion of fuel, (carbon to U^{235} ratio of 10,000 to 1), the graphite serves as a heat sink for the thermal energy generated during a transient neutron burst. A graphite reflector surrounds the fuel portion of the core. Zircaloy-3 and aluminum were used as structural materials for the fuel and reflector blocks respectively. Zircaloy-3 was selected because of its low thermal neutron absorption, formability, strength, and resistance to air corrosion at core operating temperature up to 400°C. The design of this element is shown in Figure 1. Six 4" square x 8" long graphite-urania fuel blocks are contained in a 0.025" thick Zircaloy-3 can which protects the blocks from oxidation and contains fission products. The graphite reflector blocks are 2 ft. long and are jacketed in 0.050" thick aluminum cans. The reflector sections are riveted to the fuel section and cast aluminum upper and lower fittings are attached to the reflector. The finished assembly is approximately 9' long and weighs about 100 lbs. In addition to the 312 regular fuel assemblies which were fabricated, a number of special assemblies as shown in Figure 2 were prepared. These included instrumented assemblies for

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temperature measurement, straight reflector graphite assemblies containing no fuel, assemblies with access holes for test purposes, and assemblies containing a 2" I.D. central hole for insertion of control rods. Details of the regular fuel assembly elements only are contained in this report.

A breakdown of operations performed in the fuel element fabrication is shown in a flow sheet, Figure 3. The fuel matrix fabrication may be summarized as follows:

1. Mixing the components, U_3O_8 -carbon-graphite-pitch binder.
2. Hot mixing for one hour followed by pulverizing and crushing.
3. Hot pressing into individual blocks.
4. Baking at $950^{\circ}C$.

Details of these operations have been reported by J.H. Handwerk.⁽²⁾

Finished blocks were mechanically sound having an average density of 1.72 grams/cc.

Double arc-melted Zircaloy-3 ingot stock was converted to strip and sheet by forging, blooming, hot rolling, and cold rolling with intermediate vacuum annealing. This stock was fabricated into fuel can components which were assembled, loaded with thermally outgassed fuel blocks, then evacuated and sealed. Extruded aluminum cans were attached to the fuel section and loaded with graphite reflector blocks. The addition of cast aluminum end fittings completed the fuel element assembly. A photograph of all fuel element components prior to assembly is shown in Figure 4.

Preliminary outgassing studies of the fuel matrix as depicted in Figure 5, in which a block is heated in vacuum and the gas collected and analyzed, proved that appreciable quantities of absorbed and adsorbed non-condensable gases were evolved at temperatures up to $900^{\circ}C$. Typical analyses of gas samples taken at $850^{\circ}C$ and $900^{\circ}C$ are shown in Table I.

Hydrocarbons such as methane and ethene are decomposition products from the pitch binder. In one test a block was sealed in a container which was then evacuated, back filled to atmospheric pressure with argon, and heated to 800°C. Figure 6 is a chart of the gas volume released during heating indicating that a maximum is released at 150°C. Analysis of the gas inside the container after cooling to room temperature is shown in Table II. When projected to a typical fuel element containing six fuel blocks in a Zircaloy can with a 40 mil annulus between fuel and can, the release of 1200 cc of gas per block at 150°C would result in a pressure increase of 10.6 atmospheres inside the can. Since no provision was made for removal of gas from the sealed fuel can during reactor operation, it was imperative that the blocks be thermally outgassed before being sealed. A series of tests disclosed certain requisites for outgassing variables which resulted in negligible gas evolution on recycling after exposure to air for a time interval comparable to transfer of fuel blocks from the outgassing chamber to the fuel can in production. This procedure consisted of evacuating the loaded container to 25 microns or less, heating to 900°C, holding at temperature for 12 hours, furnace cooling, and transferring the blocks to the fuel can limiting their exposure in air to not more than 30 minutes. Figure 7 shows a typical pressure vs. temperature plot for a thermal outgassing cycle with peaks at 150°C, 600°C, and 850°C indicating the greatest release of gas occurred at these temperatures. In Figure 8 fuel blocks are shown being loaded into cells used for production outgassing. These consisted of a series of 8 Type 446 stainless steel 6" schedule 80 pipes each 12' long supported horizontally in a 150 KW electric resistance type box furnace. A maximum of 10 fuel blocks could be loaded into each tube which

was manifolded with three others to a mechanical vacuum pump. The entire system was equipped with safety interlocks, alarms, and controls to provide a protective inert atmosphere for the fuel in the event of any power failure or accidental loss of vacuum in the system during an outgassing cycle. The weight loss per fuel block due to thermal outgassing was from 2.5 grams to 3.0 grams.

The sides of the TREAT fuel element cans were fabricated from 0.025" thick Zircaloy-3 sheet stock. The sheet was cut to 50-3/4" lengths and machined to 7.275" +0.000" -0.005" wide. Locating holes were punched at the ends of the sheet as shown in Figure 9. These holes were used to position each piece in a press brake while forming a U-shaped section as shown in Figure 10. Two of these sections were then clamped in a welding jig and joined by inert-gas shielded-arc welding as shown in Figure 11. The two longitudinal weld seams were radiographed for weld defects and weld thickness variations. Typical radiographs of sound and defective welds are illustrated in Figure 12. After radiograph inspection the welded cans were cut to the desired finished length of 49-3/8".

The fuel can end caps were deep drawn in a closed die from 0.093" thick Zircaloy-3 stock. In Figure 13 a sheared Zircaloy-3 blank is shown entering the die which is mounted in a 90 ton hydraulic press. A finished end cap after forming, HNO₃-HF acid cleaning, and machining of the edges is illustrated in Figure 14. The bottom end cap was inserted in the 0.025" thick wall can to form an outwardly flanged joint. Figure 15 shows the supporting jig and pantograph drive for the inert-gas shielded-arc used in welding the end cap to the can.

To facilitate joining of the aluminum jacketed reflector portion of the element to the zirconium alloy jacketed fuel portion, four triangular Zircaloy-3 end tabs were resistance welded to the end caps at each end of the fuel can. These tabs projected beyond the can and the reflector portion was riveted directly to them in the final assembly. Steps in the manufacture of these tabs are portrayed in Figure 16. Rolled 0.050" thick Zircaloy-3 strip was blanked, rivet holes punched, vacuum annealed, and an offset formed across one side. After resistance welding the tabs to the bottom of the fuel can the longitudinal seam welds, bottom end cap weld, and end tab resistance welds were all leak tested with a mass spectrometer helium leak detector. Of all welded cans which were inspected, less than 1/4 of 1% were found to leak.

As soon as outgassed fuel blocks were removed from the outgassing fixture they were weighed and loaded into the fuel cans, six blocks per can, as shown in Figure 17. The fuel can closure was then completed by inserting and welding the top end cap in the same fixture that had been used for attaching the bottom cap. A 3/8" O.D. x 0.045" wall Zircaloy-3 tube was welded to and extended through the top end cap to be used for final evacuation and sealing of the loaded fuel can.

The loaded fuel cans were assembled in groups of 12 on a vacuum manifold and evacuated for a minimum of 12 hours to a pressure of less than 1 micron. At this time all can welds including the top end cap welds were again helium leak tested before the cans were sealed. Figure 18 is a simplified diagram of the evacuation tube sealing procedure. A small piece of 0.0003" thick pure iron foil, 1/2" wide x 1" long, was inserted and centered in the Zircaloy-3 tube. The 3/8" tube and iron foil were resistance heated to a temperature of 1425-1450°C in 15 to 20 seconds by passing a 450 amp. 40 volt

D.C. current from a welding generator through a 1-1/2" long portion of the tube clamped between water cooled copper terminals. A 1/2" long portion of the heated tube was then pressed for 10 seconds between ceramic jaws of an air cylinder operated ram at a pressure of 1200 psi. After removing the pressure from the joint it was maintained at a temperature of 1325°C for 30 seconds to insure good diffusion bonding at the weld interface. A longitudinal section through a typical sealed tube is shown in Figure 19. A photomicrograph of this same area viewed at 75X is shown in Figure 20. All evacuation tube welds were pressured with 15 psi helium for 12 hours followed by a leak test. No leaking seals were detected on any of the welds. Tested fuel cans were then assembled into fuel elements.

Two end sections 24" long of 50 mil extruded aluminum were attached to the end tabs at the ends of the loaded fuel section with aluminum rivets. Machined reflector graphite blocks were then inserted in the aluminum and the ends closed with cast aluminum top and bottom fittings which were riveted to the aluminum cans to complete the assembly. Figure 21 shows completed regular fuel assembly, reflector assembly, and a control rod fuel assembly ready for insertion in the TREAT reactor core.

HANDLING
FIXTURE

EXPANSION SLOT

RIVET

1" DIA. ALUMINUM
ALIGNMENT AND
SUPPORT PIN

GRAPHITE
REFLECTOR
CANNED IN
50 mil Al

FUEL
SECTION
CANNED IN 25 mil
ZIRCALLOY-3

GRAPHITE
REFLECTOR
CANNED IN
50 mil Al

FUEL MATERIAL: URANIUM OXIDE
IN GRAPHITE

FIG. 1
TREAT FUEL ELEMENT

Fig. 2

FABRICATED TREAT FUEL ELEMENTS

Description	Total Fabricated
Fuel Assembly	312
Fuel Thermocouple Assembly	10
Mid Fuel, Reflector and Skin Thermocouple Assembly	12
Transient Thermocouple Assembly	12
Zirconium Clad Dummy Fuel Assembly	56
Aluminum Clad Dummy Fuel Assembly	210
Access Hole Fuel Assembly	20
Access Hole Dummy Fuel Assembly	10
Control Rod Fuel Assembly	32
Source Fuel Assembly	1
Total Assemblies	675

TREAT FUEL ELEMENT FABRICATION

Fig. 3

Fig. 4 - Components for Assembly of Reactor Fuel Elements

Fig. 5 - Thermal Outgassing of TREAT Fuel Block in Vacuum at 900°C .

Table I

GAS RELEASED AT ELEVATED TEMPERATURE DURING
THERMAL OUTGASSING OF URANIA-GRAPHITE-PITCH
TREAT FUEL BLOCK NO. N-25

	Volume %	
	850°C	900°C
CO	38.4	10.0
CH ₄	16.6	
CO ₂	13.9	0.7
CH ₂ :CH ₂	10.8	
H ₂	9.1	22.9
N ₂	5.3	57.2
H ₂ O	3.9	4.6
O ₂	0.1	4.1
Unidentified	Bal.	Bal.
TOTAL	98.1	99.5

Fig. 6

Table II

GAS RELEASED DURING THERMAL OUTGASSING OF
URANIA-GRAPHITE-PITCH TREAT FUEL BLOCK

	Volume %	cc
Argon	73.4	3146
CO	23.2	1000
CO ₂	2.2	94
N ₂	1.0	43
H ₂	0.12	5.1
H ₂ O (vapor)	0.10	4.3

Fig. 7

Fig. 8 - Loading TREAT Fuel Blocks into Production Outgassing Fixture

920
012

Fig. 9 - Punching Locating Holes in 0.025" Thick Zircaloy-3 Can Stock

Fig. 10 - Forming U-Section for TREAT Fuel Can in Press Brake

Fig. 11 - Welding Sections of TREAT Fuel Can

RADIOGRAPH OF LONGITUDINAL WELD

REJECT

PENETROMETER

ACCEPTABLE

Fig. 12

Fig. 13 - End Cap Blank Entering Forming Die

Fig. 14 - Finished Deep Drawn Zircaloy-3 End Cap

Fig. 15 - End Cap Welding Fixture

Fig. 16 - Steps in Manufacture of Locating End Tabs

86 026 98

Fig. 17 - Loading Outgassed Fuel Blocks into TREAT Fuel Cans

Fig. 18 - Resistance Heating & Press Welding Process for Sealing Evacuation Tube

Fig. 19 - Longitudinal Section Through Evacuation Tube Weld

Fig. 20 - Photomicrograph of Cross Section Through Evacuation Tube Weld

Fig. 21 - Completed TREAT Fuel Reflector and Control Rod Guide Elements

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