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TRI-DIMENSIONAL PLASMA COMPRESSION ASSEMBLIES

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This technical documentary report has been reviewed and is approved.

For Space Systems Division
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FOREWORD

This report was prepared in support of nuclear weapons effects activities. The work was accomplished under Air Force Contract No. AF04(695)-669.

ABSTRACT

Two configurations for achieving tri-dimensional plasma compression have been designed, and preliminary testing has been accomplished on one. The results indicate that the configuration does produce very high plasma temperatures as a result of the compression; this is evidenced by the sharp (<1 μsec), intense ($>10^9$) burst of neutrons resulting from the compression and heating of a deuterium plasma to fusion temperatures.

ACKNOWLEDGMENT

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One of the earliest concepts investigated in Project Sherwood as a means of achieving thermonuclear temperatures in ionized deuterium gas was the "pinch". First enunciated in 1933 by W. Bennet, the pinch concept utilizes the encircling magnetic field produced by high current flow in an ionized gas column to compress the ionized gas or plasma to high pressures and temperatures. The temperature achieved depends on the speed and degree of the radial compression. The pinch concept became unattractive when it was discovered that instabilities (m = o) grew rapidly and allowed the plasma to escape from the confined area.

In 1961, Filippov (Ref. 1) reported results obtained in a special plasma assembly (Fig. 1a). When working in a high pressure (~5 mm) deuterium plasma, the pinch principle was producing temperatures of ~ 2 kev and neutron yields of $\sim 5 \times 10^9/0.5\ \mu$sec burst from D-D reactions in the plasma focus.

Early in 1965, J. Mather (Ref. 2) reported similar performance from a coaxial plasma gun (Fig. 1b) in which a pinch at the end of the center electrode produced a plasma focus with temperatures of ~ 2 to 3 kev and neutron yields of $2 \times 10^{10}/0.5\ \mu$sec burst from the D-D reaction.

Since these two assemblies achieve their high temperatures primarily from a linear plus radial plasma compression produced by the driving magnetic field, it would appear that a design giving a smooth tri-dimensional (3-D) compression would produce still higher temperatures and neutron yields. Two designs which effectively accomplish a 3-D compression are shown in Fig. 2a and b. In both assemblies the electrodes are shaped to furnish the third dimension of compression. This is opposite of earlier Project Sherwood designs of pinch assemblies where discharge tubes were long or toroidal to minimize or eliminate electrode effects on the "high temperatures" produced by the pinch.

At present it is not certain if high temperatures achieved by "pinched plasma focus" assemblies will be applicable to controlled fusion power because of energy loss mechanisms inherent in these geometries. However, very high intensity bursts of fusion neutrons have been found extremely useful for irradiation purposes. Since the configuration in Fig. 2b would allow samples to be placed close to the high compression "hot spot", tests of this concept were conducted.

The assembly is shown in Fig. 3. The outer and inner electrodes are of 0.125 in. thick spun copper. The base insulator is 1 in. thick Pyrex. Energy is fed from six 14 μf 20 kv capacitors and is switched by three ignitrons through 12 low-inductance coaxial cables to the connectors on the base periphery. Two magnetic probe ports, located 90 deg apart near the base, are used to determine uniformity of plasma sheath formation. A third port is located toward the apex of the electrode, 15 cm from one of the base probes. Palladium-filtered deuterium is fed into a port also located in the side of the electrode with the pump-out on the opposite side. The parabolically-shaped outer electrode has a base diameter of ~30 cm and is ~30 cm high. A 1 in. diameter, 0.5 in. thick quartz window is located at the apex to permit viewing of the hot spot. The inner electrode is ~3 cm diameter at the base, is flared to 10 cm diameter, and has a hemispherical end. Spacing between the two electrodes at the tip is ~2 cm.

It was believed that because of the large electrode spacing at the base of the assembly, easy gas breakdown and uniform sheath formation could be obtained at much lower pressures than those used by Filippov and Mather. Also, for a given input energy, the smaller number of ions could be accelerated to higher velocities, and the resultant temperature increase would more than compensate for the loss in neutron yield due to the lower gas pressure. Consequently, most tests have been made in the 0.1 to 0.5 mm pressure range.

Although only preliminary tests have been made, the results appear to confirm the production of a very high pressure hot plasma focus by the 3-D compression assembly.

When operated at 15 kv and 0.3 mm pressure, a sharply focused high pressure pulse caused the central outer surface of the viewing window to spall (see Fig. 4). Neutrons were detected, and yield measurements were made using a silver foil-Geiger counter assembly. A photomultiplier-NaI crystal counter was used to observe burst shape. When operated at 16 kv and 0.5 mm pressure, the neutron yield from the D-D reaction was $\sim 1.5 \times 10^9$/burst, and the photomultiplier indicated a pulse width of ~0.5 μsec. The oscilloscope traces of the current waveform and the neutron pulse are shown in Fig. 5.

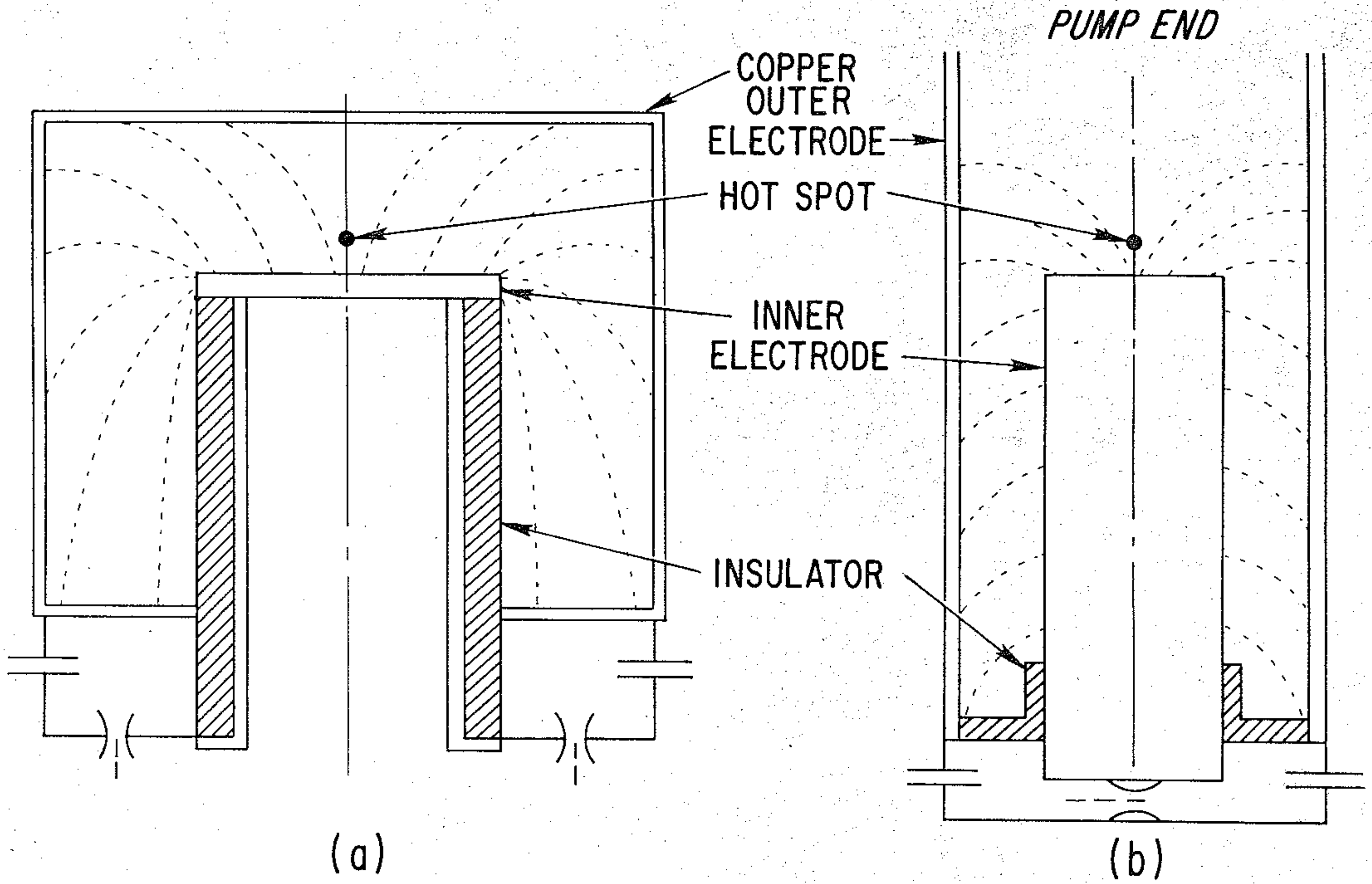

Fig. 1. Plasma Neutron Sources [(a) Filippov, et al., (b) Mather]

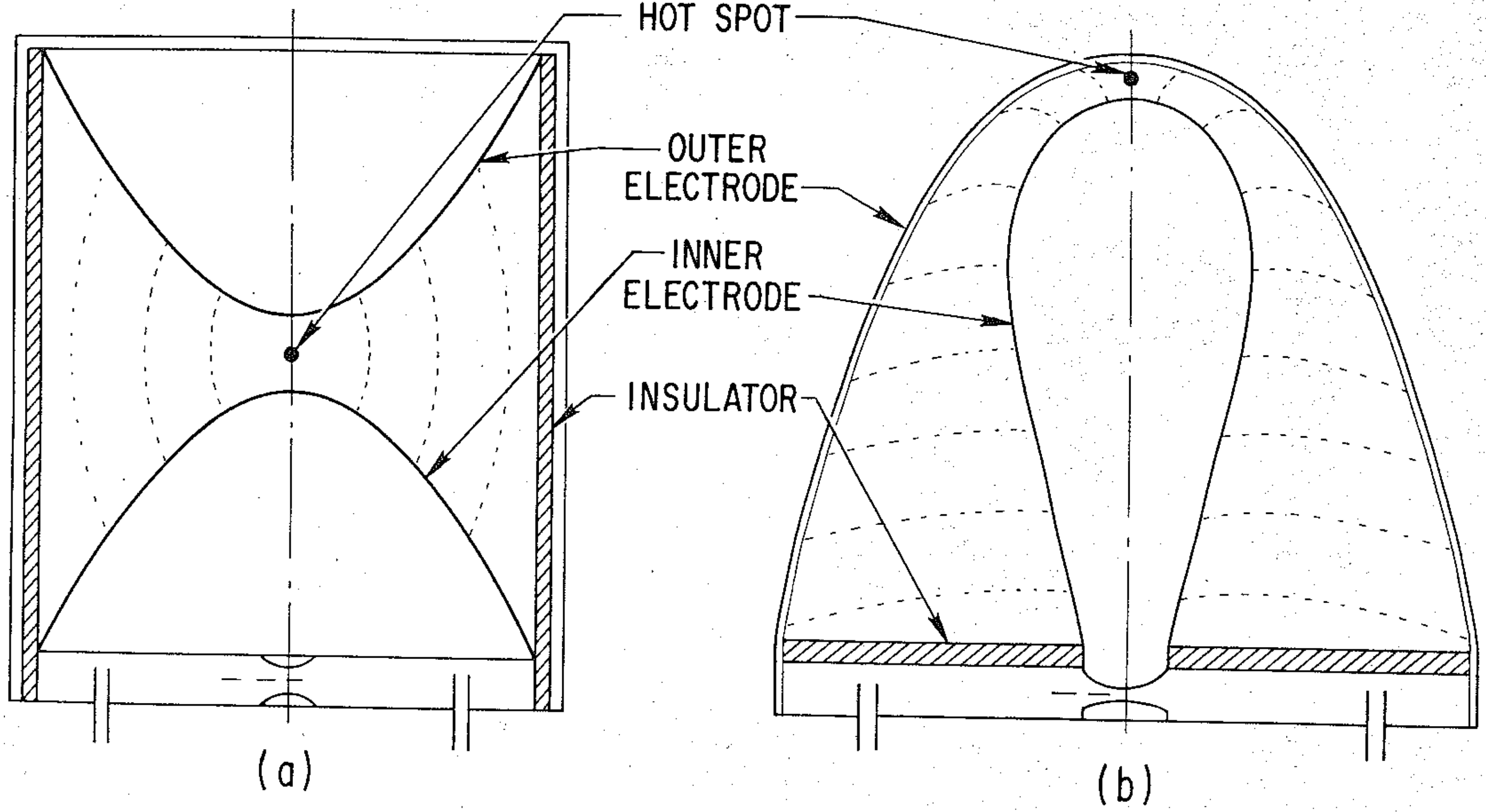

Fig. 2. Tri-dimensional Pinch Assemblies [(a) Cylinder, (b) Dome]

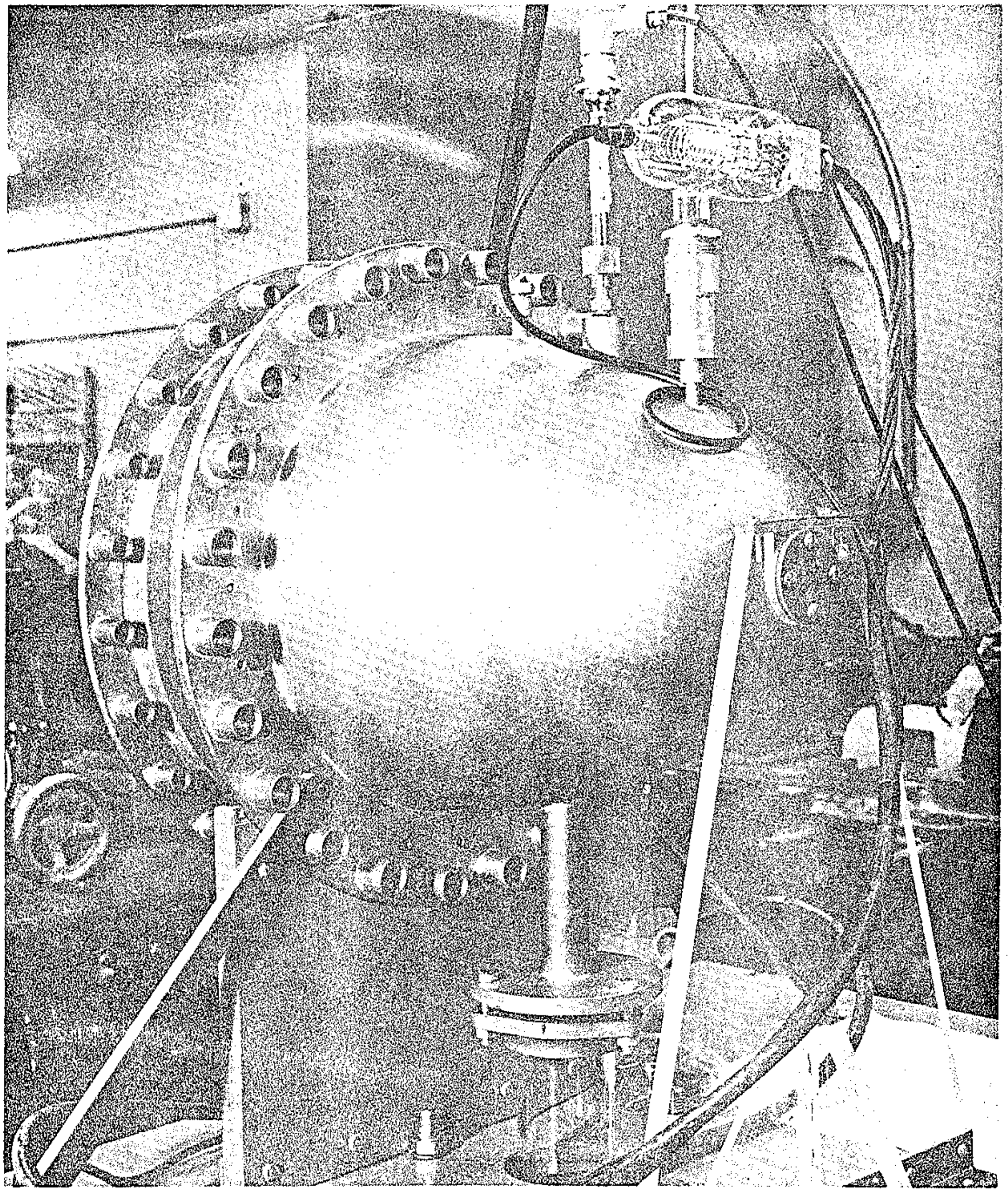

Fig. 3. Dome Tri-dimensional Pinch Assembly

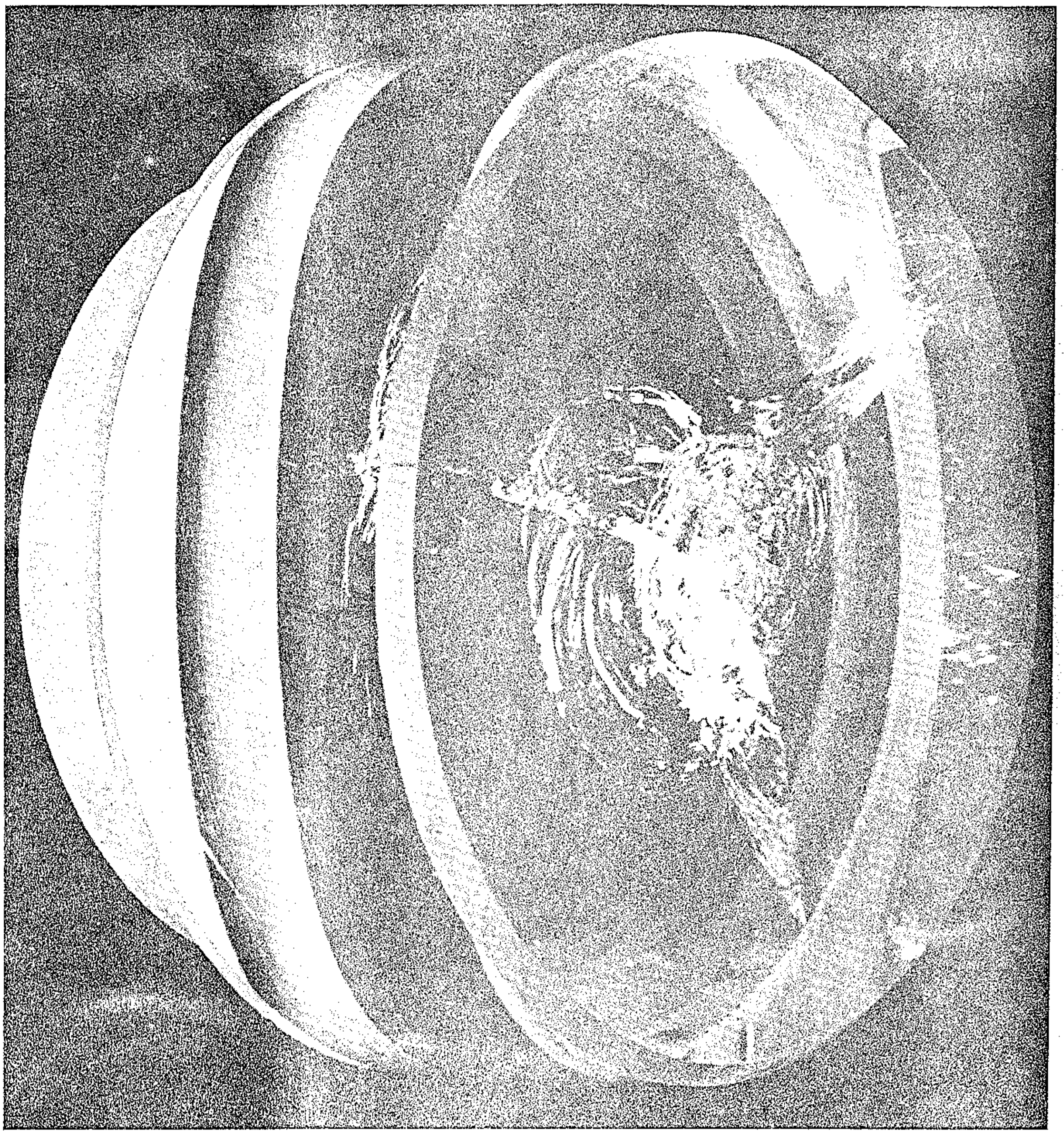

Fig. 4. Damage to Viewing Window by High Pressure Pulse (one-inch diameter)

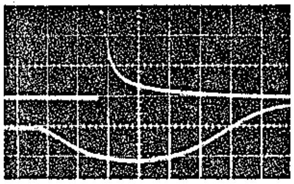

Fig. 5. Oscilloscope Traces of (a) Neutron Pulse and (b) Main Current Waveform (writing speed is 2 μsec/division)

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2. J. W. Mather, "Formation of a High-Density Deuterium Plasma Focus," Phys. Fluids, 8 (2), 366 (1965).