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FACILITY FOR PHOTOGRAPHING IN-PILE MELTDOWN EXPERIMENTS IN TREAT

by

G. H. Golden, C. E. Dickerman, and L. E. Robinson

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ARGONNE NATIONAL LABORATORY
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FACILITY FOR PHOTOGRAPHING IN-PILE MELTDOWN EXPERIMENTS IN TREAT

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I. INTRODUCTION

A. Place of Photography in Meltdown Program

In-pile experiments are being performed on sample fast reactor fuel elements, with the TREAT reactor as the source of nuclear heating, to determine the behavior of such elements under conditions of transient heating. Results of the initial experiments on metallic samples run in the absence of coolant inside opaque containers have been described.[1,2]

Availability of techniques permitting the photographing of samples during the experiments makes it possible to provide checks on deductions made from the postmortem inspections of samples exposed in opaque capsules, and to obtain information not otherwise available. When samples are photographed, it is possible not only to determine the time of failure (to compare against inferences based on sample instrumentation), but to observe the condition of the element at the time of failure, to note the types of failure at the time the initial release of material from the cladding occurs, and the condition* and rates of emission* of fuel from the cladding. Hence, high-speed optical photography of dry sample meltdown experiments are a logical extension of the opaque tests.[1,3] Development of these techniques proceeded concurrently with performance of the opaque experiments.

Of necessity, the photographic experiments must be performed on dry elements because sodium coolant would provide an opaque blanket around the elements and raise serious containment difficulties. However, experiments run in the absence of sodium are of extreme interest because of the possibility of obtaining information on causes and modes of failure, as well as the phenomena occurring during or immediately after failure, without the added complication of a coolant that might serve to redistribute the meltdown products. Photographic data on the early stages of meltdown material movement are necessary to assist in the prediction of the rates of assembly or disassembly of core material following element failure; or, in fact, are necessary to determine whether there is an initial tendency to assembly or disassembly.

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*Assuming no interference from such phenomena as release of clouds of sodium vapor originally present inside the sample to provide a thermal bond between fuel and cladding.

B. TREAT Reactor

TREAT (see Figure 1) is a thermal, graphite-moderated and reflected, pulsed test reactor designed to meet the needs of the Fast Reactor Safety Program for a versatile pulsed reactor facility capable of producing a high instantaneous and integrated neutron flux over a comparatively large sample volume.(4) Its engineering design has been described.(5) In addition, the TREAT kinetics properties have been analyzed for the simple solid cylindrical core loading,(6) and for the larger core loading with slots extending through the core and lateral reflector and typical meltdown specimens.(7)

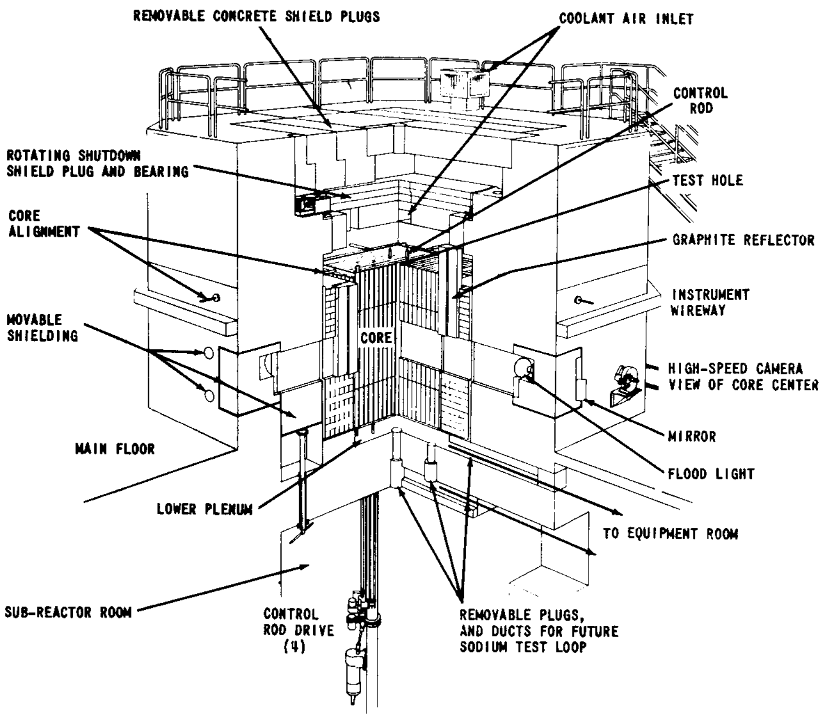

FIG. 1
CUTAWAY ISOMETRIC OF TREAT REACTOR

NEG. #112-771

Briefly, TREAT consists of a core approximately 120 cm high with top and bottom reflectors about 60 cm thick. Each fuel element is 10 cm sq in cross section, with a zirconium-clad fuel section attached to aluminum-clad upper and lower graphite reflector sections. Special fuel elements are available with large slots, nominally 56 cm high by 7 cm wide, thus making it possible to provide a large core viewing slot for photography. The lateral reflector consists of two parts: a permanent reflector with provision for opening up a viewing slot by withdrawing graphite sections remotely, and a temporary reflector which consists of "dummy" fuel elements in which graphite replaces the graphite-urania fuel sections. Some temporary reflector elements also are available with viewing slots made to the same specifications as the slotted core elements. Access holes are located in the reactor shielding at locations corresponding to the movable permanent reflector positions. TREAT is designed to permit three viewing slots: one extending through the core center from each of the north, south, and west reactor shield faces. The north and south access holes are in line so that it is possible to open up one slot extending completely through the reactor from the north to south faces.[5]

With this design, it is possible to design in-pile facilities to fit in the hole left by the removal of one or more fuel or dummy elements. It is also possible to design in-pile facilities to fit inside a viewing slot.

C. Course of Development of Facility

Original design efforts were directed toward the development of a simple transparent "package" of the same size as a standard TREAT fuel element. The package could then be handled, loaded into, and removed from TREAT in the same manner as a regular fuel element, by means of the TREAT fuel handling equipment. By equipping the package facility with windows on two adjacent sides and opening up two reactor viewing slots at right angles, it would be possible to photograph samples simultaneously from the "front" and one "side." Such a facility, however, was found to be unsuitable for general purpose use because of the sodium vapor pressure pulse observed upon sample failure in in-pile experiments[1-3] with sodium-bonded fuel elements* and the deposition of bond sodium from such samples on the transparent inner walls of the package.

Accordingly, work was directed toward a larger facility with sufficient volume to accommodate a sudden surge of high-temperature sodium and a distance of 40-50 cm between the sample and the nearest window. This design required a shift to a facility that would be inserted into the core through a viewing slot. "Side" photography of a sample could still be performed with this slot liner design by incorporating a mirror into the capsule containing the sample. With this arrangement, the facility essentially fills one core slot. Cameras and light source "see" the sample through that slot. The reactor shielding requirements at the access hole through the permanent shielding are the same as before, since this hole would be used for camera and light anyway. However, a special handling coffin and coffin-positioning rails are required.

An inert gas-handling system is provided in order to purge air from the inside of the facility, maintain an inert gas cover during the experiment, and then purge gas-borne activity from the inside of the facility afterwards. Liberal use is made in the design of multiple layers, including graphite and

*For example, EBR-II, Mark-I samples.[8]

refractory metal sheeting, to provide protection against meltdown product release and facilitate maximum reuse of slot liner parts. With relatively straightforward modifications, this facility design can be used for photographing meltdown experiments on samples preirradiated in steady-state reactors to appreciable atomic per cent burnup.

II. EQUIPMENT

A. Transparent Meltdown Facility

The most important single factor governing the design of the transparent meltdown facility is the presence of about 0.8 gm of sodium as a thermal bond in the EBR-II, Mark-I fuel element.(8) Designs based on a "package" that would fit into the hole left by removal of a TREAT fuel element from the core limited the maximum distance between the fuel element and viewing window to approximately 5 cm. Preliminary tests were made in TREAT in which mockups of the transparent crucibles required by the package design were loaded with single EBR-II, Mark-I elements and run inside a standard, opaque, meltdown capsule.(2) These experiments indicated that, in order to prevent the coating of the transparent facility window by bond sodium ejected from a melting element, it would be necessary to locate the window at a greater distance from the element. In order to achieve this separation, it was found that the transparent facility had to be designed to be used in one of the TREAT viewing slots. Locating the facility in the viewing slot offered the advantage that the facility volume could be made rather large to accommodate the expansion of gas that might be generated as the result of a fuel-element meltdown. These considerations established the facility geometry.

Each of the materials used in fabricating the transparent meltdown facility was selected to meet certain specific requirements. Components in immediate proximity to the fuel element were fabricated from Zircaloy-3, a zirconium alloy which melts at about 1800°C, does not form a eutectic with uranium, and has a low neutron activation cross section. Wherever possible the Zircaloy-3 was backed by reactor-grade graphite, which has a relatively high thermal conductivity and heat capacity, and which sublimes at about 3700°C.

Windows and mirrors were fabricated from high-purity fused silica, which has a softening point of 1667°C. The resistance of this material to thermal shock was demonstrated in a series of experiments in which molten copper that was heated to about 60°C above its melting point (1083°C) was poured into room-temperature silica crucibles. These experiments were then repeated with molten uranium heated about the same amount above its melting point (1133°C). A representative result of the first series of tests is shown in Figure 2, and of the second series in Figure 3. In both cases, localized spalling of the crucible inner surface was observed to occur at certain areas of contact with the molten metal upon solidification of the latter. This is thought to be because the molten metal wetted the wall of the crucible in these areas, giving good contact between the metal and silica (as was evidenced by the clean, unoxidized appearance of the copper surface in such areas). When the metal cooled and solidified, its contraction carried with it adhering pieces of silica. In no case did complete penetration of the crucible wall (1.6 mm thick) occur.

Fig. 2

Molten Copper Pour Test
Neg. #111-7598

Fig. 3

Molten Uranium Pour Test

The total gamma dose in the TREAT reactor core resulting from a 1000-Mw-sec transient is of the order of 10^6r.[9] Since this dose will cause a very considerable decrease in the transmissivity of most potential window materials, an experimental search was undertaken to determine what transparent material would be most suitable for use in TREAT. It was found[10] that commercial fused silica, pyroceram, and Vycor underwent appreciable darkening upon exposure to 10^5 rad in the Argonne National Laboratory gamma facility. On the other hand, high-purity fused silica was irradiated to 10^9 rads in the gamma facility with no loss of visible light transmission. Upon the basis of its resistance to both thermal shock and long-term radiation damage, high-purity fused silica was selected as the window material for the TREAT photographic system. The choice was confirmed in the design phase of the transparent facility by a photographic trial run made during a severe TREAT transient, in which a steel rod the size of a typical fast reactor fuel element was photographed in the TREAT core through two high-purity fused silica windows. No detectable transient window darkening or glow was observed.

Silicone rubber tubing was used to convey the helium purge gas within the facility, silicone rubber gaskets were used as seals and shock-mounts for the windows, and a silicone adhesive was used as a gasket cement and sealant for electrical fittings. These silicone compounds were tested in an oven and found to exhibit long-time heat stability in air at temperatures up to 260°C (500°F). As the temperature increased above this point, degradation of the silicone took place with increasing rapidity, complete degradation occurring in about 20 min at 370°C (700°F).

The outer shell of the facility, which was required to be helium leak-tight at an internal pressure of 6 psig, was fabricated from Type 304 stainless steel. Since uranium and stainless steel form a eutectic at 750°C, the latter was lined with Zircaloy-3* or graphite.

The transparent meltdown facility consists of two components, the capsule to contain the fuel element under test, and an outer leakproof shell to contain the capsule and provide an inert gas cover. The capsule itself is made up of an inner and outer subassembly, both of which are fabricated from 0.0635-cm-thick Zircaloy-3. The fuel element is located near the back end of the inner subassembly as shown in Figure 4.

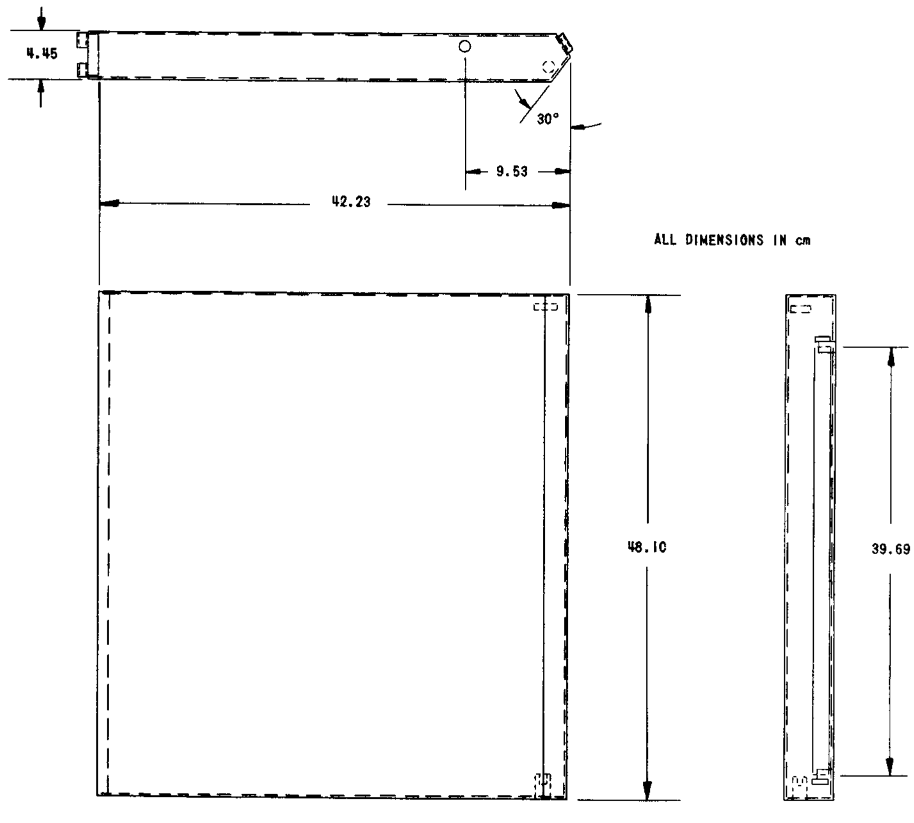

FIG. 4
INNER SUBASSEMBLY
RE-1-32322-D

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*The zirconium-iron eutectic occurs at 934°C.

One of the two walls directly behind the element is solid and is backed by 0.635-cm-thick graphite. The other wall has a 39.70 x 1.76-cm hole cut in it. A 0.635-cm-thick high-purity fused silica mirror, aluminized on both faces, covers the hole in this wall. The purpose of this mirror is to provide another view of the fuel element under test.

For meltdown experiments with irradiated fuel pins, the test capsule of the transparent assembly must be modified to permit remote handling. The modification consists of the removal of the pin-support pedestal and the upper pin clip from the inner Zircaloy capsule, and their transfer to an auxiliary loading frame. The load frame is of $\frac{1}{16}$-in.-thick Zircaloy, L shaped, and closely conforms to the inside dimensions of the inner capsule without effecting optical paths.

The outer capsule subassembly (see Figure 5) accommodates the inner subassembly as well as a 0.635-cm-thick fused silica window at its open end. The purpose of this inner window is to prevent flying fuel-element fragments from leaving the capsule in case the capsule is ruptured in an accident; it is also specifically designed <u>not</u> to be gas tight. Helium purge gas is introduced into the capsule via a 0.635-cm-OD zirconium tube at the top of the outer subassembly, and flows out around the loosely fitting window into the outer shell.

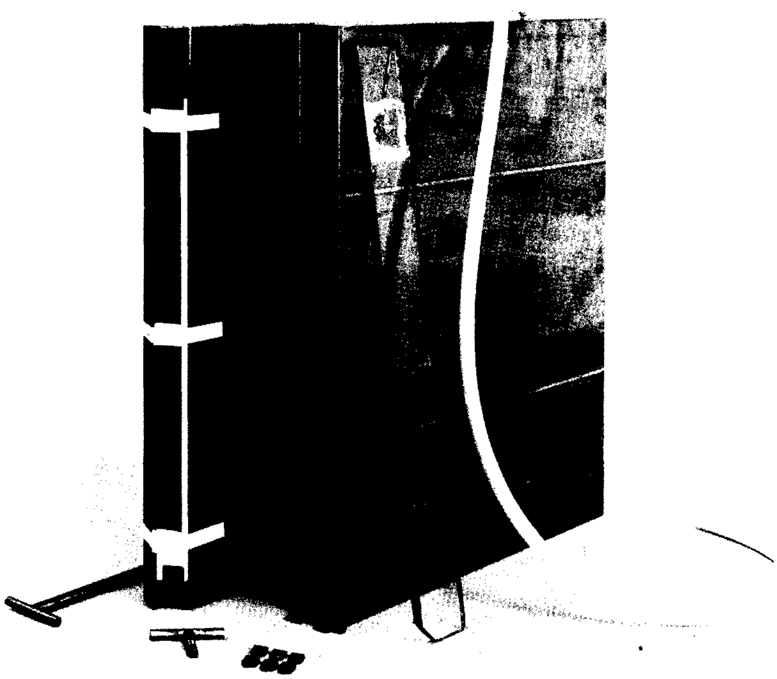

FIG. 5
INNER AND OUTER CAPSULE SUBASSEMBLIES

NEG. #112-522

The outer shell of the facility (see Figure 6) is fabricated from 14-gauge (0.199 cm - 0.0785 in.), Type 304 stainless steel. It holds the capsule, for which it serves as a gas-tight containment vessel up to internal pressures of at least 0.4 atm, when in position in the TREAT core. The shell is lined with 1.11-cm-thick graphite in the region of the capsule, except at the end, where the graphite is thicker. A 0.317-cm-thick fused silica window in a preassembled subassembly is used to seal the outer shell. The entire transparent facility is slid into and out of the reactor core by means of a pole connecting to a bayonet fitting at the bottom of the outer window subassembly. The helium purge line connections are located on top of the outer shell at the window end. A hermetically sealed electrical fitting is located on top of the outer shell, just behind the helium outlet connection. External connections to thermocouples on the fuel element are made via this fitting.

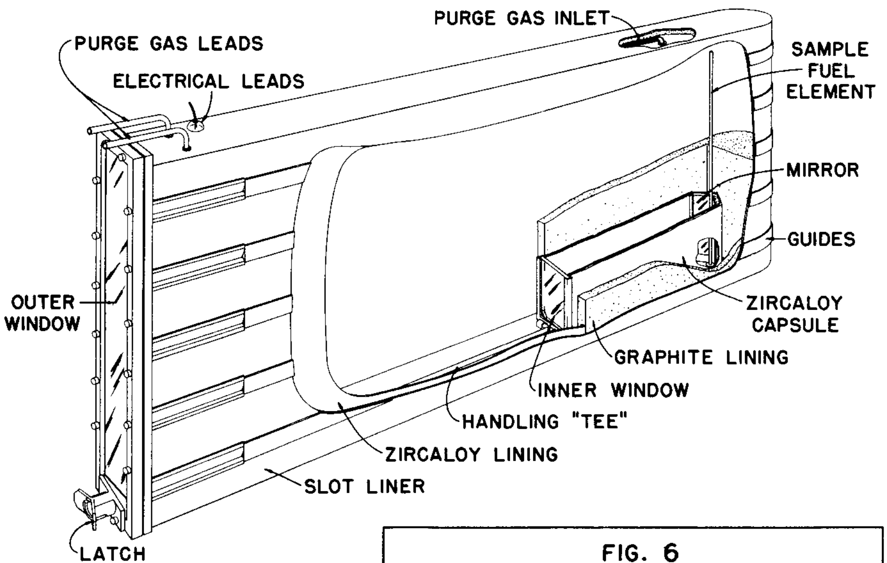

FIG. 6
TRANSPARENT MELTDOWN FACILITY

RE-6-35171-D

Each complete outer shell was pressurized to 0.4 atm (6 psig) with helium and leak checked with a helium mass-spectrometer leak detector. The testing was done in a restraining structure designed to simulate the south slot in the TREAT core (see Figure 7).

Initial testing of the system alignment and photography in TREAT resulted in the inner and outer windows being tilted about 5 degrees to eliminate reflections from the high intensity light source.

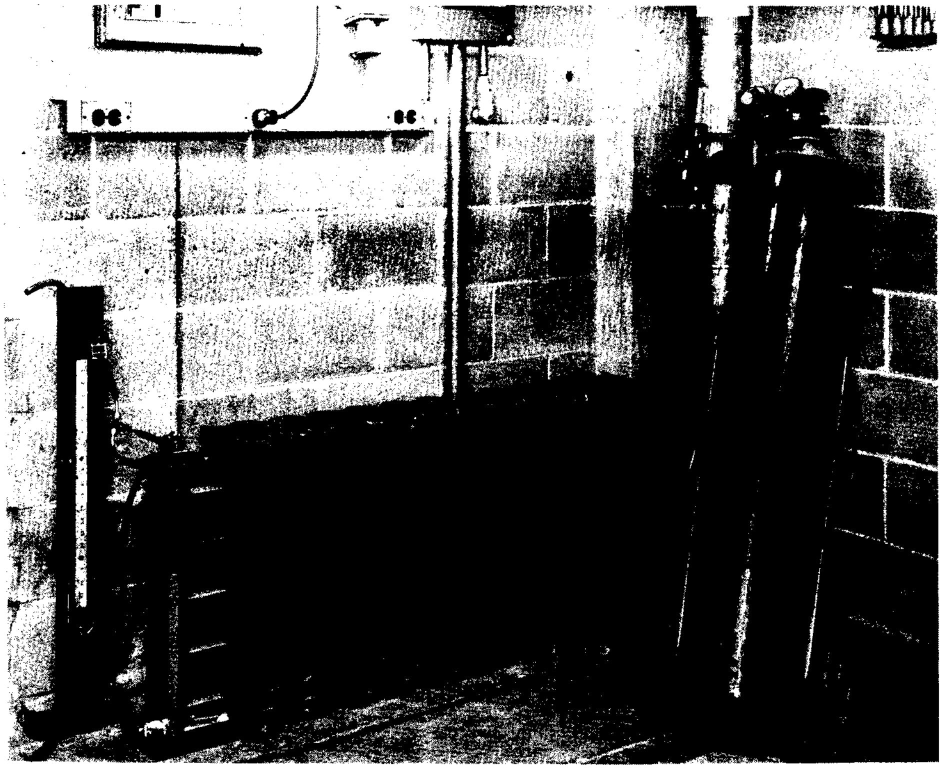

FIG. 7
PRESSURE TESTING SETUP
NEG. #112-526

B. Auxiliary Equipment

A special handling coffin (see Figure 8) is used to load the transparent meltdown facility into and remove it from TREAT, and also to transport it between the TREAT site and the designated disassembly area. The coffin design is such that it will safely hold an EBR-II, Mark-I fuel element that has been irradiated at 10^4 watts for six weeks and then "cooled" for six months, if the coffin is lined with void-free lead. The coffin is opened by lifting out the trapezoidal prism-shaped door. Two through-holes are located in the back of the coffin, one at the top and the other at the bottom. The top hole can be used to accommodate extensions to the purge gas leads from the transparent facility. The bottom hole accommodates the pole used to move the facility in and out of the coffin, and can be closed with a steel plug when not in use. The coffin itself is fastened rigidly to a bed on four wheels. The unit is designed to move on a set of rails which originates in the TREAT south access hole and extends out about twelve feet from the reactor.

A slot plug (see Figure 9) that can be positioned to extend 4 in. into the TREAT south slot is used to shield personnel working on the purge gas connections to the transparent facility.

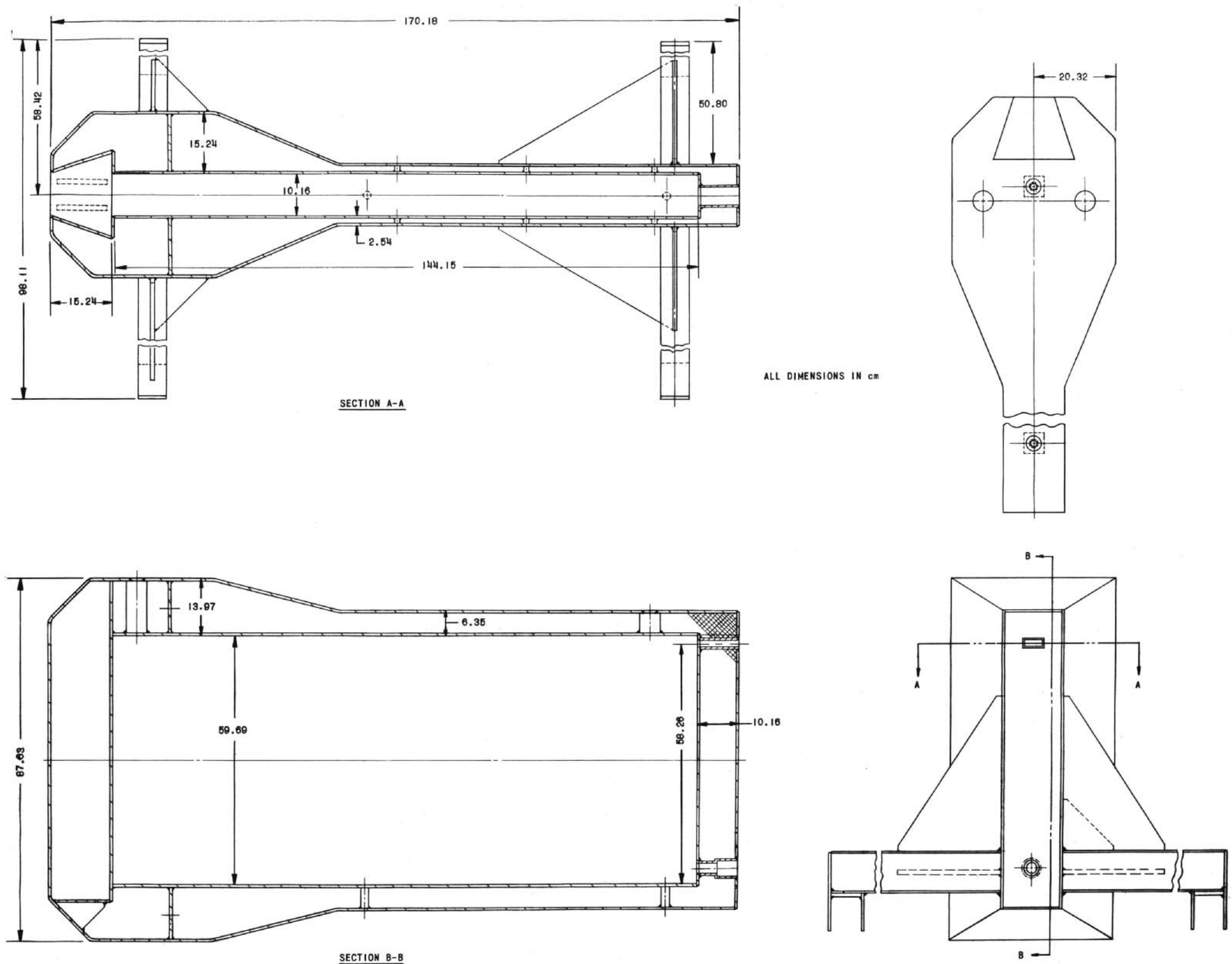

FIG. 8
HANDLING COFFIN
RE-1-23790-E

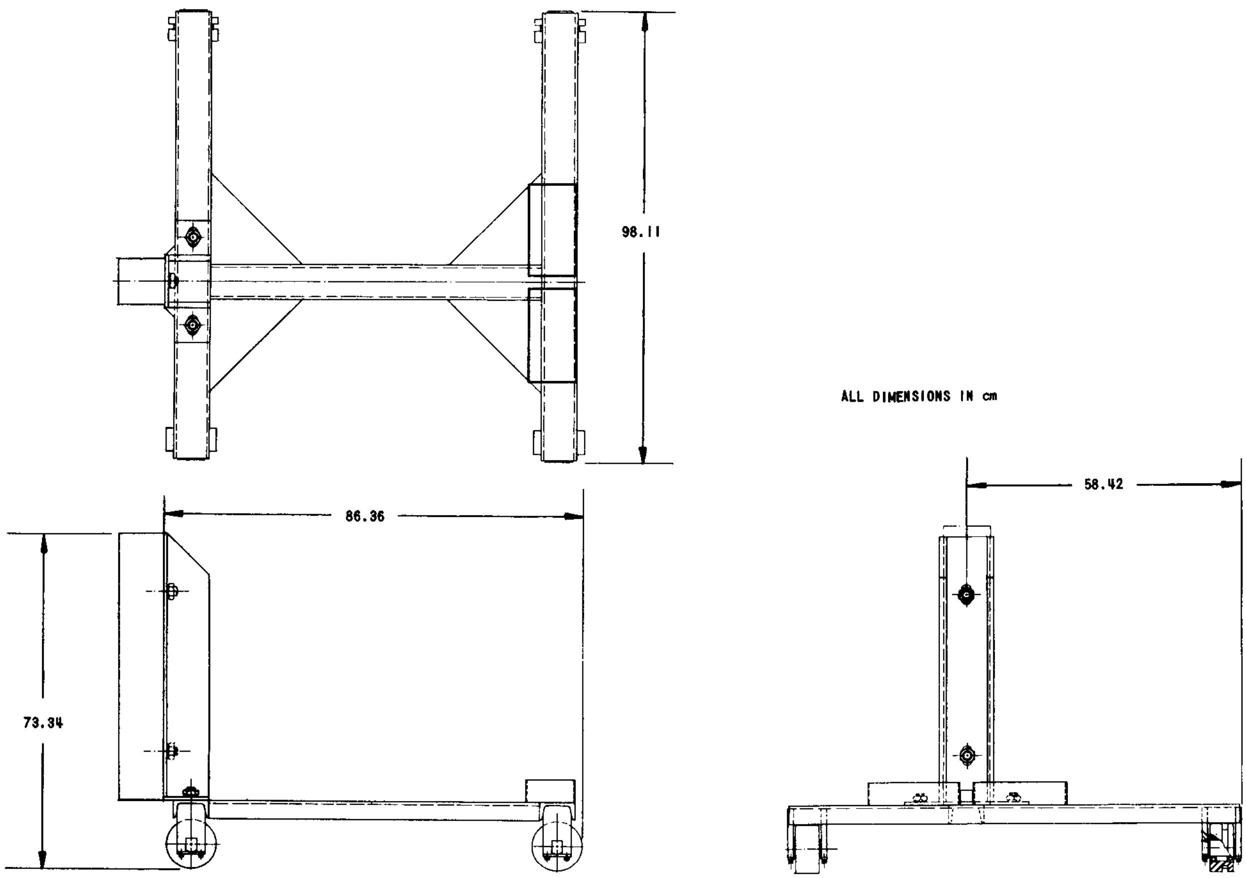

FIG. 9
SLOT PLUG

RE-I-33361-D

The plug can be filled with either lead shot or void-free lead. It has a through-hole at the bottom for the facility handling pole, and terminates an inch below the roof of the slot to accommodate the purge gas leads from the facility. The plug is mounted on a bed similar to that used for the handling coffin, except that both vertical and horizontal adjustments of the position of the plug on its bed can be made. Two trays at the back of the plug bed hold lead bricks to counterweight the plug.

A control cabinet is used to house the gas-handling circuit controls (see Figure 10). This cabinet contains the following:

(1) A fission product detector, consisting of a thin-walled, halogen-quenched Geiger tube (RCL-10309) surrounded by a Pyrex glass cartridge containing a bed of 8-14 mesh activated coconut charcoal. This detector is used to count fission product activity in the helium stream leaving the facility after a meltdown test. The detector housing is jacketed to permit the use of coolants if bed temperatures below ambient are required.

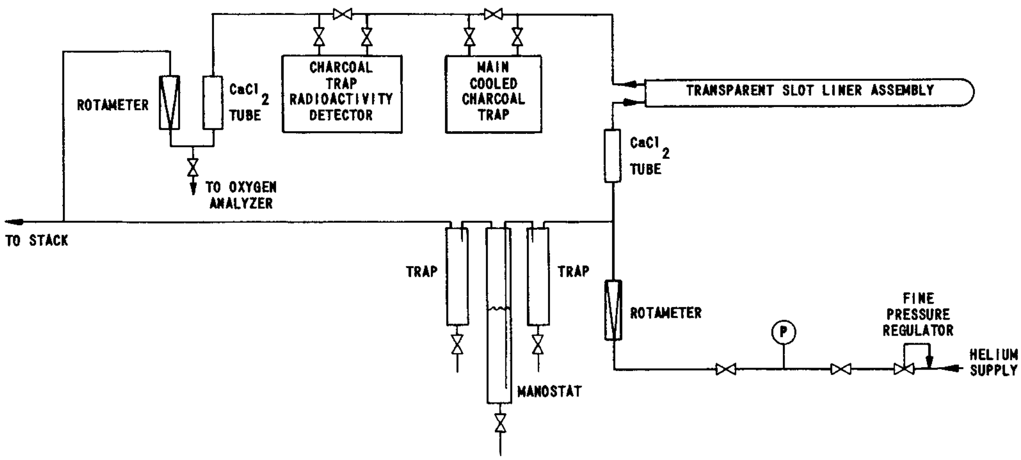

FIG. 10
SCHEMATIC DRAWING OF GAS HANDLING CIRCUIT

(2) A ratemeter (RCL-20406) to count and integrate the output pulses from the Geiger tube above. The count rate ranges on this unit are 0-200, 0-2000, 0-20,000, and 0-200,000 cpm, and the response times are 1, 5, 10, and 50 sec.

(3) A 10-mv recorder to record the output from the ratemeter.

(4) An oxygen analyzer (Beckman D-2) that has a nominal range of 0-25% and an accuracy of ± 2% of full scale. This instrument is used to measure the oxygen content of the helium purge gas leaving the transparent facility.

(5) A rotameter for determining the flow rate of the purge helium.

(6) A manostat that senses the helium stream pressure just downstream of the rotameter; the manostat is set to vent to the TREAT exhaust stack at a pressure determined by operating personnel.

(7) Backup bottles on both sides of the manostat to retain lost manostat fluid in case of an accident.

(8) Valves to control the gas flow.

A fine-control pressure regulator is used to control the pressure of the helium stream entering the control cabinet. A charcoal trap, nominally 5 cm in diameter by 40 cm long, consisting of a steel pipe capped at both ends and filled with 8-14 mesh activated coconut charcoal, is used to take up fission products carried along by the helium stream leaving the facility after a meltdown. The trap is jacketed to permit cooling with liquid nitrogen, and is shielded with lead bricks.

The camera and light systems were designed by E. N. Pettitt of Argonne National Laboratory. Briefly, they consist of two cameras, a high-intensity xenon light source, and associated mirrors. One camera is a 16-mm Fastax (WF-14) having a speed range of up to 8,000 pictures per second. The other camera is a 16-mm Arriflex having a speed of up to 64 pictures per second. The light source delivers an intense light burst of approximately 25,000 to 50,000 foot-candles at the subject for a time duration of approximately 2 sec.

The burst may be lengthened to approximately 5 sec (two-thirds reference intensity) or 10 sec (one-third reference intensity) by use of the light-control circuit. A light intensity sufficient for normal speed photography is obtained from the light system before and after bursts while the light system is on low "standby" power. The xenon lamp, reflector, and mirrors are mounted in a shielded housing that fits into the TREAT south access hole and moves back and forth on the same rails used by the handling coffin and plug.

III. PROCEDURE

A. Assembly and Insertion into TREAT

To assemble the capsule, the fuel element to be tested is first loaded into the inner subassembly and is fastened in place with a zirconium pin. The mirror and 0.635-cm-thick graphite strip are taped onto the back of the inner subassembly by means of fiberglas tape and then slipped into the outer subassembly. The inner window is installed with the thermocouple leads coming out through the notch in the window. Finally, the silicone rubber purge line is connected to the inlet at the top of the capsule.

The procedure set up for assembly with irradiated fuel is similar. First,, the irradiated fuel pin is placed in the load frame by remote manipulator handling in a cave, then is inserted into the inner capsule and locked in place with two compression latches. When in place, the load frame holds the fuel pin positively indexed in the same spatial orientation and location in the test capsule as unirradiated pins.

With the fuel pin load frame in place in the inner capsule, the outer capsule and window assembly is added by remote handling.

Prior to loading the transparent facility into the reactor, a number of preparatory steps have to be taken. These include the positioning of the rails in front of the TREAT south slot, the installation of the facility in the handling coffin and light source housing on the rails. Then the facility is loaded into TREAT, and thermocouple and purge gas connections are made. The entire gas flow system is flushed, leak-checked at a helium pressure of about one psig, and then purged to bring the effluent oxygen content in the facility down to 2% or less.

During the time that the above operations are being carried out, the light housing is wheeled into position in the TREAT south access hole, a check is made to ascertain that the silicone rubber purge line is connected between the capsule and outer shell, and then the rails are removed from the area. The TREAT shield is positioned in front of the south slot, the cameras are loaded and checked for alignment, and the oscillograph recorder circuits are calibrated. When these operations are completed and the oxygen concentration in the facility has been reduced to 2% or less, the helium flow rate through the facility is adjusted to the value to be used during and after the meltdown test, and the test is ready to be made.

B. Removal from TREAT and Disassembly

The transparent facility is allowed to "cool" in the reactor for at least 16 hr before it is removed. During this time, the south slot area is monitored for the presence of escaped fission products, the TREAT shield is removed, the rails are replaced in position, and the light housing is removed from the access hole. The purge gas lines to the facility are crimped and severed, and the thermocouple leads are disconnected. Then the handling coffin is placed on the rails, moved into the access hole, and the facility is withdrawn into the coffin. The latter is wheeled out of the access hole far enough to drop its door into place, after which it is transferred to a truck for transportation to a designated work area.

At the work area, the facility is allowed to "cool" in the coffin until its radiation level is sufficiently low that it can be removed from the coffin. The outer window is taken off of the facility and the silicone rubber purge line and thermocouple fitting are disconnected. The capsule is withdrawn from the facility and transferred to a shipping container for return to Argonne, Illinois. A new capsule is loaded into the outer shell, the outer window is reinstalled, and the facility is ready for another cycle of use.

IV. OPERATION OF FACILITY

A. Nuclear

The worth of the transparent facility in TREAT was measured to be $\Delta k = 3.1\%$,[11] in good agreement with a design prediction of 3%. The combination of slot and facility in the south half of the reactor core with an essentially solid (no slot) loading in the north half perturbed the core flux and resulted in decreasing the incremental worth of the south control rods in the inner rod ring ~30% near the horizontal midplane of the reactor. Similarly, inner ring rods in the north half of the core had their incremental worth raised ~30% near the horizontal midplane. Reactor power, as measured by detectors in the north shielding, was ~40% higher than that measured by instruments in the south shielding. However, in agreement with predictions that the thermal neutron flux depression in and near the meltdown sample would be essentially the same as that for an identical sample in the simpler standard opaque capsule,[2] the correlation between experimental results and south shield instrument output was found to be that established for the same samples in the standard opaque capsule.[2] Results of radiochemical activation measurements for a typical sample after exposure in TREAT indicated that the sample axial exposure was uniform; by means of an aluminum fission counter the axial flux shape was found constant within ±2% with no sample.[11]

B. Experimental Results

With minor adjustments, the mechanical operation of the transparent facility proceeded smoothly in accord with functional design. The slot liner was easily made gastight and maintained its integrity during handling and the transient tests. A purge rate of 3.5 liters/min reduced the oxygen content of the gas leaving the facility to less than 1% within approximately 25 min, in agreement with design calculations.

Preliminary meltdown tests with the facility in TREAT indicated the effectiveness of the facility containment and of the system for fission product absorption. Following a typical meltdown transient, the activity of the gas line to the reactor exhaust stack was essentially background at 2.5 cm, while activity in the charcoal traps reached a level of about 10 r/hr at 5 cm. The activity of the gas lines between the test capsule and the main absorber reached levels of 90 mr/hr at 2.5 cm, decreasing to 30 mr/hr within 45 min. The activity is short-lived; gamma-ray analysis of the gas showed peaks from Xe^{127} and Xe^{135} and from Ba^{140}.

Essentially all of the gas-borne activity is removed from the slot liner and capsule within 45 min with a purge rate of 3.5 liters/min. The activity remaining in the facility, following a typical meltdown transient, is about 300 mr/hr at 30 cm from the sample end of the slot liner, and 100 mr/hr at 30 cm near the slot liner window flange, after 28 hr.

Handling of the activated slot liner and test capsule proceeded smoothly according to plan, and quickly became routine.

Photographic records of fuel element failures in the transparent facility have been taken at film speeds up to about 4,000 pictures per second with the Fastax camera, using a 3-in. lens and f-stop values of 2.5 to 3.5. Kodak Ektachrome (ECO) film has been used extensively with excellent results. The slow speed Arriflex camera is usually run at a film speed of 50 frames/sec, also using color film.

To increase the uniformity and intensity of the illumination of the fuel sample, the interior of the inner capsule is coated with a thin layer of finely divided alumina in Tygon to give a diffuse white surface. This has no effect on the test, but, by lighting the back of the fuel pin, permits full use of the vertical mirror to obtain a three-dimensional view of the meltdown test. In addition, the diffuse white background was found to provide better sample delineation than the other background tested - a diffuse black (carbon) surface.

Experimental meltdown data will not be discussed herein. However, the types of information obtained may be summarized as follows. Timing of element failure was clearly marked. Release of sodium, in the case of sodium-bonded EBR-II elements, formed a cloud whose growth rate and turbulence could be observed prior to arrival at the inner capsule window and subsequent coating of the window by sodium. Release of molten fuel alloy from the metallurgically bonded Fermi-I samples also was clear; stream or droplet sizes and trajectories could be established. Qualitative information on the heights of fuel columns above points of failure was obtained by noting locations and growth of comparatively cool, dark, regions in the cladding.

Postmortem examinations of the test capsules following destructive transients yielded evidence of the violence of some sample failures. After a test of high sample energy input, agglomerates of fuel and eutectic may be liberally distributed over the walls of the inner capsule adjacent to the sample holder, and the inner window, while intact, is spalled and etched by molten globules. The size, location, and distribution of the agglomerate masses varied with the power level of the test transient. Figure 11 illustrates the dispersion of fuel, fuel cladding eutectic, and bond sodium during meltdown of EBR-II samples.

FIG. 11
FUEL ELEMENT DISPERSION
NEG. #112-844

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REFERENCES

1. C. E. Dickerman, E. S. Sowa, and D. Okrent, Fast Reactor Safety Studies in TREAT - A Status Report, Nucleonics, 19(4), 114 (April 1961).
2. C. E. Dickerman, E. S. Sowa, D. Okrent, J. Monaweck, and L. B. Miller, Studies of Fast Reactor Fuel Element Behavior Under Transient Heating to Failure. I. Initial Experiments on Metallic Samples in the Absence of Coolant, ANL-6334 (August 1961).
3. C. E. Dickerman, D. Okrent, and E. Sowa, The Fast Reactor Safety Program in TREAT, International Atomic Energy Agency Seminar on the Physics of Fast and Intermediate Reactors, Vienna, Austria (1961).
4. G. A. Freund, H. P. Iskenderian, and D. Okrent, TREAT, A Pulsed Graphite-moderated Reactor for Kinetic Experiments, Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, Switzerland, 10, 461 (1958).
5. G. A. Freund, P. Elias, D. R. MacFarlane, J. D. Geier, and J. F. Boland, Design Summary Report on the Transient Reactor Test Facility (TREAT), ANL-6034 (1960).
6. D. Okrent, C. E. Dickerman, J. Gasidlo, D. M. O'Shea, and D. F. Schoeberle, The Reactor Kinetics of the Transient Reactor Test Facility (TREAT), ANL-6174 (1960).
7. C. E. Dickerman, R. D. Johnson, and J. Gasidlo, Kinetics of TREAT Used as a Test Reactor, ANL-6458 (to be published).
8. L. J. Koch, H. O. Monson, D. Okrent, M. Levenson, W. R. Simmons, J. R. Humphreys, J. Haugsnes, V. Z. Jankus, and W. R. Loewenstein, Hazard Summary Report Experimental Breeder Reactor II (EBR-II), ANL-5719 (1957).
9. F. S. Kirn, Idaho Division Summary Report, July, August, September, 1960, ANL-6301, p. 91 (1960).
10. M. J. Janicke, Private Communication.
11. F. S. Kirn, Private Communication.

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