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"Rubber and Plastics Age" Monograph No. 13

LAWRENCE RADIATION LABORATORY
REPRINT NUMBER
1960 3 2 4
UNIVERSITY OF CALIFORNIA

PLASTICS FOR ATOM–SMASHERS

by: **JAMES O. TURNER**
LAWRENCE RADIATION LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA, U.S.A.

Work done under the auspices of the U.S. Atomic Energy Commission

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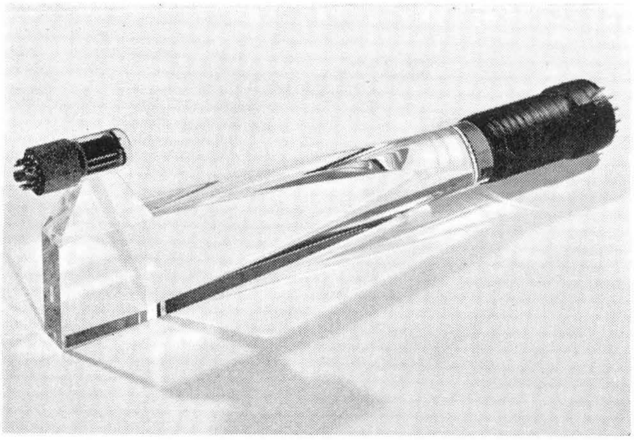

Fig. 1. Styrene Plastic Scintillator Attached to Acrylic Light Pipes Leading to Photomultiplier Tubes

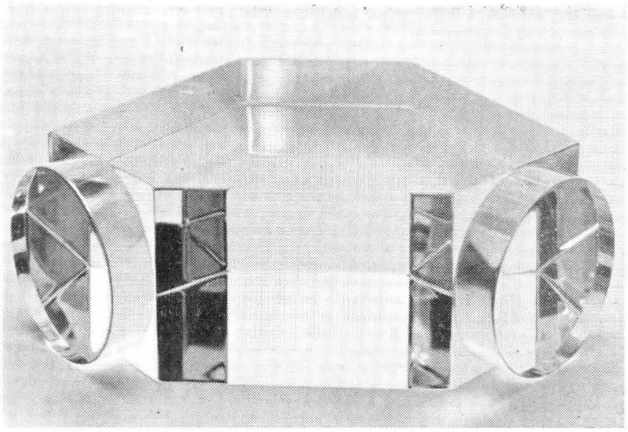

Fig. 2. Acrylic Cherenkov Counter

PLASTICS FOR ATOM-SMASHERS

By JAMES O. TURNER

"ATOM-SMASHERS," or high-energy nuclear accelerators, have produced some spectacular advances in man's understanding of the fundamental structure of matter. With their supporting apparatus, they form a class of highly complex instruments, whose designers are continually beset with tough and puzzling problems. They involve precise manipulation of pressure, vacuum, voltage, current, magnetic field, and temperature, sometimes to awesome extremes and often with microsecond timing.

In the solution of these problems many plastic materials have played indispensable parts. They provide combinations of mechanical and electrical strength, flexibility, toughness, chemical and temperature resistance, and optical and vacuum properties—without which many nuclear-particle experiments would be impossible. These materials fall into virtually every classification of thermoplastic and thermosetting resins.

Plastic Scintillators

We at the Lawrence Radiation Laboratory have come to depend heavily upon a class of materials known as plastic scintillators. The principal ingredient of this material is styrene. Certain complex organic phosphors or fluors are dissolved in the styrene monomer, and then the solution is carefully polymerised by the application of heat. When the material has solidified, it is then cut and polished to final shape, and is usually combined with one or more pieces of highly polished acrylic plastic (Fig. 1). The styrene scintillator emits visible light when traversed by beams of accelerated ionised particles. The scintillations, or flashes of visible light, are transmitted by the acrylic light pipe to one or more photomultiplier tubes. These convert the light pulses into electrical pulses, which then actuate electronic counters.

Acrylic Plastics

We also use extensively a type of accelerated beam detector known as a Cherenkov counter. This can be made of any of a number of transparent materials, and is frequently made of highly polished acrylic plastic (Fig. 2).

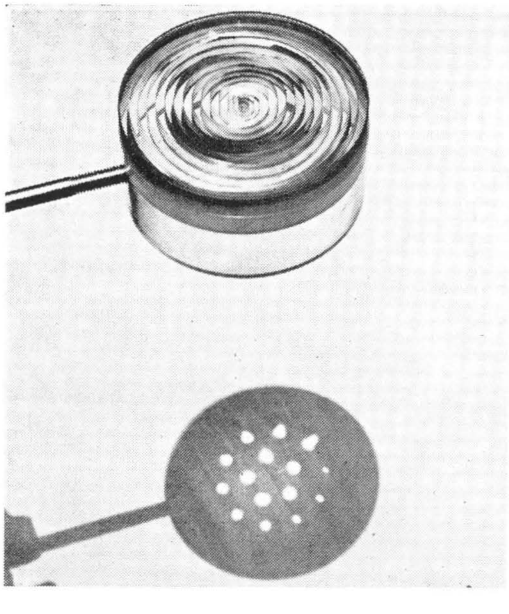

Fig. 3. Annular Separation Lens

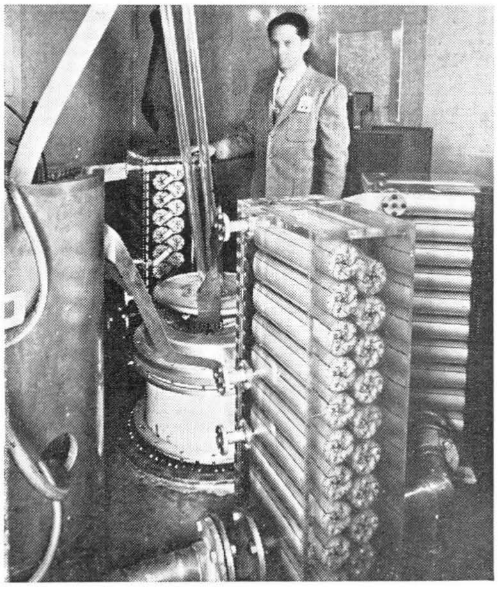

Fig. 4. Ferroxcube Reactor Boxes of Acrylic Plastic

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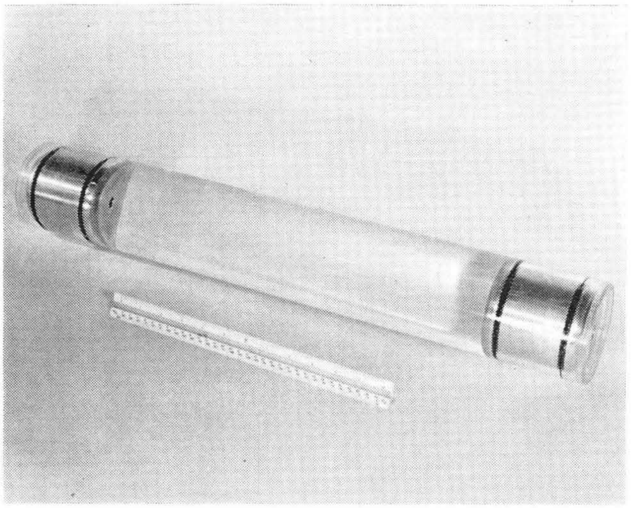


Fig. 5. Distilled-Water High-Voltage Resistor of Acrylic Plastic

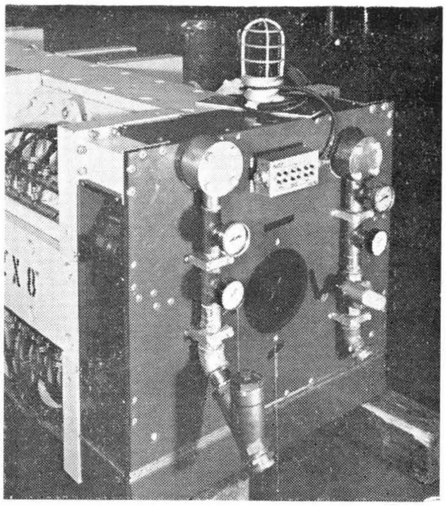


Fig. 6. Quadrupole Focusing Magnet With Vinyl Chloride Acetate Windows

This type of detector also gives off visible light pulses, which are picked up and counted in a manner similar to those from the plastic scintillators.

The high-clarity acrylic plastics have many optical applications in the shape of lenses, prisms, windows, etc. An unusual application is in a high-speed measuring projector for measuring images on film. It uses a rotating disc containing a series of slits, each at a different radius. Each slit as it rotates sweeps out an annular area. The light from each of these annular rings must be gathered and focused into a stationary photomultiplier tube. This is accomplished with an acrylic lens containing a series of concentric elements, each matching one of the annular zones but having its focus offset in a direction different from the others (Fig. 3).

The excellent electrical properties of acrylic plastics are utilised in a wide variety of ways. One application is as a container for oil-submerged high-voltage reactor cores which are part of the accelerating-electrode power supply for the Bevatron (Fig. 4). Another of these applications is as a stabilising resistor, which was constructed of an acrylic plastic tube filled with distilled water (Fig. 5).

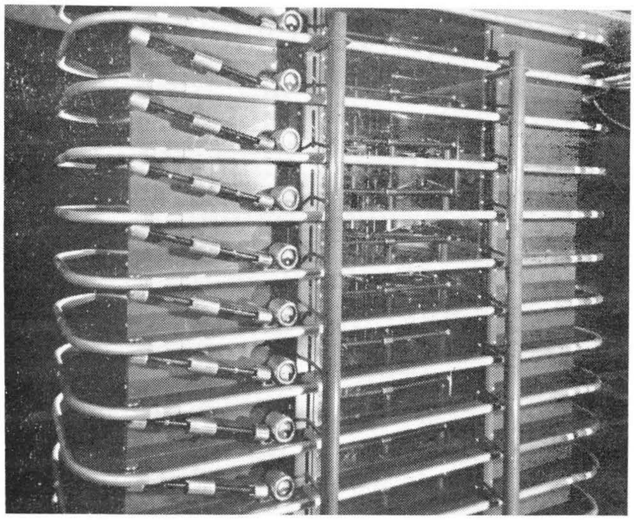


Fig. 7. Cockcroft-Walton High-Voltage Generator of Polyvinyl Chloride and Vinyl Chloride Acetate

Fire Hazard

In some cases involving the construction of high-voltage apparatus, because of the hazard of fire, we have found

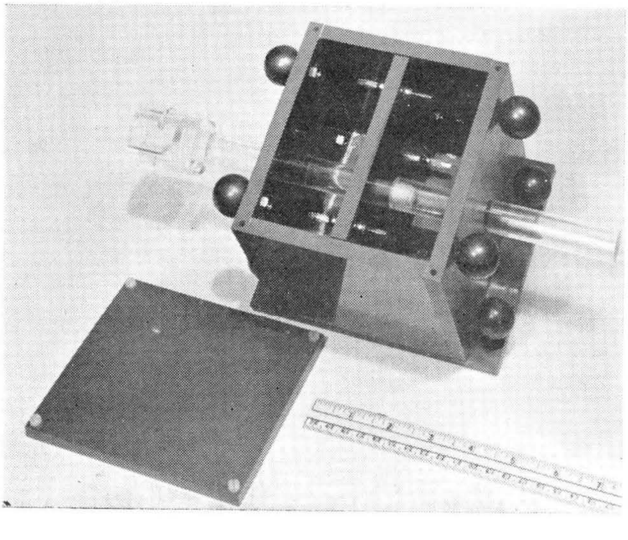


Fig. 8. Twenty-Thousand-Volt Reversing Switch of Polyvinyl Chloride

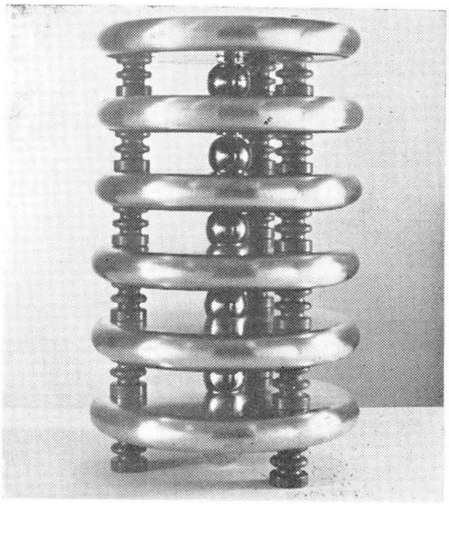
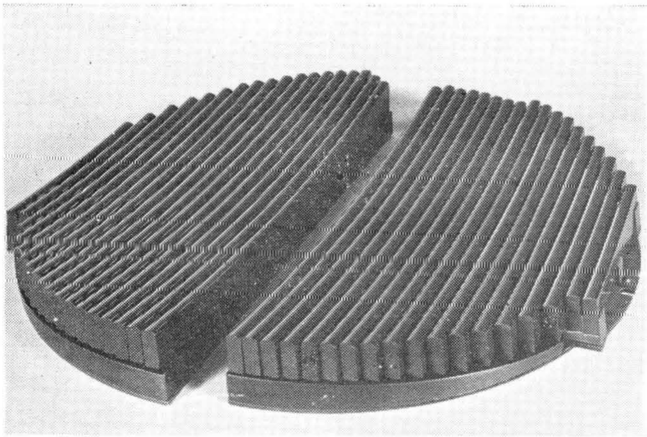
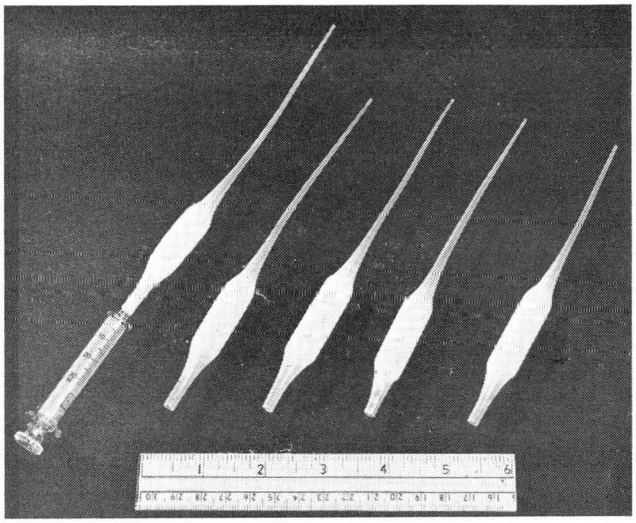


Fig. 9 400-kv. Voltage-Divider Resistor Assembly



ABOVE : *Fig. 10. Retrodirective Reflector of the 15 in. Liquid-Hydrogen Bubble Chamber*



RIGHT : *Fig. 11. 'Spitzer' Transfer Pipettes of Polyethylene*

it necessary to adopt materials of good electrical properties which are also self-extinguishing. Such a material is transparent vinyl chloride-vinyl acetate copolymer. This material is currently used more and more where both good electrical properties and transparency are required, such as in the side windows in recently constructed focusing quadrupole magnets (Fig 6). Another material which we have found quite useful in the construction of high-voltage apparatus, which also must be self-extinguishing, is polyvinyl chloride. A recently completed Cockcroft-Walton 500,000-volt generator uses PVC to enclose the end compartments of the various decks and vinyl chloride-vinyl acetate to enclose the centre sections of these decks (Fig. 7). PVC is used for many high-voltage constructions that must be self-extinguishing and are not required to be transparent. Another instance is a 20,000-volt reversing switch (Fig. 8). This material has also proved to be quite useful as a simple and easy replacement for ceramic stand-off insulators where no stock ceramic insulators are available of just the right size. Such an application is a six-deck 500,000-volt voltage-dividing resistor (Fig. 9).

We were recently faced with a problem involving a severe optical requirement. This was the construction of a highly specialised retrodirective reflector that would reflect light very accurately, would not produce any reflected images, and would withstand submersion in liquid hydrogen at a temperature of approximately minus 450°F. A system of reflecting lenses with curved cylindrical surfaces was finally worked out, and the material which we found best suited to these conditions was clear CR-39 allyl plastic plate from which the lenses were machined and polished (Fig. 10).

Polyethylene provides the solution for a number of problems. One example is for "Spitzers", or transfer pipettes for the handling of highly corrosive radioactive chemicals (Fig. 11). Another recent application is the outer enclosure of a special large ionisation chamber (Geiger counter). The lower part of the outer shell was constructed of black high-density polyethylene, and welded to it was a flat end plate of white high-density polyethylene (Fig. 12).

High Strength Materials

A material that is almost indispensible to us is high-strength polyester film. We use it for insulation of many coils involving large size square and rectangular conductors (Fig. 13), and also as containers for liquid hydrogen when used as beam targets inside vacuum tanks (Fig. 14).

A very new material which promises to be of considerable use to us because of its exceptionally high impact strength and dimensional fidelity is polycarbonate which we have already used in a number of applications. A high-precision adjusting thumb screw is a typical example (Fig. 15).

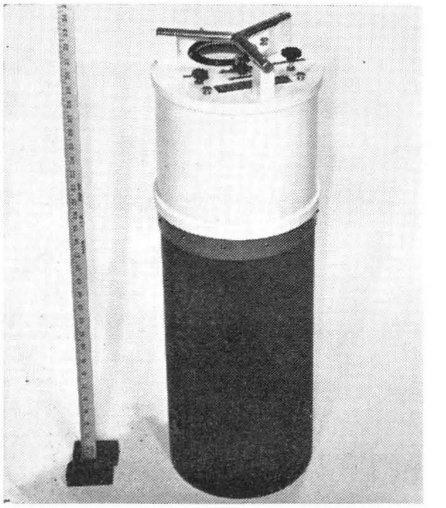


Fig. 12. Ionisation Chamber (Geiger Counter) of High-Density Polyethylene

Fig. 13. A Coil of Water-Cooled Square Copper Conductor Being Insulated With High-Strength Polyester-Film Tape

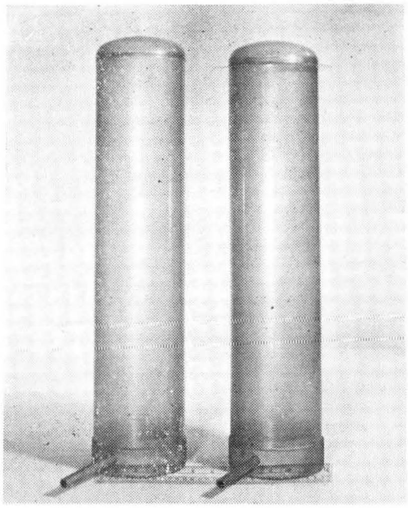


Fig. 14. Containers for Liquid Hydrogen Used as Targets for Accelerated Beams of Ionised Particles

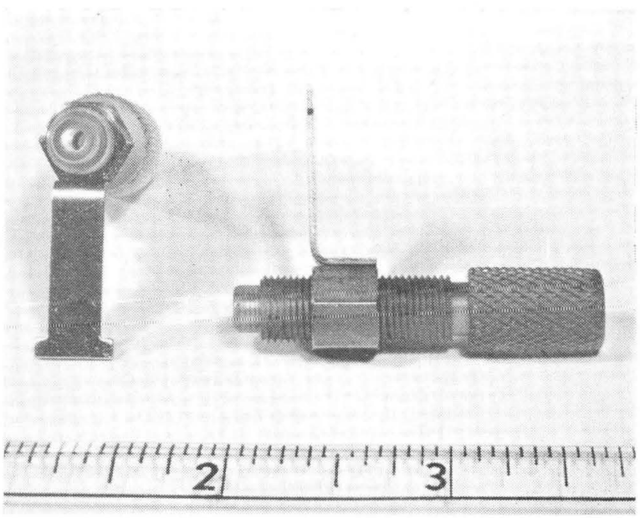


Fig. 15. Precision Adjusting Thumb Screws of Polycarbonate Plastic

Fluorethylene has many useful properties. An unusual one which we have been able to utilise is the fact that an electric arc improves rather than degrades the electrical properties of the surface of the material. This has been used in the construction of a high-current (2,000,000-amp) pulsing switch for thermonuclear research. The fluoroethylene forms the "tires" or grooves which support the large metallic arcing plates at their outer edges (Fig. 16).

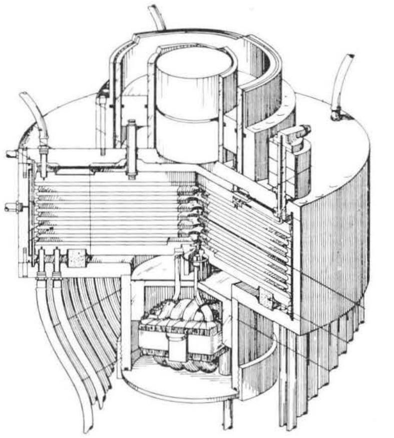


Fig. 16. Two-million ampere pulsing switch consisting of copper plates supported at the edges with fluoroethylene plastic

Soft, flexible, polyurethane sponge material has proved to be useful in a number of applications, including one which is quite unusual. An instrument called a propane bubble chamber consists of an inner compartment containing propane, around the outside of which is a much larger chamber containing a clear transparent oil. It is necessary to transmit pressure pulses from the top of the chamber to the inner compartment through this column of oil. In certain parts of the oil compartment trouble was encountered with turbulence. This was quite readily solved by stuffing this particular part of the oil chamber with polyurethane sponge which is impervious to the oil and acts as a stabilising baffle (Fig. 17).

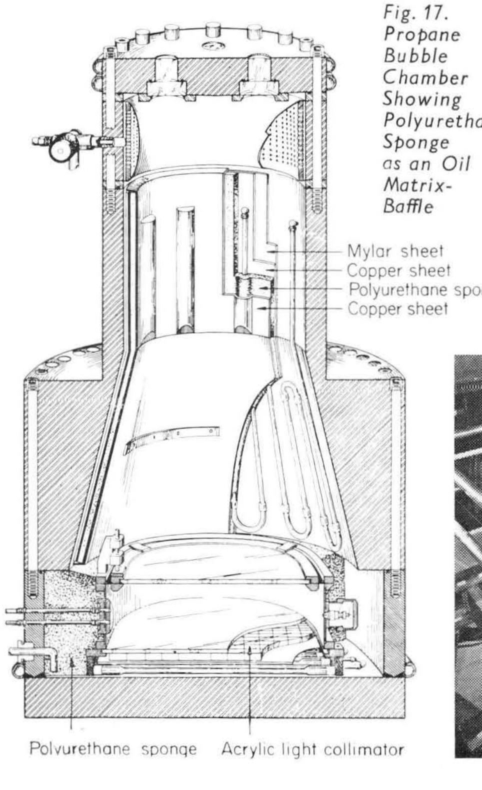


Fig. 17. Propane Bubble Chamber Showing Polyurethane Sponge as an Oil Matrix-Baffle

Laminates

One of the most useful materials to us is the industrial laminate constructed of woven glass fibre and NEMA grade G10 epoxy resin. This material has so much better mechanical, electrical, and vacuum properties than any

Fig. 18. Bevatron Rapid-Beam-Ejector Coil Supported by Epoxy and Fibreglass, Grade G-10 Laminate

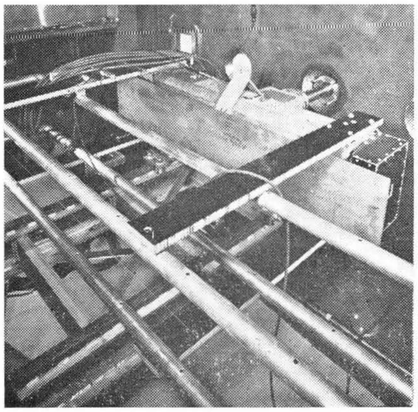
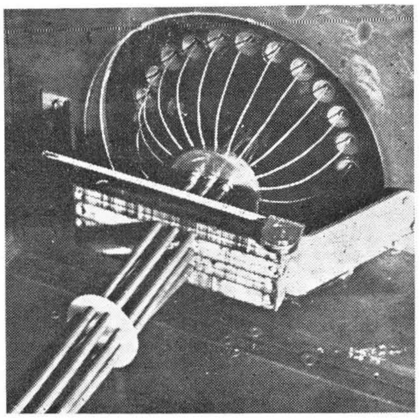
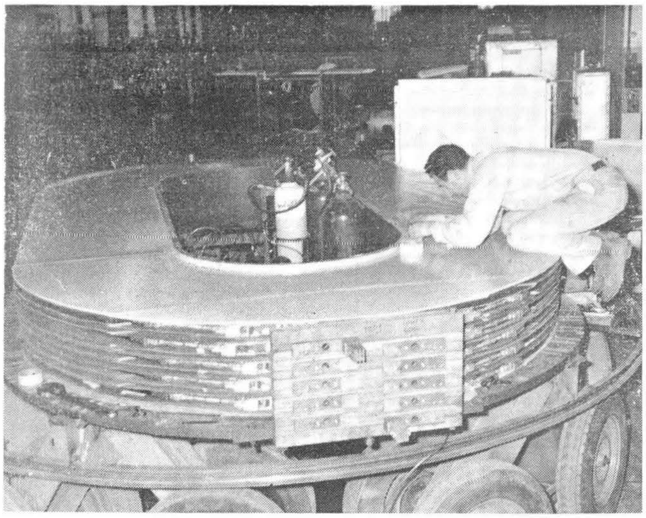
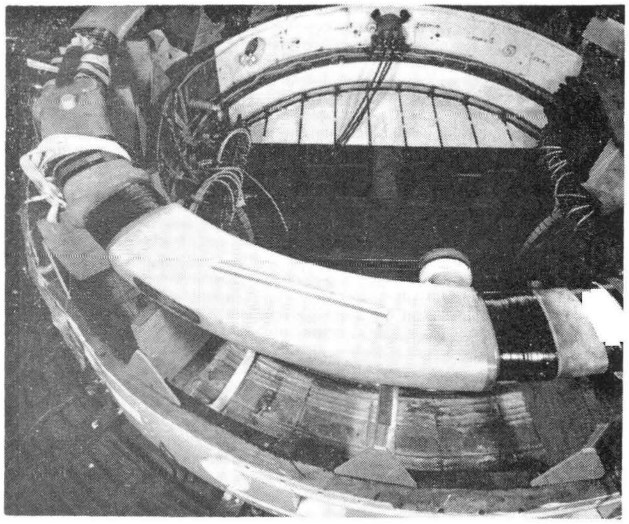
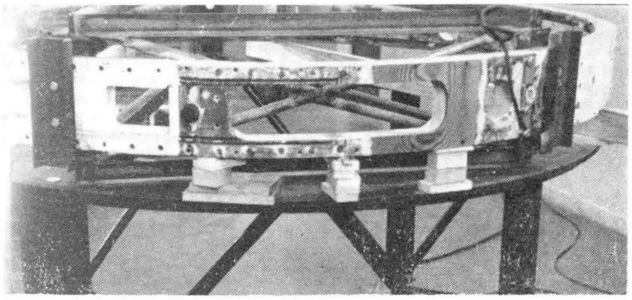


Fig. 19. Feed-Through Plate of the Bevatron Beam-Kicker Constructed of G-10 Laminate









TOP LEFT : *Fig. 20. Coil of 1.3 in-sq. copper conductors for 72in. liquid-hydrogen bubble chamber, almost completed*

TOP RIGHT : *Fig. 22. Section of vacuum tank for electron synchrotron constructed of epoxy and fibreglass, assembled into ring tank*

LEFT : *Fig. 21. Iron-epoxy mastic being applied to bubble chamber magnet*

ABOVE : *Fig. 23. Section of electron-synchrotron support ring constructed of filled epoxy resin reinforced with steel rods*

other material that it has now been adopted as standard for non-metallic constructions inside the Bevatron vacuum tank. In this connection, the material serves in a wide variety of applications involving high voltage gradients and high mechanical stresses. One example of this is an elongated coil known as the "rapid beam ejector". It is formed of copper tubing carried on a framework of G10 laminate (Fig. 18). Another representative example of many such uses is a device known as the "beam-kicker feed-through plate" for leading a high-voltage coaxial transmission line through the wall of the vacuum tank (Fig. 19).

In providing insulation and mechanical support and separation for the separate turns and layers of coils wound from large-size copper conductor, laminates made from glass fibre mat, woven cloth, and polyester resin have proved to be economical and useful. The magnet coil for our 72 in. liquid-hydrogen bubble chamber is wound with a copper-bar conductor 1.3 inches square. The conductor is wrapped with high-strength polyester film tape ; a glass mat and polyester resin strip is used to separate the turns ; a heavier glass and polyester laminate is used to separate the various layers ; and still heavier glass and polyester board is used for the top and bottom enclosures of the coil (Fig. 20).

Since it employs large quantities of liquid hydrogen, this same 72 in. bubble chamber presents a very real hazard from fire and explosion. Thus elaborate precautions are necessary to protect personnel in the building in which it is housed. One of these precautions involves the use of a window material that will not shatter as ordinary window glass does. For this reason all of these windows are glazed with a fire-resisting grade of translucent glass fibre and polyester building sheet.

Epoxy Resins

By all odds, the single material that enjoys the widest variety of uses is liquid epoxy resin. The number of different ways in which we use this material runs literally into the hundreds. A very few random examples are these. In the assembly of the 72 in. liquid-hydrogen bubble chamber, it was necessary to make a joint between the bottom of the vacuum tank and the top of the magnetic yoke that would be both mechanically and magnetically as sound as possible. In order to avoid an expensive machining procedure, the joint was filled with a mastic formulated of epoxy resin and iron powder (Fig. 21).

Our electron synchrotron comprises a ring-shaped vacuum tank approximately 8 ft. in diameter with an elliptical cross section. The original vacuum tank was constructed of quartz. Since it is sometimes necessary to replace sections of this vacuum tank, there has been a continuing effort to find a material more easily fabricated and less expensive than the original quartz. This was

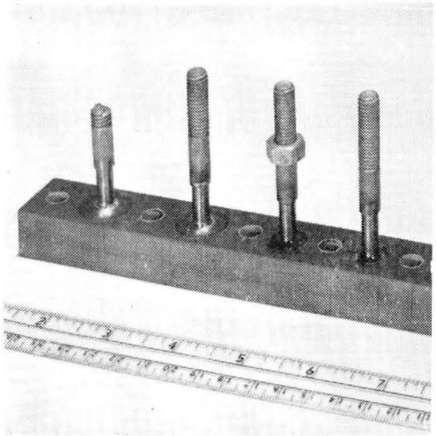


Fig. 24. Corona-free anchorage of steel bolts with spherical heads embedded in epoxy resin

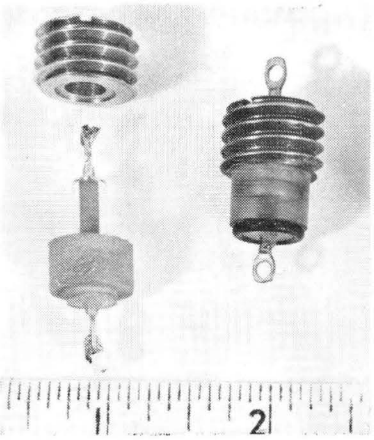


Fig. 25. Epoxy "spark plug" feed-through insulators for propane bubble chamber

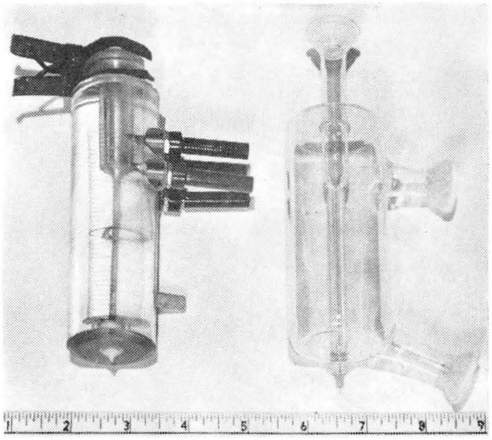


Fig. 26. (Left) Ion-exchange column for radio-chemistry cast of epoxy resin

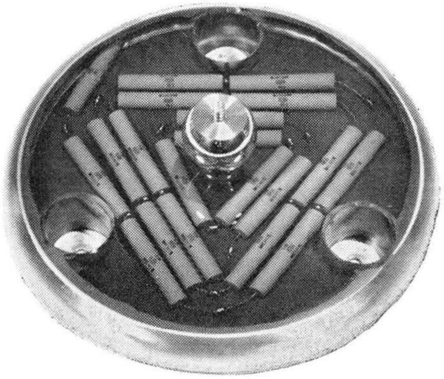
finally accomplished with the use of epoxy resin, glass fibre cloth and glass beads for fillers (Fig. 22). In this same machine it was necessary to modify a non-metallic mechanical support ring to withstand very high magnetic forces. The alteration consisted of making a large elongated window or opening in this support ring. This was accomplished by the use of epoxy resin filled with glass beads and with horizontal steel rods used for reinforcement in the manner of concrete-reinforcing steel (Fig. 23).

An insulating anchorage was required in the Bevatron for some quarter-inch steel bolts. These fastenings could not be of the usual type because of the corona resulting from an exceedingly high-voltage gradient. This was very neatly accomplished by providing spherical heads for the bolts and imbedding them in holes in the insulating support, the holes being filled with epoxy resin (Fig. 24).

The propane bubble chamber mentioned earlier required a bushing that would be a good insulator and also be impervious to the action of warm propane. This was accomplished by means of a small spark-plug type bushing cast of epoxy resin (Fig. 25).

One of the techniques used in radioactive chemistry experiments is the use of a minute ion-exchange column. This is a somewhat delicate procedure and requires very careful control of temperature and loading rates, among other things. A glass apparatus is ordinarily used for this procedure, but for certain types of experiments it is desirable to use an organic material rather than glass. This was cast of a very light-coloured epoxy resin (Fig. 26).

Fig 27. Ceramic Resistor Embedment in Soft Flexible Epoxy for Six-deck High-voltage Dividing-Resistor Assembly



In the six-deck voltage-dividing resistor mentioned earlier, each individual deck was composed of 20 ceramic resistors arranged in a copper dish. To reduce the effects of corona, it was necessary to embed these resistors in a good insulating compound. In order not to crush the resistors, we needed a compound that would be very soft and have very low shrinkage. This was neatly achieved by the use of an epoxy resin and a fatty diamine (Fig. 27).

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ABSTRACT

High-energy nuclear accelerators have produced some spectacular advances in man's understanding of the structure of matter. Many plastic materials perform indispensable functions in these machines and their supporting apparatus. Without these materials, many nuclear experiments would have been impossible. Representative examples are pictured and described.

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In some cases involving the construction of high-voltage apparatus, because of the hazard of fire, we have found it necessary to adopt materials of good electrical properties which are also self-extinguishing. Such a material is transparent vinyl chloride acetate. This material is currently used more and more where both good electrical properties and transparency are required, such as in the side windows in recently constructed focusing quadrople magnets (see Fig. 7). Another material which we have found quite useful in the construction of high-voltage apparatus, which also must be self-extinguishing, is polyvinyl chloride or "PVC". A recently completed Cockcroft-Walton 500,000-volt generator uses PVC to enclose the end compartments of the various decks and vinyl chloride acetate to enclose the center sections of these decks (see Fig. 8). Polyvinyl chloride is used for many high-voltage constructions that must be self-extinguishing and are not required to be transparent. Another instance is a 20,000-volt reversing switch (see Fig. 9). This material has also proved to be quite useful as a simple and easy replacement for ceramic stand-off insulators where no stock ceramic insulators are available of just the right size. Such an application is a six-deck 500,000-volt voltage-dividing resistor (see Fig. 10).

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A material that is almost indispensable to us is high-strength polyester film. We use it for insulation of many coils involving large size square and rectangular conductors (see Fig. 16), and also as containers for liquid hydrogen when used as beam targets inside of vacuum tanks (see Fig. 17).

A very new material which promises to be of considerable use to us because of its exceptionally high impact strength and dimensional fidelity is polycarbonate which we have already used in a number of applications. A high-precision adjusting thumb screw is a typical example (see Fig. 18).

Fluoroethylene has many useful properties. An unusual one which we have been able to utilize is the fact that an electric arc improves rather than degrades the electrical properties of the surface of the material. This has been used in the construction of a high-current (2,000,000-amp) pulsing switch for thermonuclear research. The fluoroethylene forms the "tires" or grooves which support the large metallic arcing plates at their outer edges (see Fig. 19).

Soft, flexible, polyurethane sponge material has proved to be useful in a number of applications, including one which is quite unusual. An instrument called a propane bubble chamber consists of a inner compartment containing propane, around the outside of which is a much larger chamber containing a clear transparent oil. It is necessary to transmit pressure pulses from the top of the chamber to the inner compartment through this column of oil. In certain parts of the oil compartment trouble was encountered with turbulence. This was quite readily solved by stuffing this particular part of the oil chamber with polyurethane sponge which is impervious to the oil and acts as a stabilizing baffle (see Fig. 20).

One of the most useful materials to us is the industrial laminate constructed of woven fiberglas and NEMA grade G10 epoxy resin. This material has so much better mechanical, electrical, and vacuum properties than any other material that it has now been adopted as standard for nonmetallic constructions inside the Bevatron vacuum tank. In this connection, the material serves in a wide variety of applications involving high voltage gradients and high mechanical stresses. One example of this is an elongated coil known as the "rapid beam ejector". It is formed of copper tubing carried on a framework of G10 laminate (see Fig. 21). Another representative example of many such uses is a device known as the "beam-kicker feed-through plate" for leading a high-voltage coaxial transmission line through the wall of the vacuum tank (see Fig. 22).

In providing insulation and mechanical support and separation for the separate turns and layers of coils would from large-size copper conductor, laminates made from fiberglas mat, woven cloth, and polyester resin have proved to be economical and useful. The magnet coil for our 72-inch liquid-hydrogen bubble chamber is wound with a copper-bar conductor 1.3 inches square. The conductor is wrapped with high-strength polyester-film tape; a fiberglas mat and polyester resin strip is used to separate the turns; a heavier fiberglas and polyester laminate is used to separate the various layers; and still heavier fiberglas and polyester board is used for the top and bottom enclosures of the coil (see Figs. 23 and 24).

Since it employs large quantities of liquid hydrogen, this same 72-inch bubble chamber presents a very real hazard from fire and explosion. Thus elaborate precautions are necessary to protect personnel in the building in which it is housed. One of these precautions involves the use of a window material that will not shatter as ordinary window glass does. For this reason all of these windows are glazed with a fire-resisting grade of translucent fiberglas-and-polyester building sheet (see Fig. 25).

By all odds, the single material that enjoys the widest variety of uses is liquid epoxy resin. The number of different ways in which we use this material runs literally into the hundreds. A very few random examples are these. In the assembly of the 72-inch liquid-hydrogen bubble chamber, it was necessary to make a joint between the bottom of the vacuum tank and the top of the magnetic yoke that would be both mechanically and magnetically as sound as possible. In order to avoid an expensive machining procedure, the joint was filled with a mastic formulated of epoxy resin and iron powder (see Figs. 26 and 27).

Our electron synchrotron comprises a ring-shaped vacuum tank approximately 8 feet in diameter with an elliptical cross section. The original vacuum tank was constructed of quartz. Since it is sometimes necessary to replace sections of this vacuum tank, there has been a continuing effort to find a material more easily fabricated and less expensive than the original quartz. This was finally accomplished with the use of epoxy resin, fiberglas cloth and glass beads for fillers (see Figs. 28 and 29). In this same machine it was necessary to modify a nonmetallic mechanical support ring to withstand very high magnetic forces. The alteration consisted of making a large elongated window or opening in this support ring. This was accomplished by the use of epoxy resin filled with glass beads and with horizontal steel rods used for reinforcement in the manner of concrete-reinforcing steel (see Fig. 30).

An insulating anchorage was required in the Bevatron for some quarter-inch steel bolts. These fastenings could not be of the usual type because of the corona resulting from an exceedingly high-voltage gradient. This was very neatly accomplished by providing spherical heads for the bolts and imbedding them in holes in the insulating support, the holes being filled with epoxy resin (see Fig. 31).

The propane bubble chamber mentioned earlier required a bushing that would be a good insulator and also be impervious to the action of warm propane. This was accomplished by means of a small spark-plug-type bushing cast of epoxy resin (see Fig. 32).

One of the techniques used in radioactive chemistry experiments is the use of a minute ion-exchange column. This is a somewhat delicate procedure and requires very careful control of temperature and loading rates, among other things. A glass apparatus is ordinarily used for this procedure, but for certain types of experiments it is desirable to use an organic material rather than glass. This was cast of a very-light-colored epoxy resin (see Fig. 33).

In the six-deck voltage-dividing resistor mentioned earlier, each individual deck was composed of 20 ceramic resistors arranged in a copper dish. To reduce the effects of corona, it was necessary to embed these resistors in a good insulating compound. In order not to crush the resistors, we needed a compound that would be very soft and have very low shrinkage. This was neatly accomplished by the use of an epoxy resin and a fatty diamine (see Fig. 34).

LEGENDS

Fig. 1. Styrene plastic scintillators attached to acrylic light pipes.

Fig. 2. Styrene plastic scintillator attached to acrylic light pipes leading to photomultiplier tubes.

Fig. 3. Acrylic Cherenkov counter.

Fig. 4. Annular separation lens.

Fig. 5. Ferroxcube reactor boxes of acrylic plastic.

Fig. 6. Distilled-water high-voltage resistor of acrylic plastic.

Fig. 7. Quadrupole focusing magnet with vinyl chloride acetate windows.

Fig. 8. Cockcroft-Walton high-voltage generator of polyvinyl chloride and vinyl chloride acetate.

Fig. 9. Twenty-thousand-volt reversing switch of polyvinyl chloride.

Fig. 10. 400-kv voltage-divider resistor assembly.

Fig. 11. Retrodirective reflector of the 15-inch liquid-hydrogen bubble chamber.

Fig. 12. Retrodirective reflector of the 15-inch liquid-hydrogen bubble chamber.

Fig. 13. "Spitzer" transfer pipettes of polyethylene.

Fig. 14. Ionization chamber (Geiger counter) of high-density polyethylene.

Fig. 15. Ionization chamber (Geiger counter) of high-density polyethylene.

Fig. 16. A coil of water-cooled square copper donductor being insulated with high-strength polyester-film tape.

Fig. 17. Containers for liquid hydrogen used as targets for accelerated beams of ionized particles.

Fig. 18. Precision adjusting thumb screws of polycarbonate plastic.

Fig. 19. Two-million-ampere pulsing switch consisting of copper plates supported at the edges with fluoreethylene plastic.

Fig. 20. Propane bubble chamber showing polyurethane sponge as an oil matrix-baffle.

Fig. 21. Bevatron rapid-beam-ejector coil supported by epoxy and fiberglas, grade G-10 laminate.

Fig. 22. Feed-through plate of the Bevatron beam-kicker constructed of G-10 laminate.

Fig. 23. Coil of 1.3-inch-square copper conductors for 72-inch liquid-hydrogen bubble chamber.

Fig. 24. Coil of 1.3-inch-square copper conductors for 72-inch liquid-hydrogen bubble chamber, almost completed.

Fig. 25. Liquid-hydrogen bubble chamber building.

Fig. 26. Iron-epoxy mastic being applied to bubble chamber magnet.

Fig. 27. Iron-epoxy mastic being applied to bubble chamber magnet.

Fig. 28. Section of vacuum tank for electron synchrotron constructed of epoxy and fiberglas.

Fig. 29. Section of vacuum tank for electron synchrotron constructed of epoxy and fiberglas, assembled into ring tank.

Fig. 30. Section of electron-synchrotron support ring constructed of filled epoxy resin reinforced with steel rods.

Fig. 31. Corona-free anchorage of steel bolts with spherical heads embedded in epoxy resin.

Fig. 32. Epoxy "spark plug" feed-through insulators for propane bubble chamber.

Fig. 33. (Left) Ion-exchange column for radiochemistry cast of epoxy resin.

Fig. 34. Ceramic resistor embedment in soft flexible epoxy for six-deck high-voltage dividing-resistor assembly.

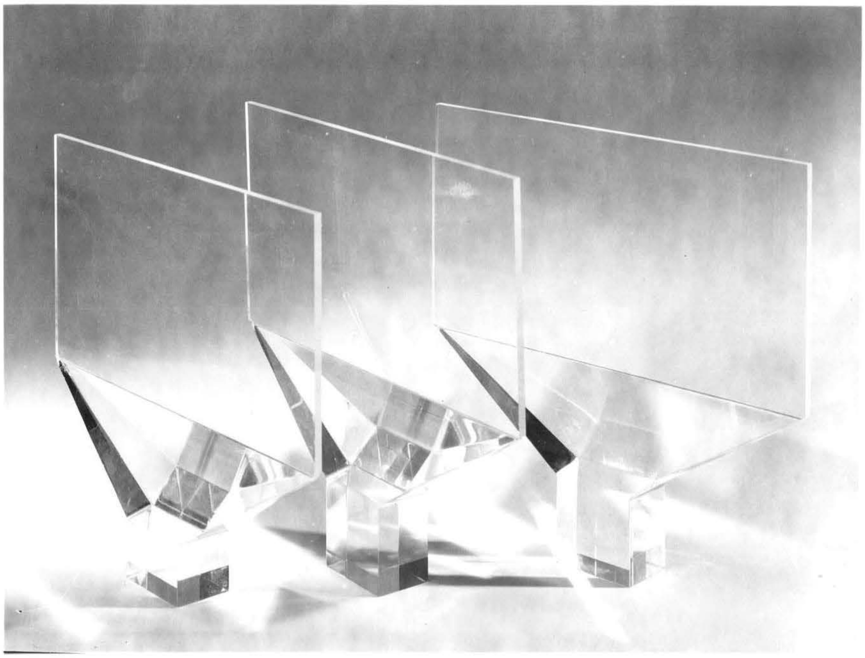


Fig. 1

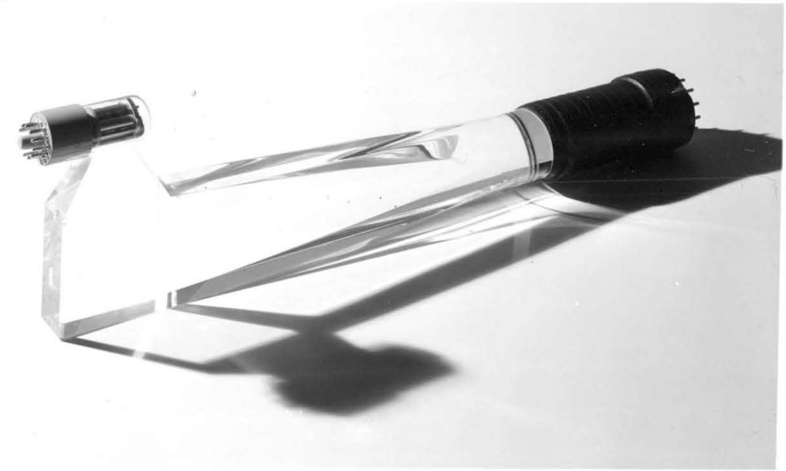


Fig. 2

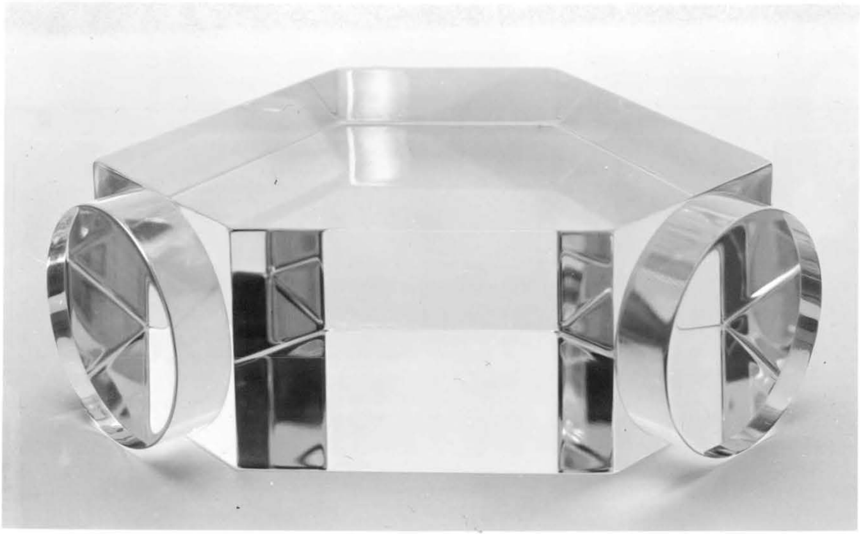


Fig. 3

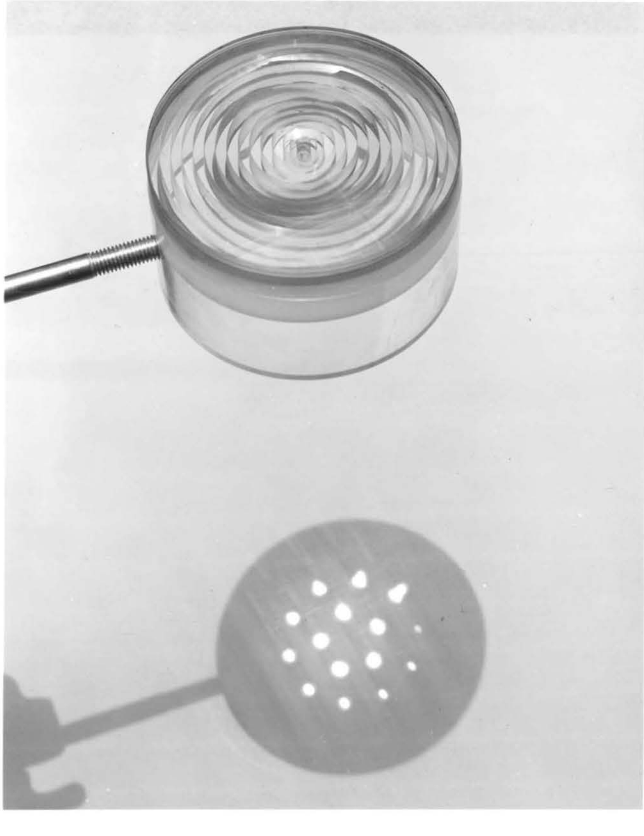


Fig. 4

Permanized

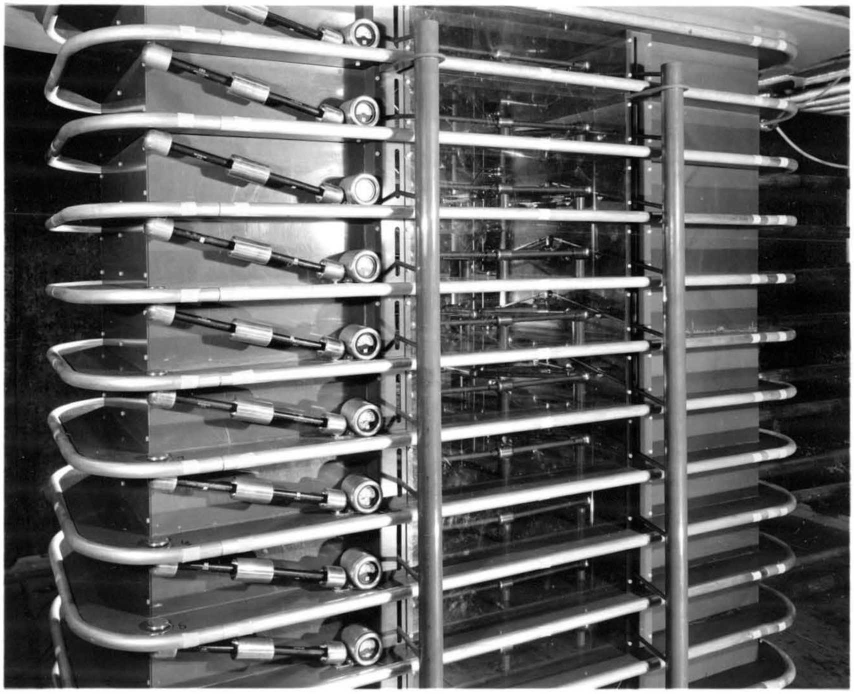
Fig. 5

Permanized
PLOVER BOND
25% COTTON FIBER
U.S.A.

Fig. 6

Fig. 7

Permanized
PLOVER BOND
25% COTTON FIBER
U.S.A.



PLOVER BOND
25% COTTON FIBER
U.S.A.

Fig. 8

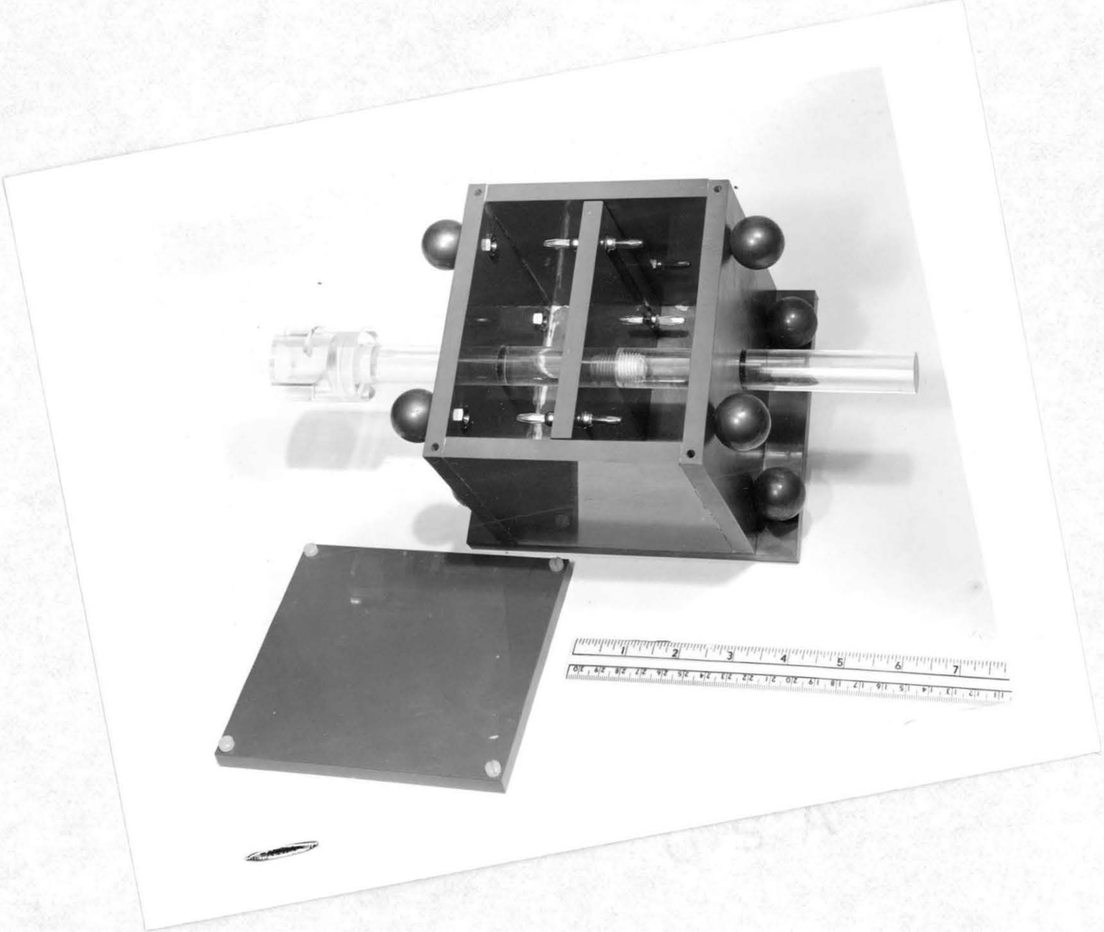


Fig. 9

Fig. 10

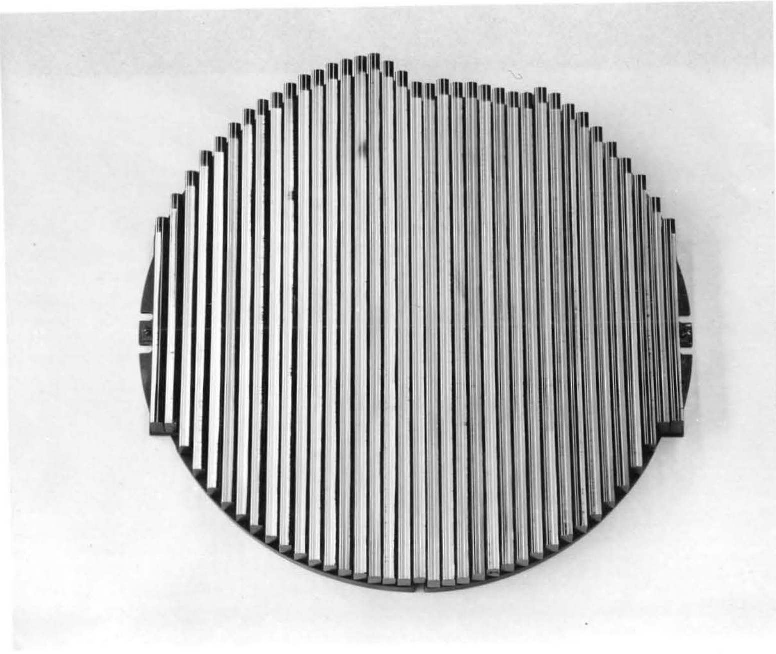


Fig. 11

Fig. 12

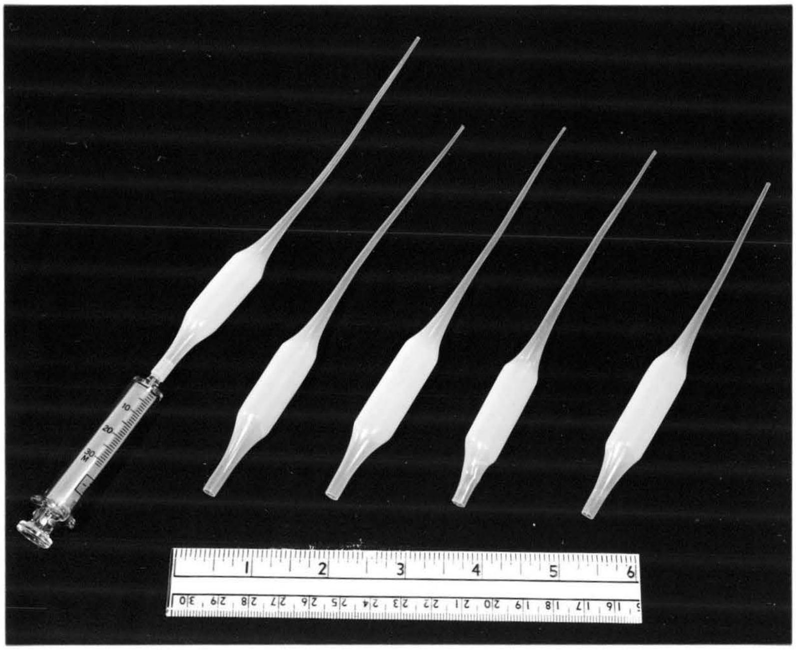


Fig. 13

Fig. 14

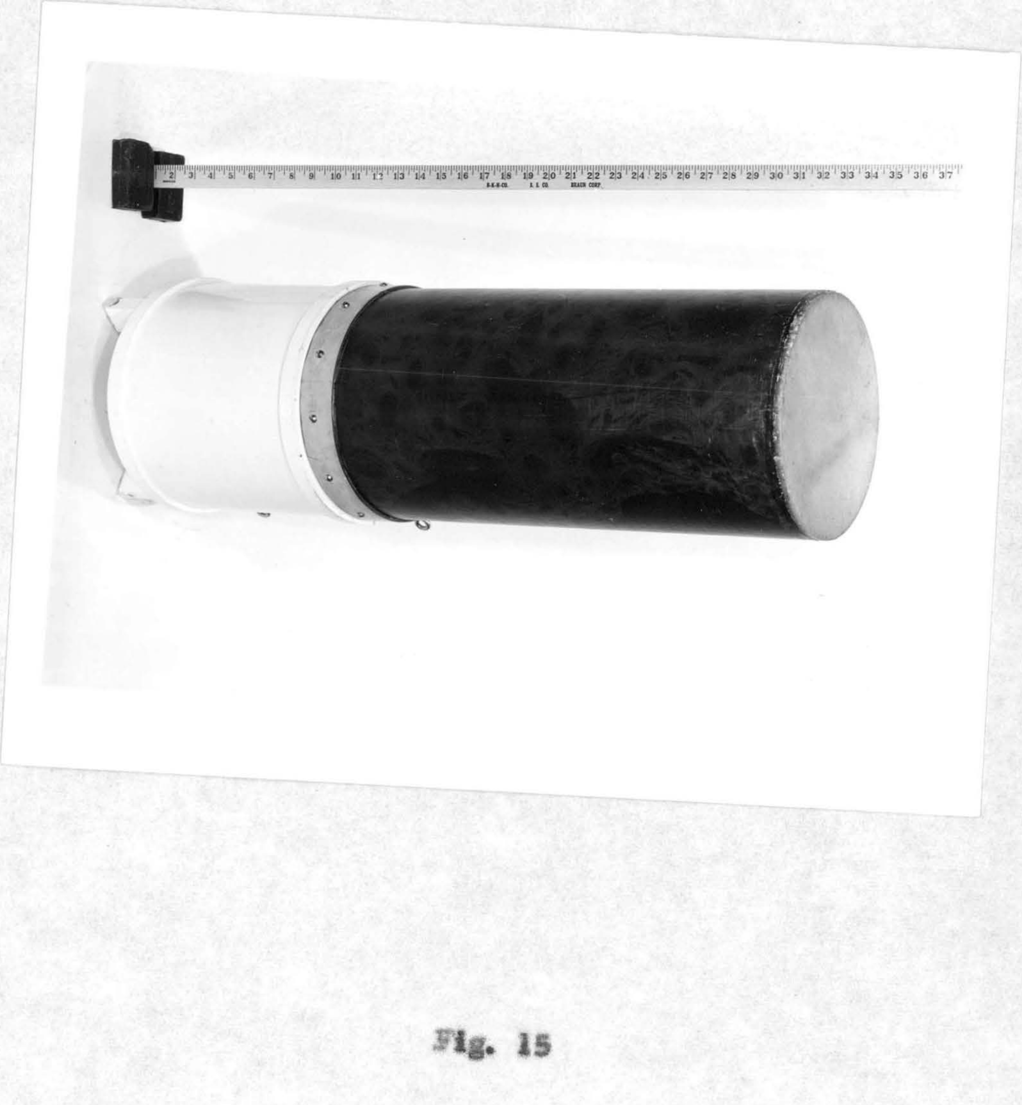


Fig. 15

Fig. 16

Fig. 17

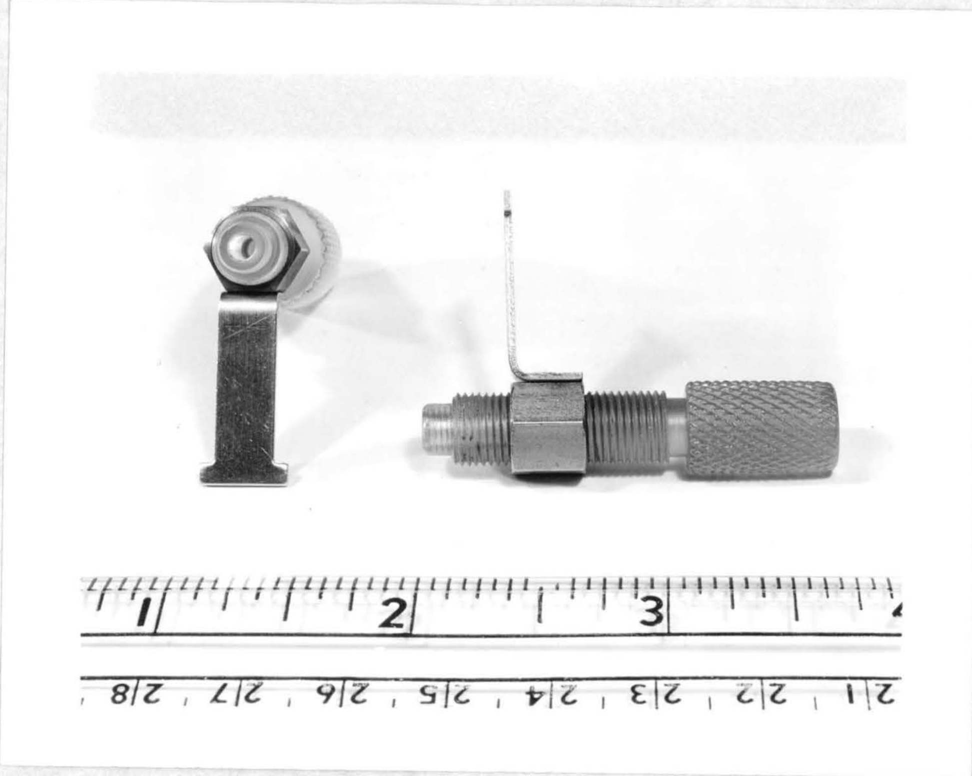


Fig. 18

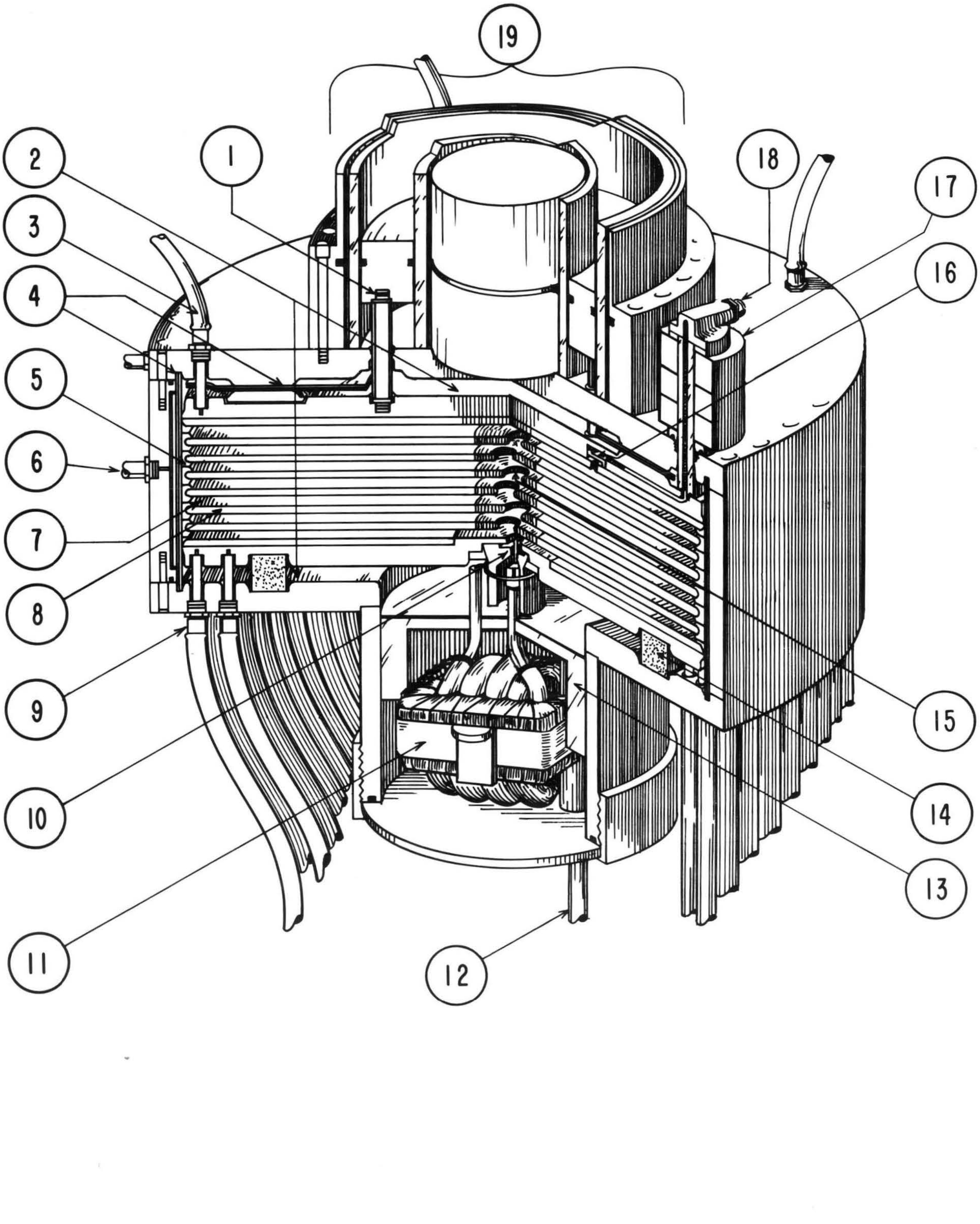


Fig. 19

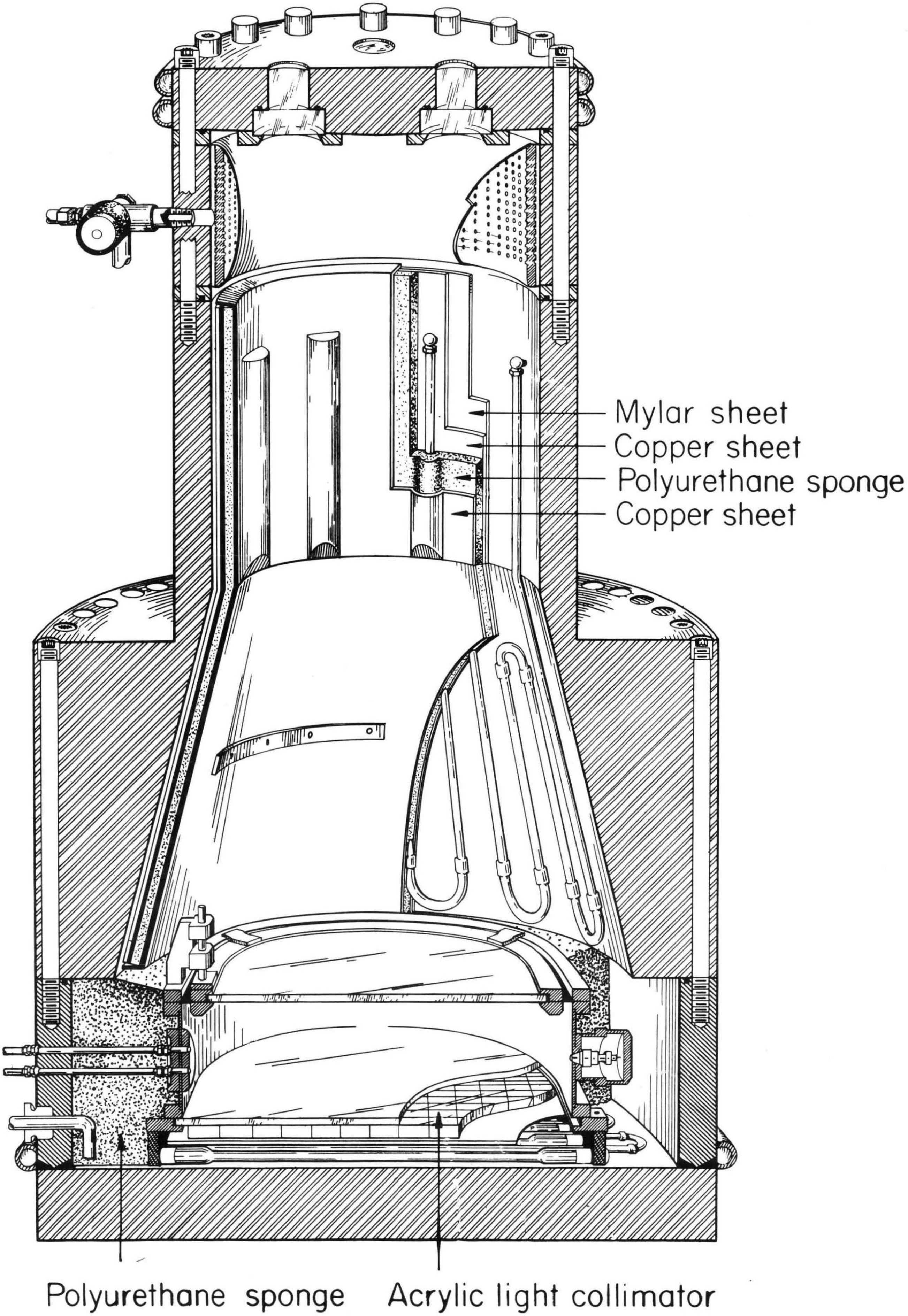

Mylar sheet
Copper sheet
Polyurethane sponge
Copper sheet
Polyurethane sponge
Acrylic light collimator

Fig. 20

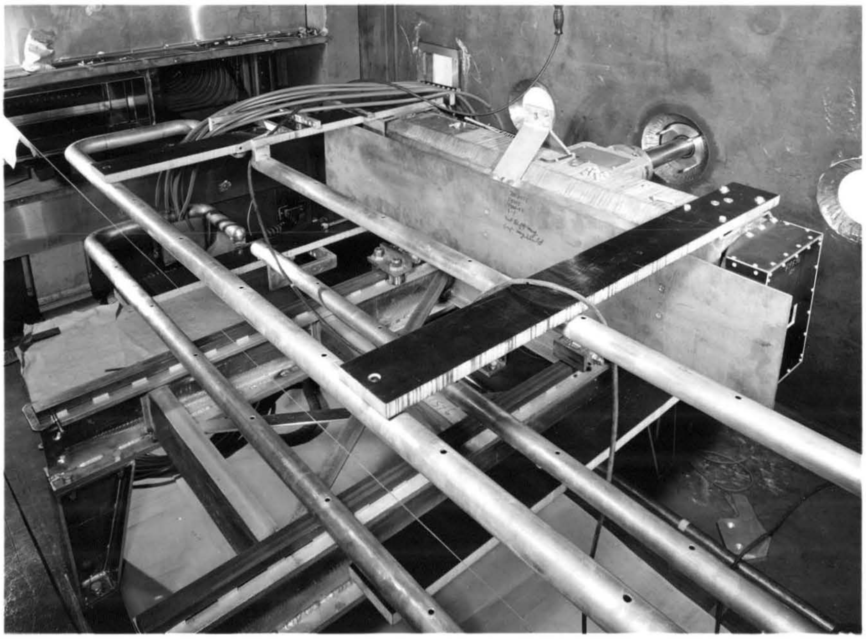


Fig. 21

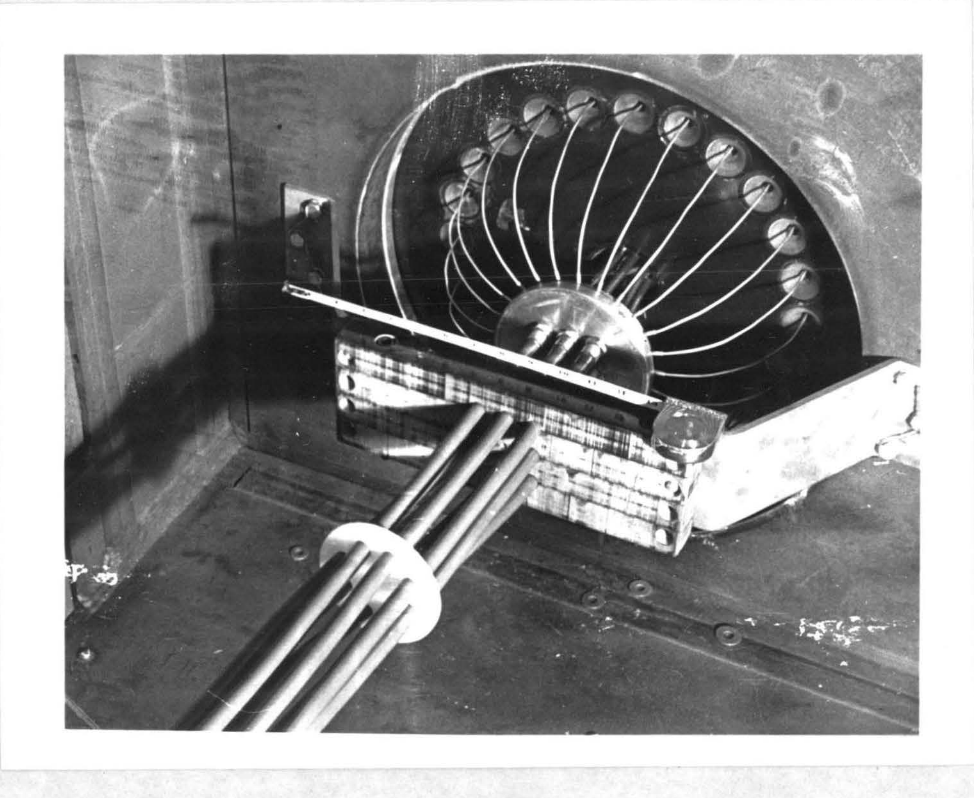


Fig. 22

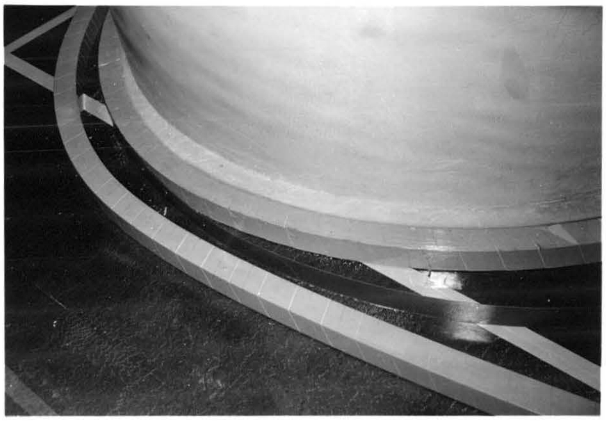


Fig. 23

Fig. 24

Fig. 25

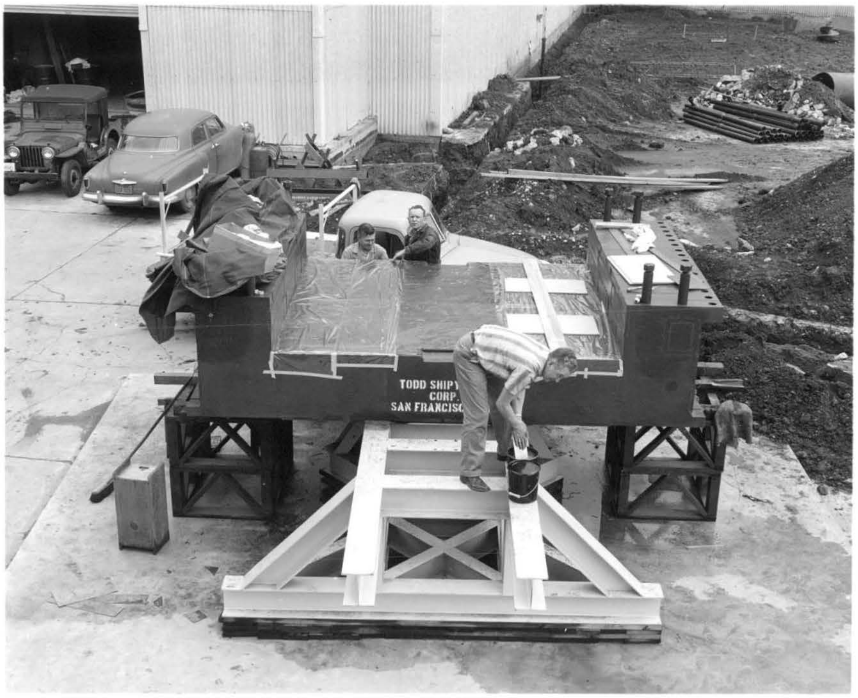


Fig. 26.

Fig. 27

Fig. 28

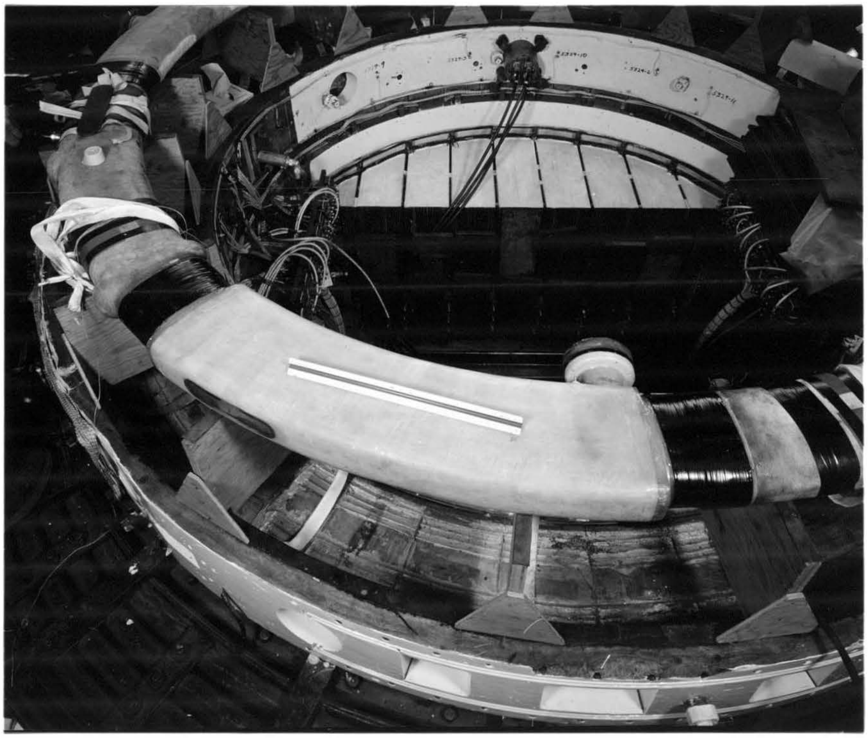


Fig. 29

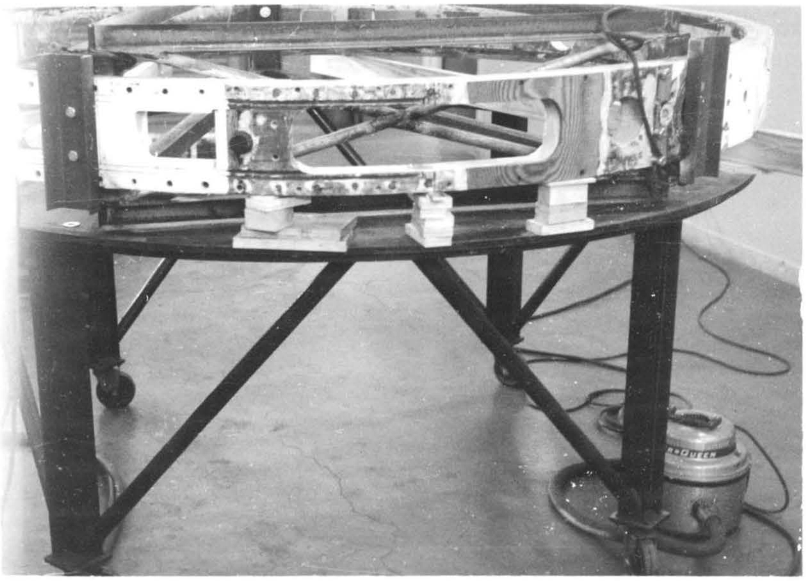


Fig. 30

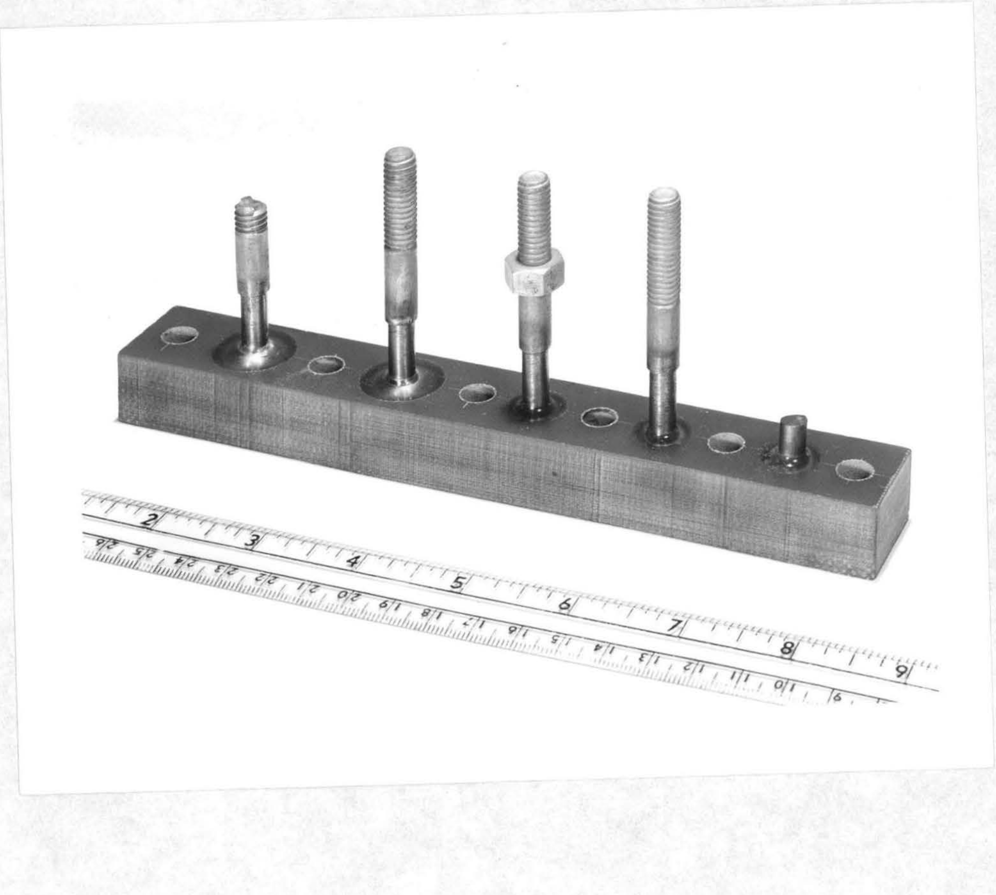


Fig. 31

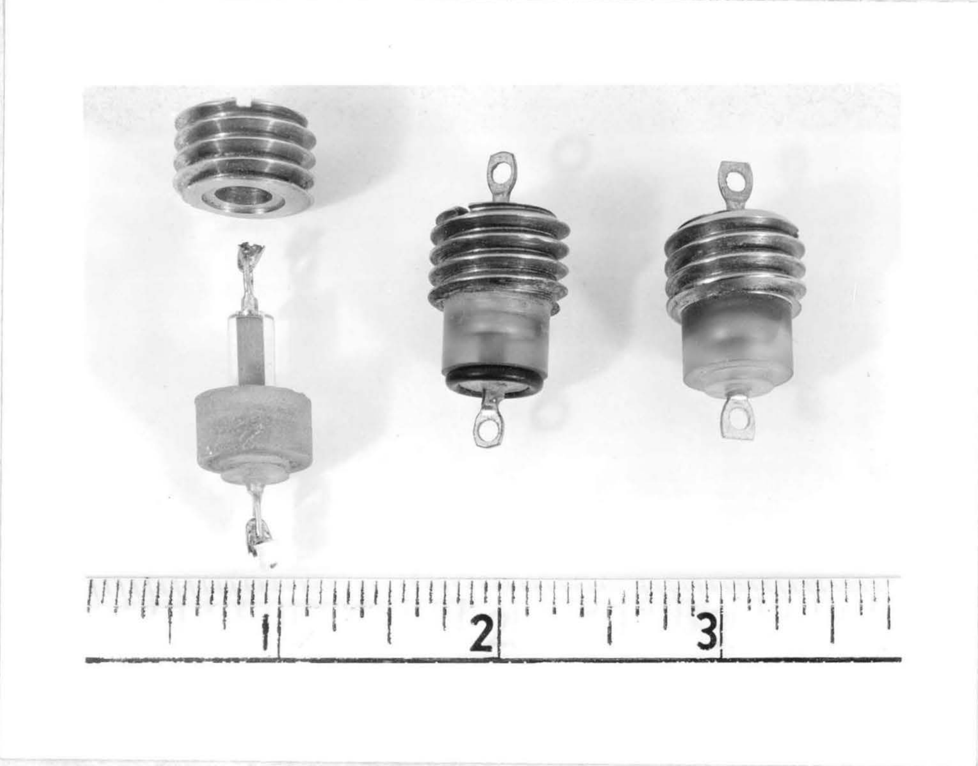


Fig. 32

Fig. 33

Fig. 34