EFFECTIVENESS OF SAND-BORON-CARBON MIXTURES FOR RADIATION SHIELDING

by

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A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
MASTER OF SCIENCE

Major Subject: Engineering

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I. INTRODUCTION

The increased interest in possible uses for "package" and mobile nuclear power reactors adds impetus to the search for materials and combinations of materials that will provide relatively light-weight and compact radiation shielding. "Package" reactors that can be shipped great distances, erected and placed into operation in a short period of time will require shielding materials that are easily transported and can be quickly put to use. These requirements suggest the use of light-weight neutron moderators and absorbers in conjunction with a gamma shield of dense material. Light materials such as sand, boron and carbon are relatively ineffective for gamma shielding and a layer of dense material is required to attenuate the gamma energies from a reactor if the total thickness of the shield is to be kept to a minimum.

Shielding from neutrons and gamma rays is necessary in reactor operations, in handling of fission products and radioisotopes and in many research operations. The inverse square law is applicable to situations where the source of radiation is a point source and the surrounding medium is air or vacuum. Shielding material can be saved by merely limiting the distance of closest approach to the source.

The effectiveness of a radiation shield is determined by the capacity of the shield to reduce the intensity of the neutron and gamma flux. Murray (3) refers to the possible employment of partial or "shadow" shielding for installations where the reactor operators can remain in a fixed location. In an airplane, for example, only the side of the reactor facing the crew needs to be heavily shielded for direct radiation. Some shielding from particles scattered by the aircraft structure and by the air would also be needed.

The ability of a material to slow down neutrons is known as the "slowing down power." It is represented by the product $\xi \Sigma_s$, where ξ is the average logarithmic energy decrement per collision and Σ_s is the macroscopic cross section for scattering. The quantity Σ_s is equal to $N_o \rho \sigma_s / A$, where N_o is the Avogadro number, ρ is the density of the material, σ_s is its microscopic cross section for scattering and A is the atomic weight. The microscopic cross section is given in units of "barns" (1 barn equals 10^{-24} cm^2) and the macroscopic cross section is in units of cm^{-1}. For a material to be a good neutron shield it should have high "slowing down power" to slow down the fast neutrons and should have a high absorption cross section to absorb the neutrons as they are slowed down. The macroscopic cross section for absorption is represented by Σ_a. Values for the absorption and scattering cross sections are dependent upon and usually vary with the neutron energies.

The relative biological effectiveness of fast neutrons is several times higher than that of slow or thermal neutrons so the main problem in neutron shielding is to reduce the energy of fast neutrons without causing secondary reactions to take place. Water is a good material for neutron shielding because the hydrogen nuclei have high "slowing down power," but it is not practical for all neutron shielding applications.

The attenuation of gamma rays depends on the shielding material and on the energy of the incident rays. No single formula can be obtained to describe the absorption of gamma rays. The three mechanisms by which gamma rays are absorbed are the photoelectric effect, the Compton effect and the pair-production process.

The photoelectric effect is most important for gamma rays with energies below 0.5 Mev and for absorbers of high atomic weight. In this effect a photon transfers its total energy to an electron in an outer shell of the atom. The ionization produced by photoelectrons accounts largely for the ionization effect of low-energy photons.

The Compton effect is most important for absorbers of low atomic weight and is the predominant process even in heavy elements when the energy of the radiation is between

0.6 Mev and 3 Mev. In Compton scattering a photon transfers part of its energy to an electron, which may be bound or free. The photon is degraded in energy and is deflected from its original path.

Pair production cannot occur when the energy of the gamma ray is less than 1.02 Mev. It takes place in the field of a nucleus which must have some recoil energy and momentum in order that energy and momentum be conserved in the system. In this process it has been postulated that an electron is raised from a negative-energy to a positive-energy state and is observed not only through the appearance of an ordinary electron, but also through the simultaneous appearance of a "hole" in the "sea" of negative electrons. This hole would appear to be a positive electron or positron. Thus, a pair of particles is created. This process is important for high gamma ray energies and for heavy elements.

One approach to the problem of shielding a source of neutrons and gamma rays is to use a structural form of dense material to attenuate the gamma rays and to fill the form with a mixture of light materials to attenuate and absorb the neutrons.

II. REVIEW OF LITERATURE

Rockwell (5), in his survey, discusses the relative advantages and disadvantages of various cheap shielding materials. He mentions the use of silica gel in containers and the possible fixing of water in silica gel, pores of cement, and porous metals. Concretes of many compositions and varieties have been used extensively for radiation shielding. Heavy aggregates involve special concrete handling problems and require great care in casting to prevent voids and cracks which would cause radiation leakage from the shield. Reinig (4) and Harris tell of the voids and leakage found in the biological shield of the Brookhaven reactor. Some of the voids were found at the periphery of experimental hole plugs, under pneumatic tube sleeves and under angle iron braces. A mixture of moderator and absorber used to fill voids that are readily accessible is borated paraffin. Colemanite, a sand containing boron, is the fine aggregate used in the special concrete shield of the Raleigh reactor.

Murray (3) states that whether a shield should be laminated or the constituents should be uniformly mixed is a matter to be determined only by experiment. Every combination of materials and geometry behaves differently and, as yet, simple engineering formulas for making predictions are apparently not available.

Henson (2) and Field (1) studied the effects of increased homogeneity upon shielding effectiveness by varying the number of laminations of shielding materials and the concentration of different shielding solutions. Henson's results indicated an increase in the effectiveness of bare laminated shields, but no increase in effectiveness was evident when the shield was sheathed with cadmium and paraffin. Field used the same shielding tank with cadmium and paraffin sheath that was used here. His results showed a general increase in shielding effectiveness as the number of laminations was increased.

III. INVESTIGATION

Sand-boron-carbon mixtures were studied here to determine their effectiveness as neutron moderators and absorbers for use in a radiation shield. Dry sand possesses some advantages as a shielding material in locations subject to thermal changes and vibration. Instead of developing large cracks and voids as concrete would under such conditions, dry sand tends to fill the major cracks and voids. Clean, high-silica sand has a high percentage of oxygen and is a good neutron moderator. Carbon is a commonly-used neutron moderator and boron is a good absorber of thermal and low-energy neutrons.

The study of the shielding effectiveness of these mixtures consists of two main parts. The first is the shielding effectiveness of various geometrical arrangements of the materials, including uniform mixtures. The second is the effect of changes in concentrations of the materials upon their effectiveness for radiation shielding.

IV. MATERIALS AND APPARATUS

A. Radiation Source

A radium-beryllium source containing 94.7 mg of radium provided the neutrons and gamma rays used in this study. The radium and beryllium were mixed together and sealed in a Monel metal right circular cylinder approximately 0.5 in. in diameter and 0.75 in. in length. Radium-beryllium sources have a continuous neutron spectrum extending from very low energies up to about 13 Mev, with the maximum intensity around 5 Mev. The neutron flux from this source is approximately 50 neutrons per square centimeter per second at a distance of 16 in. from the center of the source. A hard gamma flux with a maximum energy of 5 Mev is also associated with this source.

The source was used in its original shipping container which consisted of a seven-inch diameter lead sphere encased in paraffin and a wooden box. The cover section of wood and paraffin and the lead plug in the sphere were removed. With the shipping box placed on its side, the source provided a slightly collimated horizontal beam of gamma rays and fast neutrons and practically a plane source of slow neutrons.

B. Shielding Materials

The shielding materials used here were contained in a 9 in. by 11 in. by 16 in. 20-gage sheet iron tank and a 1¼ in. by 9 in. by 11 in. sheet iron hollow box-type insert which were placed squarely in front of and flush with the opening in the lead sphere containing the source.

The shielding materials were Illinois commercial grade white sand, powdered graphite and powdered boric acid. All materials used were sifted through a 20-mesh Tyler Standard sieve. Small particles will effect more uniform mixing and will retard the tendency for sifting when the mixtures are subjected to movements and vibrations.

Illinois (Ottawa) sand is a high silica sand and is well suited for mixing with the powdered materials used here. The moisture content of the sand was determined by oven-drying of four 4-gram samples. The content was less than 0.1 per cent, so water should have played an insignificant role in the moderation of fast neutrons by the sand.

The graphite was used as additional moderator to compare its shielding effectiveness with that of sand.

Boric acid is an excellent attenuator of neutrons since boron has a high cross section for absorption of slow neutrons. In addition, boric acid has the ability to slow down fast neutrons so that they, too, are absorbed.

C. Detectors and Apparatus

The general experimental set-up is shown in the sketch in Figure 1. The detectors and accessory apparatus are shown in Figure 2 and a block diagram of the neutron counting circuit is shown in Figure 3.

The fast and slow neutron counts were made with a General Electric boron-10 lined tube. Its approximate active counting volume was 1¼ in. in diameter and 8 in. in length. A neutron detector shield of cadmium and paraffin shown in Figure 1 increased the probability that the neutrons counted had traversed the shielding material in the tank and were not scattered into the detector from the walls or fixtures in the room. The proportional counting tube was connected directly to the amplifying circuit of a Nuclear Instrument and Chemical Corporation model 162 scaler. The scaler is equipped with a gain control and attenuator switch to permit measurement of a wide range of activities. The operating characteristics of the neutron counting circuit are indicated by the curves in Figures 4 and 5. The operating voltage was fixed at 635 volts with the gain set at 60 and the attenuator switch set on X1. The input voltage to the scaler was maintained at 112 volts by a "Stabiline" type IE5101 voltage regulator.

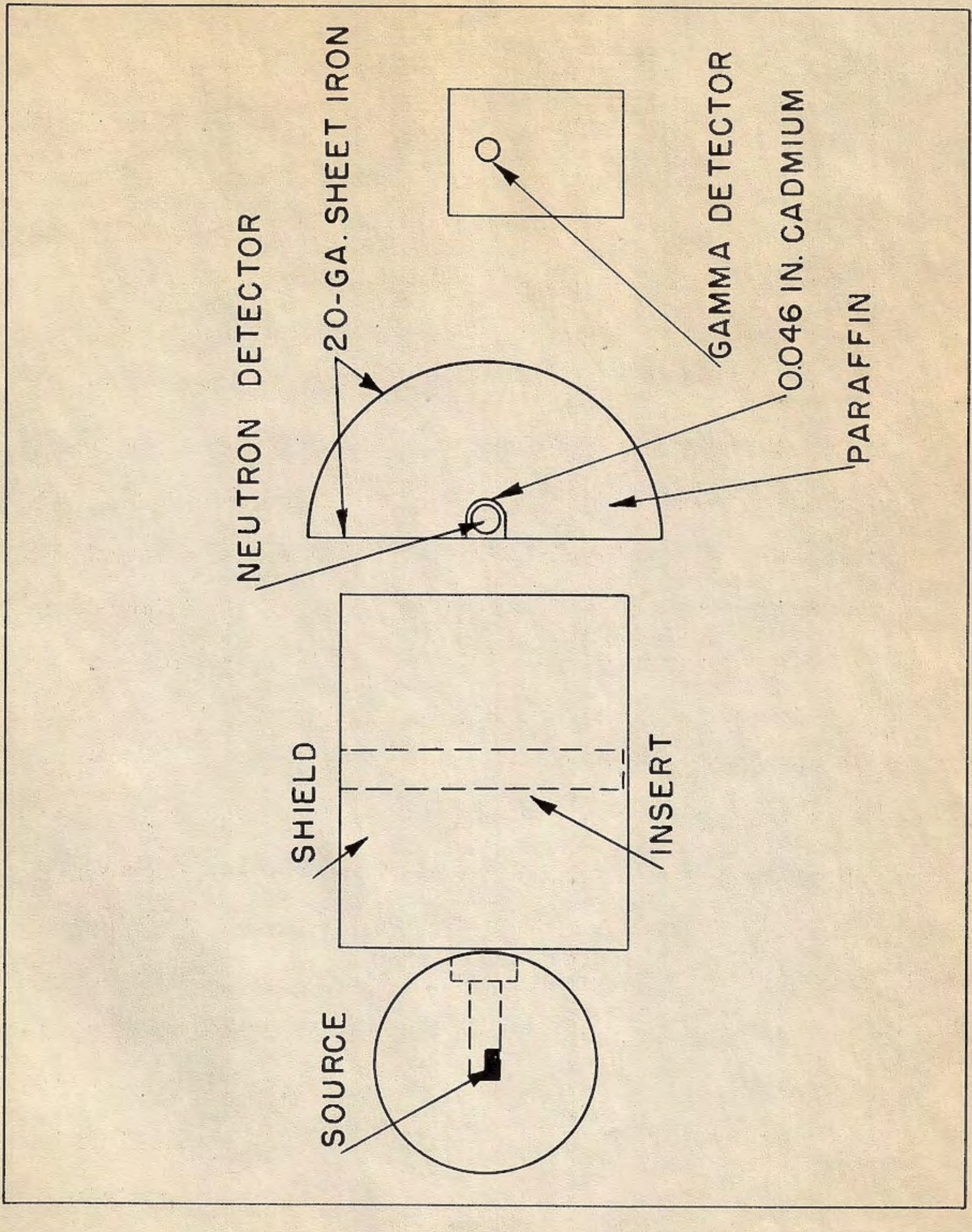


Figure 1. General experimental set-up.

Figure 2. Apparatus.

A. Voltage Regulator

B. Scaler

C. Register

D. Neutron Detector Shield

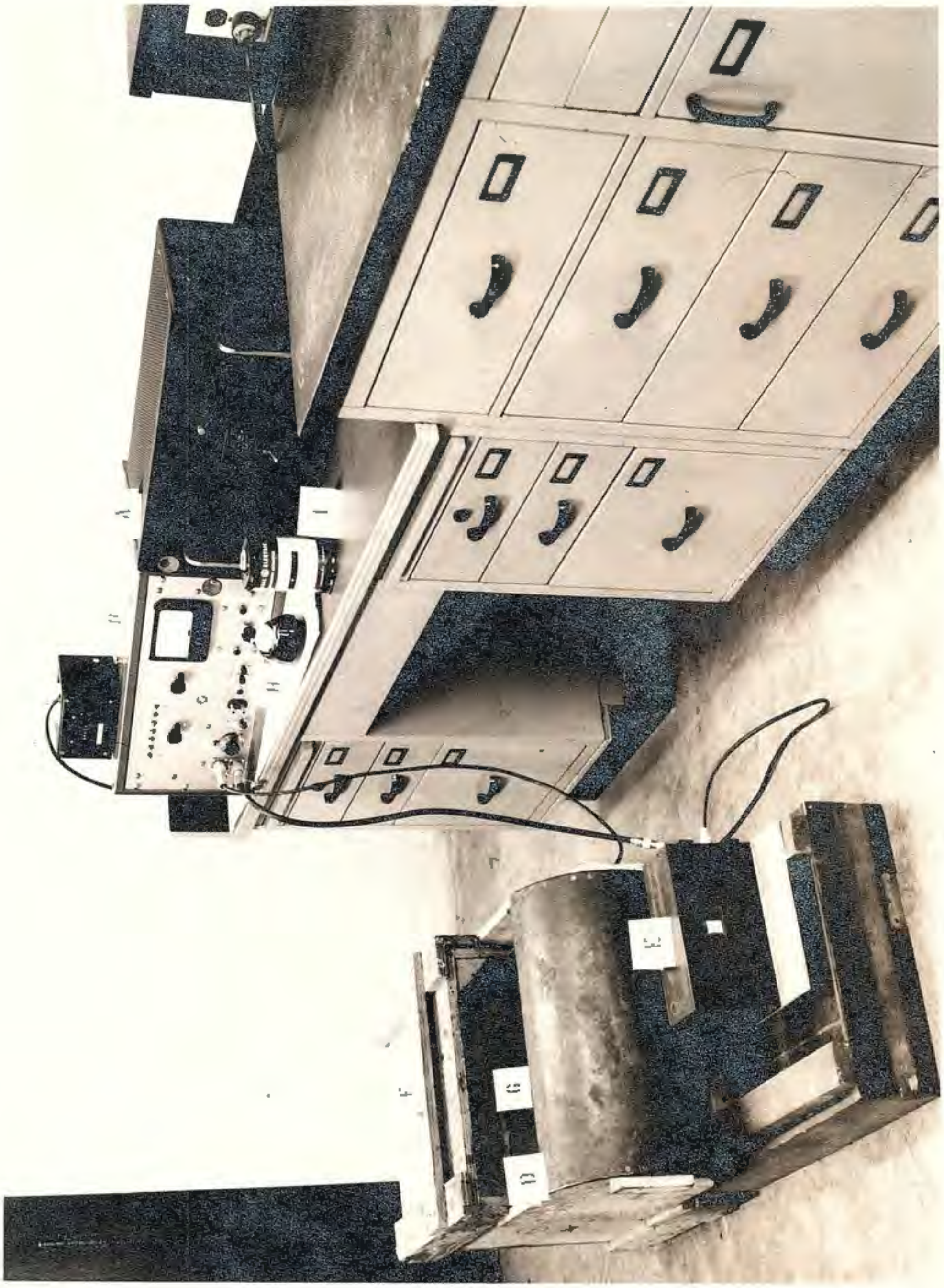
E. Geiger-Müller Tube Box

F. Source

G. Shielding Tank

H. Stop Watch

I. Radiation Monitor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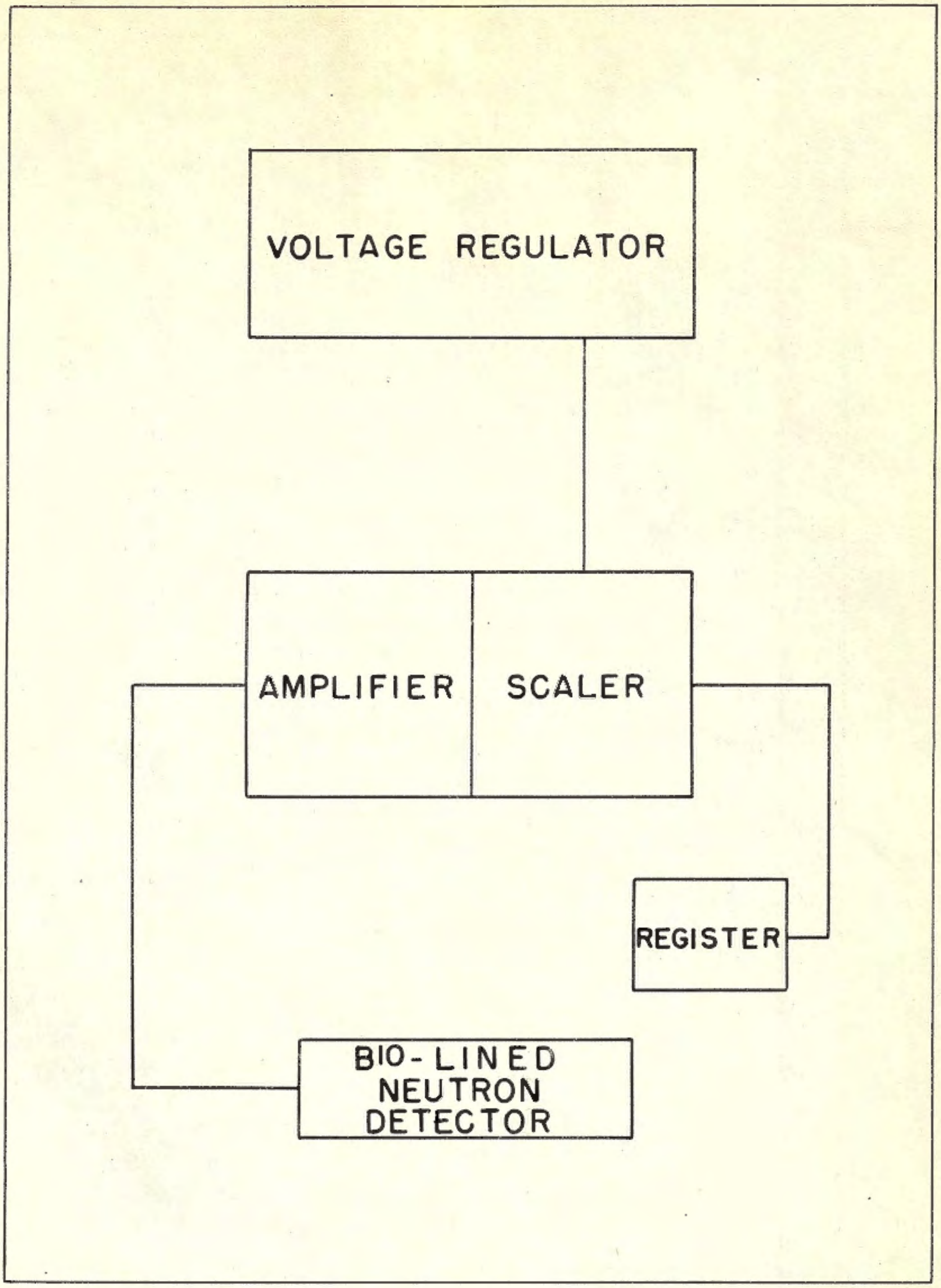

Figure 3. Neutron counting circuit -- block diagram.

The scaler was used to count gamma intensities with a Geiger-Müller tube by changing a lead connection on the back of the scaler chassis. The Geiger-Müller tube was mounted in a standard shelf type counter box which was in turn positioned on a small platform behind the neutron detector shield.

The neutron and gamma detectors were placed in the same position for each set of measurements by lining them up with guide marks on the detector shield and the shield supporting structure.

A General Electric Radiation Monitor, model 4SN11A3, and two Cambridge pocket chambers were used to monitor the radiation received during given periods while working near the source. The largest dose received during any period as indicated by the chambers worn in the shirt and trouser pockets was 15 milliroentgens during a 5-hour period. The hands probably received a somewhat higher dose from positioning the shield in front of the source. The Radiation Monitor was also used to estimate the gamma count when the shielding tank was empty because the count was too high to be registered by the scaler.

A sheet iron insert with outside dimensions of 1½ in. by 9 in. by 16 in. was placed in the tank to keep the shielding materials separated. The insert made it possible to place layers of different materials at 5 equally-spaced positions throughout the shield. Position 1 was nearest the source and position 5 was nearest the detector.

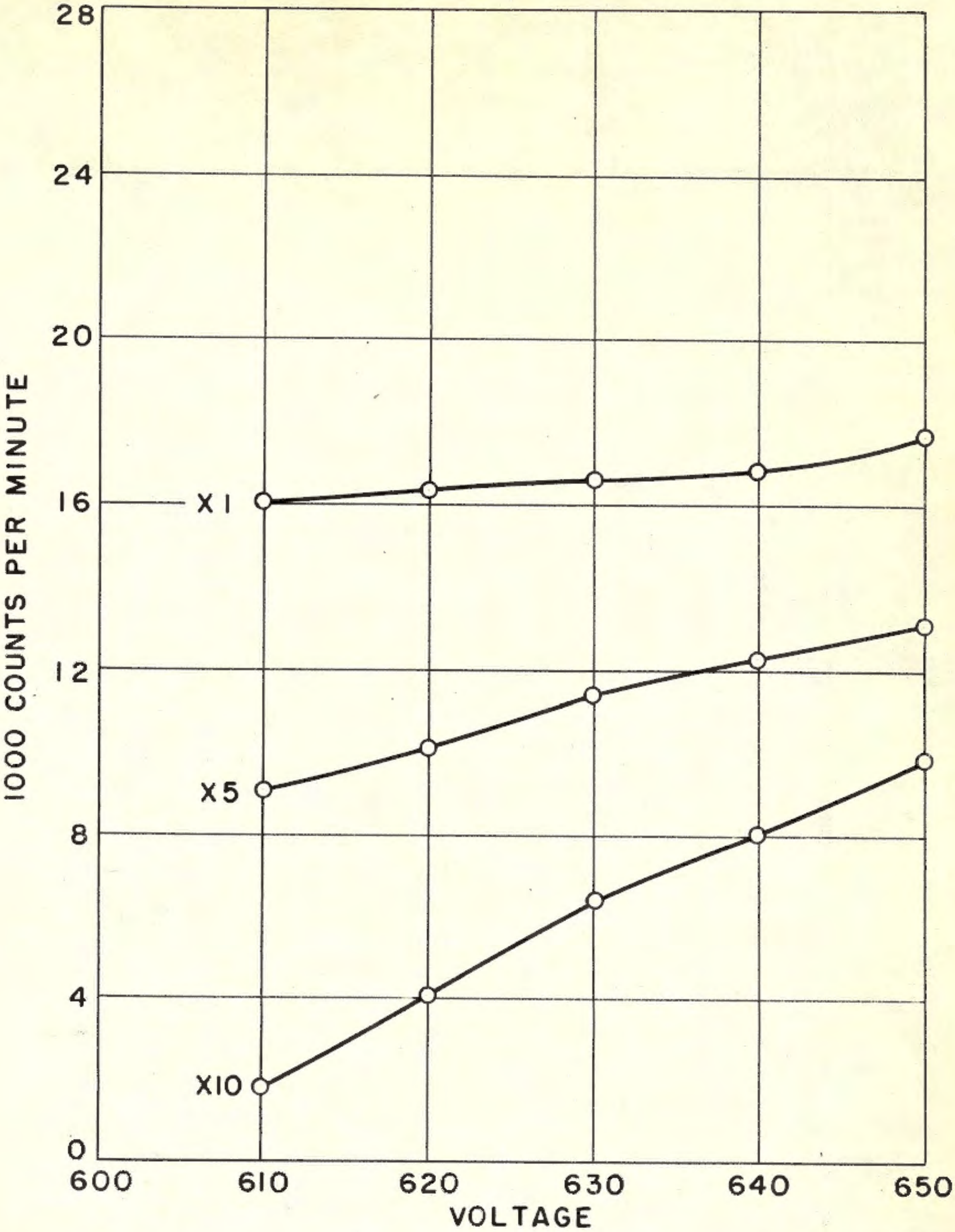

Figure 4. Operating curves for B^{10} lined neutron counter with attenuator as indicated and gain on 60.

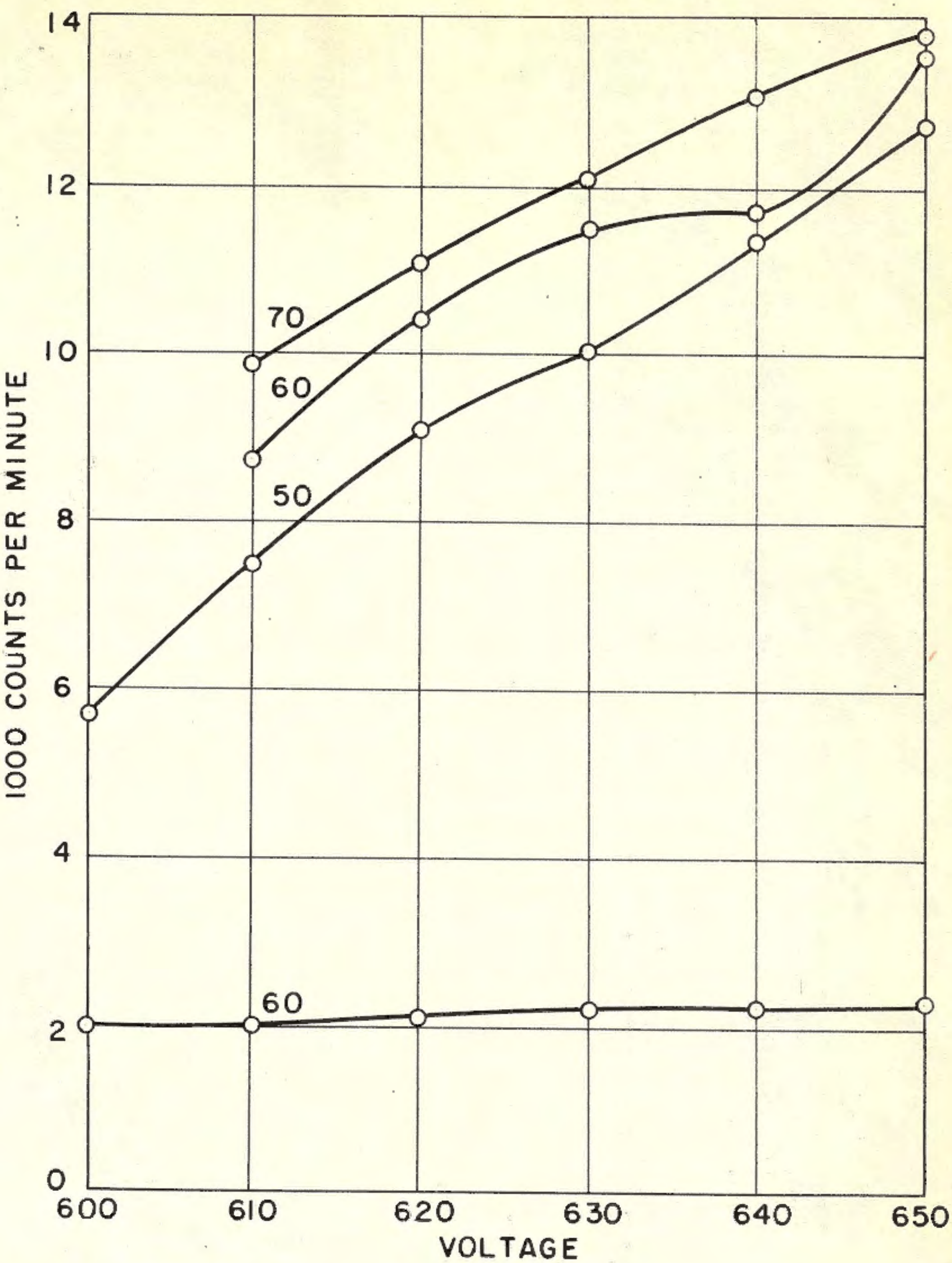

Figure 5. Operating curves for B^{10} lined neutron counter with gain as indicated and attenuator on X1.

V. PROCEDURE

A. General Considerations

Three experimental arrangements were used to determine the relative intensity of fast and slow neutrons. These arrangements are shown in Figure 6. The difference between counts for arrangements A and B was the slow neutron count used here. Slow neutrons were defined to have energies of 0.25 ev or less. The boron-10 lined tube counted neutrons of all energies to a certain extent so the 0.01 in. of cadmium was used as shown in arrangement B to block at least 80 per cent of the incident slow neutrons. A layer of paraffin was inserted between the cadmium and detector as shown in arrangement C to obtain the fast neutron counts. The paraffin slowed down part of the fast neutrons which could not otherwise be counted by the detector to the energy range where they could be counted. Thus the fast neutron count was increased by insertion of the paraffin and the relative effect of any stray neutrons scattered into the detector from outside the shield was reduced. An investigation was made to determine whether 1½ in. or 3 in. of paraffin should be used to increase the fast neutron count. It was desirable to have the detector as close to the source as possible to improve the counting geometry, but a high

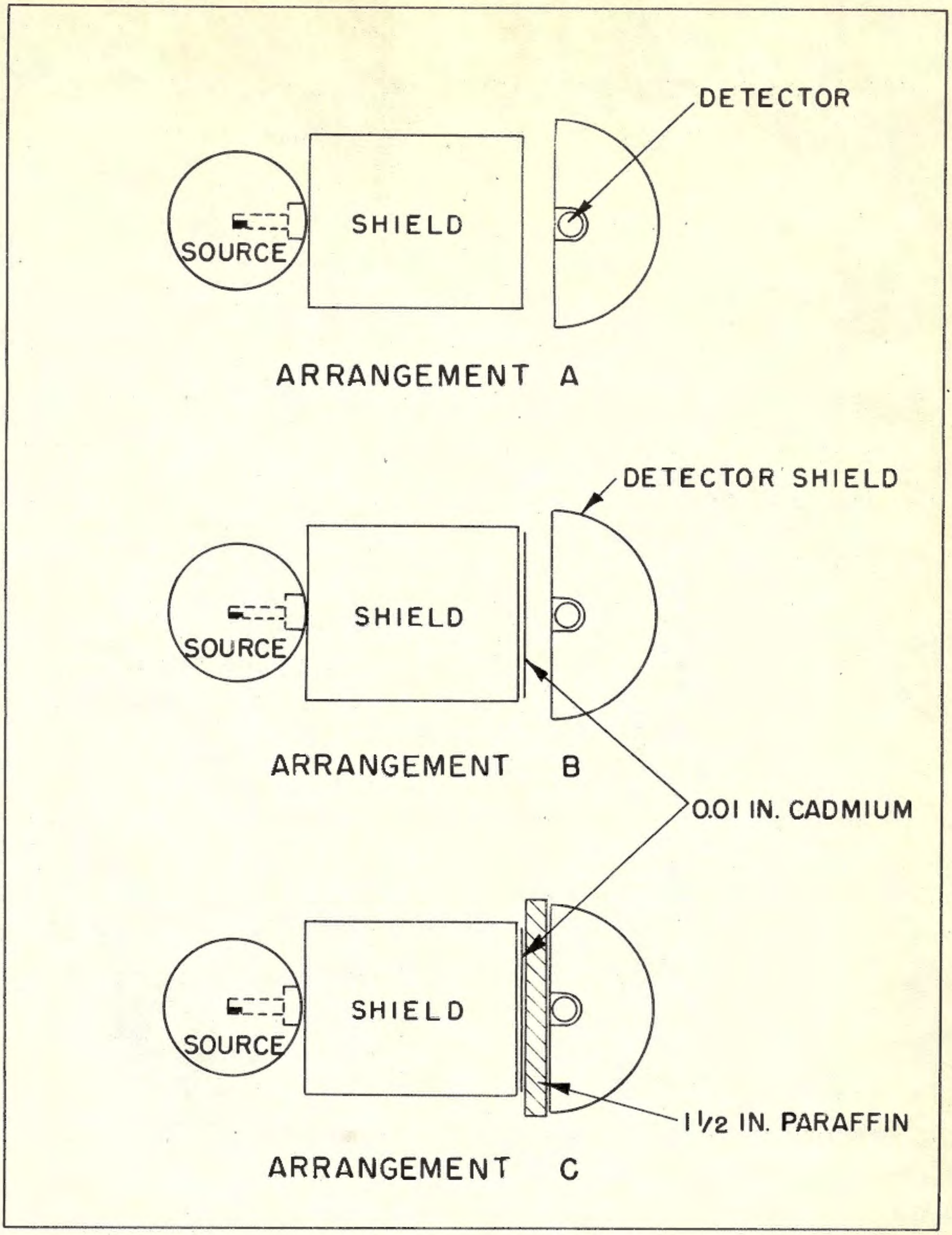

Figure 6. Experimental arrangements for neutron counting.

initial count was desired also to give better counting statistics. The shield consisted of the insert at position 1 (nearest the source) with 5.75 lb of graphite and the rest of the tank filled with sand.

The top, bottom and two ends of the shielding tank were sheathed in 0.042-in. thick cadmium sheets and 1½ in. of paraffin to reduce the effect of stray neutrons which might otherwise reach the detector without traversing the entire thickness of the shield. Counts were taken for various sand, boric acid and graphite arrangements with and without the cadmium and paraffin sheath to determine the effect of the sheath on the neutron counts.

Gamma counts were taken with the Geiger-Müller tube shielded by the materials as shown in arrangement C of Figure 6. With shielding material in the tank the gamma count was low enough to be counted by the scaler. The Radiation Monitor was placed on the platform behind the neutron detector shield to get comparative radiation values. In this manner an approximate gamma count was estimated for the empty shielding tank.

The materials used in the mixtures were weighed to the nearest 0.1 lb on a 200-lb capacity, general-purpose scale. The volume of materials in the tank was kept constant, but the weight varied between 88 lb and 97 lb as the concentrations of the materials varied. The materials were mixed by hand in a standard laundry tub. They were mixed in small quantities and then put together in the tub and mixed again. Uniformity of the mixtures was determined by sight. The mixtures were tamped only by shaking to level the top surface of the shield. The amount of shaking required to level the top surface of different mixtures was difficult to evaluate.

B. Effects of Geometrical Arrangement

Layers of sand, boric acid and graphite were used to determine what effect the positioning of the different shielding materials within the shield had upon the neutron counts. The effect of the insert upon the counts was determined by filling the insert with sand and moving it through the 5 equally-spaced positions in the tank. The insert was then filled with boric acid powder and again with graphite powder and was placed at the 5 positions throughout the shield.

The same amount of boric acid powder used to fill the insert was used to determine the effect of mixing the materials uniformly. The boric acid was mixed with the sand and the mixture was placed in the tank and insert. The insert was placed at position 5. The insert was then removed, 3 lb of sand were added to replace the volume lost by the removal of the insert and the materials were again mixed.

C. Effects of Concentration of Materials

Mixtures of sand and powdered boric acid were prepared and counted for boric acid concentrations of 1, 2.25, 4, 5.66, 8, 10 and 19.6 per cent by weight.

Sand-boric acid-graphite mixtures consisted of varying concentrations of graphite and sand. The boric acid concentration was maintained at 1.0 per cent. The different graphite concentrations used were 5.37, 13.2 and 20 per cent.

The sheet iron insert was removed from the tank when these various mixtures were used.

D. Comparisons

To determine whether the hydrogen in the boric acid was scattering the slow neutrons or whether the boron was absorbing them approximately equal weights of hydrogen contained in boric acid and distilled water were compared. A mixture of 2.45 lb of water and 10.2 lb of sand was placed in the insert at position 5. The tank contained 82.2 lb of sand.

The shielding tank was filled with 56.3 lb of distilled water to obtain neutron counts for comparison of water with the sand, boric acid and graphite mixtures.

VI. RESULTS

A. General Considerations

The individual counting rates are equal to $R = (\text{Counts} \pm \sqrt{\text{Counts}}) / \text{Time in Minutes}$. The counting rates for slow neutrons are represented by $R_S = R_A - R_B \pm \sqrt{\sigma_A^2 + \sigma_B^2}$. R_A and R_B are the counting rates for arrangements A and B, respectively, and σ_A and σ_B are the deviations in the rates.

The results of the investigation to determine the thickness of paraffin for increasing the fast neutron counts are shown in Tables 1 and 2.

Table 1

Comparison of Paraffin Thicknesses

Arrangement	Inches of Paraffin	Counting Time (Minutes)	Counts	Counting Rate
A	1.5	10	33983	3398 ± 18
A	3.0	10	30393	3039 ± 17
B	1.5	10	6529	653 ± 8
B	3.0	10	7141	714 ± 8
C	1.5	10	23274	2327 ± 15
C	3.0	10	14487	1449 ± 12
Gamma	1.5	2	55935	27968 ± 119
Gamma	3.0	2	47068	23534 ± 108

Table 2

Comparison of Paraffin Thicknesses

Inches of Paraffin	Slow Neutron Counting Rate	Fast Neutron Counting Rate	Gamma Counting Rate
1.5	2745 ± 20	2327 ± 15	27968 ± 119
3.0	2325 ± 19	1449 ± 12	23534 ± 108

The counting rates for sand in both tank and insert with the cadmium and paraffin sheath are tabulated in Tables 3 and 4 and are plotted in Figure 7.

The counting rates for sand in both tank and insert without the sheath are tabulated in Tables 5 and 6 and are plotted in Figure 7.

The counting rates for the graphite (5.1 lb) and sand (84.5 lb) arrangements with the cadmium and paraffin sheath are tabulated in Tables 7 and 8 and are plotted in Figure 8.

The graphite and sand counting rates without the sheath are shown in Tables 9 and 10 and Figure 8.

The counting rates for the boric acid (5.25 lb) and sand (84.5 lb) arrangements with the sheath are shown in Tables 11 and 12 and are plotted in Figure 9.

The counting rates for the boric acid and sand arrangements without the sheath are shown in Tables 13 and 14 and are plotted in Figure 9.

Table 3

Sand in Tank and Insert (With Sheath)

Arrange-ment	Position of Insert	Counting Time (Minutes)	Counts	Counting Rate
A	1	10	22228	2223 ± 15
A	2	10	22366	2237 ± 15
A	3	5	11062	2212 ± 21
A	4	10	21852	2185 ± 15
A	5	10	21865	2187 ± 15
B	1	10	8000	800 ± 9
B	2	10	8296	830 ± 9
B	3	10	8282	828 ± 9
B	4	10	7868	787 ± 9
B	5	10	7793	779 ± 9
C	1	5	12586	2517 ± 22
C	2	5	12680	2536 ± 23
C	3	5	12642	2528 ± 22
C	4	5	12661	2532 ± 22
C	5	5	12453	2491 ± 22
Gamma	3	1	22450	22450 ± 150
Gamma	5	1	22648	22648 ± 150

Table 4

Sand in Tank and Insert (With Sheath)

Position of Insert	Slow Neutron Counting Rate	Fast Neutron Counting Rate	Gamma Counting Rate
1	1423 ± 18	2517 ± 22	
2	1407 ± 18	2536 ± 23	
3	1384 ± 23	2528 ± 22	22450 ± 150
4	1398 ± 18	2532 ± 22	
5	1408 ± 18	2491 ± 22	22648 ± 150

Table 5

Sand in Tank and Insert (Without Sheath)

Arrangement	Position of Insert	Counting Time (Minutes)	Counts	Counting Rate
A	1	5	16778	3356 ± 26
A	2	5	16628	3326 ± 26
A	3	5	16424	3285 ± 26
A	4	5	16163	3233 ± 25
A	5	5	15953	3191 ± 25
B	1	10	6390	639 ± 8
B	2	10	6380	638 ± 8
B	3	10	6452	645 ± 8
B	4	10	6334	633 ± 8
B	5	10	6319	632 ± 8
C	1	5	10800	2160 ± 21
C	2	5	10937	2187 ± 21
C	3	5	11215	2243 ± 21
C	4	5	10904	2181 ± 21
C	5	5	10752	2150 ± 21
Gamma	1	1	22550	22550 ± 150
Gamma	2	1	22528	22528 ± 150
Gamma	3	1	22244	22244 ± 149
Gamma	4	1	22370	22370 ± 149
Gamma	5	1	22280	22280 ± 149

Table 6

Sand in Tank and Insert (Without Sheath)

Position of Insert	Slow Neutron Counting Rate	Fast Neutron Counting Rate	Gamma Counting Rate
1	2717 ± 27	2160 ± 21	22550 ± 150
2	2688 ± 27	2187 ± 21	22528 ± 150
3	2640 ± 27	2243 ± 21	22244 ± 149
4	2600 ± 26	2181 ± 21	22370 ± 149
5	2559 ± 26	2150 ± 21	22280 ± 149

Table 7

Sand and Graphite (With Sheath)

Arrangement	Position of Insert	Counting Time (Minutes)	Counts	Counting Rate
A	1	10	21914	2191 ± 15
A	2	10	22132	2213 ± 15
A	3	10	21858	2186 ± 15
A	4	10	22051	2205 ± 15
A	5	10	21697	2170 ± 15
B	1	10	8014	801 ± 9
B	2	10	8086	809 ± 9
B	3	10	8002	800 ± 9
B	4	10	8194	819 ± 9
B	5	10	7847	785 ± 9
C	1	5	12753	2551 ± 22
C	2	5	12867	2573 ± 22
C	3	5	12608	2522 ± 22
C	4	5	12460	2492 ± 22
C	5	5	12477	2495 ± 22
Gamma	3	1	26812	26812 ± 164

Table 8

Sand and Graphite (With Sheath)

Position of Insert	Slow Neutron Counting Rate	Fast Neutron Counting Rate	Gamma Counting Rate
1	1390 ± 18	2551 ± 22	
2	1404 ± 18	2573 ± 22	
3	1386 ± 18	2522 ± 22	26812 ± 164
4	1386 ± 18	2492 ± 22	
5	1385 ± 18	2495 ± 22	

Table 9

Sand and Graphite (Without Sheath)

Arrangement	Position of Insert	Counting Time (Minutes)	Counts	Counting Rate
A	1	5	16485	3297 ± 26
A	2	5	16206	3241 ± 25
A	3	5	16304	3261 ± 25
A	4	5	15948	3190 ± 25
A	5	5	15837	3167 ± 25
B	1	10	6240	624 ± 8
B	2	10	6482	648 ± 8
B	3	10	6249	625 ± 8
B	4	10	6222	622 ± 8
B	5	10	6313	631 ± 8
C	1	5	11328	2266 ± 21
C	2	5	11223	2245 ± 21
C	3	5	11405	2281 ± 21
C	4	5	11333	2267 ± 21
C	5	5	11043	2209 ± 21
Gamma	3	1	27094	27094 ± 164

Table 10

Sand and Graphite (Without Sheath)

Position of Insert	Slow Neutron Counting Rate	Fast Neutron Counting Rate	Gamma Counting Rate
1	2673 ± 27	2266 ± 21	
2	2593 ± 26	2245 ± 21	
3	2636 ± 26	2281 ± 21	27094 ± 164
4	2568 ± 26	2267 ± 21	
5	2536 ± 25	2209 ± 21	

Table 11

Sand and Boric Acid (With Sheath)

Arrangement	Position of Insert	Counting Time (Minutes)	Counts	Counting Rate
A	1	20	24730	1237 ± 8
A	2	30	33954	1132 ± 6
A	3	30	32704	1090 ± 6
A	4	30	27830	928 ± 6
A	5	30	18796	627 ± 5
B	1	20	13800	690 ± 6
B	2	30	19032	634 ± 5
B	3	30	18682	623 ± 5
B	4	30	16602	553 ± 4
B	5	30	14452	482 ± 4
C	1	10	22484	2248 ± 15
C	2	10	21598	2160 ± 15
C	3	10	20952	2095 ± 14
C	4	10	19714	1971 ± 14
C	5	10	18662	1866 ± 14
Gamma	3	1	27212	27212 ± 165

Table 12

Sand and Boric Acid (With Sheath)

Position of Insert	Slow Neutron Counting Rate	Fast Neutron Counting Rate	Gamma Counting Rate
1	547 ± 10	2248 ± 15	
2	498 ± 8	2160 ± 15	
3	467 ± 8	2095 ± 14	27212 ± 165
4	375 ± 7	1971 ± 14	
5	145 ± 6	1866 ± 14	

Table 13

Sand and Boric Acid (Without Sheath)

Arrangement	Position of Insert	Counting Time (Minutes)	Counts	Counting Rate
A	1	10	18084	1808 ± 13
A	2	15	25920	1728 ± 11
A	3	15	23778	1585 ± 10
A	4	15	17631	1176 ± 9
A	5	30	18186	606 ± 5
B	1	10	5546	555 ± 7
B	2	10	5358	536 ± 7
B	3	10	5182	518 ± 7
B	4	10	4892	489 ± 7
B	5	10	4126	413 ± 6
C	1	5	10361	2072 ± 20
C	2	5	10424	2085 ± 20
C	3	5	10268	2054 ± 20
C	4	5	10124	2025 ± 20
C	5	5	9367	1873 ± 19
Gamma	3	1	27238	27238 ± 165

Table 14

Sand and Boric Acid (Without Sheath)

Position of Insert	Slow Neutron Counting Rate	Fast Neutron Counting Rate	Gamma Counting Rate
1	1253 ± 15	2072 ± 20	
2	1192 ± 13	2085 ± 20	
3	1067 ± 12	2054 ± 20	27238 ± 165
4	687 ± 11	2025 ± 20	
5	193 ± 8	1873 ± 19	

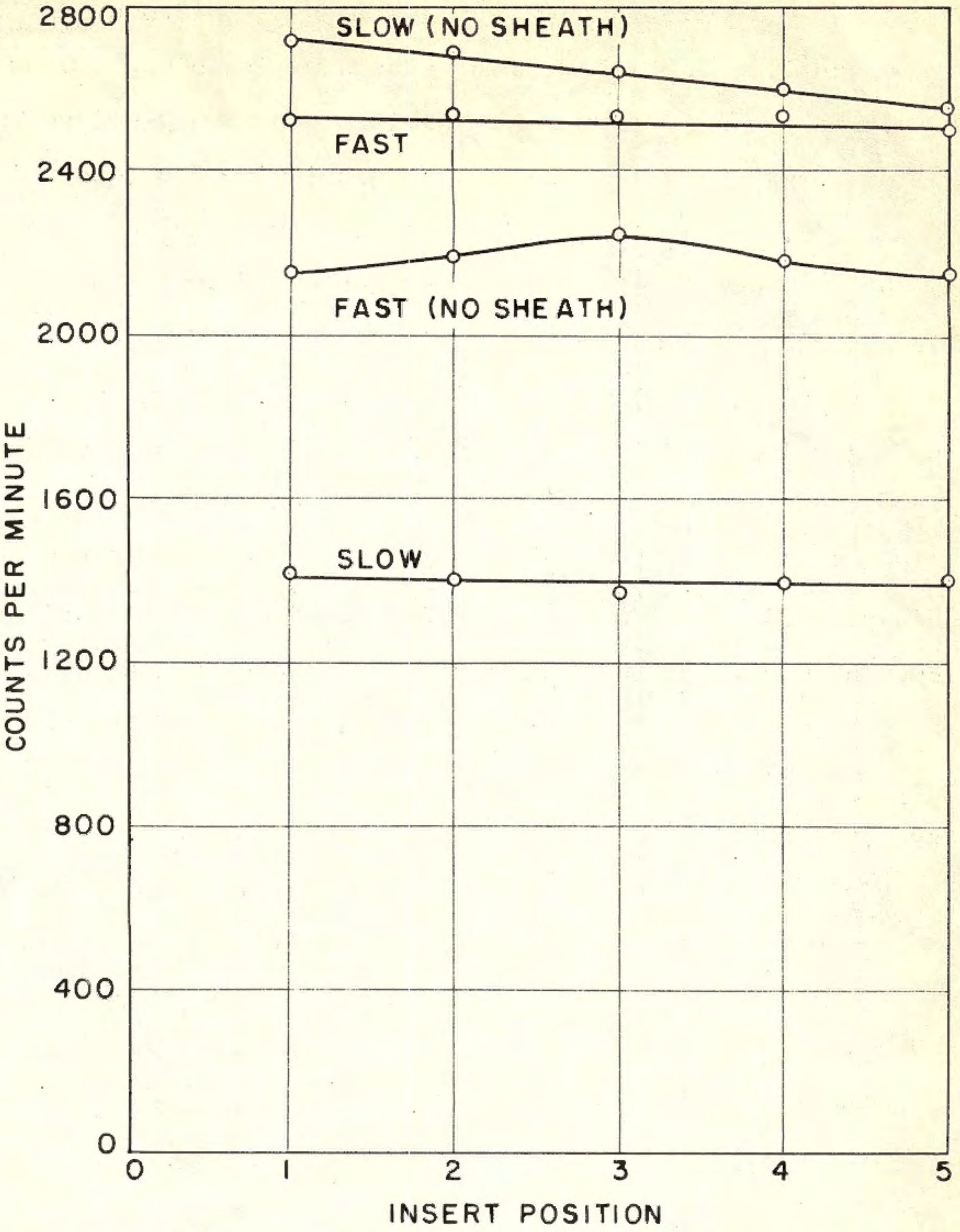

Figure 7. Neutron counts for sand in tank and sand in insert.

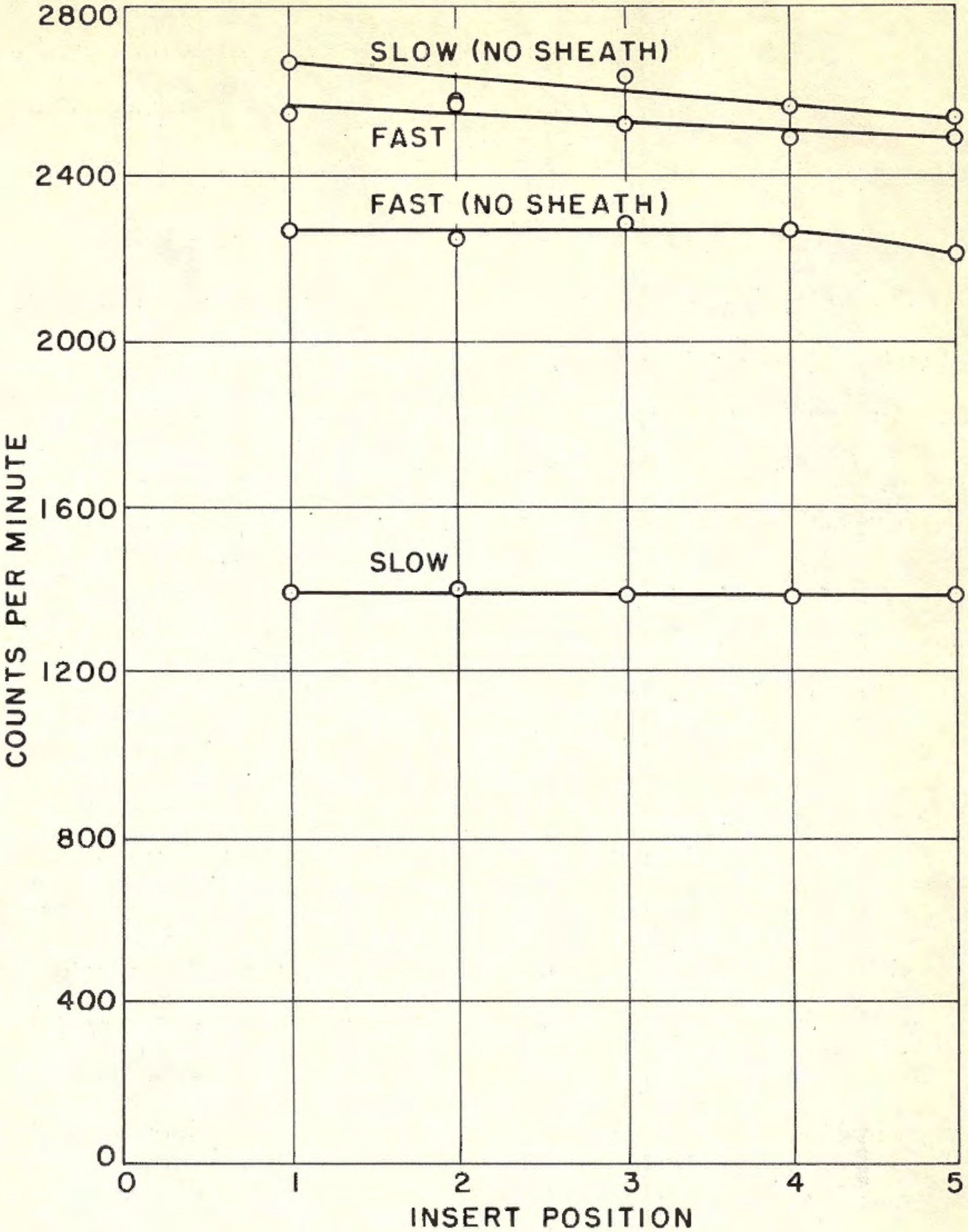

Figure 8. Neutron counts for sand in tank and graphite in insert.

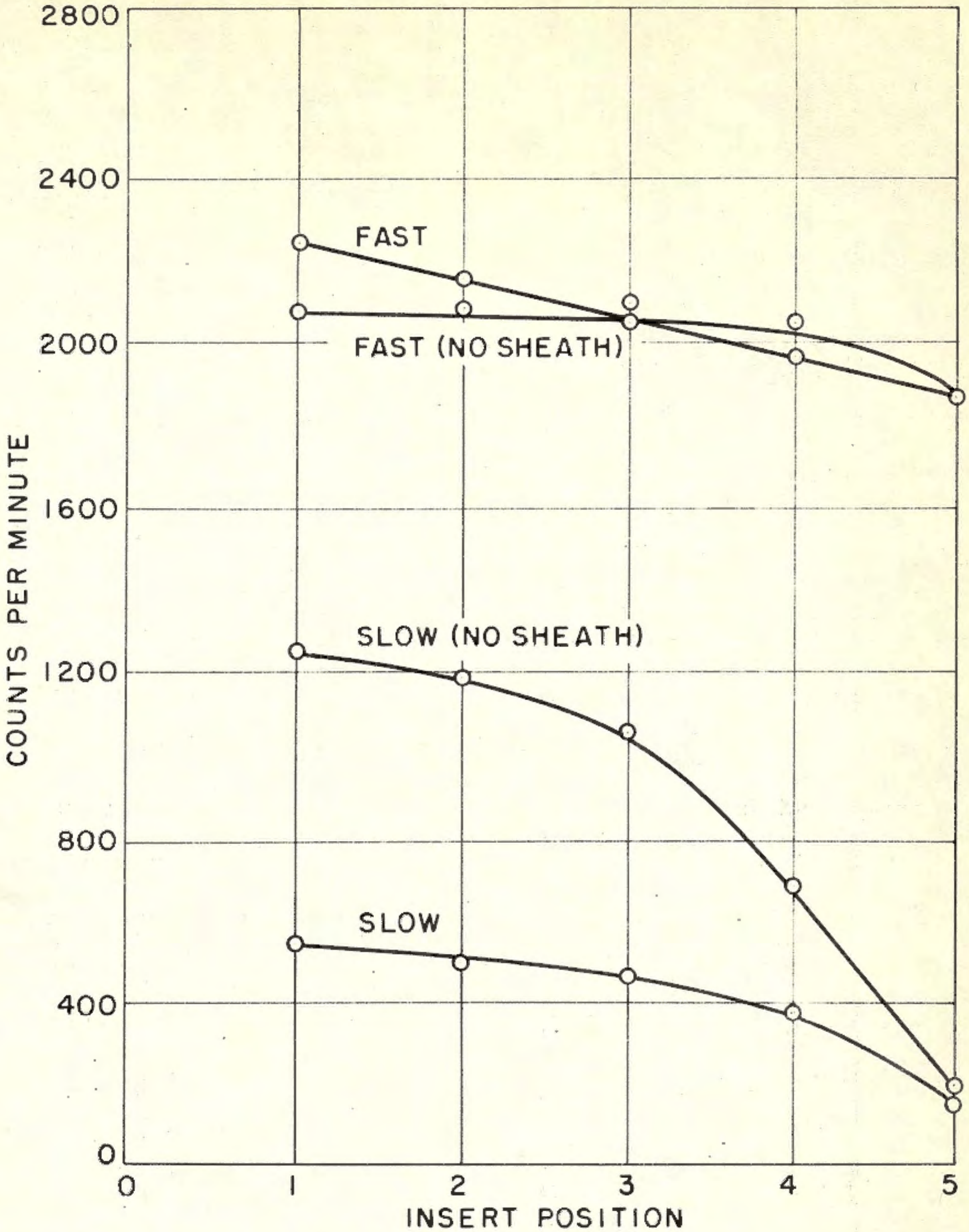

Figure 9. Neutron counts for sand in tank and boric acid in insert.

The comparative radiation values for gamma rays passing through the shielding tank when it was empty and when it was filled with sand are shown in Table 15. The conversion factor used to estimate the gamma count for the empty tank was 2980 counts per minute equalled 1 milliroentgen per hour.

Table 15

Comparative Gamma Counts

Counter	Shielding Material	Counting Time (Minutes)	Counts	Counting Rate
G-M Tube	Sand	3	76456	25485 ± 92
Rad. Monitor	Sand	35	5 mr	8.57 mr/hr
Rad. Monitor	Empty Tank	20	20 mr	60 mr/hr
(Estimated)	Empty Tank			178800

B. Effects of Geometrical Arrangement

The effects of changing the position of a layer of graphite in a sand-filled tank are shown in Tables 7, 8, 9 and 10 and in Figure 8. The weight of the graphite was 5.1 lb and the weight of the sand was 84.5 lb.

The effects of changing the position of a layer of boric acid powder in a tank of sand are shown in Tables 11, 12, 13 and 14 and the neutron counts are plotted in Figure 9.

The changes in counting rates for boric acid and sand as the two materials were uniformly mixed are shown in Tables 16 and 17. The geometry indicated as "Separate" is for 5.25 lb of boric acid in the insert at position 5. The tank contained 84.5 lb of sand. The geometry called "Mix (Insert)" is for the two materials when they were uniformly mixed and were placed in both the tank and insert with the insert at position 5. The geometry called "Mixture" is for the two materials when they were uniformly mixed with an additional 3 lb of sand which replaced the sheet iron insert. This mixture contained 5.66 per cent boric acid.

Table 16

Counts for Sand-Boric Acid Geometries

Arrangement	Geometry	Counting Time (Minutes)	Counts	Counting Rate
A	Separate	30	18796	627 ± 5
A	Mix (Insert)	40	27788	695 ± 4
A	Mixture	40	27476	687 ± 4
B	Separate	30	14452	482 ± 4
B	Mix (Insert)	40	21844	546 ± 4
B	Mixture	40	22032	551 ± 4
C	Separate	10	18662	1866 ± 14
C	Mix (Insert)	10	21130	2113 ± 15
C	Mixture	10	20896	2090 ± 14
Gamma	Separate	1	27212	27212 ± 165
Gamma	Mix (Insert)	1	23858	23858 ± 154
Gamma	Mixture	1	26684	26684 ± 163

Table 17

Counts for Sand-Boric Acid Geometries

Geometry	Slow Neutron Counting Rate	Fast Neutron Counting Rate	Gamma Counting Rate
Separate	145 ± 6	1866 ± 14	27212 ± 165
Mix (Insert)	149 ± 6	2113 ± 15	23858 ± 154
Mixture	136 ± 6	2090 ± 14	26684 ± 163

C. Effects of Concentration of Materials

The effects of varying the concentrations of sand and boric acid mixtures are shown in Tables 18 and 19 and the neutron counts are plotted in Figure 10.

The effects of varying the concentrations of sand, boric acid and graphite mixtures are shown in Tables 20 and 21 and the neutron counts are plotted in Figure 11. The boric acid concentration was maintained at 1 per cent for all these mixtures.

Table 18

Counts for Sand-Boric Acid Mixtures

Arrange-ment	Boric Acid Per Cent	Counting Time (Minutes)	Counts	Counting Rate
A	0	20	43586	2179 ± 10
A	1.0	60	60626	1010 ± 4
A	2.25	60	49062	818 ± 4
A	4.0	60	43864	731 ± 4
A	5.66	40	27476	687 ± 4
A	8.0	60	36734	612 ± 3
A	10.0	60	34798	580 ± 3
A	19.6	60	26169	436 ± 3
B	0	40	30628	766 ± 4
B	1.0	60	41572	693 ± 3
B	2.25	60	36782	613 ± 3
B	4.0	60	34494	575 ± 3
B	5.66	40	22032	551 ± 4
B	8.0	60	29056	483 ± 3
B	10.0	60	28576	476 ± 3
B	19.6	60	21378	356 ± 2
C	0	10	24543	2454 ± 16
C	1.0	10	24163	2416 ± 16
C	2.25	10	22597	2260 ± 15
C	4.0	10	22413	2241 ± 15
C	5.66	10	20896	2090 ± 14
C	8.0	10	18304	1830 ± 14
C	10.0	10	16573	1657 ± 13
C	19.6	15	19068	1271 ± 9
Gamma	0	3	76456	25485 ± 92
Gamma	1.0	1	22933	22933 ± 151
Gamma	2.25	1	23770	23770 ± 155
Gamma	4.0	1	23612	23612 ± 154
Gamma	5.66	1	26684	26684 ± 163
Gamma	8.0	1	23344	23344 ± 153
Gamma	10.0	1	23353	23353 ± 153
Gamma	19.6	3	76803	25600 ± 92

Table 19

Counts for Sand-Boric Acid Mixtures

Boric Acid Per Cent	Slow Neutron Counting Rate	Fast Neutron Counting Rate	Gamma Counting Rate
0	1413 ± 11	2454 ± 16	25485 ± 92
1.0	317 ± 5	2416 ± 16	22933 ± 151
2.25	205 ± 5	2260 ± 15	23770 ± 155
4.0	155 ± 5	2241 ± 15	23612 ± 154
5.66	136 ± 6	2090 ± 14	26684 ± 163
8.0	129 ± 4	1830 ± 14	23344 ± 153
10.0	104 ± 4	1657 ± 13	23353 ± 153
19.6	80 ± 4	1271 ± 9	25600 ± 92

Table 20

Counts for Sand-Boric Acid-Graphite Mixtures

Arrange-ment	Graphite Per Cent	Counting Time (Minutes)	Counts	Counting Rate
A	0	60	60626	1010 ± 4
A	5.37	60	60040	1001 ± 4
A	13.2	60	57980	966 ± 4
A	20.0	60	57882	965 ± 4
B	0	60	41572	693 ± 3
B	5.37	60	40176	670 ± 3
B	13.2	60	38520	642 ± 3
B	20.0	60	39702	662 ± 3
C	0	10	24163	2416 ± 16
C	5.37	10	22207	2221 ± 15
C	13.2	10	21102	2110 ± 15
C	20.0	10	21890	2189 ± 15
Gamma	0	1	22933	22933 ± 151
Gamma	5.37	2	44852	22426 ± 106
Gamma	13.2	2	47481	23740 ± 109
Gamma	20.0	2	46439	23220 ± 108

Table 21

Counts for Sand-Boric Acid-Graphite Mixtures

Graphite Per Cent	Slow Neutron Counting Rate	Fast Neutron Counting Rate	Gamma Counting Rate
0	317 ± 5	2416 ± 16	22933 ± 151
5.37	331 ± 5	2221 ± 15	22426 ± 106
13.2	324 ± 5	2110 ± 15	23740 ± 109
20.0	303 ± 5	2189 ± 15	23220 ± 108

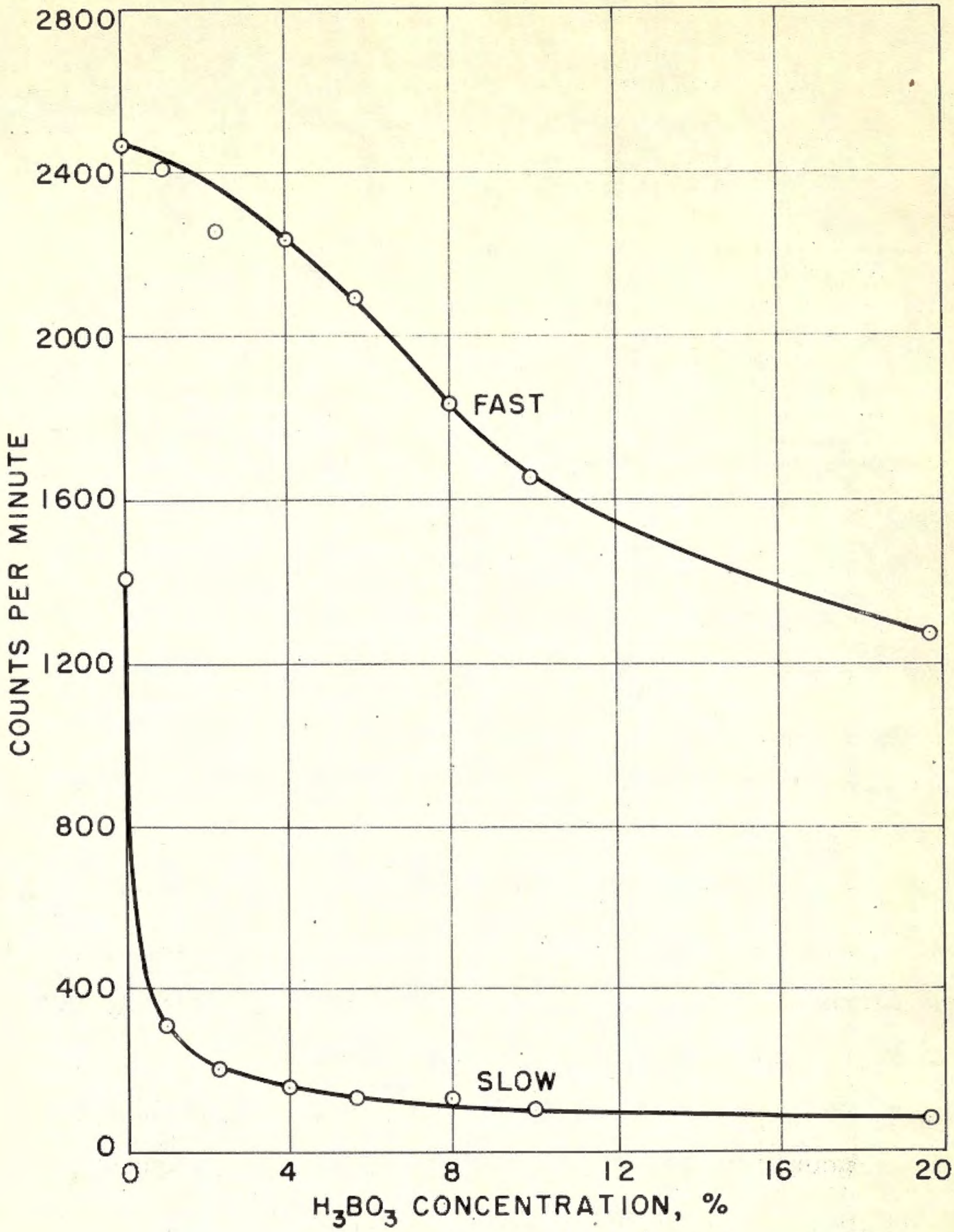

Figure 10. Neutron counts for sand-boric acid mixtures.

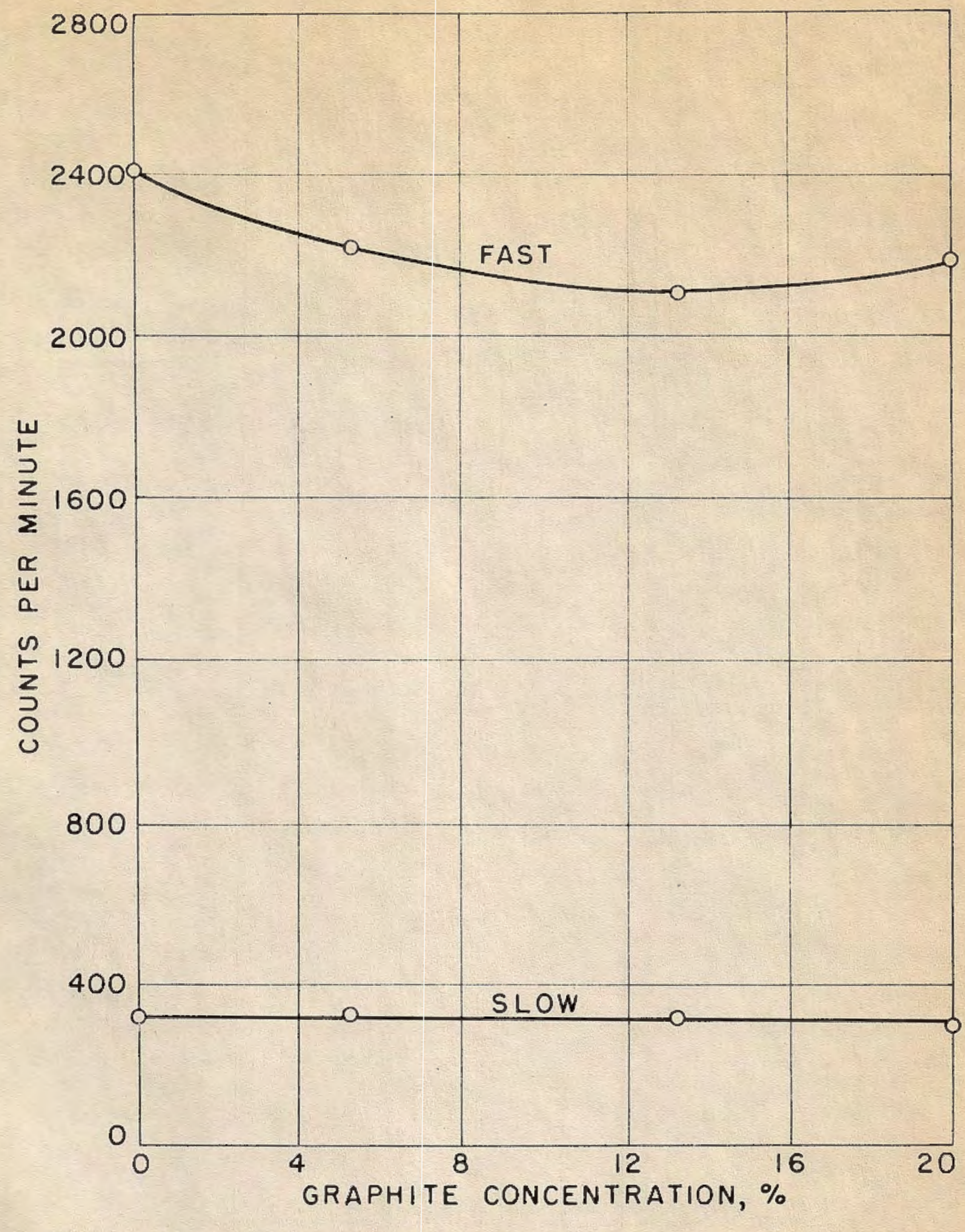

Figure 11. Neutron counts for sand-boric acid-graphite mixtures.

D. Comparisons

The neutron counts for 2.45 lb of water at position 5 are tabulated in Table 22 and are compared in Table 23 with the counts for 5.25 lb of boric acid placed at position 5.

Table 22

Neutron Counts for Water and Sand

Arrange-ment	Position of Insert	Counting Time (Minutes)	Counts	Counting Rate
A	5	15	42440	2829 ± 14
B	5	30	44508	1484 ± 7
C	5	10	21472	2147 ± 15

Table 23

Neutron Counts for Water and Boric Acid

Material	Slow Neutron Counting Rate	Fast Neutron Counting Rate
Water	1345 ± 16	2147 ± 15
Boric Acid	145 ± 6	1866 ± 14

The neutron and gamma counts for the tank full of distilled water are tabulated in Table 24 and are compared with other materials in Table 25.

Table 24

Counts for Distilled Water

Arrangement	Counting Time (Minutes)	Counts	Counting Rate
A	60	52128	869 ± 4
B	60	7836	131 ± 1
C	60	14786	246 ± 2
Gamma	3	136530	45510 ± 123

Table 25

Comparison of Shielding Materials

Shielding Materials	Slow Neutron Counting Rate	Fast Neutron Counting Rate	Gamma Counting Rate
Empty Tank	3869 ± 28	7802 ± 28	178800
Sand	1413 ± 11	2454 ± 16	25485 ± 92
Sand-1% H_3BO_3-13.2% Graphite	324 ± 5	2110 ± 15	23740 ± 109
Sand-19.6% H_3BO_3	80 ± 4	1271 ± 9	25600 ± 92
Water	738 ± 4	246 ± 2	45510 ± 123

VII. DISCUSSION

The counting rates shown in Table 2 help to explain the reason for using 1½ in. of paraffin instead of 3 in. to increase the fast neutron counts. The slow and fast neutron counts were both increased an appreciable amount by using half the thickness of paraffin and by moving the neutron detector 1½ in. nearer the source.

The cadmium and paraffin sheath effectively stopped the stray slow neutrons which would have otherwise been scattered into the shielding tank. Reductions in the slow neutron counts are indicated by the curves in Figures 7, 8 and 9 when the shielding tank was sheathed. The fast neutron counts were higher when the shielding tank was sheathed. The higher fast neutron counts with the sheath were probably caused by the reflection of high-energy neutrons from the source which were scattered back into the tank by the paraffin sheath.

Calculations based on the number of atoms of the materials used in the insert indicate that the graphite presented 90 per cent more scattering cross-sectional area to the neutrons than did the sand and the boric acid presented 325 per cent more scattering cross section than the sand did. The sand, however, was calculated to be 16 times more likely than the graphite to absorb the neutrons and the boric acid was calculated to be 28,000 times more effective than the graphite for absorbing the neutrons. Figures 7 and 8 indicate that the sand and the graphite attenuated the neutrons to about the same extent.

Less than 4 per cent change in shielding effectiveness was noted for the positioning of the insert when it contained sand or graphite. When the insert contained boric acid powder the neutron counts decreased as the insert was placed at greater distances from the source. This is shown by the curves in Figure 9. It seems reasonable to say that the boric acid was most effective for absorbing neutrons at the positions farthest from the source after the neutrons were moderated by the sand.

The slow neutron count was observed to be the same for the boric acid and sand whether they were separate or were mixed uniformly. Table 17 indicates that the materials were more effective for reducing the fast neutron count when they were kept separate and the boric acid was positioned farthest from the source.

The gamma count was lowered when the materials were mixed. The powdered boric acid tended to fill the voids between the grains of sand and thus might have caused a reduction in the gamma count. The degree of tamping would have an effect on the gamma count, but the degree of tamping for the different mixtures was hard to evaluate. The gamma count increased when the sheet iron insert was removed because the iron was a good attenuator of gamma rays.

The curves in Figure 10 show that the slow neutron count was reduced very little by increasing the concentration of boric acid beyond 2 or 3 per cent. The fast neutron count, however, decreased steadily with increased concentrations of boric acid. The sand-boric acid mixtures started to pack and lost their dry sand characteristics at a concentration of 8 per cent boric acid.

The sand-boric acid-graphite mixtures shown by the curves in Figure 11 indicate less than 5 per cent increase in effectiveness when the concentration of graphite was increased. The mixtures packed and lost their dry sand characteristics at graphite concentrations of between 5.37 and 13.2 per cent.

The results of the water substitution for boric acid on a basis of equal weights of hydrogen at insert position 5 indicated that the boric acid was more effective in reducing the neutron counts.

When the shielding tank was filled with water only the results were somewhat different as Table 25 shows. Water was definitely the most effective shield of the materials and mixtures used here for reducing the fast neutron count.

Its slow neutron and gamma counts were twice as high as those for the mixtures which contained 1 per cent boric acid.

VIII. CONCLUSIONS

The following conclusions seem justified for the effectiveness of the mixtures and material arrangements used here for "shadow" radiation shielding:

1. A 5.66 per cent concentration of boric acid powder is more effective for neutron shielding when it is placed at a position farthest from the radiation source than when it is uniformly mixed with the sand and distributed throughout the shield.
2. Addition of graphite to a sand-boric acid mixture with a resultant decrease in the sand concentration does not increase the effectiveness of the shield for neutron or gamma shielding.
3. A sand-boric acid mixture with a boric acid concentration of 19.6 per cent reduces the fast neutron count to about one-half the count for sand alone. The mixture reduces the slow neutron count to about one-seventeenth the count for sand and it has about the same gamma ray count.
4. Sand-boric acid mixtures are less effective than water for neutron shielding, but are almost twice as effective as water for shielding from gamma rays.

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X. ACKNOWLEDGMENTS

This study was conducted as a part of the graduate program in Engineering with a minor in Nuclear Science. Participation in this course of study was sponsored by the United States Air Force Institute of Technology, Wright-Patterson Air Force Base, Dayton, Ohio.

The author wishes to express appreciation to Dr. Glenn Murphy for his helpful suggestions, criticism and encouragement.

The author is grateful to Dr. A. F. Voigt and the Iowa State College Institute for Atomic Research for the use of the laboratory and equipment.

Thanks are extended to Dr. G. R. Town and the Iowa Engineering Experiment Station for assistance in the procurement of the materials used in this study.