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August 3, 1956

Printed for the U.S. Atomic Energy Commission

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ABSTRACT

A bismuth fission chamber of greatly improved sensitivity is described. It responds to neutrons or protons and has a threshold of 50 Mev.

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The ion chamber that is described was intended for health physics surveys of neutron and proton fields, as well as for applications in cosmic-ray and high-energy nuclear physics research. The methods of chamber design that have been developed in the course of this work are applicable to the construction of any pulse ion chamber in which it is desired to have a plate area on the order of 50 square feet. The large electrical capacity of such a chamber had been a deterrent to its use in the past. The sensitivity that has now been achieved is one count in approximately 300 very-high-energy neutrons per cm^2 .

In order to eliminate response to γ rays and nuclear star events it was decided to use a material to coat the ion chamber plates that would have a high fission threshold, and then operate the device so that only fission events could be detected. At energies above 1 Mev bismuth is the only element suitable for this purpose.¹ Its fission threshold is near 50 Mev for either neutrons or protons, and by 270 Mev the cross section has risen to 180 millibarns. We do not have measurements at greater energies than this, but there is reason to believe that the cross section does not rise much higher.

The fission fragments from Bi have a range on the order of 1 mg/cm^2 , and there is some evidence that only the top $1/2 \text{ mg/cm}^2$ of a Bi coating can be thought of as "effective" in producing detectable fission events. As a result it was decided to space the plates $1/4$ in. apart thus providing approximately 1 mg of gas path length when the pressure is 1 atmosphere and the fragment travels perpendicular to the plates. Owing to the very limited effective depth of the bismuth it is necessary to provide a very large area in order to have a significant counting rate.

¹ E. L. Kelly and Clyde Wiegand, Phys. Rev. 73, 1135 (1948).

Bismuth fission chambers have been made before,² but not with nearly the area in this one. The total area of the plates in our present chamber is $63,000 \text{ cm}^2$, so that we have 31.5 grams of effective Bi, even though the coating is actually 1 mg/cm^2 deep.

The vacuumtight case of the ion chamber shown in Fig. 1 is made of 1/2-in. - thick aluminum with a flange, gasket groove, and lid at each end to facilitate assembly. Inside the chamber 43 plates 12 in. in diameter and 0.040 in. thick are spaced 0.25 in. apart on eight rods. Alternate plates are supported (as one unit) by four of the rods, but are separated by the 0.25-in. spacings from the other plates and their four supporting rods. The rods are fastened at each end to heavy rings, in turn held in place in the case by eight radial set screws. This rugged construction was chosen to reduce microphonic response. The plates are coated on each side by vacuum evaporation of 1 mg/cm^2 of Bi.

It was at first intended to connect the plates in series, using a voltage of about 5 kv across the whole stack to provide a field strength of about 200 volts/cm. It was found that the series connection did not provide uniform or adequate sensitivity across the stack, and therefore fissions occurring on more remote plates could not be detected with equal sensitivity. In addition, the high voltage necessary for the series connection gave rise to high-voltage breakdowns. A simple connection of alternate plates in parallel, while it permitted use of a low voltage, gave an electrical capacity of about $8000 \mu\text{f}$, which made the signals much too small to detect. In order to isolate each plate and yet take advantage of the large total area of the 43 plates, alternate plates were connected to individual triodes, and the plates of the triodes were tied together. This system did not work because the noise of all the triodes was competing with a desired signal from only one.

What was needed was a method of allowing one of each pair of plates to be connected to the input of the preamplifier when a signal was available between that particular pair of plates, but having the capacity of that pair of plates disconnected when such a signal was not present. This desirable arrangement (as suggested by William Goldsworthy and James Robison of this laboratory) is achieved by the connections shown in Fig. 2. One set of alternate plates is connected directly to the negative side of a 300 v battery through a simple filter. The plates of the

² Clyde Wiegand, Rev. Sci. Instr. 19, 790.

other set are connected to one another by 200- μ henry inductances forming, in conjunction with the interplate capacitances, a delay line. To eliminate reflections, one end of this line is terminated in its characteristic impedance by a 750- Ω resistor. The other end of this delay line is connected to an auto pulse transformer, giving a 5-to-1 voltage gain. This provided better impedance matching to the input of the preamplifier.

There is a 5 μ sec delay down this entire line. Therefore a particular signal may be delayed from zero to 5 μ sec. If it were desired to do coincidence work to better than 5 μ sec, both ends of the delay line could be brought out, and if the resulting double pulses were photographed, the location of the pulse in the chamber along with its resulting delay could be determined to perhaps 0.25 μ sec.

The signal from the pulse transformer is amplified by 100 db by a low-noise preamplifier and low-noise linear amplifier of UCRL design. The average signal coming from the pulse transformer is about 100 μ v. Since the counting rates with this chamber are often quite low, in spite of the large amount of effective bismuth, the pulses coming from the linear amplifier are both photographed and recorded in duplicate on registers in order to have a check on the long-time stability of the electronic circuits. A conventional driven-sweep oscilloscope and moving-film camera are used. Calibration pulses of a known size are automatically fed into the circuit between the pulse transformer and preamplifier at regular intervals and recorded on the film as a check of reliability. The discriminators controlling the registers are gated off when the calibration pulses are being fed in.

The chamber is filled to 20 lb/in² absolute with 95% A and 5% CO₂. It has been found that this is an optimum pressure; more pressure increases recombination and less pressure allows the average fission fragment to hit the opposite plate before the end of its range. It has been found, by reversing the polarity, that the bismuth on both the delay-line-collector set of plates and the high-voltage set is effective. That on the high-voltage set of plates is about 2 to 3 times as effective as that on the delay-line set.

As the 184-inch synchrocyclotron is not in operation at present, the chamber has been partially calibrated during a run at the UCRL Bevatron. Here 6.2-Bev protons struck a target, producing a variety of particles. The magnetic field of the Bevatron deflected all the charged particles away from the chamber, leaving principally neutrons and γ 's of several Bev. A transition curve shown in Fig. 3 was run using 0, 0.5, 2, 6, and 12 inches of lead. A twin chamber having no bismuth was used to subtract any effect that might be caused by the aluminum plates. Above a few volts bias this subtraction proved to be small. The small slope of these curves is consistent with the attenuation of neutrons by lead and is equivalent to a mean free path of about 200 grams/cm², which is as close to the geometric cross section mean free path for lead of 180 grams/cm² as can be expected of these rough preliminary measurements. Apparently the response to γ rays, known from other experiments to constitute about 1/3 the neutral particle beam, is quite small, for no steep attenuation--which would be characteristic of γ -rays--is seen at all.

The relative integral bias curves for the chamber with the bismuth and for the twin control chamber without the bismuth are shown in Fig. 4. It is seen that under the worst conditions at 10 volts the ratio is 4 to 1, but that this has risen to 25 to 1 at 20 volts and above this is as much as 500 to 1. The difference in slopes of the bismuth and nonbismuth curves is interpreted as an indication that the processes responsible for the pulses are fundamentally different, namely heavy-element fission on the one hand and light-element star formation on the other.

During the Bevatron run a comparison was made with a previously calibrated chamber containing 1 gram of effective bismuth and having a sensitivity of 1 count per 10⁴ neutrons/cm² at 290 Mev. It was found that the large chamber had a counting rate, when extrapolated to zero bias, 37 times that of the little chamber, which is to be compared with a ratio of about 21 in the amount of effective bismuth contained. This measured ratio gives a sensitivity of about one count per 300 very-high-energy neutrons per cm² (assuming that the fission cross section does not vary rapidly with energy above 300 Mev).

A Cf^{252} spontaneous fission source has been incorporated into each chamber, but for simplicity has not been shown in Fig. 2. The high voltage to this source can be switched off or on from the outside, making a fairly high counting rate of bona fide fission pulses available at any time for circuit test and calibration purposes.

The integral bias curve arising from 500 Cf^{252} pulses is shown in Fig. 5. That the slope of this curve is much steeper than that arising from the bismuth fissions is interpreted as a result of the difference in the mechanics of the two fission processes themselves, and of the fact that the Cf^{252} is extremely thin.

This chamber will sometimes be used in the presence of charged particles, such as very-high-energy protons and pions, which can initiate fissions as easily as neutrons can because their energy is so far above the Coulomb barrier potential. In order to separate the effect of the charged particles a complete blanket of Geiger tubes is being constructed for the bismuth-containing chamber, and each fission event will be recorded as being either in coincidence with a Geiger pulse or not.

The authors wish to thank the operating crews of the UCRL 184-inch cyclotron and Bevatron for their cooperation in the experimental calibrations of this fission chamber.

This work was done under the auspices of the U.S. Atomic Energy Commission.

LEGENDS

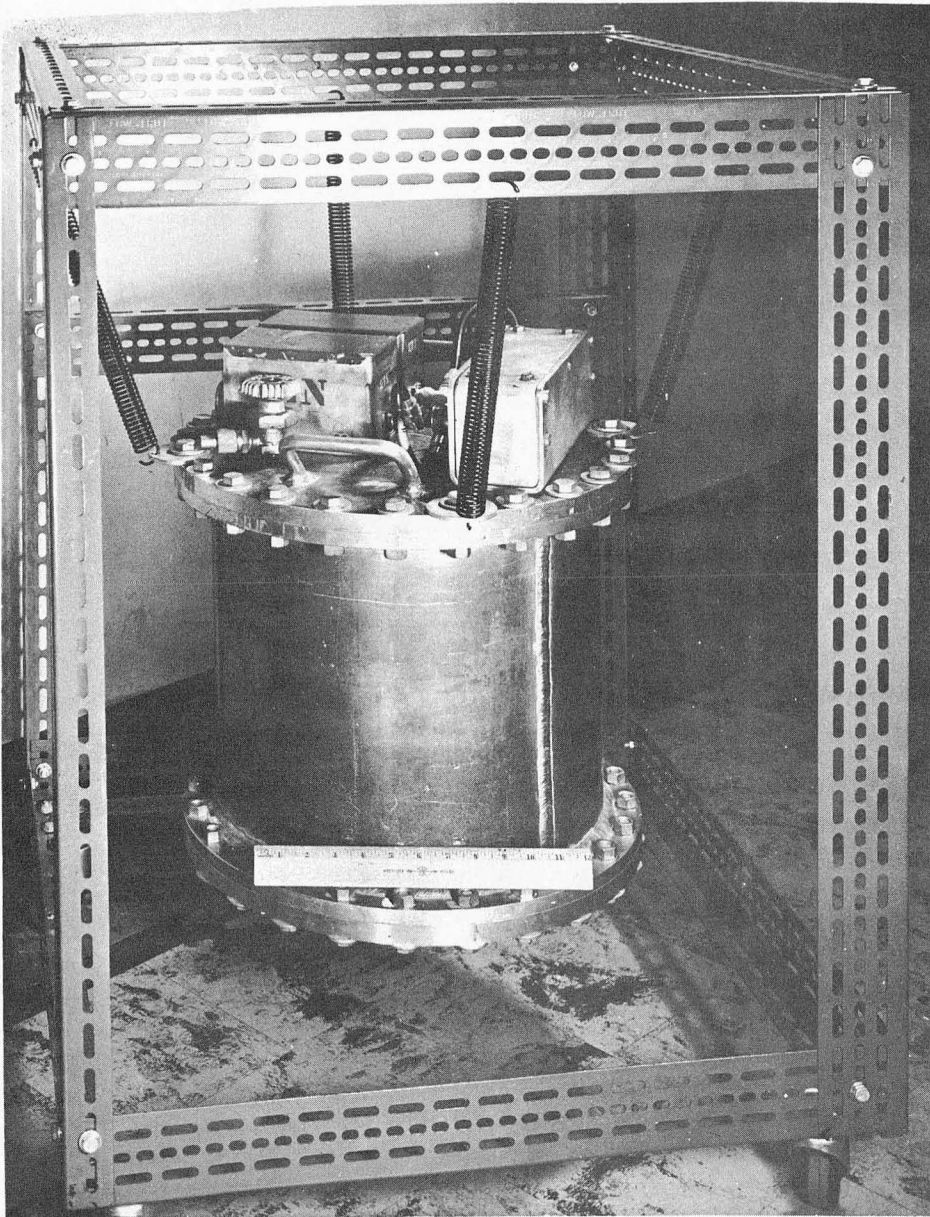
Fig. 1. Vacuum case of bismuth fission chamber made of 0.5-in. -thick dural. The low-noise preamplifiers and signal control box are shown on top of the chamber.

Fig. 2. Schematic diagram of the interior arrangement of the bismuth fission chamber. The plates are seen to be spaced by ceramic insulators and washers along bars which are in turn held to the case by supporting rings at each end. Half the plates are connected to the battery contained in the signal control box on top of the chamber. The other half of the plates are connected in series through 200-microhenry inductances, making them into a distributed delay line having an over-all delay of about 5 micro-seconds. One end of the line is terminated in its characteristic impedance of 820 ohms, while the other end of the line is connected to an autotransformer which serves to match impedances.

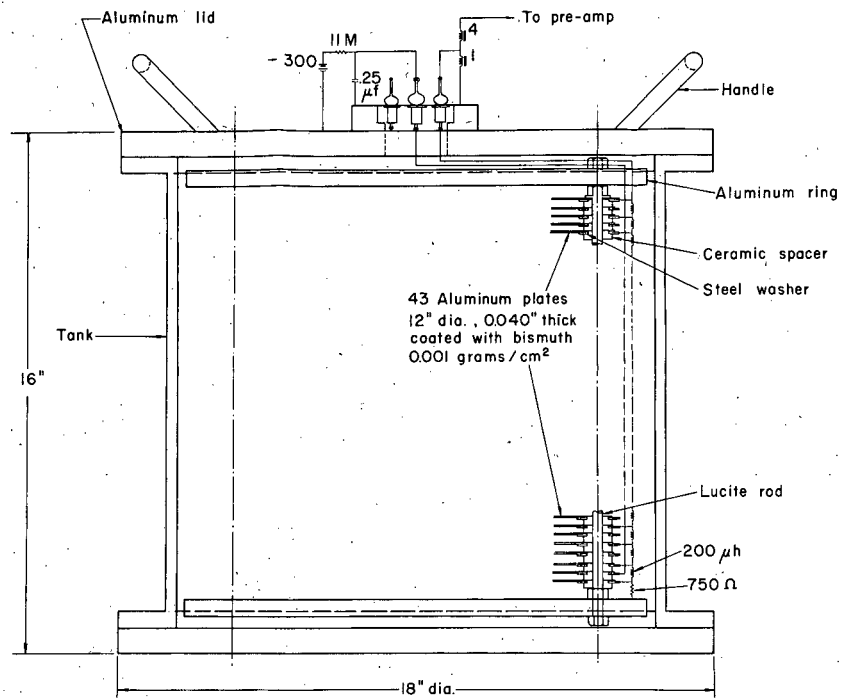
Fig. 3. Transition curve for various thicknesses of lead up to 12 in. for the neutral beam of the University of California Bevatron. These curves indicate that there is no measurable response to gamma rays, even though these are known to constitute a major part of the neutral beam. The slopes of these curves are consistent with the attenuation of neutrons by lead.

Fig. 4. Integral bias curves for the bismuth-coated chamber and for its twin with no bismuth. Above 20 volts bias the ratio of counting rates is as much as 500 to 1.

Fig. 5. Integral bias curve of 500 californium-252 spontaneous-fission pulses. The steeper slope of this curve is thought to arise from the difference between the spontaneous californium fission and the induced high-energy neutron fission of bismuth.

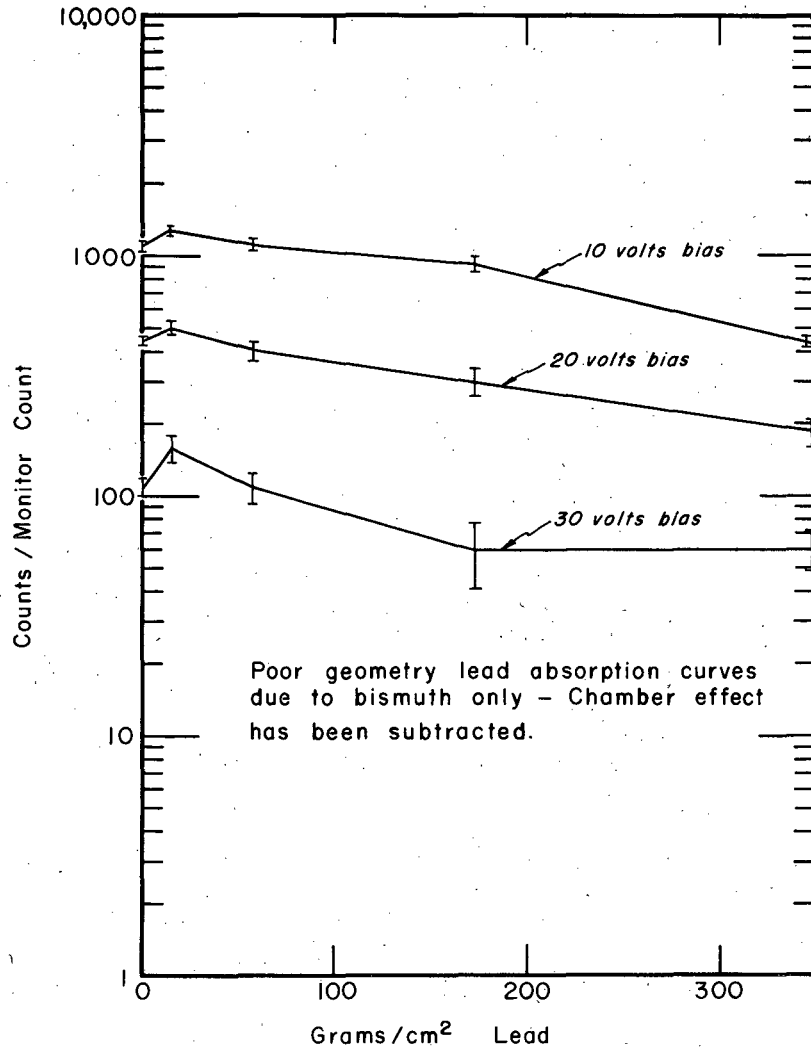


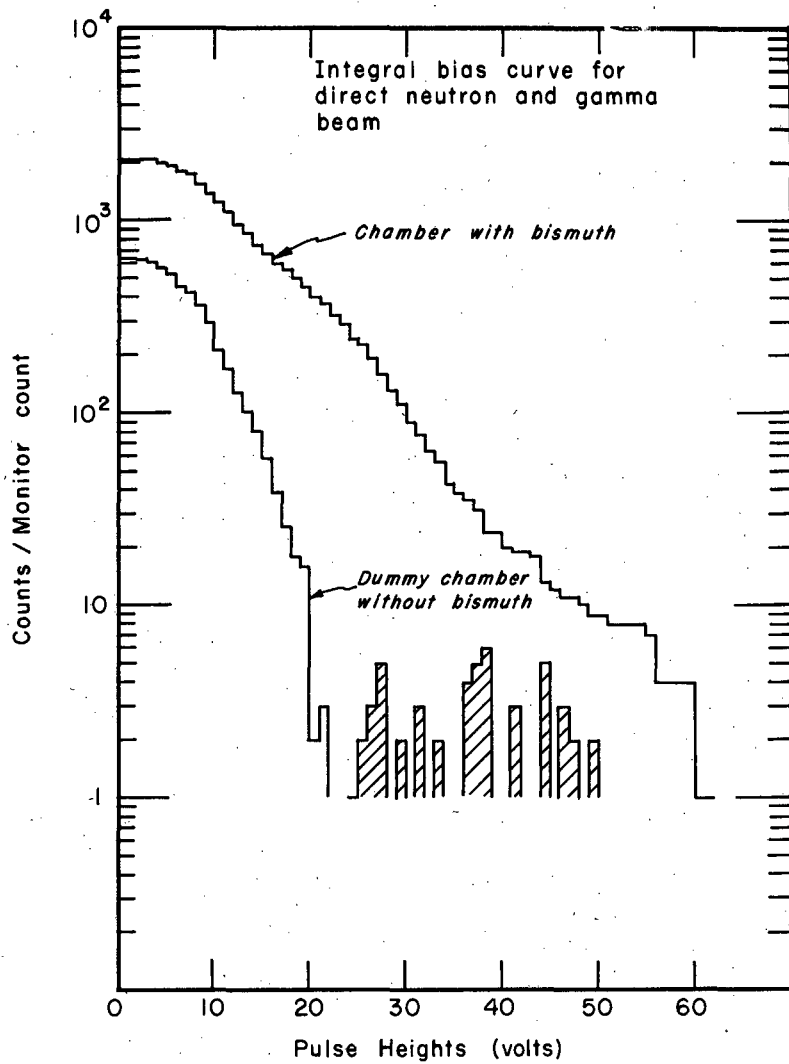
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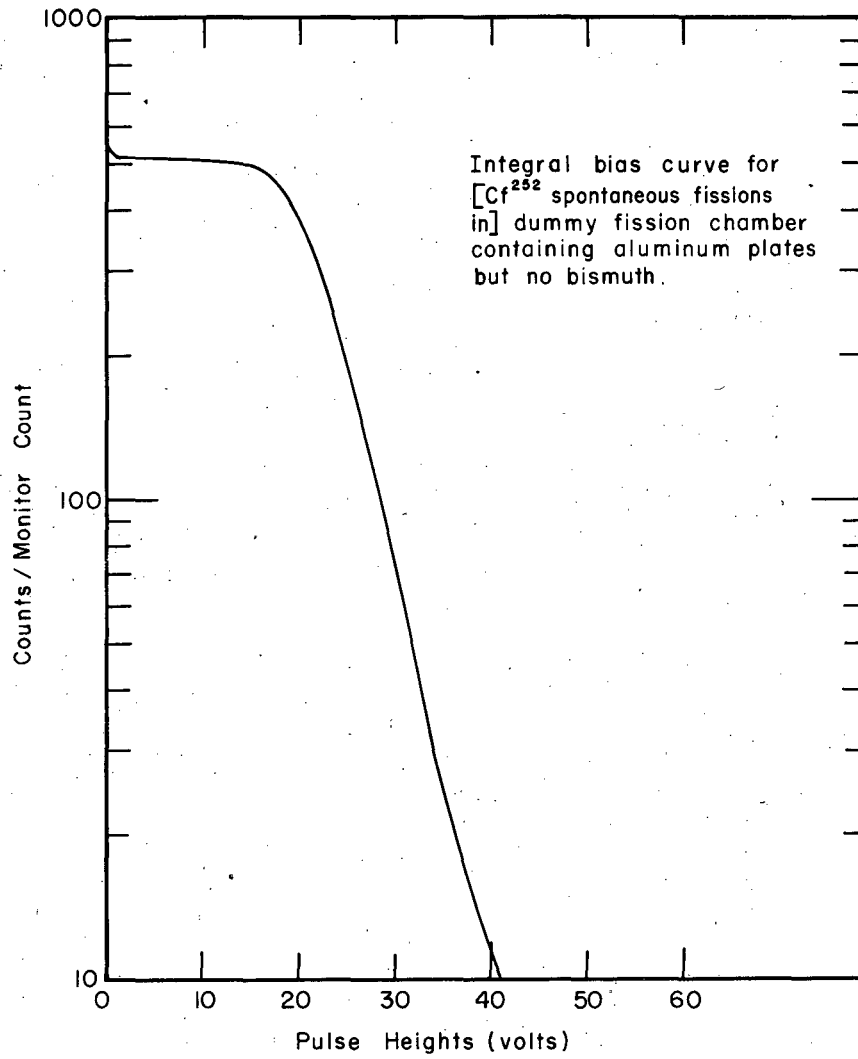


physical arrangement of the
bismuth fission chamber.

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