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DESIGN, PERFORMANCE, AND EVALUATION OF SHIELDING WINDOW FOR FARET CONTAINMENT CELL

by

T. W. Eckels and A. Smaardyk

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I. INTRODUCTION

Viewing windows have been provided in the Fast Reactor Test Facility (FARET)¹ cell structure. Since the cell-structure walls are 5 ft thick for shielding, the windows have been designed with material thicknesses of glass and oil, which are equivalent in shielding value to that of the cell wall. Normally, viewing windows for cell operations are designed specifically for personnel radiation protection, and they also act as an atmospheric barrier between the cell and the surroundings. For the window application to FARET, unique requirements of pressure, impact, and temperature resistance have been superimposed. Additional design and supporting experiments were developed for ascertaining the satisfactory performance of the windows. Since future large fast reactors are likely to utilize a containment-cell structure for access to the core,^{2,3} the demonstration of adequate window performance will be prerequisite to the usefulness, if not the practicability, of the cell concept. Thus, the development of the windows for the FARET application has also provided basic information for the application of windows for advanced, sodium-cooled, fast-breeder-reactor systems.

II. BASIC WINDOW REQUIREMENTS

The basic requirements for the FARET windows pertain first to the operations to be viewed within the cell, and secondly to the structural integrity as an integral component of the cell structure.

A. Viewing Requirements

Figure 1 shows the locations of major equipment in the cell structure and the placement of the windows with respect to the equipment. The principal operations and components to be viewed through the windows are as follows:

1. Raising and lowering of reactor head to allow access to reactor core. Provisions have been included for lifting the reactor head up into a cell annex at the roof elevation of the cell proper. The control-rod drives installed on the reactor head will remain with the head during the transfer

operation. Before the reactor-head movement, all control rods will be released from the drives and a cover-locking mechanism will be unlocked.

Fig. 1. In-cell Window and Equipment Locations

2. Transport of fuel within the cell by the fuel-handling machine. The fuel-handling machine traverses the cell on a traveling bridge, which spans the width of the cell. By handling one fuel subassembly at a time, this machine can remove and install fuel subassemblies at the following locations: (a) the reactor; (b) the wet-fuel storage tank; (c) the cutoff machine; (d) individual dry storage holes for new, unirradiated subassemblies; and (e) the fuel-transfer port, which communicates to a passageway under the floor and outside the cell at the southeast corner of the cell. A fuel-transfer coffin will be positioned in this passageway for receiving the cut-off portions of the irradiated subassemblies. In addition to the normal handling of the fuel subassemblies, the fuel-handling machine must be capable of handling and coupling instrument connectors.

3. A fuel storage tank (containing sodium and cooled with NaK), located within the cell and below cell floor level. This tank is provided with a rotatable shielded cover for indexing of a loading port over an appropriate fuel-element storage position. The indexing operation will be accomplished by a programmed semiautomatic procedure. The loading port has a shielding-plug cover, which is removed by the in-cell crane.

4. The cutoff machine, which will remove approximately 7 ft from the top end of each FARET fuel subassembly. The shortened fuel element

can then be transported away from the reactor site, utilizing the EBR-II fuel-transfer coffin available at the nearby EBR-II reactor.

5. Use of the in-cell crane for removal of various floor plugs and for transport of various equipment items for removal, installation, or maintenance.

6. Use of auxiliary manipulative devices or tools, which may be required for maintenance of cell equipment, for servicing of penetrations, or for special test operations.

7. Capability for maneuvering of portable television equipment within the cell, if required at a later date.

A principal objective of the FARET facility includes the installation of in-reactor loops for in-pile experiments. Operation of such loops with attendant high risks of fuel-element failure could result in possible extensive contamination of the cell and/or in-cell components. Thus, the ability to adequately view cleanup operations through the cell windows, possibly augmented by television cameras, was also considered in laying out the overall viewing requirements.

The plan view (Fig. 2) shows the maximum effective horizontal viewing angles. Also shown is a line on the floor parallel to the wall and at a distance of 3 ft 9 in., which represents the viewing restriction imposed

Fig. 2. Horizontal Viewing Angles

by the 61° maximum effective viewing angle downward. (The maximum effective viewing angle is ~ 3 to 5° less than the maximum extreme viewing angle commonly used in shielding-window specifications. At the extreme viewing angle, the field of a view is 0° .) Figure 2 shows adequate viewing coverage from the west-wall operating area of the major in-cell equipment.

Since the floor level outside the cell is $4\frac{1}{2}$ ft above the cell floor (see Fig. 3), a considerable width of cell floor in front of each window will be invisible to any window in that wall. With a maximum effective downward viewing angle of 61° (extreme angle: 66°), this width is 3 ft 9 in. It would be more desirable for the two floors to be at the same level; in that case, the cell floor could then be seen to within 1 ft of the wall in which the window was located. Although the figure shows considerable blind area (area not visible through window) in the upper cell volume, the principal routine operations to be seen are near the floor level. Also, one window in the south wall covers a major portion of the blind area in which only the in-cell crane is situated.

Fig. 3. Vertical Viewing Angles

Six windows were to be installed, five at the lower level (window reference line 9 ft above the cell floor) and one at a height of 18 ft in the west wall at a point opposite the reactor (see Figs. 2 and 3). Provision was made for possible later installation of three additional windows at the lower level in the east wall, and for three additional windows at the upper level, one centered in each end wall and one in the east wall opposite the reactor.

The initial six windows allow adequate observation of the principal operations within the cell. Remote performance of in-cell maintenance may require closed-circuit television and/or the additional shielding windows described above.

B. Structural Requirements

The requirement that the window assembly remain leaktight at pressures to 30 psig necessitated special attention to gasket design and subsequent proof-testing of the assembly. The important sealing points are indicated in Fig. 4. A hydrostatic pressure test on a window test fixture indicated that simple flat gaskets placed between plane polished glass and a machined steel surface (gasket perimeter of ~12 ft) would be satisfactory for glass and steel surfaces that are flat within 0.005 in. The material thickness of the steel section for supporting the window slab and gasket was chosen such that less than 0.003-in. deflection was anticipated for the test. Actual measurements by use of strain gages indicated deflections less than 0.001 in. for test pressures up to 160 psi. The rigidity inherent in the design of this steel section is considered important for preventing localized bending stresses in the glass.

III. SHIELDING-WINDOW DESIGN

A shielding window has been designed and is composed of three dry units (A-2, B-1, and B-2) of 6-in.-thick slabs of 3.3-density glass, and an oil-filled tank unit (see Fig. 4). The interior of the tank can accommodate two 4-in.-thick slabs of 6.2-density glass (T_2 and T_3), or two 8-in.-thick slabs of 3.3-density glass, with virtually no change in the viewing angles or in the shielding capability. For either combination of materials, an effective index of refraction of ~1.56 was obtained. Using this index of refraction and a reasonable glass area for slab A-2 ($3\frac{1}{2}$ ft square) consistent with overall window cost and ability to withstand a pressure of 30 psig, the remaining slabs were arranged so that a maximum downward viewing angle of 66° and an upward viewing angle of 44° were achieved.

For a window of this thickness, any further increase in the extreme viewing angles would be at rapidly increasing cost in shielding glass and also rapidly increasing optical distortion of the view at those angles. Side-ward extreme viewing angles of 53° were provided. Calculations indicate that the light transmittance will vary from a minimum of 14.5% to a maximum of 22.5%, depending on the glass combination used. The low value is comparable to the light transmittance through windows installed in the EBR-II Fuel Cycle Facility.⁴ The shielding afforded by the window is equivalent to a 5-ft-thick wall of ordinary concrete. The tank unit is removable from the exterior of the cell. The inner two dry units can be removed with in-cell manipulators and a crane.

Fig. 4. FARET Shielding Window

Several design features used previously for the window design of the Fuel Cycle Facility (FCF) of the EBR-II have been incorporated into the FARET shielding windows as follows:

1. "Hourglass" shape. For this window design, glass slabs of smallest area are located toward the midwall position rather than at the operator's face of the window, such as for a stepped window design. For given maximum viewing angles, the hourglass shape design permits smaller-area slabs at the hot face of the cell than are possible with the more conventional design. This design also results in lower total weight of shielding glass per window. (See Table I.)

TABLE I. Size and Weight Comparison of Hourglass and Stepped Window-design Configuration

	Stepped	Hourglass
Total glass weight, lb	5300	4620
Size of largest slab, in.	44 x 51	40 x 42
<u>Parameters Common to Both Designs</u>		
Window thickness, ft		5
Aperture, in. ^a		
Height		23
Width		28
Maximum extreme viewing angles, degrees		
Downward		66
Upward		43
Sideward		53

^aAperture measured at operator's face of the window for the stepped design, and at midwall position for the hourglass design.

2. The location of the primary-pressure seal (Koroseal gasket under B-2 slab) at a distance from the cell side wall. This feature allows for the installation of two heavy slabs, which essentially protect the sealing member from excessive radiation and possible physical damage. Thus, the primary-pressure glass slab B-2 should retain its integrity for the lifetime of the cell, whereas the two heavy preceding slabs may require replacement due to radiation damage.

3. Provisions for the remote replacement of the glass assemblies that protect the sealing slab B. To accomplish this feature, Unit A frame supporting glass A-1 and A-2 is hinged so that it can be swung into the cell

and lifted off the hinge pins by means of the in-cell crane and a manipulator. A special fixture can then be installed on the hinge pins for withdrawing the B-1 assembly. Removal of the B-1 assembly is then like that for the A unit.

4. A tank-type unit, replaceable from the operator's side. Because of the presence of sealing slab B-2, the tank unit may be replaced while retaining an atmospheric seal between cell and surroundings. Glass slabs T_2 and T_3 within the tank provide the necessary shielding.

5. A welded, pressure-tight, steel window-cavity liner for the installation of the window components. This unit is welded to the steel lining of the cell to form a pressure-tight connection. It is also welded to the outer cell plates only to conform to structural requirements. After testing for leak tightness, concrete is poured to surround the cavity liner. A primary seal (see Fig. 4) is formed by means of a gasket and installation of B-2 slab into the cavity. The additional shielding members, B-1, A-2, and A-1, are then installed according to the procedure under 3. After the installation of the tank unit, a secondary sealing gasket is installed, which bridges the gap between the tank unit and the cavity liner. The annular volume surrounding the tank unit, sealed by the primary and secondary gas seals, is then pressurized with argon gas at a nominal pressure of 1 psig. In this manner, the tightness of the window with respect to the cell atmosphere can be monitored, and the possibility of cell out-leakage is prevented. The cavity is capable of withstanding the 30-psig design pressure for containment and can also be pressurized for proof-testing, if desired.

The parameters for the design of the FARET windows are shown in Table II. Because of significant similarities in design, the design requirements for the Fuel Cycle Facility of EBR-II are included.

TABLE II. Design Requirements for FARET and EBR-II Windows

	FARET	EBR-II (FCF)
<u>Cell Conditions</u>		
<u>Pressure</u>		
Normal, in W.G.	-4 to 0	-4 to 0
Design, psig	30	1
Ambient outside cell, psia	12.5	12.5
<u>Temperature, °F</u>		
Normal operation	120	100
Design	165	150
Transient design	1900	not applicable
<u>Gamma Radiation</u>		
Dose rate at cell face, R/hr	2.5×10^5	1×10^6
Annual integrated dose, R	2.5×10^7	3×10^9
Attenuation	1×10^8	1×10^{10}
Concrete thickness, ft	5	5
Concrete density, lb/ft ³	145	220

TABLE II (Contd.)

	FARET	EBR-II (FCF)
<u>Optics</u>		
Light transmittance, % (to illuminant A ^a)	14 (min)	14.9 average ^b
<u>Maximum Viewing Angles, degrees</u>		
Upward	45	42
Downward	65	63
Sideward	52	53
<u>Leak Rates, scf/day</u>		
In-leakage at -4-in. W.G.	0.01	0.01
Out-leakage at 30 psig, 32°F	36	-

^aIlluminant A: panchromatic light source (2848°K color temp), as defined by C.I.E. (International Commission on Illumination).

^bMeasured.

IV. EXPERIMENTAL PROGRAM

A series of three tests demonstrated the resistance of the multiple-glass-slab arrangement to high pressures, high temperatures, and missiles.

Fig. 5. Glass Mounting Arrangement for Impact Test, Exploded View

A. Test No. 1: Pressure Tests

In Test No. 1, a slab of 3.3-density lead shielding glass, 44 in. long, 29 in. wide, and $8\frac{1}{2}$ in. thick, was placed in a steel test fixture and pressurized with water to 160 psig. The steel test fixture included parts shown in Fig. 5, such as the test frame, the sealing gasket, glass slab Y, the cushion gasket, frame 1, and an additional heavy steel cover plate. The equipment arrangement for this test is shown in Fig. 6. The front view indicates the placement of the strain gages used to measure the strain of the glass at the outside face and that of the steel gasket-support section. Four reference shelves were used to measure the distance to the glass surface at various hydraulic pressures to indicate the compression and permanent set of the gaskets. The rear view shows the heavy cover plate (4 in.) used for the low gas-pressure, leak test and the high-pressure hydrostatic test. The gas-pressure leak test consisted of pressurizing the test fixture and observing the change of pressure for several days. The results of these leak

112-4797-A (A) Front View

- (1) Steel Section Gage
- (2) Glass Slab Gages
- (3) Gasket Compression Reference Shelf
- (4) Test Fixture

112-4798-A (B) Rear View

- (1) Gas Leak Test Gage
- (2) High-pressure Gage
- (3) Fixture Cover Plate Flange
- (4) High-pressure Master Gage
- (5) Manometer for Leak Test
- (6) Hydrostatic Equipment

Fig. 6. Pressure-test Setup

tests and the hydrostatic tests are shown in Table III. At 160 psig, the maximum bending stress for the glass was ~900 psi (see Appendix A). This is three times the value calculated for slab B-2 (see Fig. 4) at a cell design pressure of 30 psig. The pressure test has also demonstrated the adequacy of a two-side clamping of frame 1 (see Fig. 6) to apply appropriate sealing-gasket clamping of slab Y. Also, for the test pressures applied, it was adequate to use flat gaskets of Koroseal 116 (1/8 in. thick by 1 in. wide) for sealing the glass-to-metal joints without using retaining grooves. No gasket slippage was observed throughout the test.

TABLE III. Summary of Pressure Tests
Glass area, 1276 in.²; gasket area, 144 in.²;
gasket thickness, 0.125 in.

Pressure, psig		Time at Pressure	Gasket Pressure, psi	Total Gasket Compression, in.	Permanent Set, in.	Leak Rate, scf/day
Gas	Hyd					
-	-	-	200	0.006	-	-
5	-	5 days	250	0.008	-	None observed
-	60	15 min	525	0.026	0.021	None observed
-	160	15 min	1400	0.041	0.023	None observed
-	160	43 min	1400	0.047	0.027	None observed
6-4	-	12 days	-	-	0.027	0.03 at 5 psig ^a
25-5	-	20 days	-	-	0.027	0.35 at 15 psig ^a

^aAverage pressure.

B. Test No. 2: Impact Test

In Test No. 2, the test components were arranged as shown in Fig. 5. Each glass slab was 8½ in. thick. This test was devised to observe the extent to which the first two window slabs (A-2 and B-1) could be subjected to missile loads and still maintain overall window integrity. The test arrangement is shown in Fig. 7. A 16-lb, cast-steel ball was dropped from a height of 16 ft. The ball was released by opening a circuit to an electromagnet holding the ball. High-speed cameras, started in conjunction with this circuit, were used to record the ball movement and the effect of impact on the glass.

Following the impact, the steel ball bounced upward for 5½ ft. Thus, the energy calculated to have been absorbed by the glass is equal to the loss in potential energy, or,

$$(16 - 5.5) \text{ ft } (16) \text{ lb} = 168 \text{ ft-lb.}$$

Figure 8, a closeup view of the effects of the impact, shows the damaged upper glass slab X. However, the underlying slab Y remained intact. Thus, in the actual window, slab B-1 would have remained undamaged under the same circumstances. Furthermore, only one heavy slab protected the next sealing member in the test fixture, while in the actual window design two heavy slabs (A-2 and B-1) protect the sealing glass member B-2.

112-5019-A

- (1) Electromagnet for Ball Release
- (2) Ball Rebound Scale
- (3) Steel Ball at Point of Impact
- (4) Test Fixture

Fig. 7. Impact-test Setup

C. Test No. 3: Thermal-shock Test

To obtain an indication of the capability of the window assembly to withstand exposure to sudden large atmospheric-temperature changes on the cell side, thermal-shock Tests 3A, 3B, 3C, and 3D were devised. The source of a large temperature change may be conceived as that resulting from a sodium-air reaction.

The test setup in Tests 3A, 3B, and 3C used an assembly of two glass slabs in the test fixture (see Fig. 9) and an additional cover plate simulating the actual design (A-1, Fig. 4). In Test 3D, the cover plate was removed.

The cover glass, 1/2-in.-thick tempered glass, was installed 1 in. from the test slab. The gasket material used for the cover glass was 1/16-in.-thick lead sheet to resist higher temperatures. A bank of infrared heaters (Ni-chrome elements in quartz tubes) was selected for a heat source. The heaters were placed 10 in. from the glass surface. A heat trap, constructed by placing aluminum foil backed up with Transite panels around the heater bank, as shown in Fig. 9B, prevented thermal convection. The test fixture was then entered partly into the heat trap.

Tests 3A and 3B (Appendix B) were of short duration (5-10 min) and resulted in modest increases in glass temperatures with no indication of damage to any of the test components.

During Test 3C, a power of 13.2 kW was applied to the heaters for 20 min, then increased to 16.1 kW for 18 min. At this point, the glass surface temperatures were 490 and 430°F for the cover plate, 260 and 120°F

112-5018-A

- (1) Ball Rebound Scale
- (2) Steel Ball at Approximate Point of Impact
- (3) Test Fixture

Fig. 8. Appearance of Upper Glass Slab after Impact

112-5474-A

- (A) Test Setup and Instrument Arrangement
- (1) Temperature Recorder
 - (2) Thermocouples on Cover Plate
 - (3) Thermocouples on Slab X
 - (4) Thermocouples on Slab Y
 - (5) Voltage Control for Heaters

112-5473-A

- (B) Test 3C with Cover Plate Glass Elements after Test
- (1) Heater Bank (4-3300 W Units)
 - (2) Glass Elements Exposed to Heaters

112-5497-A

- (C) Test 3D without Cover Plate Glass Elements after Test
- (1) Thermocouple Lead Wires
 - (2) Damaged Slab X
 - (3) Undamaged Slab Y

Fig. 9. Setup for Thermal-shock Test

for the first test slab X, and 110 and 90°F for the second slab Y (see Fig. 10). There was no visible damage to the glass test components or to the Koroseal 116 gaskets used for supporting the test slabs X and Y (Fig. 9B).

Fig. 10. Glass-slab Surface Temperatures (A) for Test 3C; (B) for Test 3D

The gas layer between the cover plate and the first test slab X served as a good insulator. The test demonstrated that the cover plate can withstand a high temperature gradient ($\sim 120^\circ\text{F}/\text{in.}$) without failure; therefore the cover plate would protect the heavy glass slab behind it.

It is conceivable that the cover plate could break simultaneously with an increase in cell temperature. Therefore, Test 3D was conducted without a cover plate, thus exposing the heavy $8\frac{1}{2}$ -in.-thick glass slab X directly to the heat source. As in Test 3C, 13.2 kW was applied for 20 min. The power was then increased to 16.1 kW for only 11 min, when slab X cracked extensively (Fig. 9C) but remained in place in its frame. When the glass cracked, power to the heaters was turned off and the test components were allowed to cool. The heavy glass slab Y remained intact throughout the test. During the test, the Koroseal gasket on the high-temperature side of glass slab X softened and flowed at approximately 290°F , and the glass cracked when its surface temperature reached 342°F (Fig. 10B).

A comparison of the slab X temperatures obtained in the two tests shows that more heat was stored at the time of failure in Test D than in Test C. Yet, no serious temperature increase in slab Y was noted, while the cold-side surface temperature of slab X actually dropped after the power was cut. This indicates that slab X continued to serve as a good insulator ($k = 0.5 \text{ Btu/ft}^2\text{-}^\circ\text{F-ft}$).

V. CONCLUSIONS

A shielding window, possessing high integrity, has been designed for use in a reactor containment structure. This has been accomplished mainly by the appropriate placement and sealing arrangement of thick glass slabs. Conservative capability to withstand, without damage, over two times the required design pressure of 30 psig has been achieved. High resistance to potential missile damage has been included, mainly by the ability of the first slab to absorb impact while protecting successive slabs. For extreme temperature conditions associated with "maximum credible accident" criteria, tests have demonstrated the window integrity in the same manner of protection. In this case the first slab, even if cracked, would serve as an insulating member protecting the next slabs. A high degree of visibility has been achieved by the selective arrangement of windows, adequate glass area, and a combination of glass slab sizes and thicknesses resulting in desirable angles of view. In addition, EBR-II design features for replacement of glass components have been incorporated in a manner such that replacement may be done while the integrity of the cell is maintained.

APPENDIX A

Calculations for Hydrostatic Pressure Test

In a chapter on "Simply Supported Rectangular Plates," Timoshenko⁵ gives the following formula for calculating maximum bending stress:

$$(\sigma_x)_{\max} = \frac{6(M_x)_{\max}}{h^2} = \frac{6\beta qa^2}{h^2}$$

where

$(\sigma_x)_{\max}$ = maximum bending stress in x direction,

$(M_x)_{\max}$ = maximum bending moment = βqa^2 ,

h = thickness of plate, in.,

a = width of plate, in.,

b = length of plate, in.,

β = numerical factor, a function of the ratio b/a and of ν ,

ν = Poisson's ratio for material of plate,

and

q = uniformly distributed load, lb/in.².

The values of β are furnished in a table (p. 133 of Reference 5) for various b/a ratios for $\nu = 0.3$ (for steel). For other values of ν , the given value of β must be multiplied by $(1 - \nu^2)/0.91$. For the 29 x 44 x 8½-in. test slab of glass, $\nu = 0.22$, $b/a = 44/29 = 1.5$, $\beta_{\text{steel}} = 0.0812$, and $q = 160$ psig. Therefore,

$$\beta_{\text{glass}} = \frac{1 - (0.22)^2}{0.91} (0.0812) = 0.0848;$$

$$\sigma_{\max} = \frac{6(0.0848) 160 (29)^2}{(8.5)^2} \approx 940 \text{ psi.}$$

For a range of permissible working stresses for annealed glass in tension, Shand⁶ gives 500 to 1500 psi, and for tempered glass from 1500 to 4000 psi. Heavy shielding window slabs are usually not fully annealed; therefore ~900 to 950 psi seemed a reasonable maximum for the pressure test. Hydraulic pressure was thus set at 160 psig.

The calculated maximum bending stresses for the first four heavy glass slabs of the FARET window design were as shown in Table IV. Cell pressure was assumed to be 30 psig.

TABLE IV. Calculated Bending Stresses

Slab	Dimensions, in.			β	$\sigma_{\max}$, psi
	a	b	h		
A-2	40	42	6	0.0540	432
B-1	34	35	6	0.0524	304
B-2	30	37	6	0.0676	304
T-1	24	30	4	0.0690	447

APPENDIX B

Calculations for Thermal-shock Test and Discussion of a Previous
Experimental Infrared-heating Test on a Heavy Glass Slab

In the experiment, cell gas temperatures of 1900°F were simulated. This temperature is considered much in excess of that anticipated for abnormal conditions such as may be conceived for a sodium-burning incident within the FARET containment structure. Also, for the experiment, heat releases of 60 and 750 Btu/ft² were considered for the abnormal condition. This would correspond to a total heat release of ~600,000 and 7,500,000 Btu, respectively. The latter number may be arrived at by considering a stoichiometric reaction of all of the oxygen in a volume containing 50,000 ft³ of air with sodium for an exposed cell surface area of ~10,000 ft². Transient temperatures were calculated by means of a finite-difference method on the basis that approximately 80% of the energy would be absorbed in the first 6 min, another 5% in the next 6 min, and the balance over a relatively long period of time. Thus, only the input conditions during the first 6 min are of principal interest. The results of the calculations are shown in Table V.

TABLE V. Estimated Transient Conditions for
Total Energy Release

Time from Start of Energy Release, hr	Case I: 60 Btu/ft ²		Case II: 750 Btu/ft ²	
	Glass Heat- transfer Rate, Btu/hr-ft ²	Cover-plate Surface Temp, °F	Glass Heat- transfer Rate, Btu/hr-ft ²	Cover-plate Surface Temp, °F
0	-	80	-	80
0.01	2,060	80	25,700	307
0.02	1,030	104	12,850	340
0.03	670	109	8,350	370
0.04	360	116	4,500	357
0.05	256	119	3,200	350
0.06	171	122	2,140	335
0.07	120	125	1,500	325
0.08	92	126	1,150	313
0.09	79	128	985	305
0.10	69	130	860	296

In setting up the experiment, an attempt was made to simulate the heat-transfer rates for Case I. The heat-transfer rates for Case II could not be simulated because of limitations in the test heating apparatus. However, the glass temperature for Case II could be simulated by increasing the heat rates of Case I approximately 20% and applying heat rates for extended time periods (Tests 3C and 3D).

In Test 3A, heater rated power was applied initially for 1 min to reach stable output of the heaters. Then the voltage was reduced in a step-wise fashion to simulate heat-transfer rates for conditions shown in Case I of Table V. The cover-plate temperature increased 50°F, which is close to the estimated temperature. This heat application produced no ill effects. The surface temperature of the first heavy slab increased by only 17°F. Thus, for heat-release rates corresponding to 60 Btu/ft² of glass surface, the window integrity should be adequate. In Test 3B, the conditions of Case I of Table V were exceeded as an intermediate step to simulate Case II conditions. For this test, full power was applied for 4 min and then gradually reduced to zero power over 6 min. The cover-plate glass temperature increased by 100°F; the surface temperature of the first heavy glass slab increased by 25°F. It is estimated that the severity of the test (thermal shock) was of the order of four times that of Test 3A. Again, no ill effects were observed.

In Tests 3C and 3D, attempts have been made to simulate the transient conditions shown in Case II of Table V. Since the heater capacity is insufficient to approach the calculated initial heat-transfer rates shown in Table V, the heater bank was operated at 120% of rated power (16.1 kW) and for a sufficient duration to approximate the heat input in Table V.

A heating bank of four 3300-W units, consisting of Nichrome-in-quartz tubes, each rated at 1100 W, was used as a heat source. This type of heat source was selected because its peak radiant-energy emission is in the wavelength region of 2.5 microns at 1900°F. These characteristics have been considered as an upper bound of those that would be associated with a sodium-air reaction. A tungsten-filament infrared heat source was considered unsatisfactory because its peak radiant-energy emission is in the wavelength region of 1.15 microns at 4000°F, and shielding glass would transmit such infrared radiation (~95-99% per inch). For a wavelength of 2.8 microns and greater, the transmittance is less than 4% per inch. This means that for radiant-energy sources below 2000°F, the peak temperature will occur virtually at the exposed surface, and the energy absorption will be roughly 50% in first quarter-inch, 30% in the next quarter-inch, and the remainder in the balance of the window. For a 4000°F radiant-energy source, it is estimated that a peak temperature in the glass would occur at a depth of approximately 2.5 in.

The heaters were operated above the rated power to achieve heating rates estimated in Table V (approximately 2060 Btu/hr-ft²). An efficiency of radiant-heat emission of 60% was assumed for the experiments.

In 1959 in support of design work on the shielding windows for FCF of EBR-II, Pittsburgh Plate Glass Company⁷ conducted infrared-heating tests on heavy glass slabs (4 to 8½-in. thick). Their tests were to simulate

the internal heating from sustained high-level gamma irradiation. The information gained was not directly applicable to the present problem since thermal shock was being avoided in their tests. The rated output of their infrared heating bank was 600 W/ft^2 , equivalent to $\sim 2050 \text{ Btu/hr-ft}^2$. The infrared energy being absorbed by the glass was calculated to be about 700 Btu/hr-ft^2 , which gives an overall efficiency, for infrared output, of about 34%.

Proportional on-off control was used to supply power to the tungsten filament heat lamps in 20% steps from zero power to 100% rated power. Each power setting was maintained until a steady-state temperature distribution through the glass was approached.

The thermal-shock Test 3D performed at Argonne had a peak power output about 165% of the test performed at Pittsburgh Plate Glass Company. The peak temperatures at which glass breakage occurred in the above tests ranged from 215 to 320°F above ambient air temperature; for the ANL test, breakage occurred at about 255°F above ambient air temperature.

The results of the early tests were of benefit in the design of the ANL experiments for the FARET shielding window.

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