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PORTABLE FAST- AND SLOW-NEUTRON SURVEY METER

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ABSTRACT

To meet the need for a portable survey instrument that will estimate the radiation hazard from fast and slow neutrons, a proton-recoil and BF_3 proportional counter were combined into one instrument utilizing the same high-voltage supply and count rate meter circuitry. The instrument is lightweight, has high sensitivity, is essentially nondirectional, and possesses good gamma-ray discrimination. Three ranges are provided, enabling one to read from 0 to 300 to 3000 or to 30,000 slow neutrons/cm^2-sec. The sensitivity of the fast-neutron counter is approximately proportional to energy from 0.1 to 20 Mev, and the three ranges correspond to 0 to 100 to 1000 and to 10,000 Mev/cm^2-sec. With some prior knowledge of the neutron spectrum to be measured, a fair estimate of the radiation hazard due to fast and slow neutrons can be obtained with this instrument.

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INTRODUCTION

Portable neutron instrumentation has not attained the development and simplicity enjoyed by other types of radiation-detection instruments, chiefly because of the basic physics involved. Fast-neutron detectors depend upon nuclear cross section, and therefore have inherently low efficiencies as well as being energy-dependent. Attempts to overcome some of these disadvantages have met with moderate success.[1,2,3] Usually when one condition is satisfied another must be given a secondary role or balanced by some other method. The presence of gamma rays in all neutron fields is an additional factor affecting neutron dosimetry which must be taken into account because of the different Relative Biological Effectiveness of neutrons and gammas.*

The desirable features for a neutron detector are high efficiency, known directional characteristics, energy independence or dependence varying in a known manner, and the ability to distinguish gammas from neutrons. Attempts have been made to incorporate these features into an instrument that responds to fast and slow neutron radiation. A fair estimate of the neutron hazard can be obtained by the use of this survey meter. The instrument employs a BF_3 proportional counter, and a proton recoil counter, either of which can be selected to drive a count-rate meter. Figure 1 is a block diagram of the elements that are described in detail in following paragraphs. Proportional counters were chosen because they have good gamma discrimination, are essentially nondirectional, and are small enough and have low enough power requirements for a portable instrument.

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[1] B. J. Moyer, Nucleonics <u>10</u>, No. 5, 14 (1952)

[2] G.S. Hurst, Rev. Sci. Instr. <u>22</u>, 981 (1951)

[3] B. W. Thompson, Nucleonics <u>12</u>, No. 5, 43 (1954)

* The current R.B.E. is thought to be approximately 10 for fast neutrons and about 2.5 for slow neutrons.

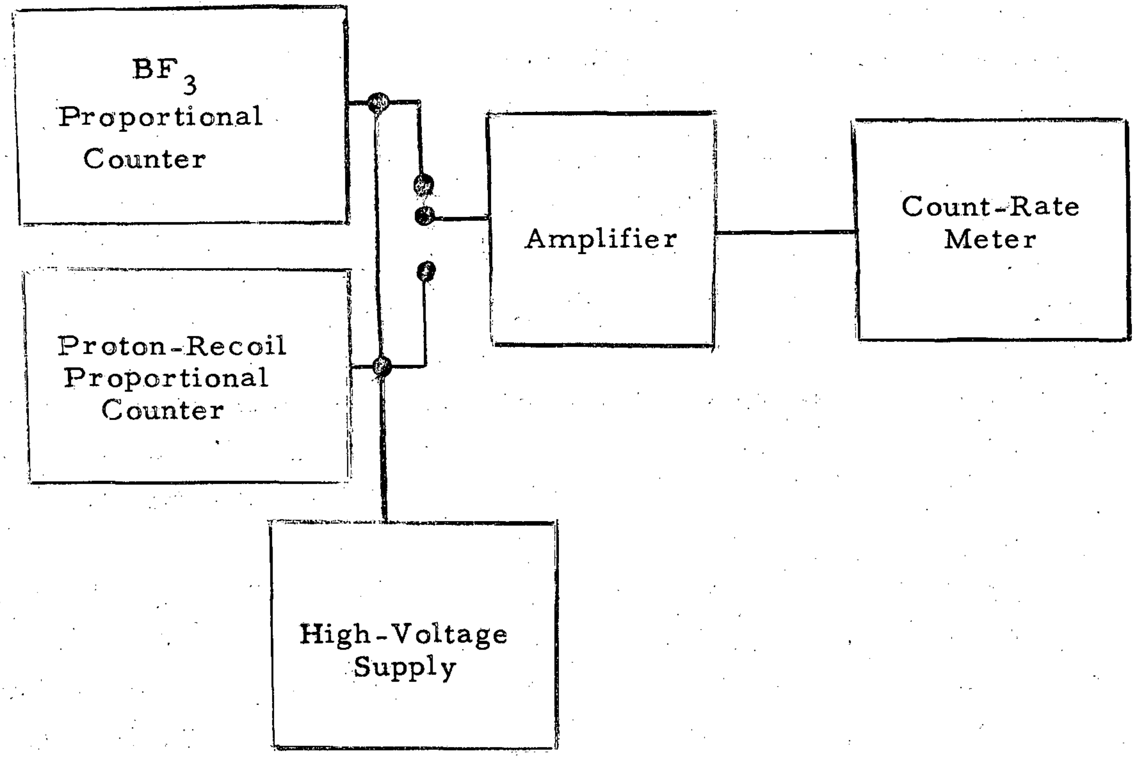

Fig. 1

Block Diagram of Instrument

THEORETICAL REQUIREMENTS

Fast-Neutron Counter

The theory of the proton-recoil counter as employed here is extensively developed in Ref. 1 and extended in Ref. 3. It will suffice to say that the sensitivity is proportional to the energy as shown by the curve of Fig. 2 and Ref. 1. The number of counts observed, C, is proportional to the energy flux density:

$$C = K \int \phi(E)\, E\, dE \tag{1}$$

where K = a calculable constant depending on the amount of hydrogenous material, and other design features of the instrument,

E = the energy of the incident neutrons,

$\phi(E)$ = flux density per unit range of energy.

It is clear that it is necessary to know something of the neutron spectrum being considered and to be able to estimate a mean neutron energy in order to interpret the results obtained from the counter in terms of biological effects. An estimate of the measured spectrum can usually be made by prior knowledge of the original neutron distribution, with a correction for the energy shifts brought about by passage through intervening shielding.

Equation (1) can be employed to specify a counter's dimensions. It is reasonable to choose 100 Mev cm^{-2} sec^{-1} as a full-scale reading on the most sensitive range and also desirable to have a counting rate of approximately five counts/second correspond to this energy flux density. From Ref. 1,

$$\sigma R \simeq 10^{-26} E, \tag{2}$$

$$C_1 = 10^{-27} N_h A \int \phi(E)\, E\, dE, \tag{3}$$

where σ = n-p cross section at energy E (cm^2),

R = Maximum range in counter wall material of the recoil protons from neutrons of energy E (cm),

N_h = number of hydrogen atoms/cm^3 in wall material,

A = area of hydrogenous material of the detector (cm^2).

Substituting numerical values and accounting for those protons not detectable below the usual gamma bias setting, we find the area of hydrogenous material needed is about 1000 cm^2. The thickness can be chosen from the

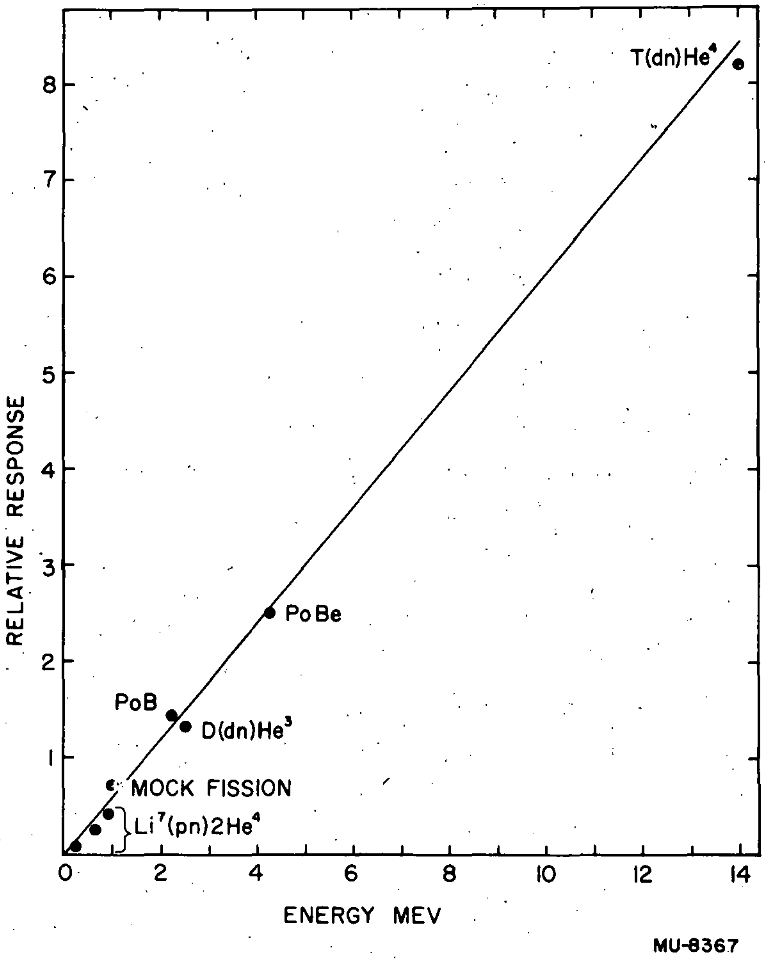

Fig. 2 Response of the Proton Recoil Counter

curves of Ref. 1, and is usually taken as 1/8 inch for the energy interval from 0.1 to 20 Mev.

Slow-Neutron Counter

If one considers slow neutrons to be those that are strongly captured by boron, a BF_3 proportional counter can be used to estimate the slow-neutron flux.

Usually the flux around any amount of shielding is sufficiently peaked at thermal energies to allow one to approximate the slow-neutron radiation hazard by assuming that the cross section at thermal energies applies over the entire energy interval to be measured by a boron counter.

Then one may write the expected counting rate C_2:

$$C_2 = \phi_s V N_B \sigma_B \tag{4}$$

where ϕ_s = slow-neutron flux (Ns/cm^2 sec),

V = active volume of the counter (cm^3),

N_B = number of B^{10} atoms/cc of the counter gas,

σ_B = boron^{10} capture cross section at thermal energy.

The range of counting rate C_2 should be about the same as that of C_1 in order to simplify the electronics so that both counters can drive the amplifiers at the same gain setting. A practical survey meter with three ranges in factors of ten would have an upper limit of approximately 500 counts per second, from considerations of the response of proton-recoil counter. The presently accepted slow-neutron tolerance is around 1500 Ns/cm^2 - second. A practical counter should be able to measure up to about 20 times tolerance and have the most sensitive range read up to a maximum of 300 Ns/cm^2 - sec. Putting these values into Eq. (4), one realizes the product VN_B is very small. The use of enriched B^{10} is hardly necessary, but the enriched element was used because of its availability in the purified form. If N_B is expressed as a function of the pressure P for the design specifications imposed, the product VP equals 40 cm^4 where P is expressed in cm of mercury. A lower limit of P equal to 1.0 cm Hg was readily measurable on the present BF_3 system, which makes the dimensions of the counter reasonable as shown in Fig. 3. In this simple type of counter construction it is necessary to increase V by about 20 percent to take care of end effects and to make up

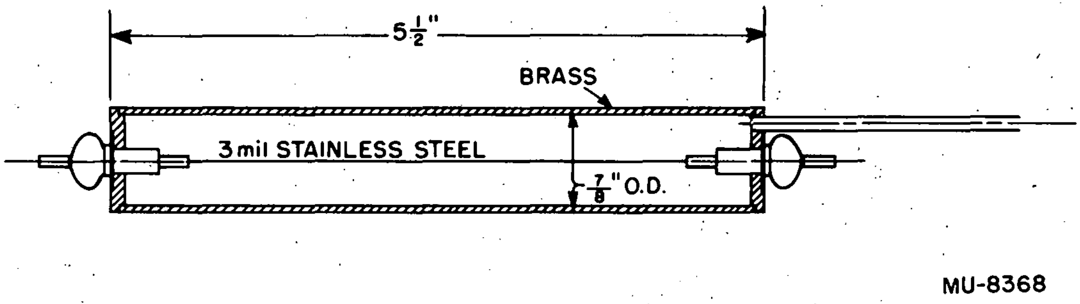

Fig. 3 BF_3 Counter

for those disintegrations originating near the walls and so oriented that the alpha particle or the recoiling Li nucleus actually strikes the walls therefore losing only a fraction of its energy in the gas and producing a pulse that is not of sufficient amplitude to be counted.

COUNTER CONSTRUCTION

At the pressure used (1.0 cm Hg), the BF_3 counter does not have good operating characteristics. Because of the small volume the probable wall effects, and the necessity of adding some inert gas to take care of the voltage characteristics, it was decided to bring the counter pressure up to one atmosphere with dry argon. The characteristic curve of Fig. 4 indicates the operation of the counter. It is seen that there is a 200-volt plateau.

The proton-recoil counter was constructed by coating a sheet of polyethylene with a thin layer of adquadag and forming it into the cathode of a proportional counter. Aluminum was used for the cylinder walls to make them as light as possible. Araldite* bushings were used as insulators and the counter was vacuum sealed with cold-setting Araldite. The counter assembly is shown in Fig. 5. Leaving the space between the ends of the counter and the polyethylene increases the probability that those protons emerging near the ends of the polyethylene will lose most of their energy in the counter gas before striking the ends of the counter.

Again to simplify the electronics, both counters should operate at the same high voltage. From Fig. 4 an operating voltage of 1500 volts could be chosen. A family of characteristic curves for the proton-recoil counter at different pressures is indicated by Fig. 6. From these curves it is seen that an operating pressure of 68 cm Hg of the filling gas ACO_2 (96% A, 4% CO_2) will allow the use of 1500 volts operating voltage. It is worth while to note the increase in relative gamma-ray sensitivity due to wall effects as the gas pressure is reduced. It would be desirable to operate at a high pressure, but a compromise between the two counters and hv supply difficulties must be met.

Electronics

The instrument contains the basic count-rate meter circuit described in Ref. 3. Table I is representative of this circuit for this type of oper-

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* Trade name of thermal-setting plastic manufactured by Ciba Co., N. Y., N. Y.

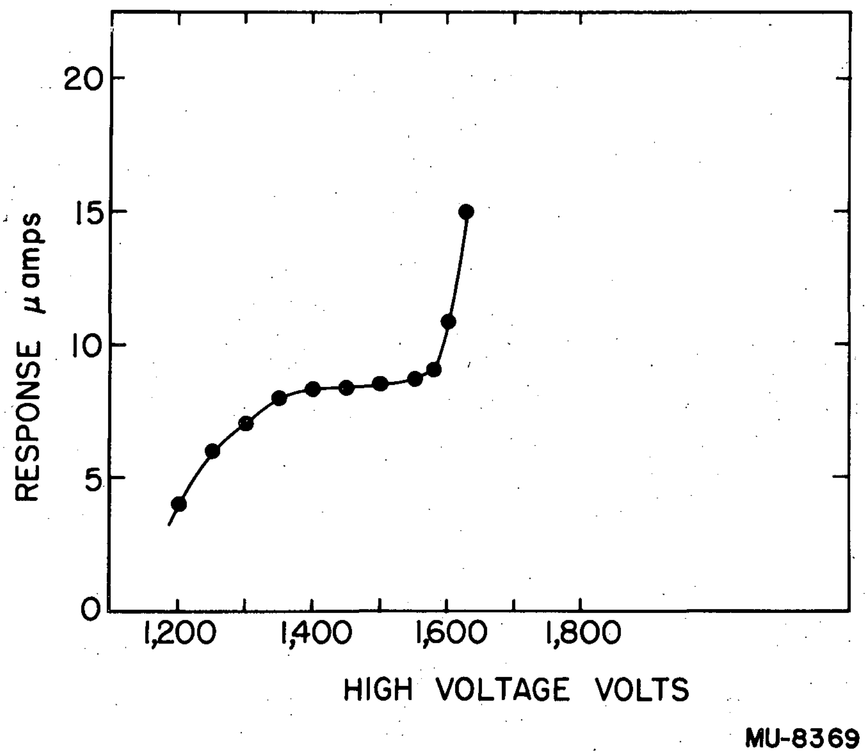

Fig. 4 BF_3 Counter Characteristic Curve

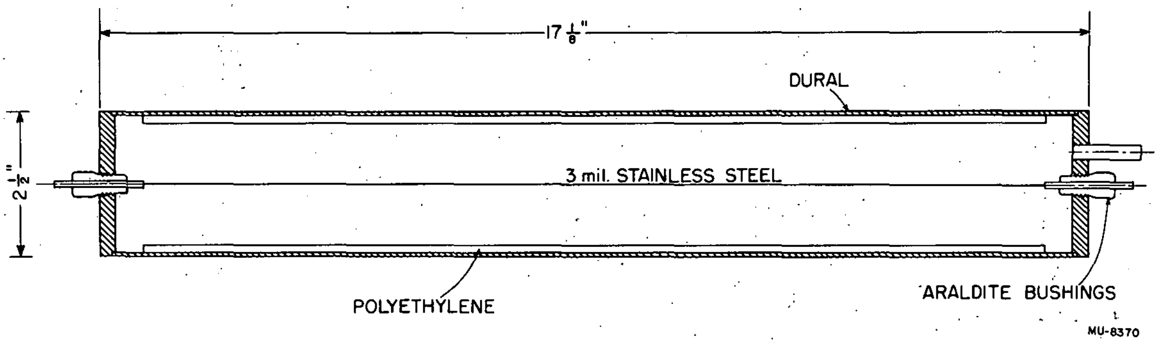

Fig. 5 Proton-Recoil Proportional Counter

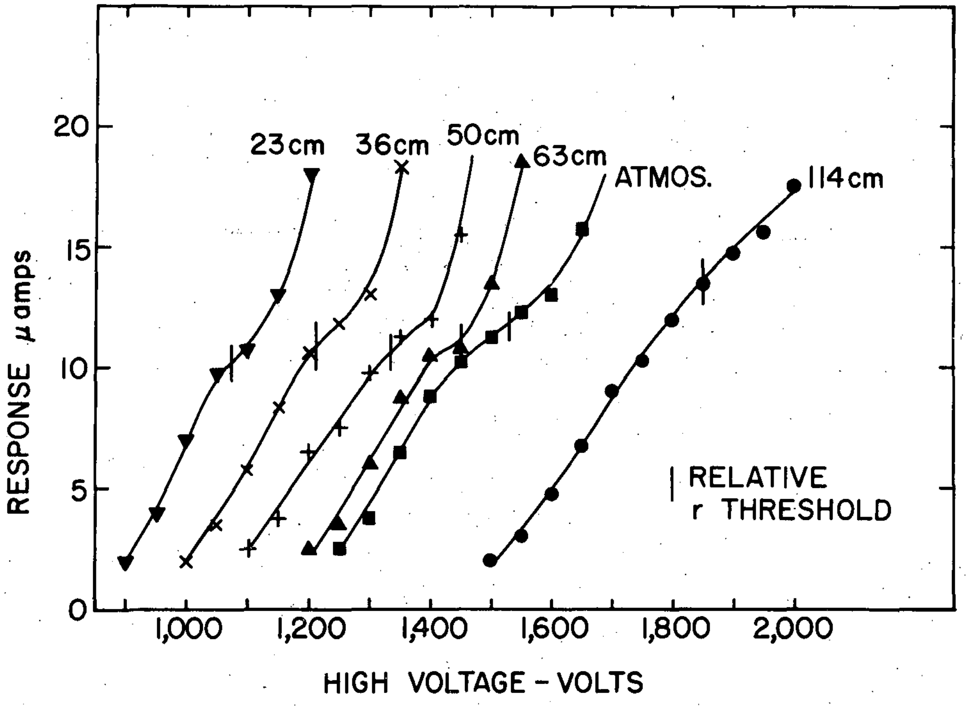

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Fig. 6 Voltage and Pressure Characteristics of the Proton-Recoil Counter

TABLE I

Typical Operating Characteristics of the Count-Rate Meter Circuit

Input Pulse 10 μsec Wide, 10 mu High

Unit	Voltage at Start	Voltage for 10% Change of Meter Reading
Amplifier Filament	1.5	1.2
Multivibrator Filament	1.5	0.9
Plate Voltage	67-1/2	57

ation. After consideration of the available types of high-voltage supplies, it was decided to use a vibrator type powered by ordinary flashlight 'D' cells. Table II is a list of the supplies investigated, giving comparative values of power consumption, weight, and battery life. Figure 7 is a detailed schematic of the count-rate meter circuit and the vibrator supply. Adequate shielding is provided by enclosing the hv supply and its batteries in an aluminum box.

Calibration

The instrument is calibrated by comparing it to a known source such as PoBe. Typically, when 100 mr/hr Ra gammas are biased out, the sensitivity is such that 15 Mev/cm^2 of PoBe neutrons will yield one count per second. The slow-neutron calibration is accomplished by using a hollow concrete cube, Ref. 4, to moderate fast-neutron sources. The plateau of the BF$_3$ counter allows a wide range of discriminator setting permitting the two counters to be adjusted to operate at the same voltage and amplifier gain.

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[4] H. W. Patterson, B. J. Moyer, B. W. Thompson, UCRL Report (to be published).

TABLE II

High-Voltage Supply Operational Data

Type	Current Drain	Battery Voltage	Power Required	Battery Voltage at Failure	Battery Type	Battery Life	Weight of Supply and Batteries
	ma	v	mw	v		hr	lb.
Vibrator UCRL	50	3	150	1.93	US100	88	1.73
	50	3	150	1.94	2 'D' cells	58	1.43
	50	3	150	1.92	4 'D' cells	162	1.93
Vibrator (Vict. 532)	95	3	285				1.37
Vibrator (Vict. 517)	60	4.5	270				2.03
Vibrator (Nuclear 2019)	36	3.0	108				1.70
Relaxation Osc. and Plate Batteries	50 3.2	1.5 135 } 500					1.63

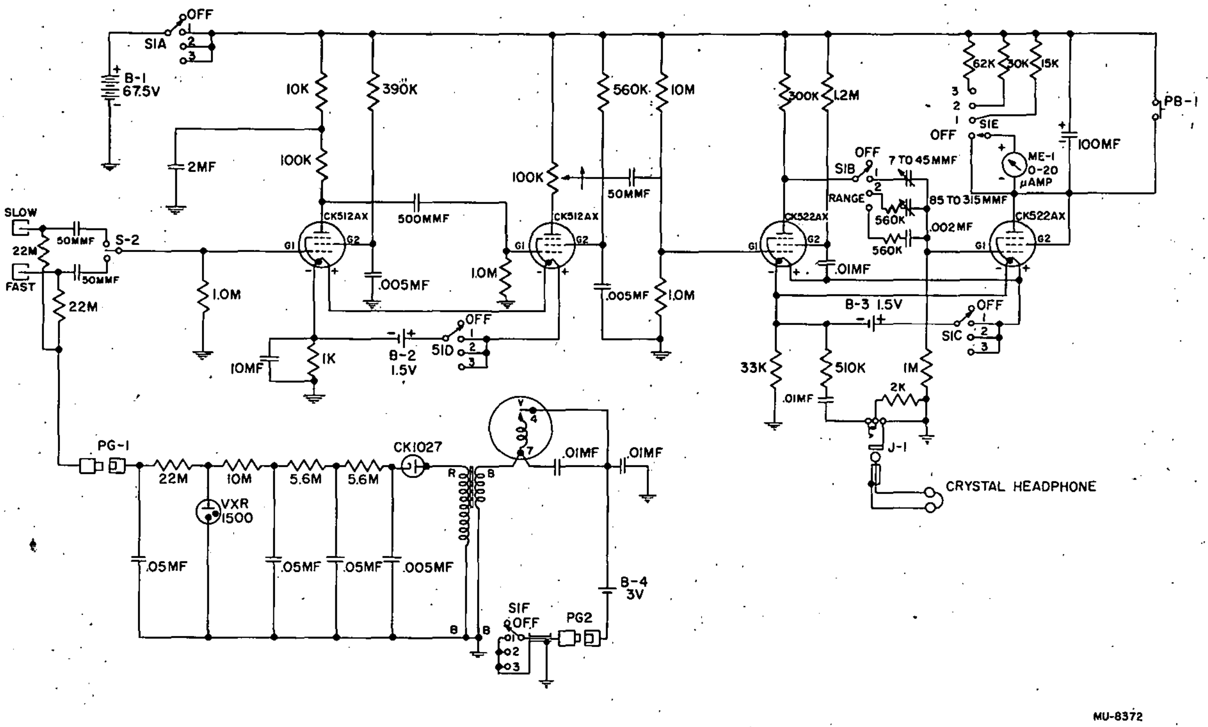

Fig. 7 Schematic

CONCLUSIONS

If the neutron spectrum to be measured is known well enough to approximate a mean energy, then one can with this instrument evaluate the radiation hazard due to fast neutrons. If the measurements are being made near neutron sources with extensive shielding, then the neutron spectrum is sufficiently peaked at thermal energies to allow use of the BF_3 counter to estimate the slow-neutron flux.

The instrument is compact and portable, weighing only ten pounds. Its principal features are the combination slow- and fast-neutron counter in one chassis with only a simple switch to choose the desired counter. Its high sensitivity, nondirectional characteristics, and the ability to bias against gammas make it a valuable tool in estimating the radiological hazard due to neutrons.

ACKNOWLEDGEMENTS

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