observe the growth rate; but in each bombardment the number of disintegrations observed could be accounted for by the alpha decay of Fm^{252} (7.04-Mev peak) to Cf^{248} (6.26 Mev).[3] The observed increase in the yield of the 7.04-Mev alpha emitter relative to Fm^{254} with increased cyclotron energy further agrees with the assignment of the 7.04-Mev alpha energy to Fm^{252}.

A small amount of a 6.85-Mev alpha emitter with a half-life greater than 10 days was also observed in each bombardment. This was tentatively assigned to Fm^{253}. However, results on this are preliminary and further work is being done.

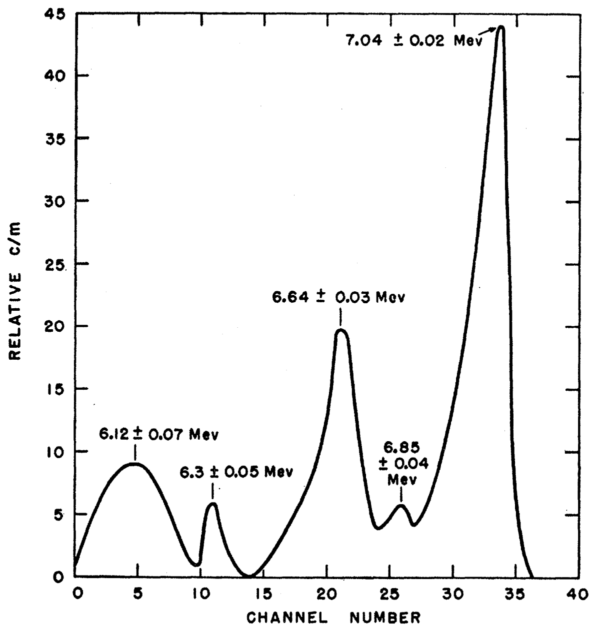

FIG. 1. Pulse analysis of fermium fraction 98 hours after bombardment.

A lower limit of 3000 days was set for the spontaneous fission half-life of Fm^{252}.

Assigning the 7.04-Mev alpha energy to the decay of Fm^{252}, indicates a more marked anomaly at 152 neutrons in the alpha-decay energies of the fermium isotopes than occurs in the case of the californium isotopes.[1]

The authors would like to acknowledge the aid of T. Keenan of the Los Alamos Scientific Laboratory and H. Diamond and D. Metta of this laboratory in the chemical separations involved. We want to thank the Argonne cyclotron group for performing the irradiations. We also wish to express our appreciation to D. Henderson for performing the alpha pulse analyses and aiding in the interpretation of the data.

† Based on work performed under the auspices of the U. S. Atomic Energy Commission.

[1] Ghiorso, Thompson, Higgins, Harvey, and Seaborg, Phys. Rev. **95**, 293 (1954).
[2] B. Harvey (private communication).
[3] Ghiorso, Rossi, Harvey, and Thompson, Phys. Rev. **93**, 257 (1954).

Liquid Xenon Bubble Chamber*

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A PARTICLE detector capable of detecting gamma rays with high efficiency in addition to giving accurate information concerning the paths, velocities, and energies of charged particles should be of great value in studies of elementary particles and high-energy nuclear phenomena. It was pointed out by one of us[1] that a bubble chamber filled with a liquid of high density and large atomic number would have these properties. Of a number of possible liquids, xenon seemed the most promising because it is nontoxic, noncorrosive, chemically stable, and was expected to require convenient pressures and temperatures for bubble chamber operation.

The investigation of xenon as a filling liquid for bubble chambers was carried out in an aluminum chamber with a sensitive volume one inch in diameter and one-half inch deep along the camera axis. The expansion mechanism, photographic apparatus, and chamber construction were closely similar to those of bubble chambers already described,[2] except that the temperature of the circulating air was maintained by dry ice cooling. The measurements of the temperature of the liquid inside the chamber were indirect and may be in error by as much as two degrees C.

As a preliminary test of the operation of the entire system, the chamber was filled with ethylene which has a vapor pressure curve almost identical with that of xenon in the range of temperatures of interest here. Figure 1 shows the tracks of electrons produced in ethylene by gamma rays from a 100-mC radium beryllium source held 8 inches from the center of the chamber, when the chamber was at $-18°C$.

When the chamber was filled with liquid xenon and run under closely similar conditions immediately after the ethylene experiments, no tracks were obtained. The chamber was then altered in an attempt to produce tracks in xenon by enlarging the expansion channel to expand the chamber faster, and by replacing the original Teflon gaskets and diaphragm by butyl rubber to avoid the excessive absorption of xenon exhibited by the Teflon. Still no tracks could be seen.

Shortly after these failures to observe tracks, we learned[3] that gaseous xenon had been found to be an efficient scintillating material, so that some sizeable fraction of the energy lost by an ionizing particle in liquid xenon might escape in optical radiation instead of being deposited locally in the xenon itself. Other experiments recently completed in this laboratory[4] seemed to indicate that the operation of a bubble chamber depends upon the local deposition and thermalization in the liquid of energy from the ionizing particle. To capture locally the energy which was

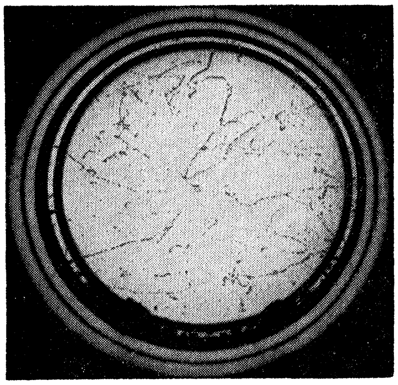


FIG. 1. Tracks of electrons produced by gamma rays from a 100-mC radium beryllium source placed 8 in. from the center of a bubble chamber 1 in. in diameter filled with liquid ethylene at $-18°C$. The density of the liquid is about 0.5 g/cm^3. The duration of the light flash is 5 msec and the flash occurred 3 msec after the expansion was initiated.

escaping in optical radiation, we dissolved some ethylene in the liquid xenon in the hope that it would "quench" the scintillation effect by collisions of the second kind. With less than 2% by weight of ethylene, the bubble chamber became radiation sensitive and produced copious tracks of electrons when exposed to a 25-mC radium beryllium source of gamma rays as shown in Fig. 2. A large number of pictures have been taken of this xenon chamber and indicate that the track formation is reasonably insensitive to the temperature and to the proportion of ethylene.

As a particle detector the xenon bubble chamber has properties similar to those of nuclear emulsion. The density of the liquid is 2.3 g/cm^3, the radiation length is 3.1 cm, and the Coulomb scattering constant is about the same as that of emulsion. Since the accuracy of scattering measurements increases as $L^{\frac{3}{2}}$, if L is the length of track measured, the xenon bubble chamber should yield useful scattering measurements because of the long track lengths possible, even though the accuracy of determining coordinates of points on a track is less by at least a factor ten than for emulsions. There is no basic limit on the possible size of xenon bubble chambers for use with pulsed accelerators. It competes in cost with large emulsion stacks because the liquid can be used indefinitely for many experiments. The main advantages of the xenon bubble chamber are that scanning of the photographs is easy and gamma rays can be detected efficiently by their production of Compton electrons at low gamma energies and electron pairs at high energies. Association of these gamma rays with their parent events should be easy because of the very low background of events per picture in bubble chambers, and the very rapid bubble growth which allows simultaneity of events to be estimated by bubble size to less than a millisecond. It therefore should be possible, using a xenon bubble chamber, to study directly those decay modes of unstable particles involving gamma rays and neutral pions, which decay rapidly in flight into gamma rays, and other nuclear processes in which gamma rays are emitted. It should be possible to determine the energies of gamma rays by multiple scattering measurements of the electron pairs.

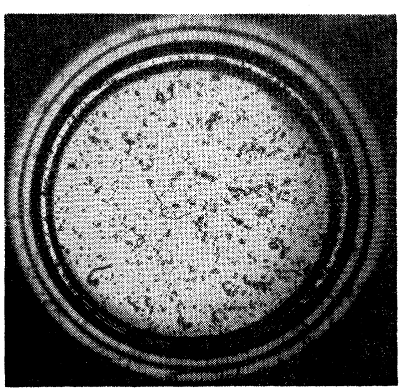


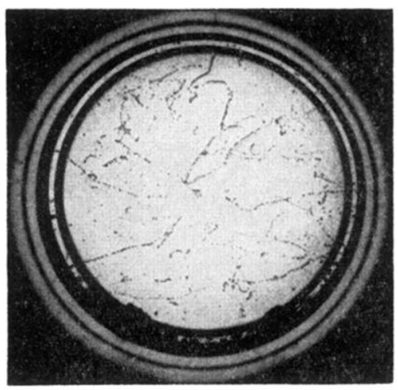
FIG. 2. Tracks of electrons produced by gamma rays from a 25-mC radium beryllium source placed 8 in. from the center of the same chamber filled with liquid xenon containing 2% by weight of ethylene and operated at $-19°C$. The density of the liquid is about 2.3 g/cm^3 and the lighting conditions are the same as in Fig. 1.

We would like to thank Dr. Cyril Dodd and C. Graves and L. O. Roellig for help in making some of the early runs. The Linde Air Products Company generously donated to the University of Michigan the xenon used in our experiments.

Note.—After our experiments were completed, we learned in a telephone conversation with Dr. Keith Boyer of the Cyclotron Group at the Los Alamos Scientific Laboratory that the high speed and scintillation efficiency of xenon gas depends only very slightly on pressure from a few millimeters of mercury up to 3 atmospheres. A small admixture of a few tenths of a percent of gaseous hydrocarbon, however, is found to practically destroy the scintillation effects. If the same mechanism is at work in the scintillation "quenching" as in the xenon bubble chamber, we might expect the large scintillation efficiency of xenon to extend to the liquid state at $-20°C$ and 20 atmospheres of pressure.

It seems rather remarkable that the same effect should be found under such different thermodynamic conditions. Perhaps it will be possible to adjust the percentage of hydrocarbon admixture so that the liquid xenon retains some of its scintillating efficiency and also produces bubble tracks. Then one might be able to observe spatial as well as temporal data for each nuclear process of interest. Thus decay times of particles, for example, could be associated with their identity as revealed by their daughter particles, etc.

* This work was supported partly by the National Science Foundation and the U. S. Atomic Energy Commission.
[1] D. A. Glaser, *Proceedings of the Fifth Annual Rochester Conference on High Energy Physics* (Interscience Publishers, Inc., New York, 1955).
[2] D. A. Glaser and D. C. Rahm, Phys. Rev. **97**, 474 (1955).
[3] R. Eisberg (private communication).
[4] D. A. Glaser and L. O. Roellig (to be published).



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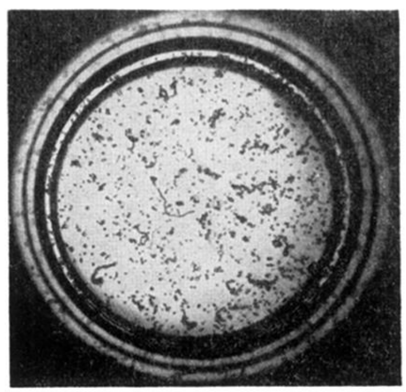

FIG. 2. Tracks of electrons produced by gamma rays from a 25-mC radium beryllium source placed 8 in. from the center of the same chamber filled with liquid xenon containing 2% by weight of ethylene and operated at $-19°C$. The density of the liquid is about 2.3 g/cm^3 and the lighting conditions are the same as in Fig. 1.