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BUBBLE CHAMBER SAFETY MEETING

June 28, 1960

Reported by
Joseph M. Harrer

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BUBBLE CHAMBER SAFETY MEETING

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INTRODUCTION

A bubble chamber safety meeting was held June 29, 1960, at Argonne National Laboratory; R. H. Hildebrand presided. The objective, as established in the opening discussion, was to consider factors affecting bubble chamber safety and to determine basic safety rules applicable to design, construction, and pressure testing. It was agreed that discussion of operating rules, while equally important, would not be included. A list of the people in attendance is given below.

People Attending the Meeting

N. Balai	Argonne National Laboratory (RE)
R. Brittan	Argonne National Laboratory (RE)
A. V. Crewe	Argonne National Laboratory (PAD)
D. R. Getz	Argonne National Laboratory (HEP)
E. L. Goldwasser	University of Illinois
Luciano Guerriero	Massachusetts Institute of Technology
Robert Handler	The University of Chicago
J. M. Harrer	Argonne National Laboratory (PAD)
Paul Hernandez	Lawrence Radiation Laboratory, University of California
R. H. Hildebrand	Argonne National Laboratory (HEP)
V. P. Kenney	University of Kentucky
R. H. Kropschot	National Bureau of Standards
U. E. Kruse	University of Illinois
William J. Larson	Argonne National Laboratory (IHS)
K. B. Martin	Argonne National Laboratory (HEP)
Andres Peekna	Midwestern Universities Research Association
George Tautfest	Midwestern Universities Research Association
R. W. Thompson	Argonne National Laboratory and The University of Chicago
William Tuttle	Brookhaven National Laboratory
S. Courtenay Wright	The University of Chicago

DESCRIPTION OF CHAMBERS PRESENTLY IN USE OR IN DESIGN

Chicago Chamber (A), described by R. H. Hildebrand.

Status: In operation for 1 year.

Fluid: Hydrogen, 70 psi vapor pressure.

Size: 14 cm deep, 23 cm diameter, 10 liter capacity.

Window: 10 in. diameter, 1 in. thick Herculite glass.
Tested for thermal shock in change from room to liquid nitrogen temperature.

Body: Stainless steel, 90-100 psi operating pressure.

Expansion: 3 direct-operation bellows, about 10^6 total expansion.

Vacuum Tank: Tested to 50 psi, capacity 10 liters of liquid hydrogen, 1 in. thick glass windows.

Chicago Chamber (B), described by S. C. Wright

Status: In design.

Fluid: Hydrogen, 70 psi vapor pressure.

Size: 6 by 12 in.

Window: $1\frac{1}{4}$ in. thick full tempered glass.

Body: High strength aluminum.

Expansion: Piston, of titanium alloy.

Mura Chamber, described by G. Tautfest

Status: In design.

Fluid: Hydrogen, 200 psi.

Size: 15 in. deep, 200 liter capacity.

Window: 30 in. diameter 4 in. thick half tempered glass.

Body: Copper alloy.

Expansion: Piston, 12 in. diameter, 2 in. travel.

Vacuum Tank: Not designed, 2 in. by 3 in. viewing ports.
A splash pan is planned for protection against hydrogen spills.

Magnet: 35 kilogauss with 5 kw excitation.

Remarks: In window design the principal concern is with the flange and bolt details. The use of an arbitrary safety factor of 2.5 to 1.6 is not considered the best practice. We are considering using the stress values due to the natural frequency response to the expansion period as a basis for safety factor design. Concern is felt for the stresses and heat load imposed on the chamber by the magnet. We plan to use nylon or steel spacers to take mechanical stress.

U. of Illinois Chamber, described by E. L. Goldwasser

Status: In design.
 Fluid: Hydrogen.
 Size: 14 in. diameter, 8 in. deep, 22 liter capacity.
 Window: 16 in. diameter $1\frac{1}{2}$ in. thick tempered glass.
 Body: Copper.
 Expansion: Piston, 5 in. diameter.
 Vacuum Tank: Rectangular, 1 in. by 2 in. by 6 in.
 Remarks: A beam window of Mylar or beryllium may be used for operation in an X-ray beam. P. Hernandez remarked that Mylar windows sometimes give trouble due to an electric charge buildup. He later reported (by letter to J. M. Harrer, July 14) that a Mylar window has been in use on the 4 in. chamber at Berkeley for about a quarter million pulses. It is $\frac{7}{8}$ in. diameter and 0.010 in. thick. The Mylar is prestressed at room temperature to the operating pressure, which is held during cooldown to cause a minimum deflection at low temperature.

Argonne National Laboratory Chamber, reported by R. W. Thompson

Status: Design not started.
 Size: Will be large.

U. of Kentucky Chamber, reported by V. P. Kenney

Status: In design.
 Fluid: Hydrogen.

Size: 15 in. or more, as required to achieve a field of about 100 kilograms.

Remarks: Consideration is given to the use of unusual materials, such as Pyro-ceram (Corning) which has high impact strength.

BROOKHAVEN ACCIDENT

Window Failure

A window failure occurred in the bubble chamber at Brookhaven on June 25, 1959. The failure, described by L. Guerriero, occurred while the chamber, which uses a methyl iodide-propane mixture, was being tested for leakage with nitrogen. The chamber was brought up to 480 psi twice, then reduced to atmospheric pressure to repair small leaks. Pressure was then increased to 480 psi the third time and held for 30 minutes. Then the glass failed. The general arrangement is shown in Figure 1.

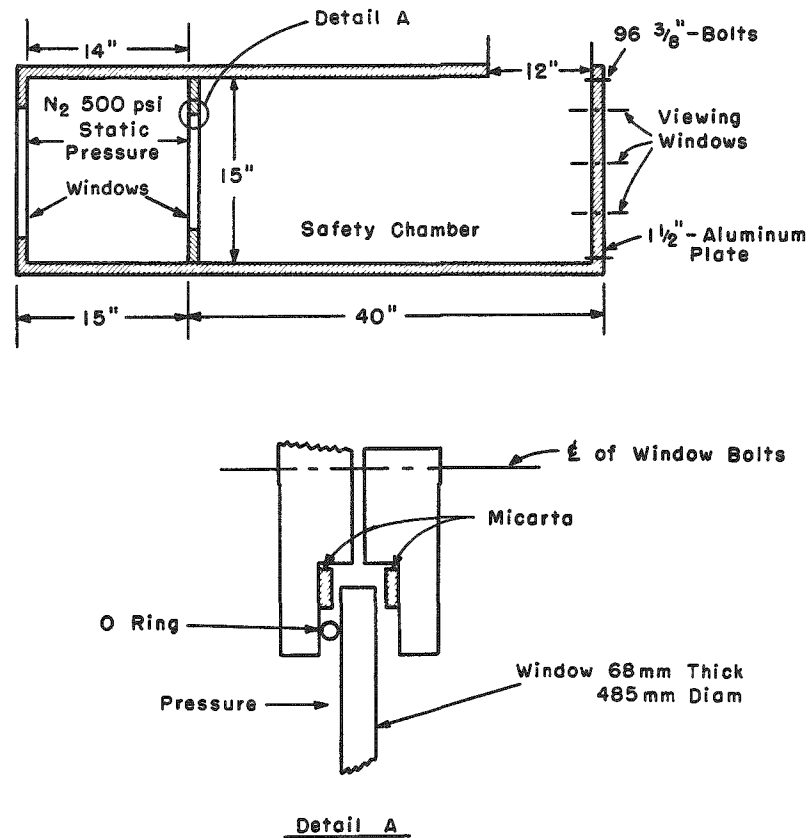


Fig. 1. Brookhaven Chamber

The 96 bolts, each $\frac{3}{8}$ in. in diameter, holding the end plate of the safety chamber did not rupture, but were bent and stripped from the chamber. The safety chamber cover was hurled against storage cabinets several

feet away, crushing one of them. Glass fragments from the window attained velocities of 200-300 meters per second. Few pieces were as large as one inch in diameter. Most of the glass was reduced to a powder.

The glass, manufactured by Schott and Company, Germany, was 68 mm thick, 485 mm in diameter, and supported on a 381-mm diameter frame. It was tempered and had been tested to about 300 atmospheres by the manufacturer.

Discussion

A. V. Crewe suggested that tightening the flange may have induced stresses in the glass. Such stresses might be found by examining the glass under polarized light when the bolts are tightened. If the O-ring seal were placed on the low pressure side of the glass, the flange bolts need not be pulled up so tightly. This might prevent overstressing the glass.

William Tuttle read a separate report on the accident, adding some of the information given above.

Model Tests

After the window failure, rupture tests were run to gain additional information on how the glass acts when it ruptures. Pressures were measured and recorded as a function of time by coating the glass and setting up instruments. Normal plate glass, not tempered, was used. Figure 2 shows the test equipment and the results for two cases.

When helium gas instead of propane was used, the rise time to 70 percent of the final pressure was about one millisecond. Fragments of glass scored the side of the safety box section. First, the safety box end was removed and the glass photographed to show the effect of glass movement after rupture. Glass fragments moved at 200 meters per second in a narrow angle and at 50 meters per second at a wide angle. Next, the complete safety box was removed. In this case the glass fragments moved at 200 meters per second in a narrow angle and 100 meters per second in a wide angle. The comparisons show the effect of safety chamber confinement on glass movement.

At 60 cm from the original glass face, the glass fragments had separated in the line of flight (perpendicular to the original window face) to a distance five times the original plate thickness.

Second Brookhaven Chamber Design

The experience gained at Brookhaven is being applied in a new 20-in. chamber design, of which the general layout is shown in Figure 3. The new design was described by William Tuttle.

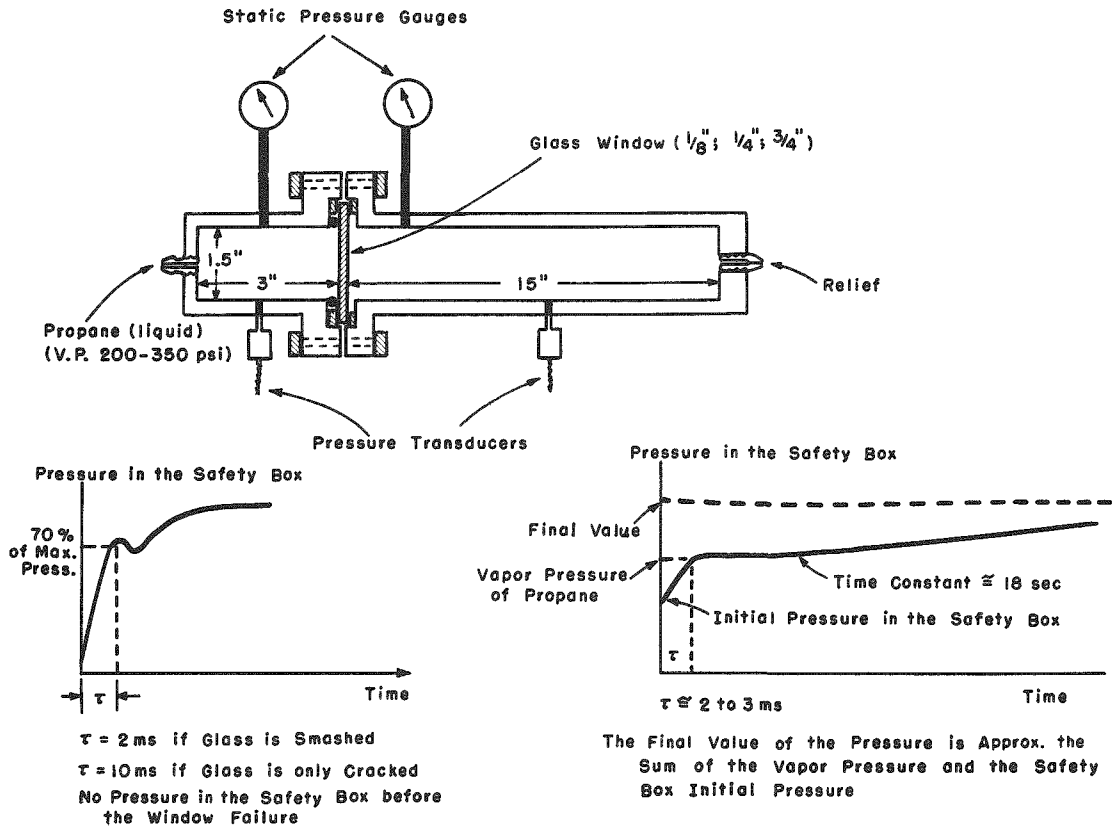


Fig. 2. Brookhaven Model Tests

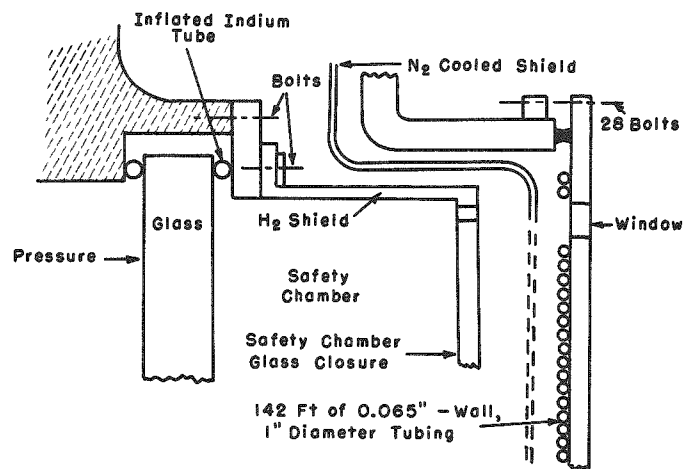


Fig. 3. New Design of Brookhaven Chamber

The provision of a shock absorber installed at the end of the chamber is a feature of this design. It is made of one-inch tubing with a wall thickness of 0.065 inch. Seventy foot pounds per inch pressure is required

to deform the tubing from 1 to 0.735 inch. Thus the total 142 feet of tubing can absorb 10,000 foot pounds of pressure. Assuming the glass does not disintegrate upon release, the total shock impact to be absorbed is 8260 foot pounds, based on a 5-inch acceleration in 0.005 second.

The safety chamber end is held by a ring of 28 bolts, S.A.E. 6150, each of $\frac{1}{2}$ -inch diameter, with a total allowable stress of 20,350 pounds at 160,000 psi per bolt. The total impact resisting strength of the assembly is therefore 570,000 pounds.

The designers plan to provide a 45-degree angle mirror to preclude the necessity for direct viewing.

The Safety Committee does not favor using a vacuum tank designed to be deformed by a pressure rise if the chamber liquid is suddenly released.

DISCUSSION OF SAFETY FACTORS

In a general discussion of safety, several participants offered suggestions applicable to design and operation.

ASME Code

Opinions were sought on the desirability of relaxing code design criteria for chamber and associated equipment. Most of those present were opposed to relaxing safety factors, thinking they should rather be increased. These opinions were based on the fact that the code is for static pressures, while the chambers are subjected to pressure pulsing. W. Tuttle stated that the recompression cycle can produce a momentary pressure rise three times the normal operating pressure. He favored testing chambers at several times the working pressure, with the windows blanked off. P. Hernandez stated that if a safety committee desired to relax code requirements, it should do so only in individual cases after carefully reviewing all factors involved.

Handling Hydrogen Spills and Leaks

Outside vents should be provided for pumping out the vacuum system. Hydrogen occasionally explodes in Kinney pumps, but without regularity. The explosion is usually confined to the oil reservoir or vent line. Solenoid-operated valves to close the vacuum pump lines are installed at Berkeley. They are operated by vacuum system interlocks.

Safety Precautions

The following precautions were suggested:

1. Never pressure test glass at room temperature.
2. Over design the vacuum chamber to provide maximum containment.
3. Seek a means of detecting local stress induced by seal tightening in glass. The polarized light system requires some study and testing.
4. Before use, test a liquid hydrogen chamber and glass to some overpressure at operating temperature. Then operate without letting the unit return to room temperature.
5. Establish a value of allowable design stress. Berkeley used 40 percent of yield.

A table of pressures (Table 1) used for the Berkeley and Chicago chambers was drawn up to see if a reasonable overpressure test value could be established.

Table 1

PRESSURES IN THE CHICAGO AND BERKELEY CHAMBERS

	Chicago (psig)	Berkeley, hydrogen (psig)	Berkeley, deuterium (psig)
Operating pressure (max)	100	80	120
Relief valve setting (low temp test)	150	110	145
Rupture disk design	210	145	175
Chamber test without glass	200	200	200
Vacuum chamber test	50	200	200

The normal overpressure test seems to be about 1.5 times the operating pressure, based on relief valve setting.

Design Safety.

S. C. Wright suggested using a two-layer window installed so that the inner glass contained the pressure with the outer spaced a few thousandths of an inch away and not in contact. If the inside glass ruptured, it

would not damage the outside due to the short acceleration distance. Each glass would have a low probability of rupture, possibly 1 percent, giving a large factor of improbability for a double rupture.

A knife edge design for window sealing, shown in Figure 4, was described by R. H. Hildebrand. The indium-coated copper ring must be braced to prevent tilting. The ring sealing edge in contact with the glass is flattened to 0.025 inch by pressure applied to the compression ring as the screws are tightened.

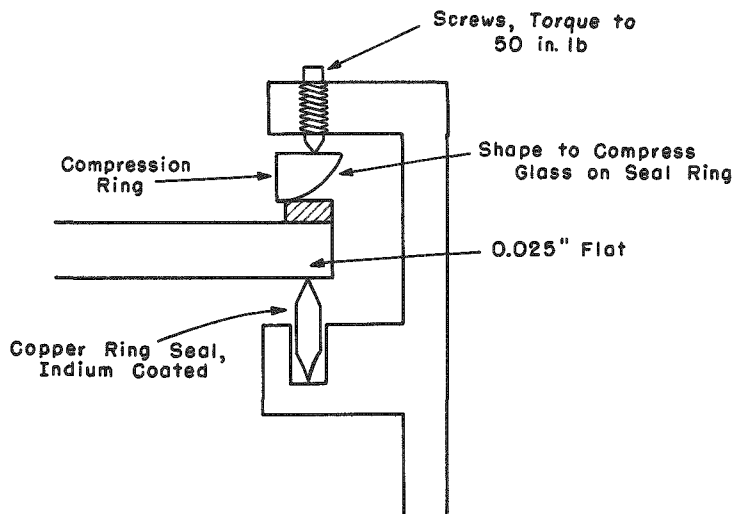


Fig. 4. Knife Edge Seal for Windows

DETONATION OF HYDROGEN

R. H. Kropschot discussed experience with hydrogen fires and explosions. Hydrogen gas in concentrations of 4 to 74 percent in air can undergo combustion. Concentrations of 18 to 60 percent can detonate when the mixture is confined. The usual minimum condition for confinement is a floor and three walls; in some cases a floor and two walls may suffice. One liter of hydrogen in a stoichiometric mixture with oxygen will produce an explosion equal to 2 pounds of TNT. A hydrogen fire is invisible, or transparent. Heat strata can be recognized in the flame, but there is no color.

The safe distance from a hydrogen fire depends upon several factors. These include quantity of hydrogen, humidity of the air, wind, and type of clothing. M. G. Zabetakis of the U.S. Bureau of Mines recommends the following for hydrogen spills:

<u>Pounds of hydrogen spilled</u>	<u>Distance to inhabited building</u>
0-200	100 feet
200-1000	150 feet
1000-5000	200 feet

A hydrogen fire does not radiate a large amount of heat. For a flame temperature of 3700F, the emissivity is 0.09.

Very little data are available, but an explosion occurred in a test cell at Boulder under confinement conditions as defined above. Detonation occurred and the flame came over the walls, burning personnel. A building 200 feet away was jarred by shock. An electric spark in the test cell may have caused the explosion. The cell layout is shown in Figure 5.

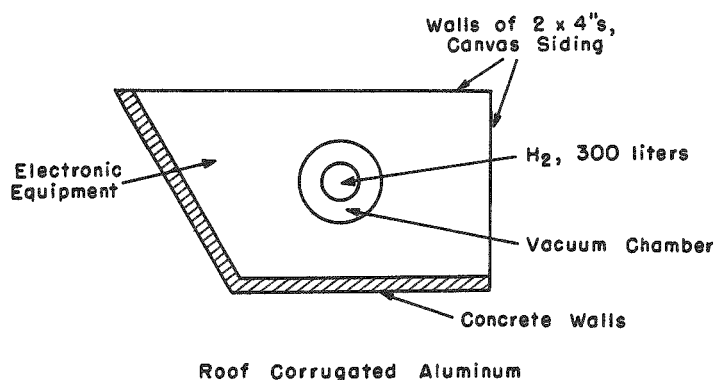


Fig. 5. Boulder Laboratory Test Cell

Discussion of Containment Structures

A steel plate cylinder or silo with a blowoff roof could be used to confine bubble chamber experiments. The space should be well ventilated. Released hydrogen will rise at 3 to 6 feet per second. Use of a silo or similar container reduces gross ventilation requirements, and minimizes the space in which explosion proof electrical construction must be used.

Detailed tests are required to evaluate the effectiveness of silos. Hoods are probably as good, although at Brookhaven hydrogen clouds missed hoods installed over the equipment. Block houses presently in use are probably as good as silos. The effect of a plastic blowoff roof was not evaluated.

DISCUSSION OF GLASS

The discussion, led by R. H. Kropschot, included temperature effects, fatigue, and reports on two series of fracture tests.

Temperature Effects

When glass is stressed for a prolonged time at room temperature, the glass breaks due to fatigue failure. The effect does not occur at liquid nitrogen temperature, but does at carbon dioxide liquid temperature. If the glass is stressed in an evacuated chamber after baking, there is no fatigue effect.

The apparent explanation is that the failure is caused by moisture condensed in small surface imperfections. Surface imperfections are almost always present, even in polished glass since the grinding is not deep enough to remove them. In tempered glass surface compression results from rapid cooling during manufacture. It is still advisable not to use minimum dimensions for design strength calculations. P. Hernandez used a design strength of 8300 psi and a safety factor of four for the Berkeley chamber window design.

Data on Breakage Stress Tests

These were introduced from a memorandum by E. Denton. Rupture tests were performed at room temperature on five plates of tempered glass, each approximately 1 inch thick and 10 inches in diameter. Three of the plates had been ground and polished to a depth of nearly 0.005 inch on each side (in preparation for use in the Chicago Bubble Chamber). Small fiducial marks had been etched to a depth no greater than 0.001 inch near the centers of these plates.

Since the purpose of the tests was to indicate the potential hazard to personnel engaged in leak testing window seals, test pressures were applied slowly as compared with the normal 1000-psi per second rates occurring during a bubble chamber expansion cycle.

The deflection at the center of each window was completely linear, with a slope of 0.0056 inch per 100 psi while the pressure rise was continuous. Over a 500-psi cycle, however, each window showed a maximum hysteresis of about 10 percent.

Results showed that the grinding, polishing, and etching did not affect the strength of the glass. They also showed that an increase from one to 20 psi in the pressure increase rate appears to double the strength. The results are tabulated below. In addition, a table giving Bureau of Standards figures, taken from the Cryogenics Data Book, UCRL-3421, page 90, is shown for comparison.

Table 2
GLASS RUPTURE TESTS

(From E. H. Denton Report)

Sample description	Sample condition	Rupture pressure, psi	Maximum stress at center, psi	Rate of stress increase, psi/sec
<u>Herculite Glass</u> (Pittsburgh Plate Glass Co.) 1 in. th. 10 $\frac{3}{8}$ in. Dia. 10 in. Dia. Exposed Area	U	780	39,000	$\frac{1}{4}$
	A	650	33,000	1
	G-P	700	35,000	$\frac{1}{6}$
	G-P-E	875	44,000	4
	G-P	1,250	63,000	20

(National Bureau of Standards Figures from UCRL-3421)

<u>Borosilicate</u>	U	-	10,400	800
<u>Crown-2</u>	A	-	7,500	800
<u>Optical Glass</u> (296° K)	A	-	5,500	10
	A	-	5,000	1

U - Unabraded
A - Abraded
G-P - Ground and Polished
E - Etched

Optical Glass Breakage Tests

Tests were made with both abraded and nonabraded optical glass, and the breakage stress as a function of the percentage of samples breaking was plotted. The stress for nonabraded was about twice that for abraded glass. The curves are close together at the point where the breaking value was 7000 psi for one percent of the samples tested.

At a pressure rise rate of 800 psi per second, the breakage stress for various temperatures was as follows:

<u>degrees Kelvin</u>	<u>psi</u>
300	7,500
194	9,500
76	10,400
20	10,400

Note: Fifty percent of the samples did not fail at these pressures.

Rate of Cooling Effect

No good experimental data are available for thick windows. Cooling can produce high stresses. Data extrapolated from tests with one-inch thick samples indicate that 24 to 48 hours are required for cooling 5-inch thick windows.

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- Balai Influence of Exposure to Liquid Helium on the Tensile Properties of Various Stainless Steels. Copy attached as Appendix.
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- Hernandez H. P. Hernandez, J. W. Mark and R. D. Watt, Designing for Safety in Bubble Chambers, The Review of Scientific Instruments, Vol. 28, No. 7, pp. 528-535 (July 1957).

Note: The name given at the left is the person calling attention to the reference.

APPENDIX

Influence of Exposure to Liquid Helium on the Tensile Properties of Various Stainless Steels

(From unpublished report by International Nickel Co. 67 Wall St., N. Y.)

SUMMARY

Studies were made of the result of exposure to the temperature of liquid helium on several commercial stainless steels and a few experimental iron-nickel-chromium-molybdenum alloys. The Bayonne Research Laboratory found that a slight improvement in tensile strength occurred in the case of Type 321 stainless steel, and a substantial improvement was registered for an experimental 12% chromium, 8% nickel, 2% molybdenum alloy, both in strength and ductility. The improvements are believed to be associated with austenite transformation resulting from exposure to as low as 4.2°K, but the microscope was unable to reveal any traces of such transformation.

None of the other alloys was appreciably affected.

DATA AND DISCUSSION

The materials tested and the results obtained as shown in Table I. All of the specimens were in the form of sheet specimens 1 to 2 in. wide by 9 in. long, except the Incoloy, which was tested in $\frac{3}{4}$ in. bar form, 6 in. long. The experimental alloys were annealed 30 minutes at 2000 F and water quenched. The commercial alloys were already in the mill annealed condition except the Type 304 stainless, which was tested both half-hard and annealed.

At the Massachusetts Institute of Technology the specimens were cooled to 80°K (minus 315°F) in liquid nitrogen, then further cooled to 4.2°K (minus 452°F) in liquid helium for 22 hours. Following this, the temperatures varied from 4.2°K (minus 452°F) to 12°K (minus 438°F) during a 12 hour period, from 4.2°K to 44°K (minus 380°F) during a 14 hour period, and from 44°K to 250°K (minus 9°F) over a $42\frac{1}{2}$ hour period.

The results of the tensile and hardness tests shown in Table I indicate that most of the materials were unaffected by the exposure at low temperatures. However, the Type 321 stainless steel increased slightly but definitely in tensile strength and hardness, and the 12% chromium, 8% nickel, 2% molybdenum alloy increased in strength and hardness considerably and in ductility as well.

Table I

TENSILE PROPERTIES OF STAINLESS STEELS EXPOSED TO LIQUID HELIUM

Material	Before exposure				After exposure			
	0.2% yield strength, psi	Tensile strength, psi	Elongation 2" %	Rockwell hardness	0.2% yield strength, psi	Tensile strength, psi	Elongation 2" %	Rockwell hardness
Type 304	39,000	87,000	63	B81.5	37,500	87,500	65.5	B81
Type 304 (Half Hard)	136,500	151,000	11	C35	139,000	154,000	10	C35
Type 321	26,000	76,500	65	B64	25,000	81,000	58	B75
Type 347	42,000	88,500	53	B83	42,000	89,000	54	B83.5
Type 310	30,500	79,500	54	B73	31,000	80,500	55	B74
Incoloy	34,000	85,000	45	B76.5	34,000	85,000	46	B78
12Cr, 8Ni, 2Mo	40,500	88,000	31	B82.5	43,000	106,000	53	B93.5
18Cr, 8Ni, 2Mo	49,000	111,000	56.5	B92.5	49,000	111,000	55	B88
18Cr, 14Ni, 2Mo	49,500	101,000	39	B88.5	46,500	101,000	42.5	B85.5
30Cr, 14Ni	62,000	106,500	35.5	B94.5	59,000	106,000	36.5	B90

These improvements are believed associated with additional austenite transformation to ferrite or martensite. Qualitative measurements with a hand magnet confirmed this surmise and also revealed a slight increase in magnetism for Type 304, both half-hard and annealed and for Type 310 stainless steels. The latter changes were evidently too minor in nature to affect the strength properties.

The microscope was unable to detect any structural transformation in any of the alloys, and it must therefore be assumed that such transformation is sub-microscopic in character.