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FAST-NEUTRON SURVEYS USING INDIUM-FOIL ACTIVATION

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ABSTRACT

Activation of indium foils by thermal neutrons has been applied to measurement of fast-neutron fluxes. Foils are encased in paraffin spheres placed in cadmium boxes. The high-energy neutrons that penetrate the cadmium become thermal neutrons; the thermal-neutron flux is proportional to the incident fast-neutron flux over a range of about 20 kev to 20 Mev. The foils are removed from the boxes and counted on a methane-flow proportional counter. High instantaneous neutron fluxes are easily detected and counted by use of these foils. Many simultaneous measurements have been made easily by this method.

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About a year ago our understanding of radiation fields at the Bevatron and other accelerators had progressed to a point at which we recognized the need for more information, and therefore for another method to measure exactly the neutron fluxes existing there. Many locations near these accelerators are quite inaccessible for radiation measurements during operation. This inaccessibility made it necessary to develop a method for remotely surveying such areas. Also, simultaneous measurements at various locations are often necessitated because radiation patterns change as operating conditions change. We are in the process of determining as many of these patterns as possible at the Bevatron (our chief concern during recent years), the cyclotron, and the heavy-ion linear accelerator. There was need also for a method that did not require large amounts of electronic equipment.

We have found that the activation of indium foils by thermal neutrons can be applied to the measurement of fast-neutron fluxes. The foils are activated by exposure to the neutron flux, then removed for counting.

Foils weighing 300 to 500 mg are placed inside paraffin spheres (3 in. in radius) which are in turn placed inside boxes made of 1/32-in. cadmium (Fig. 1). The cadmium absorbs the slow neutrons present in the incident flux, and the paraffin moderates the high-energy neutrons, which then activate the indium.

A 0.005-in.-thick foil is mounted in a 0.007-in.-deep depression in a thin lucite disc. The lucite disc fits into a milled depression in either the spherical paraffin moderator or an aluminum plate used on the counting system. The foils are thus accurately positioned during both the exposure and the counting process.

The counting was originally done by using a standard G-M tube, surrounded by a 3-in.-thick lead shield, and a scaler; however, as a later development in the technique, the foils are now counted in a gas-flow proportional counter designed and built at this laboratory. Standard Radiation Laboratory counting equipment is used. A block diagram is shown in Fig. 2.

The counter is calibrated prior to the start of a run by using a Cs^{137} source. Cesium-137 was chosen because it decays to give β-particles of about the same energy as those from indium, and it has a useful half life. Integral bias curves are shown in Fig. 3 for two different high voltages and for three different amplifier gains. In nearly all cases the discriminator is set at 10 volts and the counter is normally operated at 3000 volts. This gives a counting rate equal to 93% to the zero-bias counting rate. The counter has a background counting rate of 8 counts per minute. The gas used is methane of at least 99.9% purity; however, heating gas as supplied by the local utility company has been found to work well. The gas is passed through the counter at from 30 to 50 cc per minute. Counting rate is independent of gas-flow rate over a wide range.

The foils as now used give a counting rate of 12 counts per minute per gram of indium for a fast-neutron flux of 1 neutron per cm^2 per second. The response of the foils has been checked by exposing them to Po-Li, mock fission, and Po-Be neutron sources as well as neutrons from the d-d and d-t reactions. The results of these exposures are shown in Fig. 4.

The 3-in. thickness of paraffin was chosen after consideration of the response of enriched BF_3 proportional counters to the same range of energies and to various thicknesses of paraffin. Most of the curves of counting rate vs paraffin thicknesses show an efficiency peak in the region of 2 to 3 in. of paraffin over the range from 30 kev to about 20 Mev.

In measurements made at the Bevatron the presence or absence of targets correlated very well with the activation of the individual foils. As many as 16 measurements are made simultaneously around the magnet ring and tangent tanks. In some of these areas, conventional counters and electronics are disabled owing to the exceedingly high instantaneous flux that is characteristic of pulsed machine operation. The indium foils are of course immune to errors caused by these high counting rates.

In addition, for counting by conventional methods, this number of simultaneous measurements would require an impressive quantity of electronic equipment. When it is desirable to correlate corresponding data from several simultaneous foil surveys, a monitor foil is placed in the center of the Bevatron pit. All runs are then normalized to this monitor.

Table I

	Targets		Beam conditions		
Run 1	Location	Material	Energy (Bev)	Intensity (protons per pulse)	Pulse rate (pulses per minute)
1 Jan. 1957	WIN	0.016 in. Mylar + 0.001 in. Al	6.2	$\sim 3 \times 10^{10}$	10
	69^{o} SOW	0.5 in. Al 0.00025 in. Al			

Comments:

1. WTT - Center foil behind concrete shield, peak is obscured.
2. NTT - Peak produced by 69^{o} target.
3. ETT - Peak probably related to injector apparatus in tank.
4. STT - Peak probably related to SOW spillout control foil and induction electrode in tank.
5. Magnet quadrants - Low uniform levels.

	Location	Material	Energy (Bev)	Intensity (protons per pulse)	Pulse rate (pulses per minute)
Run 2 30 Jan. 1957	WIN	0.5 in. C	6.2	$6\text{-}8 \times 10^{10}$	10
	$1^{o}59'$	1 in. C			
	SOW	0.00025 in. Al			
	EIS	6 in. Cu			

Comments:

1. WTT - Foil in the clear; peak very pronounced.
2. NTT - Peak essentially absent.
3. ETT - Peak much higher than Run 1, associated with clipper located here.
4. STT - Peak as for Run 1 — spillout control foil and induction electrode.
5. Magnet quadrants - Same as Run 1

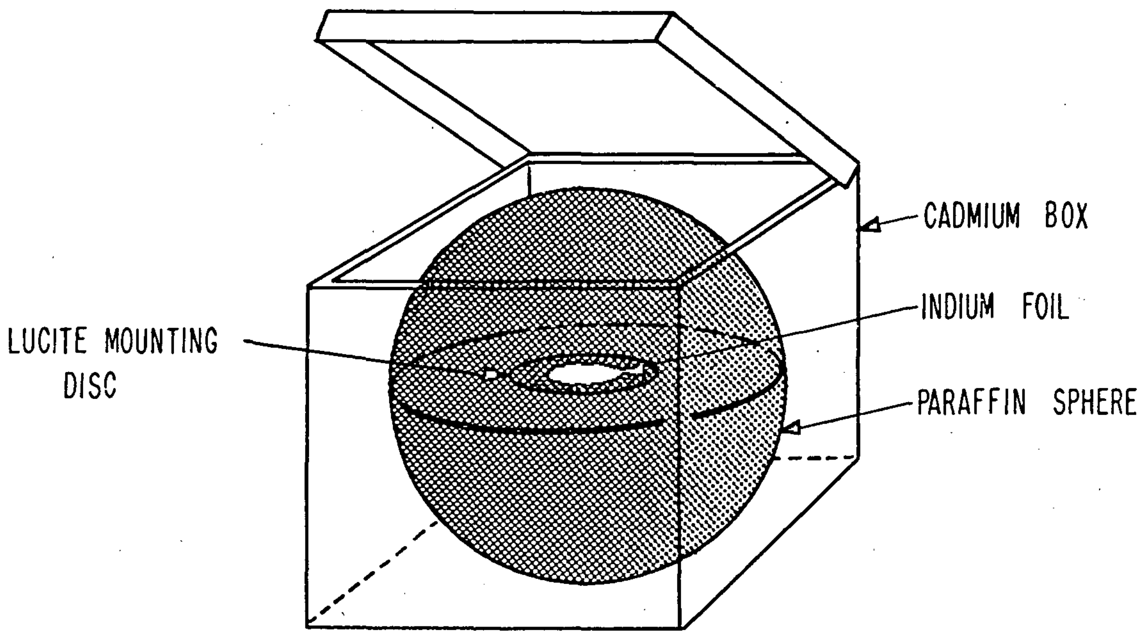

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Fig. 1. Phantom view showing placement of indium foil inside paraffin sphere and cadmium box container.

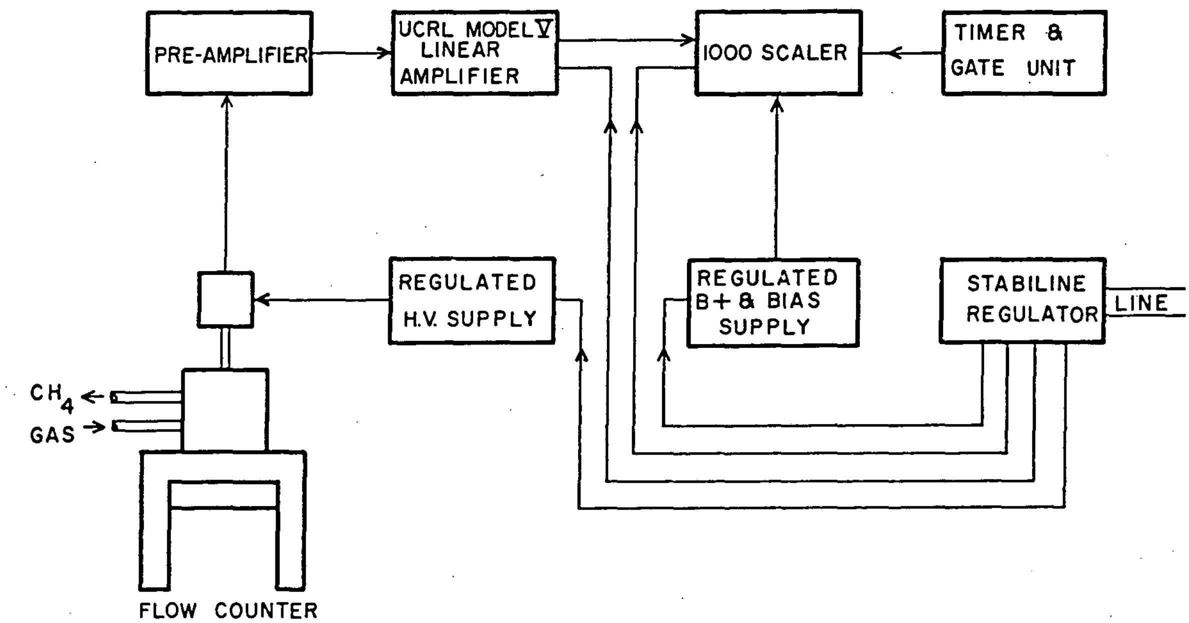

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Fig. 2. Electronics block diagram for proportional counter.

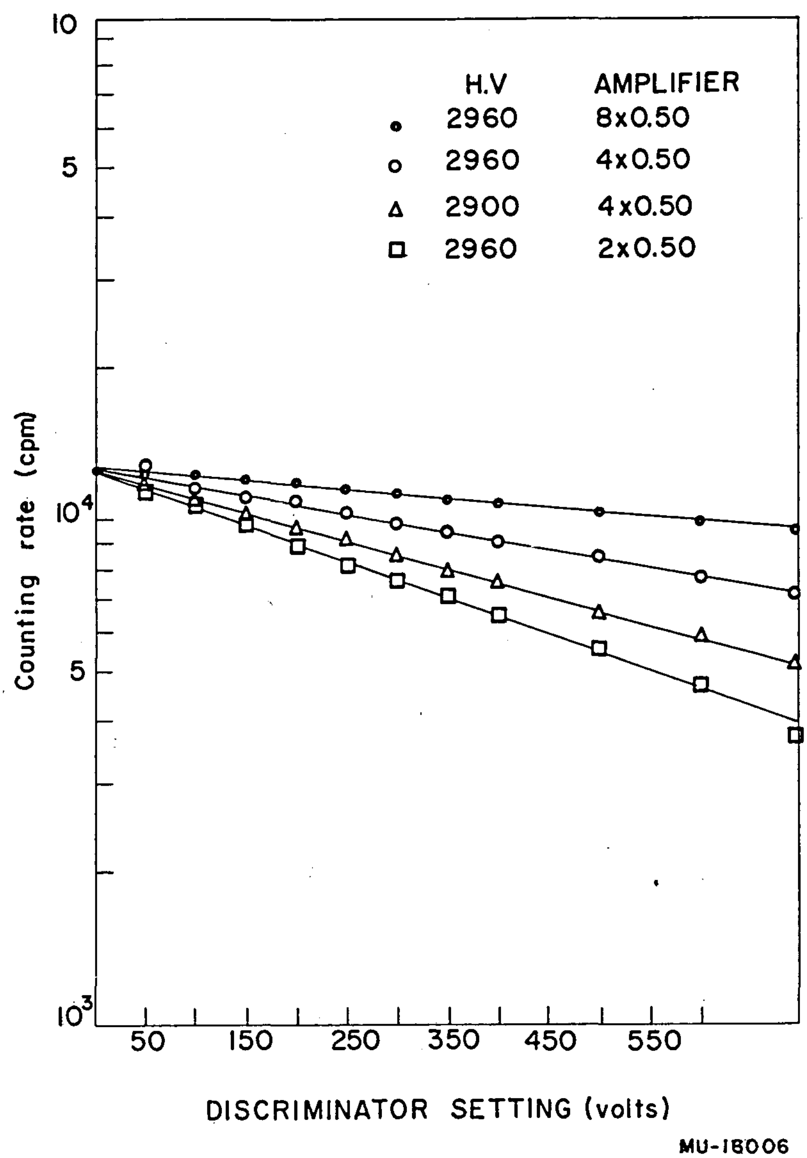

Fig. 3. Proportional counter integral bias curve. Cs^{137} source.

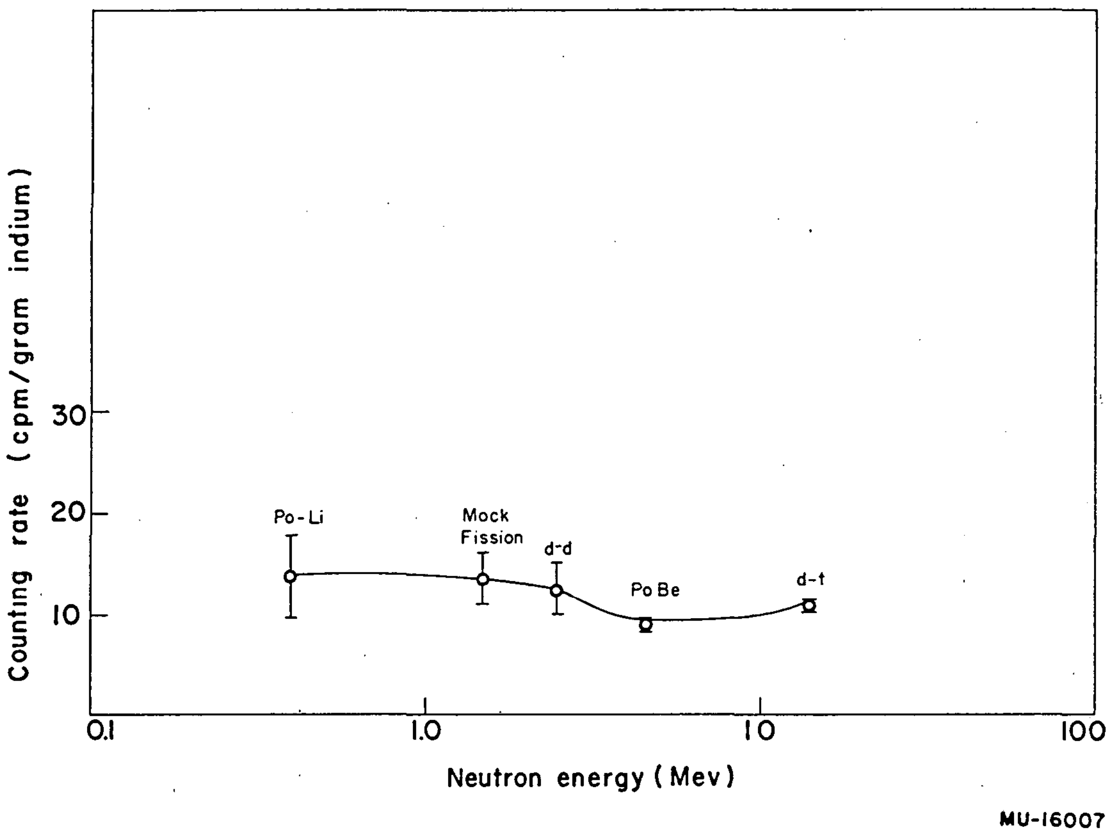

Fig. 4. Counting rate vs neutron energy. (cpm/gram of indium due to 1 neutron per cm^2 per second.)

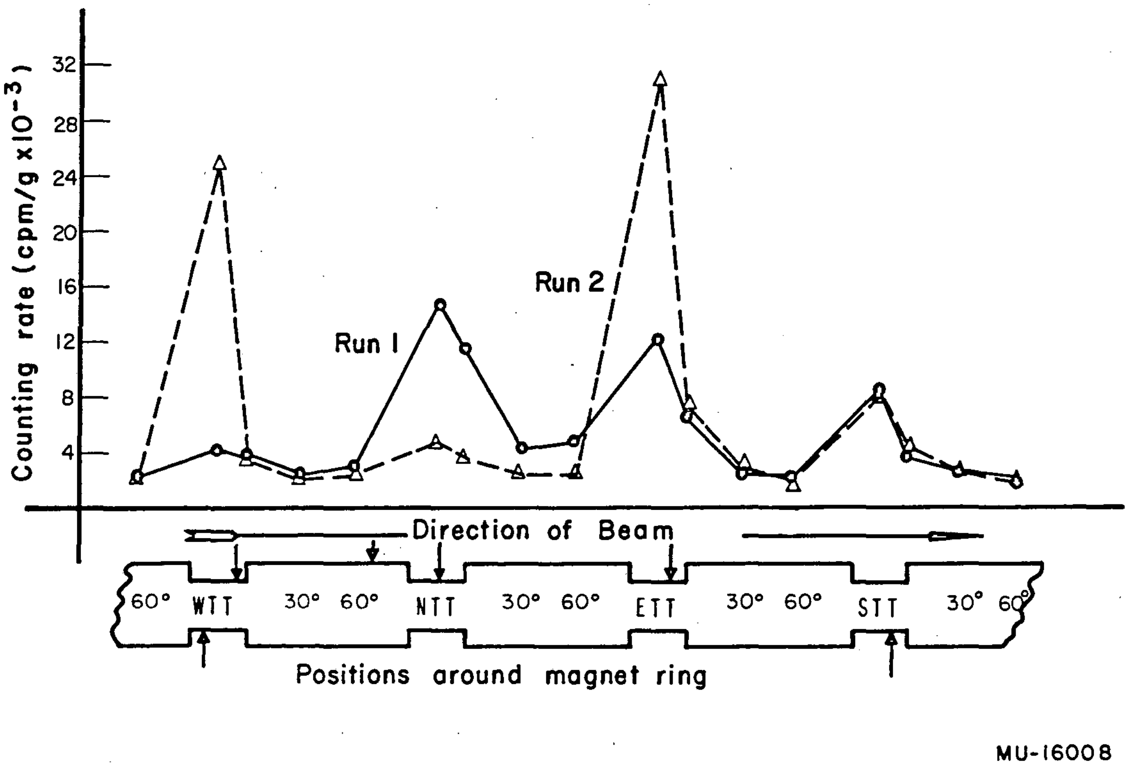

Fig. 5. Counting rates at various positions around Bevatron magnet ring. (Actual activity of moniter foils, Run 1-1850 cpm/g; Run 2 - 4480 cpm/g.)

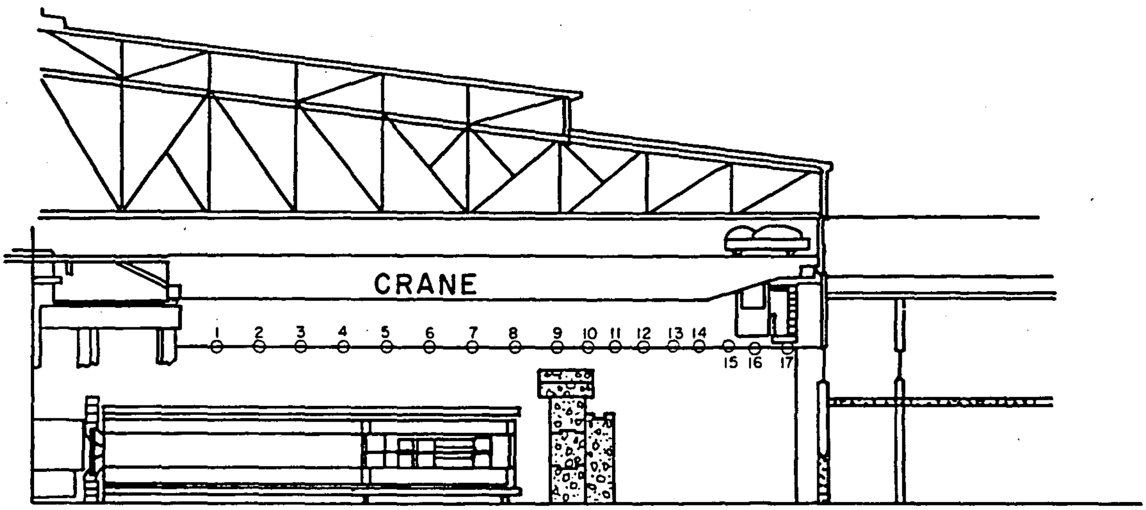

Fig. 6. Section view of Bevatron and building through Bay 20 showing radial positions of indium foils.