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APPARATUS FOR HIGH-SPEED PHOTOGRAPHIC EXPERIMENTS WITH IRRADIATED FAST-REACTOR FUEL SPECIMENS

by

L. E. Robinson and C. August

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Reactor Technology

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Reactor Analysis and Safety Division

August 1970

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ABSTRACT

The standard, transparent TREAT fuel-meltdown facility was redesigned for experimental use with irradiated fast-reactor fuel specimens. The stainless steel slot liner was formed of a single sheet, with integral ribs rolled in, for greater rigidity and ease of fabrication. The redesigned test capsule has a fuel-holding frame automatically locked in position during remote loading. A Zircaloy auxiliary lining was added to ease decontamination and increase the reusability of the facility. A removable auxiliary flange was used to centralize inert gas and electrical connections and to clamp the refractory lining to the slot liner. An in-line, remotely operated assembly apparatus was designed to permit remote handling, spot welding, and fuel loading.

I. INTRODUCTION

Direct observation of the course of meltdown experiments in TREAT by means of high-speed photography is a very useful method that allows postmortem reconstruction of mechanisms of fuel-sample failure. This technique has been extended to permit study of the behavior of test samples previously irradiated so as to contain appreciable concentrations of fission products.

In general, photographic experiments with preirradiated elements combine salient features of photographic tests with unirradiated samples and opaque tests with preirradiated specimens. The design of the in-pile apparatus for use with preirradiated fuel was based on redesigning previous equipment for photographic meltdown experiments with unirradiated samples[1] to satisfy the requirements of remote assembly, remote handling, and shipment to TREAT.

II. DESCRIPTION OF THE TREAT TRANSPARENT FACILITY

A. Test Capsules

Figure 1 shows the basic layout of the TREAT transparent in-pile facilities, both for unirradiated and irradiated samples. The sample fuel pin is contained in a double-walled, Zircaloy test capsule, approximately 4.5 cm wide by 48 cm high by 42 cm long, having a total wall thickness of 0.125 cm. The front of the capsule has a 0.625-cm-thick fused silica window (the "inner window" of the entire subassembly) attached, but not sealed, to the capsule. Behind the sample, there is an oblique, front-surfaced mirror and a complementary, 0.75-cm-thick graphite slab which provides extra heat capacity for the containment wall closest to the test element. Capsule inner walls are coated with a special paint mixture consisting of powdered alumina in a high-temperature base paint that supplies a diffuse, high-reflectance background for photography.

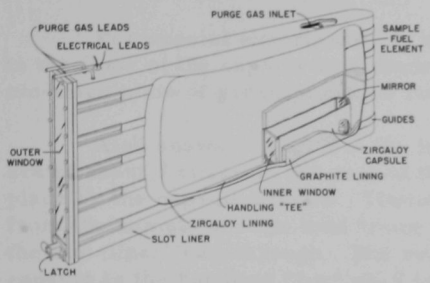

Fig. 1. Cutaway View of TREAT Transparent In-pile Facility. ANL Neg. No. 112-1223.

Figure 2 shows a disassembled test capsule. The window (made from UV-grade artificial fused silica) slides down two tracks in the front of the outer capsule. One lower corner of the window is cut off to permit free circulation of the inert cover gas from the capsule to the remainder of

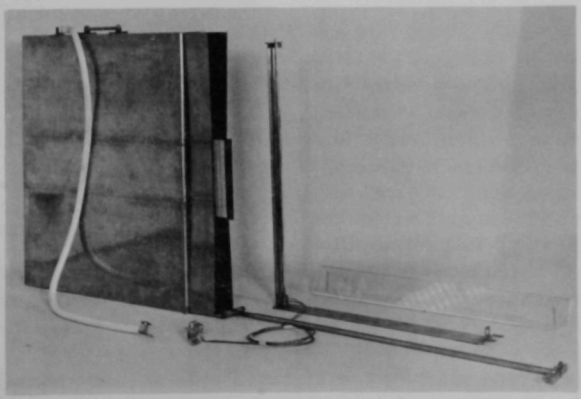

Fig. 2. Disassembled Test Capsule. ANL Neg. No. 112-2981.

the entire slot-liner assembly. The cover-gas inlet is attached to the white, silicone rubber tube connected to the rear of the capsule top. In front of the window in Fig. 2 is the test-sample load frame, which is designed to hold the sample and any special instrumentation such as fuel motion detectors, and to support instrumentation and thermocouple lead wires. The load frame slides into the capsule and is latched in place by tabs in the closed end of the inner capsule when it is inserted fully in the outer capsule.

For special experiments in which additional heat capacity is needed in the floor of the capsule to contain very high-energy meltdowns, a 0.625-cm-thick plate of graphite can be located beneath a similar load frame.

Also shown in Fig. 2 is the inner-wall section of the capsule, withdrawn about 7 cm from the rest of the capsule. This section is locked into place by the capsule window. Thermocouple lead wires are shown running from the sample and the load frame to the connector that is plugged into the slot-liner lead-through. The rod which extends from the front of the capsule is the handling "tee" used to insert the capsule into the slot liner. The cross handle locks into place inside the flange of the slot liner, and the threaded shaft (adjusted with a torque wrench) holds the Zircaloy capsule in position in the back of the assembly. Figure 3 shows the inner and and outer (0.063-cm wall) components of the Zircaloy capsule. Side tabs inside the front of the inner capsule lock behind the window to hold the dual walls of the subassembly together.

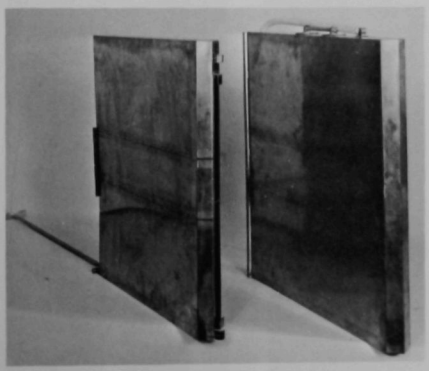

Fig. 3. Back View of Inner (left) and Outer (right) Zircaloy Capsule Components. ANL Neg. No. 112-2979.

B. Slot Liners

Figure 4 shows the front of the slot liner, made of stainless steel, with the handling tee locked into the slot-liner window-flange slots at the bottom of the window, and the instrumentation lead wires running up from the notched handle of the tee to the slot liner through connector at the top of the flange. The flange top has inlet and outlet quick-disconnect connections that seal shut automatically when disconnected from the cover-gas system at TREAT, and also the short lead-wire extension provided for plugging into the experimental circuits at TREAT.

The flange subassembly consists of two main parts: the stainless steel main flange, which is welded to the stainless steel slot liner, and a stainless steel auxiliary flange, which is bolted to the main flange and sealed by a silicone gasket. Figure 5 shows the front of the slot liner, with the test

capsule partially inserted and the auxiliary flange removed to show its connections and gasket from the rear. The two steel pegs on the front of the auxiliary flange, shown obliquely at opposite corners, are for use in aligning the outer-window subassembly during remote-loading operations. The auxiliary flange was designed as a semipermanent part, and is removed only for changing the lead-through components when new instrumentation is required. Another view of the upper connections and the alignment pegs is shown in Fig. 6.

The slot liner is lined with a 0.063-cm-thick Zircaloy shell. In the region of the test capsule, there is an additional layer of 0.53-cm-thick graphite. The front of the subassembly is sealed by a 0.27-cm-thick, fused silica (UV-grade) window. Figure 7 shows the slot liner with the inner Zircaloy liner withdrawn about 5 cm to show the Zircaloy flange that is held between the main slot-liner flange and the auxiliary flange, and the window-flange subassembly. The raised horizontal bands running around the slot liner are integral ribs, formed directly by rolling, in the 0.20-cm-thick steel slot-liner walls to stiffen them. These bands are shown clearly in Fig. 8, which is a back view of the liner.

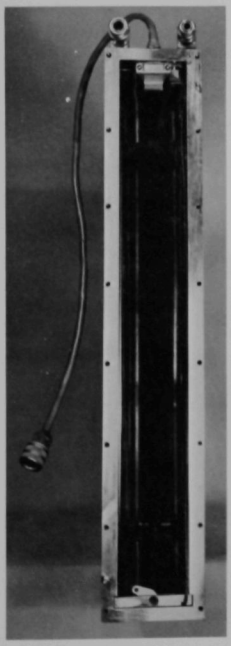

Fig. 4

Front View of Slot Liner with Capsule in Place, without Outer Window. ANL Neg. No. 112-2976.

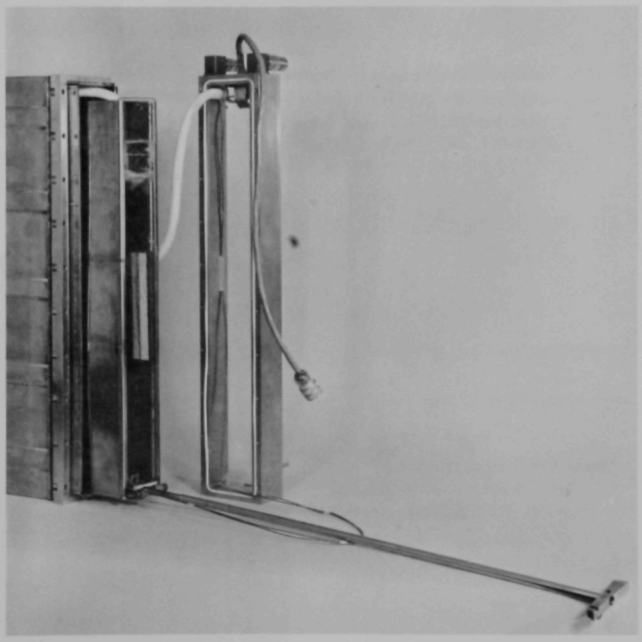

Fig. 5

Front End of Slot Liner with Capsule Partially Inserted and Auxiliary Flange Removed. ANL Neg. No. 112-2982.

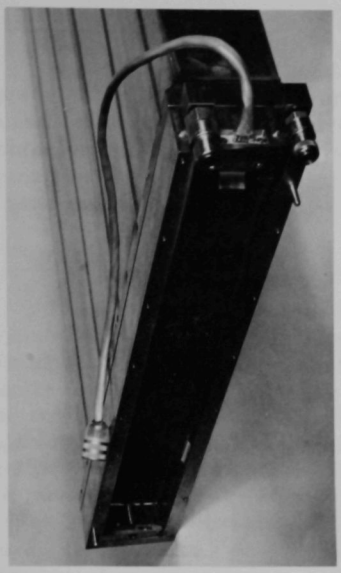

Fig. 6. View of Slot-liner Front, Showing Upper Details and Alignment Pegs. ANL Neg. No. 112-2974.

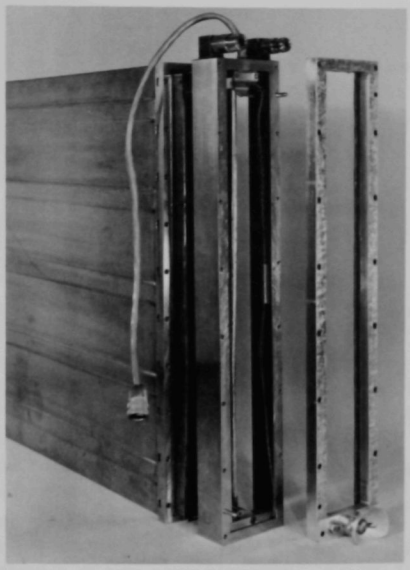

Fig. 7. Exploded View of Slot-liner Front End Showing Relationship of Main Flange, Auxiliary Flange, and Window-flange Subassembly. ANL Neg. No. 112-2977.

Fig. 8

Back View of Assembled Slot Liner, Showing Stiffening Bands. ANL Neg. No. 112-2980.

C. Handling Coffin

A handling coffin is used at TREAT to transfer a slot liner from its shipping coffin to the reactor, and to align and position the liner for insertion into and removal from the reactor core. The coffin used for unirradiated samples[1] was modified for previously irradiated specimens by replacing the original lead-shot filling with cast lead and by adding auxiliary shielding near the sample position.

D. Shipping Coffin

The shipping coffin (see Fig. 9) is a lead-shielded box which contains two slot-liner assemblies in separate, individually sealed compartments. Internal shielding is included between the two compartments (which open on opposite faces) so that, with one compartment empty and its shielded door open, the radiation through the door opening from the outer compartment would not be higher than the radiation levels outside the coffin walls. Each slot-liner assembly is secured in its compartment by brackets on a gasket plate inserted behind the compartment doors, preventing liner rattling inside the cask and window breakage during shipping. The coffin, in turn, is secured by cables to a shock-mounted shipping pad. With this arrangement, no windows have been lost in more than a dozen experiments. As of January 1, 1969, this coffin design is not approved for shipping outside AEC installations. The shipping coffin-pad assembly is shown in Fig. 10.

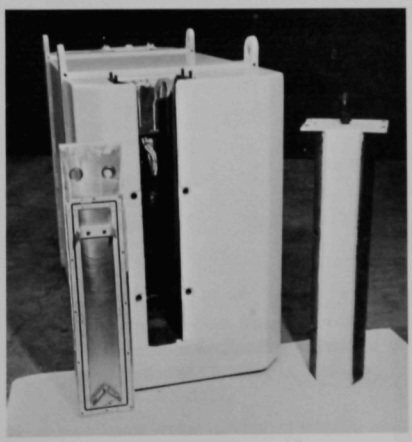

Fig. 9. Shipping Coffin (with door removed) and Transparent Assembly in Place Inside. ANL Neg. No. ID-103-7580.

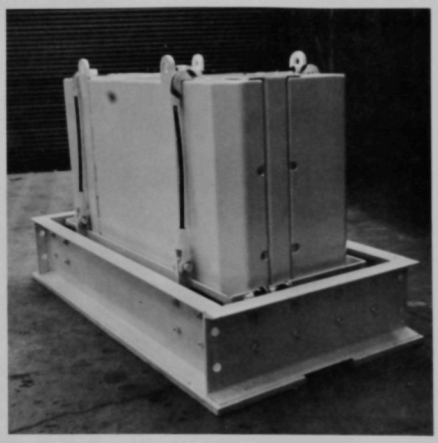

Fig. 10. Shipping Coffin-Shipping Pad Assembly. ANL Neg. No. ID-103-7582.

III. REMOTE OPERATIONS

Figure 11 shows the remote-loading apparatus through a cave window. In the front, on the table, are the welding tweezers used for attaching thermocouples to the surface of the test sample with the manipulators. The sample proper is in its load frame; the load frame and Zircaloy capsule are fastened in the remote-assembly jigs. In the foreground are the mechanical manipulators. A close-up of the remote welding of a bare wire thermocouple to the preirradiated sample is shown in Fig. 12.

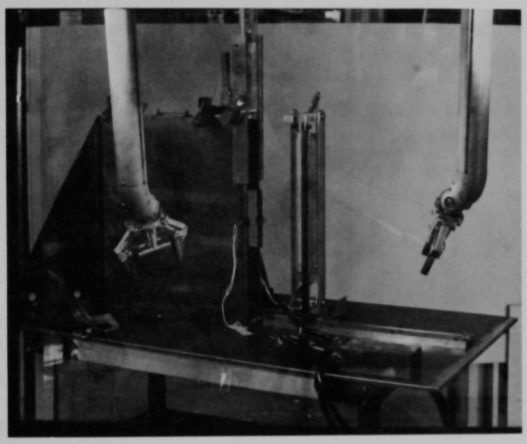

Fig. 11

View through Cave Window of Remote Loading of Capsule. ANL Neg. No. 112-2433.

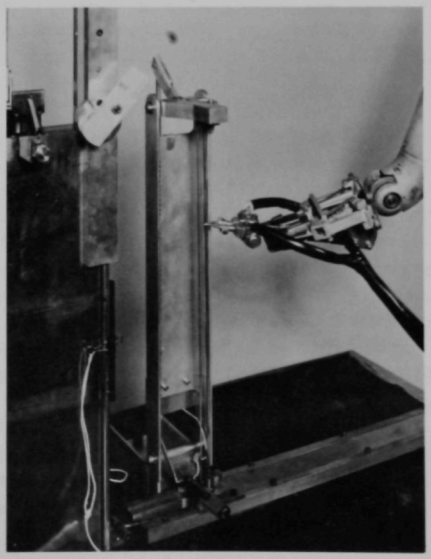

Fig. 12

Close-up of In-cave Attachment of Thermocouple to Cladding of Preirradiated TREAT Sample. ANL Neg. No. 112-2431.

After capsule assembly, the capsule is locked into its slot-liner assembly (cf. Fig. 4), the gas and instrumentation leads are plugged into the inside of the auxiliary flange (cf. Fig. 5), and the window-flange subassembly is bolted in place (cf. Figs. 6 and 7) using a pneumatic screwdriver adapted for the manipulators. The slot-liner flanges and connections are then checked for leaks using a helium mass-spectrometer leak detector with a "sniffer" attachment to sense helium escaping from the liner.

During the loading of the capsule, the slot liner is positioned, partly extended, in its shipping-coffin compartment. After successful remote checking of the assembly, the liner is moved completely into its compartment, the gasket plate is positioned, the shielded compartment door is lowered and dogged, and the coffin is removed from the cave. The remote operations used for the first experiments with this apparatus are outlined in the Appendix.

IV. SAFETY CONSIDERATIONS

To reduce the possibility of slot-liner failure due to local stress concentrations, the slot liner is made from a single piece of 0.20-cm-thick stainless steel. (The previous liners for unirradiated samples had top and bottom plates welded to the sides, and the stiffening ribs were separate bands spot welded to the liner proper.[1]) The spot welds were eliminated by the integral stiffener design (cf. Fig. 8). One weld at each top and bottom was eliminated by replacing the separate top and bottom plate design with tops and bottoms formed in halves from the same steel sheet as the side. Top and bottom welds were thus restricted to the flange end, the round sample end, and a single middle seam running the length of the slot liner.

Because of the stiffening bands and the round back end it was possible to design the unit for a routine proof test of 0.6 atm gage prior to each experiment. Proof tests were performed originally using a mock-up[1] of the mechanical side restraints of the TREAT viewing slot (essentially a succession of vertical line contacts at 10-cm intervals). Postloading proof tests were made inside the handling coffin, using grid-like inserts on either side to mock-up the slot environment. This ability to withstand pressure at least 0.6 atm above normal, coupled with the 52-liter internal volume of the liner, was sufficient to accommodate experimental requirements for the capability to meet accidents including the following:

(1) Air atmosphere in slot liner caused by malfunction of cover-gas system, not detected on system instrumentation. This includes possible reactions with the fuels and with sodium released upon failure of sodium-bonded fuels.

(2) Decomposition of paint inside Zircaloy capsule.

(3) Overpressures caused by accidental excessive energy input to sample.

The Zircaloy capsules have safely contained meltdown of the samples. In addition, the double-walled capsule construction provides a convenient method of loading cadmium neutron absorbers to shape sample neutron flux or to shield the entire sample: "sandwiches" consisting of a layer of cadmium foil between two layers of fiberglass are held between the two Zircaloy walls. Because of this multiple-layer construction, the low-melting cadmium is thermally shielded from local overheating by spattered molten fuel or sodium.

V. USE OF APPARATUS

The apparatus for photographic experiments on fast reactor fuel failure has been in routine use for approximately five years. It has functioned satisfactorily in experiments with metallic samples[2] and with oxide samples.[3,4] Slot liners have been reused routinely. The remote-assembly Zircaloy capsules were made to be interchangeable with the earlier bench-assembly capsules,[1] and have been routinely reused in experiments with both unirradiated and irradiated pins.

APPENDIX

Summary* of Operations with Transparent Slot-liner Facility for Meltdown Tests with Preirradiated Fuel Samples

1. Equipment (to be used in large cave with tram-type remote-operated chain hoist)

   a. Handling Coffin: Contains

      (1) Coffin seal plate
      (2) Slot-liner assembly
      (3) Outer-window subassembly (including safety covers for pressurized leak test)

   b. Slot Liner: Contains modified transparent capsule consisting of

      (1) Outer capsule
      (2) Inner capsule
      (3) Load-frame holding sample
      (4) Sample thermocouple wiring harness and connector
      (5) Inner window
      (6) Gas connections
      (7) Miscellaneous small accessories (clips, springs, toggles, etc.)

   c. Handling and Test Equipment: Includes

      (1) Loading table
      (2) Spotwelder with transformer and welding tweezers
      (3) Leak detector with sniffer
      (4) Instrument cart
      (5) Pneumatic screwdriver with balancer
      (6) Simpson multimeter
      (7) Helium bottle
      (8) Miscellaneous accessories (hook, etc.)
      (9) Shield for capsule during study of deposited activity inside slot liner
      (10) Coffin carriage

2. Procedure

   a. Loading

      (1) Sample Installation
         (a) Remove oxide film from sample surface at thermocouple locations.
         (b) Position and lock sample into load frame.
         (c) Spotweld thermocouple and ground wires to cladding.
         (d) Insert load frame into capsule.
         (e) Lock load frame, sliding inner capsule into outer capsule.
         (f) Unlatch window and lower into outer-capsule slots.

*Summary prepared March 4, 1964.

(2) Capsule Transfer and Installation

(a) Raise capsule with auxiliary hook, align capsule, and insert into slot liner.

(b) Attach T-handle extension, running screw in fully.

(c) Slide capsule into slot liner until about 12 in. of handle remains outside slot liner.

(d) Connect gas line and Cannon connector; check electrical circuits.

(e) Push capsule in fully, put extension handle into its seat: lock there.

(f) Apply 12-in.-lb (counter-clockwise) torque to handle adjustment.

(3) Slot-liner Closing

(a) Place outer window and flange assembly on locating pins.

(b) Fasten with socket-head machine screws, tightened with pneumatic screwdriver.

(c) Attach gas lines and purge to check flow.

(d) Leak check at 1.0 psig; release overpressure and remove gas connections.

(e) Remove window cover and push slot liner into coffin.

(4) Coffin Closing

(a) Enter cave, avoiding direct beam from open coffin (should be $\lesssim$10 R at opening).

(b) Disconnect electrical lead.

(c) Position coffin seal plate.

(d) Lower coffin door.

(e) Dog and seal.

b. Unloading

(1) Opening Coffin and Slot Liner

(a) Remove coffin door and seal plate.

(b) Record background radiation.

(c) Pull slot liner 4 or 5 in. beyond coffin and wedge to prevent sliding back.

(d) Apply window cover and remove machine screws with pneumatic screwdriver.

(e) Remove outer-window subassembly.

(f) Turn in (clockwise) extension handle and unlatch.

(g) Withdraw handle about 18 in.; disconnect electrical and gas leads.

(h) Withdraw the handle until about 2 in. of capsule appear and unscrew the handle.

(i) Bring out the capsule, attach the auxiliary hook, remove the capsule, and place it in a plastic bag.

(j) Close the bag about the hook and place the capsule behind the shield.

(k) Monitor and take smears from the slot liner and Zircaloy sock.

(l) Replace the window, insert the slot liner into the coffin, install the seal support plate, and lower the door.

(2) Capsule Disassembly

(a) Take coffin out of cave.

(b) Place capsule on loading table and remove bag.

(c) Engage and lock the capsule on the table.

(d) Remove capsule window and withdraw inner capsule about 3/4 in.

(e) Withdraw load frame from capsule; engage and lock it onto the loading table.

(f) Unlock the sample pin remains from the load frame and sever any thermocouple wires still attached to the cladding.

(g) Remove sample pin remains.

3. Desired in Preirradiated Postmortems

a. Close-up Photographs

(1) From the points of cladding failure.

(2) Emitted fuel residues.

b. Samples to be Taken

For:

(1) Density measurements

(2) Metallographic examination

(3) Spectrographic analysis

From:

(1) Fuel clumps at failure points

(2) Deposits at charred points on inner walls of test capsule

(3) Cross section at fuel pin at intact portion.

c. On First Removal of Slot-liner Window

(1) Activity check on inner walls of Zircaloy inner liner, front to back of slot liner.

(2) Repeat activity check on slot liner when test capsule is removed.

(3) Activity check on slot-liner inner liner following cleanup.

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