LIQUID XENON-FILLED WIRE CHAMBERS*

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Abstract

We describe several types of small liquid xenon-filled chambers, each optimized for a particular property such as a real time spatial resolution of ±15 μ, a time resolution of $\pm 10^{-7}$ sec, or a pulse height of 10^{-12} coulomb. Larger chambers combining all these properties will be of great value at NAL energies, and we describe some of the techniques necessary for their construction.

Introduction

In 1968, Luis Alvarez suggested that a filmless particle detector with ±10 μ space resolution could be developed by using a liquified noble gas as the detection medium.[1] He reasoned that a thousand-fold increase in density (when compared with gas-filled wire chambers) would simultaneously permit a decrease in detector thickness and an increase in ion statistics. Other resolution-limiting factors such as electron diffusion and δ-rays would also be significantly reduced. Operation at one atmosphere pressure would allow the technique to be used over large areas and readout would be simplified if the initial ionization could be amplified in the liquid.

Single Wire Chambers

We have been operating liquid xenon-filled single-wire proportional chambers for two years.[2,3] Figure 1 shows our single-wire chamber design, and Fig. 2 shows the pulse height of the 279-keV photopeak as a function of operating voltage for 2.9-, 3.5-, and 5.0-μ anode wires. The chamber counts well and the pulse-height curves are reproducible to ±10% every time the chamber is filled.

As mentioned in Ref. 2, the single-wire chamber produces two classes of avalanche pulses. The first type are proportional in size to the initial ionization and rise in $\sim 2 \times 10^{-7}$ sec [see Fig. 3(a)]. The second "Geiger" type are larger ($\sim 2 \times 10^{-12}$ C), uniform in size, and rise more rapidly [see Fig. 3(b)]. The rise time shown in Fig. 3(b) is limited by the rise time of our charge amplifier. When the "Geiger" pulses are observed directly on an oscilloscope, the true rise time of $\sim 10^{-8}$ sec may be seen (see Fig. 4).

Using the two collinear gamma rays from a ^{22}Na source, we measured the time resolution of a single-wire liquid xenon chamber to be $\pm 10^{-7}$ sec. During this test electronegative impurities restricted the effective diameter of the chamber to approximately 1 mm. For details see Ref. 5.

For decades the gas filling in wire chambers has included quenching agents to suppress sparking and to increase the size of the pulses. We have found that 2000 ppm ethylene (C_2H_4) in liquid xenon also permits higher operating voltage and larger pulses. This comparison is shown in Fig. 5.

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Multi-Wire Proportional Chambers

We have designed and built a liquid xenon multi-wire proportional chamber specifically for detecting gamma rays in nuclear medicine. (For gamma rays in the 0.15 to 10-MeV range this approach provides an unprecedented combination of detection efficiency, spatial resolution, and potential for up-scaling.)[4] This chamber is shown in Fig. 6 and consists of 24 3.5-μ wires spot-welded to kovar pins sealed with glass to holes in the ceramic base. The wires are spaced 2.8 mm apart, and the wire plane is centered between two cathode planes spaced 15 mm apart. The gross detection efficiency for 280-keV gamma rays is 65%. At an operating potential of -4500 V the liquid gain is 10, and under these conditions the spatial resolution was measured to be 3 mm FWHM, demonstrating that the wires amplify independently without the addition of a quenching agent.

For the development of a chamber possessing high spatial resolution for charged particles, however, it is very important to demonstrate amplification by arrays of much more closely spaced wires. To this end we ran three arrays of five wires 3.5 μ in diameter with spacings of 150, 300, and 1000 μ between opposing cathodes spaced 5 mm apart in a small test chamber. With a 1000-μ spacing, gain sets in at 3800 V, reaching 10 at 5000 V. A further increase in voltage at the 1000-μ spacing and observation of gain at the 150- and 300-μ spacings was prevented by the occurrence of sparks between the flat cathode and the wires of the anode. Very recently we have learned that these sparks are initiated by field emission from the cathode. We will continue studies with closely spaced anodes (50 to 300 μ apart) using specially polished cathodes and the addition of ethylene to suppress sparking and provide larger gain.

In previous papers we have reported on schemes for producing closely spaced narrow conducting strips on an insulating substrate. Heidenhain Corporation can produce sub-micron chrome lines on glass or Mylar.[6] In addition, we have made Noryl[7] pressings with sharp ridges 50 μ apart and then vacuum deposited metal at a grazing angle to produce conductive strips several μ wide at the top of the ridges (see Fig. 7).

Recently we have devised a method of attaching fine wire to a substrate in such a way that 98% of the wire does not touch the substrate. A Noryl pressing is made, producing sharp ridges 100 μ wide, 100 μ high, and 1 mm apart. Then 5-μ wire is wound around the ridges at right angles. The assembly is placed in a magnetic field while a current is passed through the wire. This serves to heat the wire and press it into the edge of the ridge. The result is shown in Fig. 8.

Multi-Wire Ionization Chambers

Electron avalanche in the liquid is essential in reducing the complexity and cost of the readout. It is quite possible, however, using present technology, to build a liquid xenon multi-wire ionization chamber having no liquid gain with a space resolution of ±10 μ and a time resolution of ±20 nsec. Unfortunately the readout requires that a low-noise charge-sensitive amplifier be attached to each wire, increasing the cost by approximately $20 per wire, and severely limiting its applications in physics experiments. Figure 9 shows the excellent spatial resolution that we have measured for the ionization mode.[2,8]

Gamma-Ray Detection

The density and atomic number of liquid xenon make it attractive for the absorption and detection of gamma rays. In order to study the energy resolution obtainable, we built an ionization chamber with a Frisch grid. The chamber and experimental setup are shown in Fig. 10. The best resolution for 279-keV gamma rays obtained thus far is 10.5% FWHM (shown in Fig. 11), comparable to NaI(Tl). The amount of liquid xenon required for the absorption of a multi-GeV electromagnetic shower is quite expensive ($3/cc) but there is hope for the future. For every megawatt-year generated by nuclear power reactors, 57 grams of Xe are produced. The only important contamination is 10.76-yr ^{85}Kr, which can be reduced to levels of 10 pCi per STP liter Xe by distillation followed by a series of dilutions (with atmospheric Kr) and redistillations. C. A. Rohrmann[9] estimates that by 1980 the annual recovery of xenon will exceed 10 tons per year at a cost of 25¢ per liquid cc.

Summary

We have developed several versions of liquid xenon-filled chambers, each optimized for a particular property such as unexcelled real time spatial resolution (±15 μ), good energy resolution (±5% for 279-keV gamma rays), good pulse height (10^{-12} coulomb for minimum ionizing particles passing through 0.7 mm liquid Xe), or good time resolution (±10^{-7} sec for a 1-mm-thick chamber). We are working on the technology to allow us to combine several such properties in chambers covering useful areas.

Acknowledgments

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Appendix - Selected Properties of Liquid Xenon

Boiling point	-108.10°C (1 atm)
Freezing point	-111.8°C (1 atm)
Density	3.057 g/cc
STP gas/boiling-liquid volume ratio	518.9 (1 atm)
e^- drift velocity[10]	1×10^5 cm/sec at 60 V/cm 2×10^5 cm/sec at 500 V/cm 3×10^5 cm/sec from 3 to 60 kV/cm
Ion pairs per 100 μ	2000 (minimum ionization)
Energy loss per 100 μ	43 keV (minimum ionization)
Radiation length	25 mm
Collision length	450 mm
Present cost	$3/cc

References

[1] L. W. Alvarez, Lawrence Radiation Laboratory, Group A Physics Note No. 672, 1968, unpublished.

[2] R. A. Muller, S. E. Derenzo, G. Smadja, D. B. Smith, R. G. Smits, H. Zaklad, and L. W. Alvarez, Phys. Rev. Letters 27, 532 (1971).

[3] Recently workers at Dubna have reported on some excellent new work using a single-wire proportional chamber filled with high-pressure gases and solidified noble gases: A. F. Pisarev, V. G. Pisarev, and G. S. Revenko, Dubna Reports JINR - P13 - 6450 and JINR - P13 - 6449 (1972).

[4] H. Zaklad, S. E. Derenzo, R. A. Muller, G. Smadja, R. G. Smits, and L. W. Alvarez, Trans. IEEE NS-19, 206 (1972).

[5] S. E. Derenzo, D. B. Smith, R. G. Smits, H. Zaklad, L. W. Alvarez, and R. A. Muller, Lawrence Radiation Laboratory Report UCRL-20118 and NAL Summer Study Report SS-181 (1970).

[6] Heidenhain Corporation, 8225 Traunreut, West Germany.

[7] Noryl is a class of thermoplastic resins manufactured by General Electric, Noryl Avenue, Selkirk, New York 12158.

[8] The collimated alpha source used in Ref. 2 is described in Lawrence Radiation Laboratory Report UCRL-20857 (1971).

[9] C. A. Rohrmann, Isotopes and Radiation Technology 8, 3, 253 (1971).

[10] L. Miller, S. Howe, and W. Spear, Phys. Rev. 166, 871 (1968).

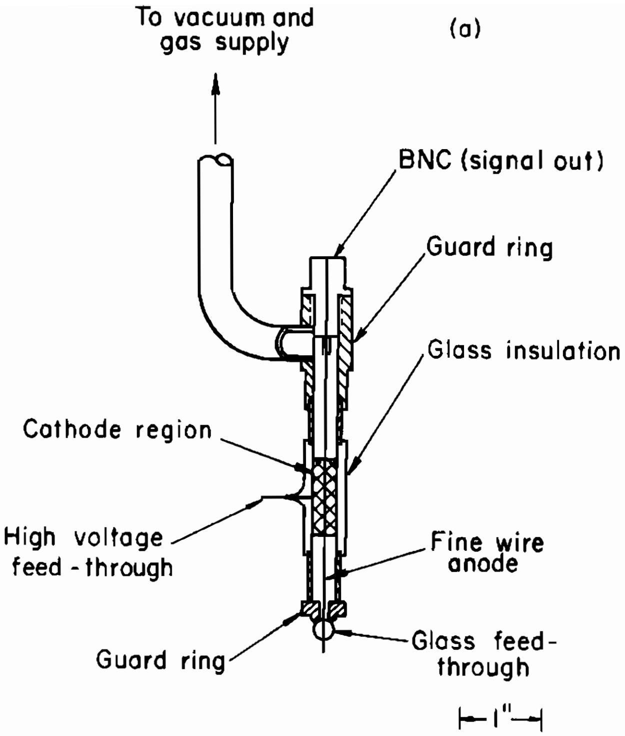

Fig. 1. Liquid xenon single-wire proportional chamber.

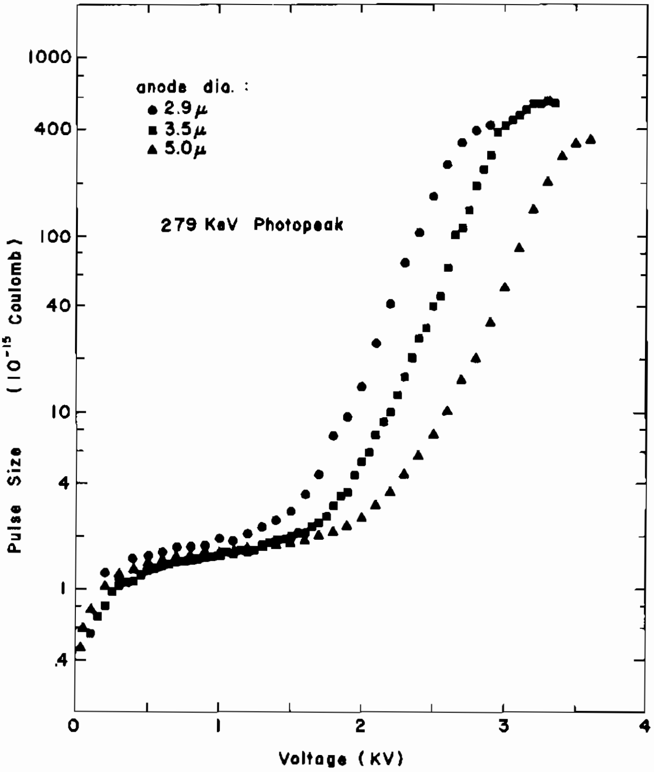

Fig. 2. Pulse height vs voltage in liquid xenon single-wire proportional chamber with 8-mm-diam cathode and 2.9-, 3.5-, and 5.0-μ-diam anodes. Signal is 279-keV photopeak from ^{203}Hg source.

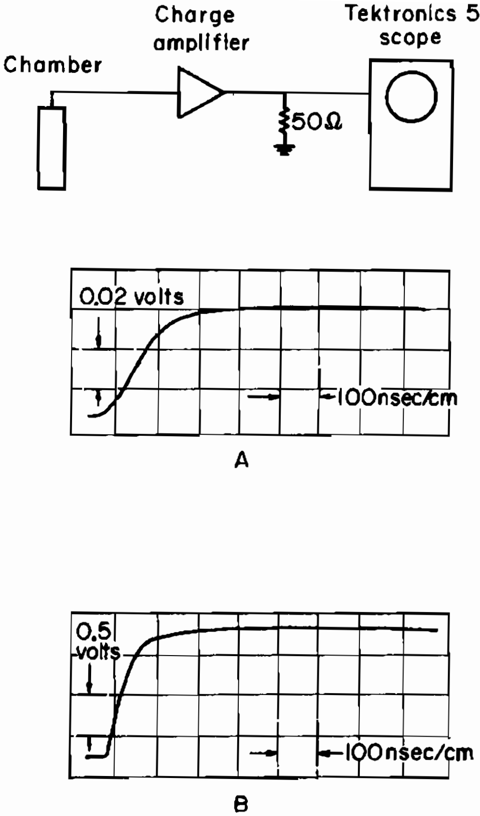

Fig. 3. Pulses from chamber of Fig. 1 seen on a charge amplifier with a gain of 0.4 V/pC. A: proportional pulse. B: "Geiger" pulse.

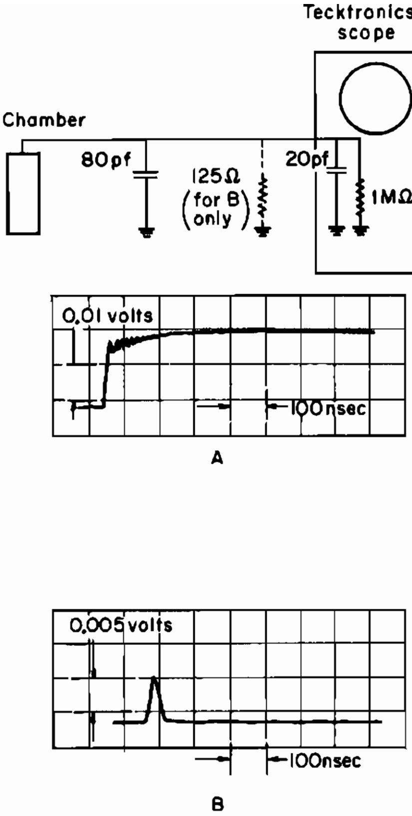

Fig. 4. "Geiger"-type pulses from chamber of Fig. 1 seen directly on an oscilloscope. A: 1-megohm load. B: 125-ohm load.

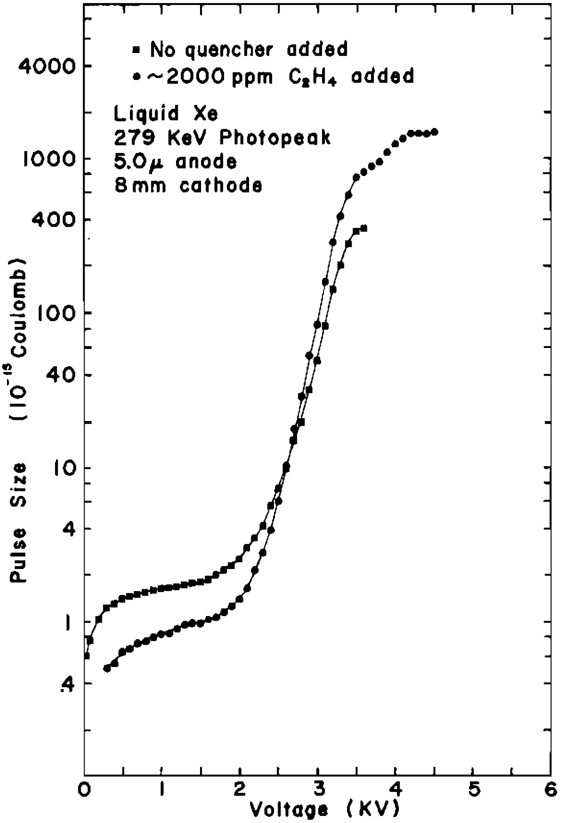

Fig. 5. Pulse height vs voltage in single-wire chamber for 5-μ anode in pure liquid xenon and in liquid xenon containing ~ 2000 ppm C_2H_4.

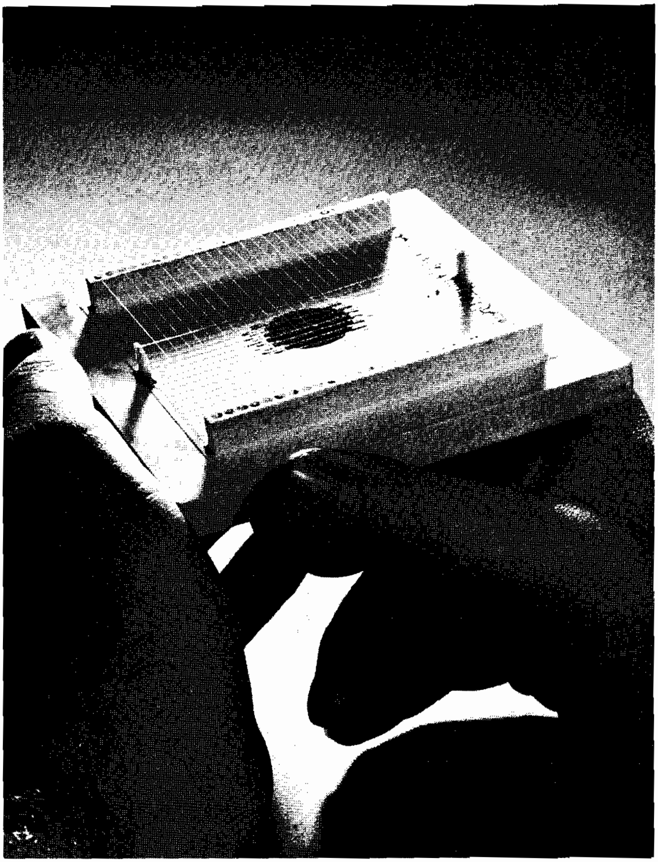

Fig. 6. Gamma-ray chamber 15 mm thick, containing 24 3.5-μ-diam wires and 24 cathode strips. A: shows ceramic chamber wall and support for anode wires and cathode strips.

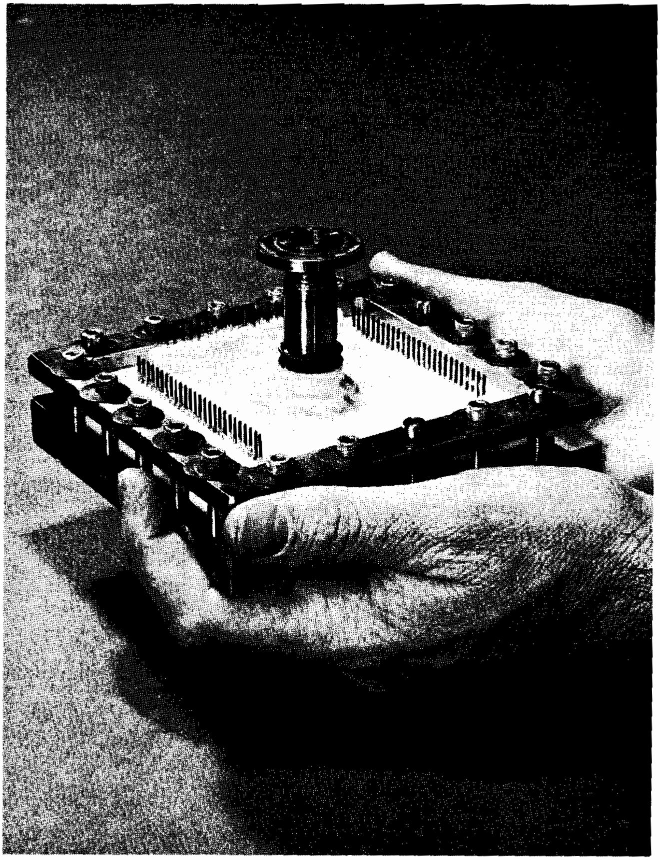

Fig. 6. Gamma-ray chamber 15 mm thick, containing 24 3.5-μ-diam wires and 24 cathode strips. B: shows assembled chamber.

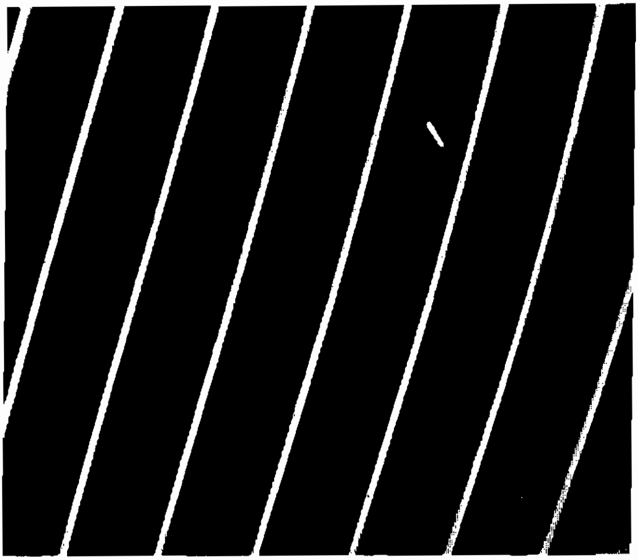

Fig. 7. Array of conducting strips produced by vacuum depositing metal at a grazing angle onto a series of Noryl ridges 40 μ wide and 100 μ apart.

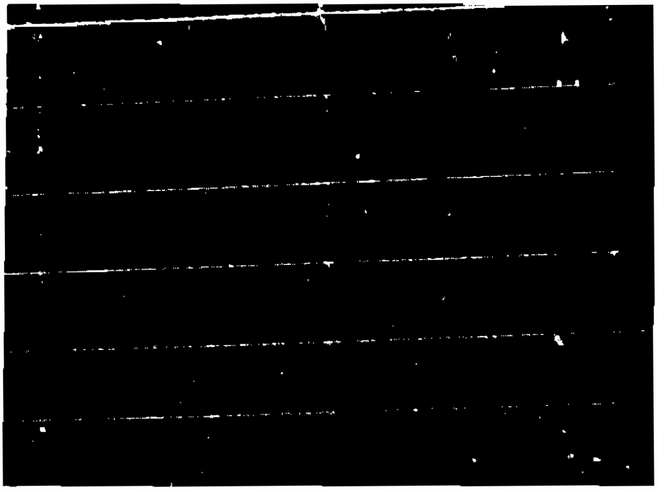

Fig. 8. Array of 5-μ wires bonded to Noryl ridges 1 mm apart. Current is passed through the wire in a magnetic field to heat the wire and press it into the ridges.

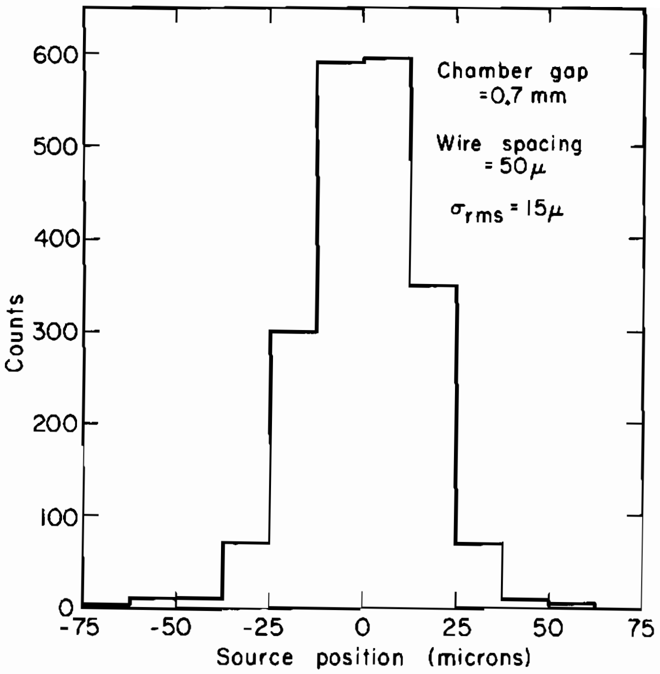

Fig. 9. Image of a 38-μ wide collimated alpha source detected by a 0.7-mm-thick liquid xenon ionization chamber. (See Refs. 2 and 6 for details.)

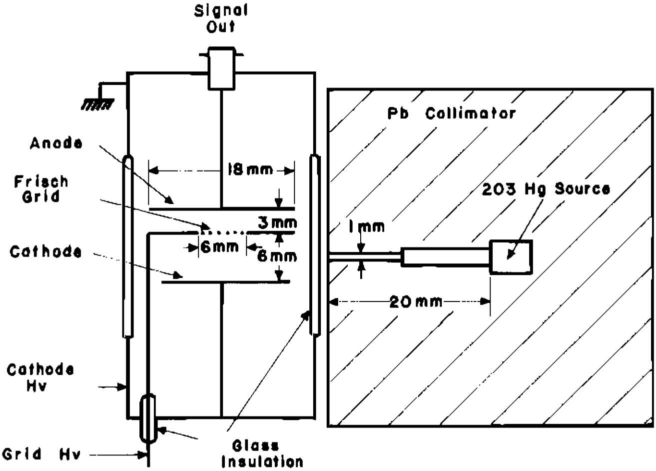

Fig. 10. Liquid xenon ionization chamber with Frisch grid and collimated gamma source.

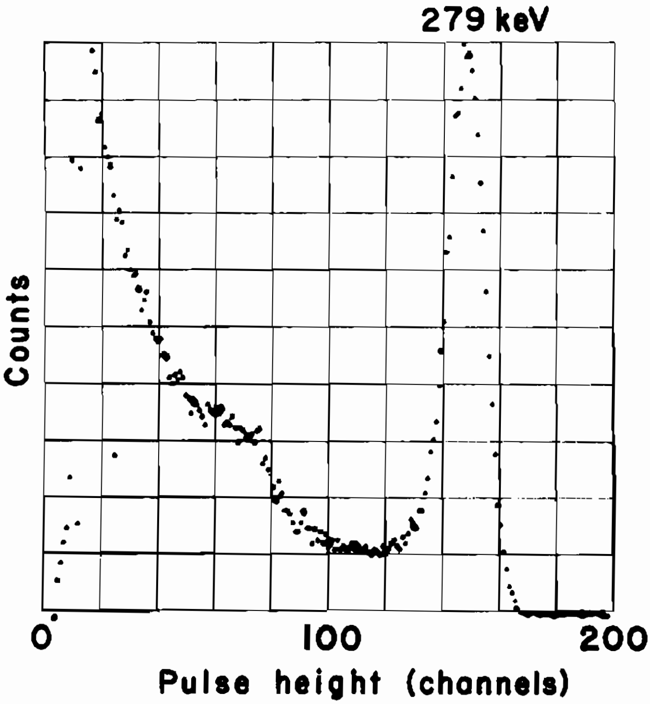

Fig. 11. Pulse-height spectrum for 279-keV gamma rays seen in setup of Fig. 10. FWHM is 10.5%, comparable to NaI(Tl).