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U. S. NAVAL SUBMARINE MEDICAL CENTER

Submarine Base, Groton, Conn.

LOW LEVEL ALPHA COUNTING:

Description of a Device for Increasing Counting
Efficiency Aboard Submarines

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ABSTRACT

The design and use of a new device for increasing low level Alpha counting efficiency of the standard AN/PDR-56 Alpha Particle Meter is described. Directions for its construction, list of materials required, photographs and diagrams are furnished. The practical application of shipboard utilization of such a device is pointed out.

ADMINISTRATIVE INFORMATION

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INTRODUCTION

Accurate alpha particle counting is and has been a problem for the forces afloat. The basic detection principle is that of a scintillator coupled to a photomultiplier circuit. Since it is mandatory to have a rugged instrument capable of withstanding field use by personnel with varying degrees of training the scintillation detector provides a reasonably rugged, as well as accurate instrument for this purpose.

SCINTILLATION DETECTORS

The development of modern scintillation detectors was started by Coltman and Marshall (1) in 1947, at which time they reported the successful use of a photomultiplier tube for counting the light scintillations which were produced by alpha, beta, and gamma radiation. Since 1947 the scintillation detector has become the most versatile instrument available for nuclear radiation detection. •

These devices came into use primarily to meet a demand for counters capable of higher counting rates and shorter resolving times. It is necessary to employ a fast counting rate in order that the average count rate will be high and thus insure that the rate of true coincidences will be reasonably high for each individual event. The shorter resolving time insures that the ratio of chance coincidences to true coincidences is small.

The theory of operation of the scintillator is basically divided into six consecutive events. The nuclear particle being detected produces a flash of light in the scintillator. By means of a light pipe and reflector, a large fraction of the light is transmitted to the photocathode of a photomultiplier tube. The photoelectrons emitted at the photocathode are multiplied many times by means of the electron-multiplier section of a photomultiplier tube. The resulting current pulse produces a voltage pulse at the input of a preamplifier. This pulse, after passing a discriminator and pulse shaper, is counted by an electronic counter.

A wide variety of scintillators are in use today. Most of the scintillators are of one of the following types of material (2):

1. Single crystals of organic material, such as anthracene or trans-stibine crystals;

2. Organic materials dissolved in organic liquids, such as terphenyl in xylene or polyvinytoluene. Terphenyl is also incorporated in polystyrene as a solid solution;

3. Single crystals of inorganic material, such as NaI(Tl), LiI(Sn), or LiJ(Eu);

4. Inorganic powder, such as ZnS(Ag).

In addition to the above materials, xenon and other inert substances in gaseous, liquid, and solid states are employed as scintillators (3).

THEORY OF INORGANIC-CRYSTAL SCINTILLATORS

The inorganic scintillators are crystals of inorganic salts, primarily the alkali halides, containing small amounts of impurities as activators for the luminescent process. A pure alkali halide crystal has a valence band of energies which is normally completely filled with electrons and a conduction band of energies which is normally empty. The latter lies above the valence band and is separated from it by a forbidden band of energies in which the electrons cannot exist. Imperfections in the crystal, such as impurity atoms or lattice vacancies, create energy levels in the forbidden band at isolated points throughout the crystal. The passage of nuclear radiation through the crystal raises electrons from the valence band to the conduction band. An electron in the conduction band is in an excited state. When the electron returns to the valence band, which is its ground state, the excess energy is given up. An excited electron in the conduction band wanders through the crystal until it comes into the vicinity of an imperfection and thus drops to the energy level associated with the imperfection. From this new level it may drop to the valence band by the emission of radiation. Thus, the process of fluorescence in scintillators. As an alternate, the electron may lose its energy by a radiationless process. This is referred to as quenching since it prevents radiation.

The inorganic crystals possess the desirable property of transparency for their own fluorescent radiation. This property exists since the photon energy is less than that energy defect between the valence and conduction bands. It is the transition between these bands which constitutes the principal optical absorption. The addition of small quantities of the appropriate impurity atoms create fluorescence centers. These impurities are known as activators. Thallium, tin, and silver are the most commonly used activators.

Silver-activated zinc sulfide is a very satisfactory scintillator for alpha particle counting. This material has a very high efficiency for conversion from nuclear energy to light but its transparency is low. However, by preparing the zinc sulfide scintillator in a layer of thickness comparable with the range of the alpha particles to be detected, the lack of transparency is avoided. Although other types of radiation which may be present will also produce scintillations in the zinc sulfide, these can, as a rule, be discriminated against because of their relatively small intensity.

DISCUSSION OF ALPHA PARTICLE SURVEY METER

Recently a new instrument, designed as an NBC tool, has been furnished the Forces Afloat as the basic alpha particle survey meter. The AN/PDR-56 is a rugged, fairly compact survey instrument which fulfills shipboard requirements. The instrument is capable of detecting alpha particles of 3 Mev or greater with a maximum count rate of 10^6 counts per minute (cpm). Detection efficiency is stated at greater than 11% with an accuracy of $\pm$ 20% for the lower count rates and $\pm$ 10% for count rates between 10^4 and 10^6 cpm. Accuracy is based on calibration with plutonium-239.

The AN/PDR-56 consists of the following major components:

1. Radiacmeter   IM160/PDR-56

2. Main Probe   DT224/PDR-56

3. Auxiliary Probe   DT228/PDR-56

4. Check Source, Thorium-232

The sensitive area of the main probe for alpha detection is 17 square centimeters/ for the auxiliary probe, the sensitive area is 10 square centimeters. The AN/PDR-56 uses the scintillation properties of a silver-activated zinc

sulfide screen in both detection probes. This type of detector effectively discriminates against beta, gamma, and neutron radiation. The auxiliary probe is readily applicable to shipboard alpha surveys, while the larger main probe is rather unwieldly, and frequently unuseable, because of its size. The auxiliary probe is adaptable to counting swipe surveys for loose surface alpha contamination, as well as air particulate or liquid samples.

A promising aspect of the instrument is the accurate correlation between the count rate information provided by the linear meter scale, the audible headphone clicks, and the quantity of activity being detected. The major difficulty arises in equating the meter readings and auditory response to familiar quantities of activity. Technical manual, NAVSHIPS 94170, provided with the instrument, is undergoing revision at the present time. This revision will clarify this discrepancy and promulgate the fact that one count per minute (cpm) is equivalent to one micro micro curie (uuc) of activity in the area immediately adjacent to the scintillator, and also that the auditory response from the photomultiplier circuit is such that one click as heard via the headphones is equal to one count (4). Utilizing these facts, the versatility of the instrument is readily seen.

When alpha particles, in air, are counted by the scintillation method, it is found that their detectability decreases gradually up to certain distance from the source, after which detection decreases sharply. This distance is the range and is directly proportional to the initial energy of the alpha particle. For alpha particles, empirical equations have been developed to relate energy and range in air. One such equation which fits with fair accuracy for the energy range from 4 to 7 Mev is:

$$R = 0.309E^{1.5},$$

where R is the mean range in centimeters at normal conditions and E is the alpha-particle energy in Mev. At lower energies, the dependence on energy is more nearly proportional to $E^{0.75}$, while at higher energies an E^2 dependence fits better.

The characteristics of alpha particles complicate their detection. Since the detecting instrument can only provide an indication of the particles producing scintillation, appropriate consideration must be given the counting technique applied. Under ideal conditions, most alpha survey detectors are calibrated for a 2 pi geometry. A 2 pi geometry assumes that 50 per cent of the particles are emitted toward the detector, and that all particles so emitted

under the sensitive area of the probe are detected and indicated by the instrument. The normal calibration of AN/PDR-56 is slightly less than 2 pi.

Since alterations in source-detector geometry will greatly influence instrument response, it was thought advisable to construct a reproducible technique for each counting situation. This technique provides for a constant geometrical relationship between the AN/PDR-56 auxiliary probe (DT228/PDR-56) and the source as obtained from swipe surveys, particulate air surveys, and liquid samples. In all but the most unusual of circumstances, the auxiliary probe will be used for sample counting because of its small size and its adaptability to a reproducible counting geometry.

The mainstay of this technique is a detector-sample holding device designed to accommodate the standard 1 15/16 inch diameter aluminum planchet and the DT228/PDR-56 probe. The sensitive area of the probe is centered directly above the sample surface. The maximum distance separating the sample from the scintillator screen is approximately 6.4 mm. (dried liquid sample) with a minimum distance of approximately 3.2 mm. (standard filter disc for air particulate detection). Since the minimum sensitivity of the AN/PDR-56 is 3.0 Mev, this places the scintillator easily within range of this energy level. Counting of air particulate, as well as liquid samples, utilizing this geometry device reveals predictable as well as reproducible count rates.

EVALUATION OF GEOMETRY DEVICE

To evaluate the geometry device, its count rate data were correlated to count rate data for the same sample provided by a Nuclear Measurement (NMC) Model PC-3A gas-flow proportional counter. The gas used was a mixture of 90% Argon and 10% Methane at a flow rate of approximately 0.77 cc./min. Low-level alpha particle activity samples were normal atmospheric air (10 to 35 cubic meter samples). Sampling was done with a standard Navy portable air particle sampler, IM151/HD. As was expected, spectographic analysis revealed the predominant activity to be the equilibrium decay daughters of radium. High-level activity samples used were AEC licensed standard calibration sources, Plutonium-239 and Radium-226, 62,100 dpm and 29,820 dpm respectively.

The technique for use of the geometry device is extremely simple and allows for a reproducible geometry for each counting situation. The sample holding planchet is placed in the base block and the detector holder is then

placed in position above the sample. Finally, the auxiliary probe DT228/ PDR-56 is placed in position and evaluation of the sample can begin. Background is determined by counting a clean planchet with or without filter disc, as is appropriate, for a minimum of two minutes (T_b) by stop watch, using a small hand counter to record events. Once the background is determined, the sample is placed in position and counted by the same method. The sample counting time (T_s) used was a nimumum of six minutes, to insure a valid, statistical count for the sample. The sample counting time was varied, with the longest counting time being 30 minutes. However, as the counting times were varied, care was taken to insure that the $T_s T_b$ ratio was never less than 2.5, generally remaining 3.0. Use of the headphones is imperative, since experience has shown that a single click via the headphone will cause a linear-scale variation of as much as 50 to 100 cpm (10^3 scale). The clicks are easily heard and only when the count rate begins to exceed 90-100 cpm is the operator's ability to accurately record the events impaired. It was found that even though the meter indication was widely fluctuating, the audible click-rate as heard via the headphones is constant from operator to operator. By repeated observations it was found that the count rate by headphones is about a factor of three less than the meter indicated count rate.

The low-level alpha activity samples were first counted by the proportional counter and then counted with the geometry device. Of the 100 air samples drawn, each was counted twice by both methods. Corrected count rates as determined by the geometry device, did not at any time exceed $\pm$ 10% of the proportional counter count-rate for the individual samples.

In the absence of low-level calibration standards, the detector efficiency of the geometry device was evaluated using the high-level standards mentioned previously. The following is a summary of the correlation data:

1. Pu-239 calibrated source (62,100 dpm), 25 determinations.

	Geometry Device	PC-3A
Mean count rate	36,000 cpm	31,735 cpm
Mean efficiency	57.9%	51.1%

2. Ra-226 calibrated source (29,820 dpm), 25 determinations.

	Geometry Device	PC-3A
Mean count rate	16,000 cpm	15,270 cpm
Mean efficiency	53.6%	51.1%

Since the above count rates far exceed the ability of man to use the head-phones, the count rates were recorded as indicated on the linear scale meter. There is considerable needle oscillation and the indicated rates are an average value. It is assumed that the high efficiencies determined for the geometry device have at least two grossly misleading factors contributing to fairly large positive errors:

a. Alpha scatter-in and recoil from the semipolished aluminum surface at the high count rates;

b. Inaccuracy of linear scale readings at high count rates due to meter oscillation.

The efficiency of the proportional counter was constant; weekly alpha efficiencies over the previous six months ranged between 50.7% and 51.4%, using the same standard reference sources throughout.

COMMENTS

Utilizing the proportional counter's efficiency as a standard, the calculated efficiency of the geometry device for low-level activity was found to be 49.7%. Assuming this same efficiency as the true efficiency for the geometry device, the expected true count rate of the high-level activity standards fell within ± 10% of the count rates as determined by the proportional counter.

When utilizing the above technique and the geometry device, the minimum sensitivity to 250 cpm, as described in NAVSHIPS 389-0266, appears to be excessive (5). Experience has shown that the count rates of 20 cpm over background are readily reproducible.

The geometry device was constructed from a hardwood block six inches long by 1 3/4 inches thick by 3 3/4 inches wide. The planchet holder, fixed in the base block, centers the planchet and the removable detector holder centers the scintillation screen directly above the center of the planchet. The detector holder is 1/4 inch, 3-ply birch plywood. The planchet holder, made of the same hardwood as the base block, is glued with WELDWOOD PLASTIC GLUE to the base block. Following sealing and finishing with white shellac, a 1/16 inch piece of nonskid rubber was glued to the base block with ARMSTRONG No. 1200 CONTACT CEMENT. Total construction time was approximately 15 hours and was done in a home workshop.

The following five figures and three pictures (Figure 6) are presented as guides to the fabrication and use of this geometry device. Below is a list of the material needed for construction of the device. It is hoped that the simplicity of design, ease of construction, and ready application to shipboard low-level alpha counting techniques will be sufficient inducement for the widespread use of this geometry device.

LIST OF MATERIALS

1.	Hardwood Block	6" x 3-3/4" x 1-3/4"
	a. Base Block	6" x 3-3/4" x 1-5/16"
	b. Planchet Holder	6" x 3-3/4" x 3/16"
	c. Detector Holder Insert	6" x 3-3/4" x 1/4"
2.	Birch Plywood, 3 ply	2-3/4" x 2-1/2" x 1/4"
	a. Detector Holder	2-23/32" x 2-15/32" x 1/4"
3.	Nonskid Rubber	6" x 3-3/4" x 1/16"
4.	WELDWOOD PLASTIC GLUE	
5.	ARMSTRONG CONTACT CEMENT No. 1200	
6.	White Shellac	

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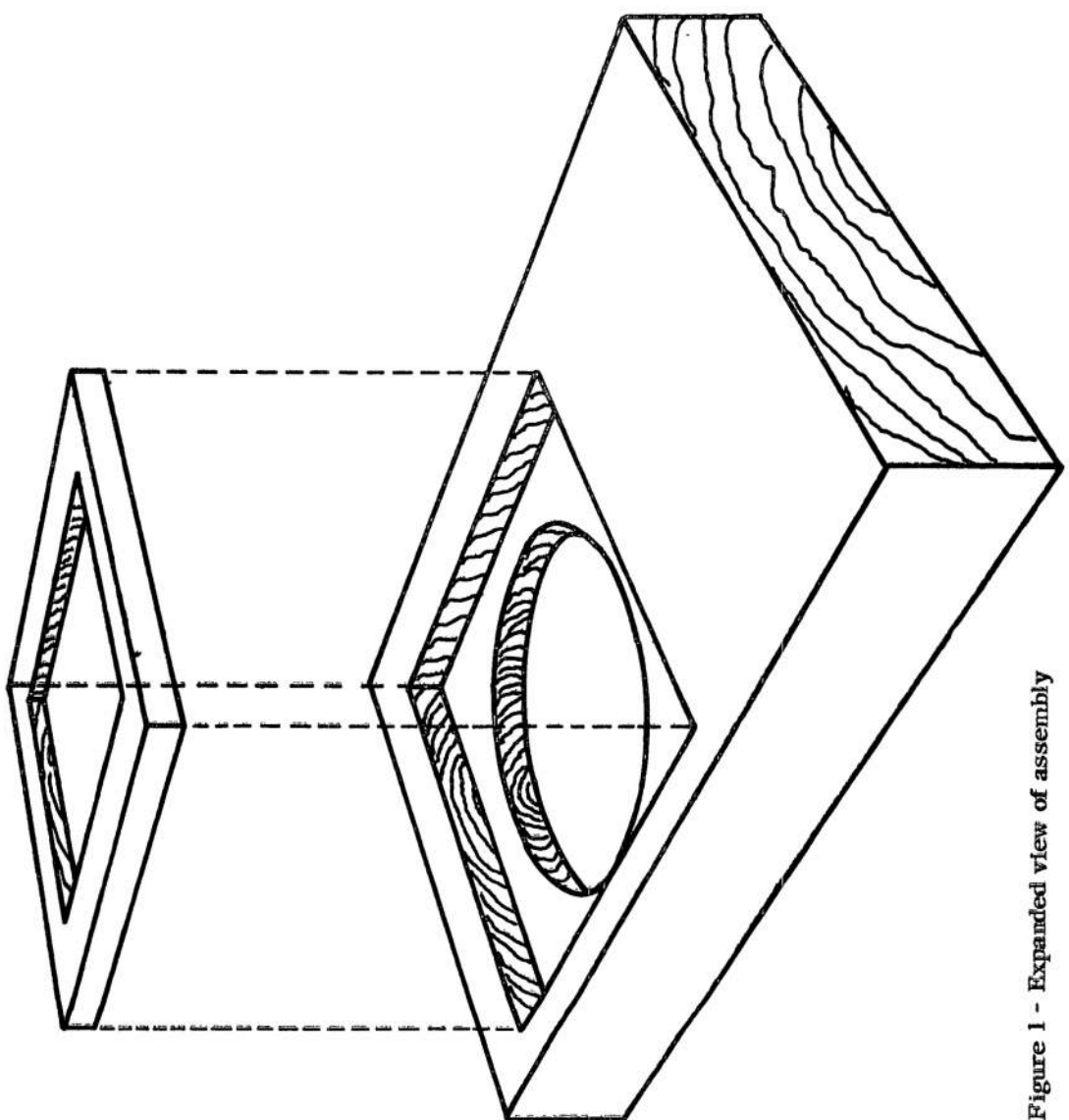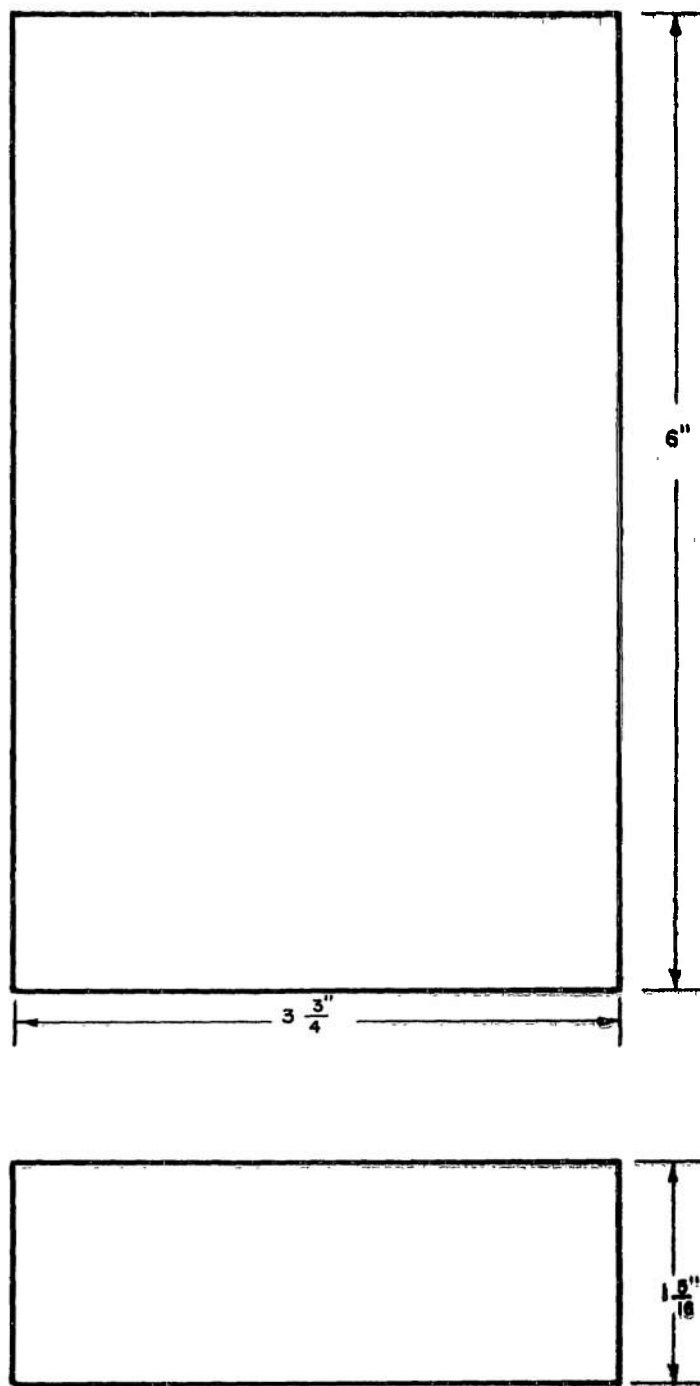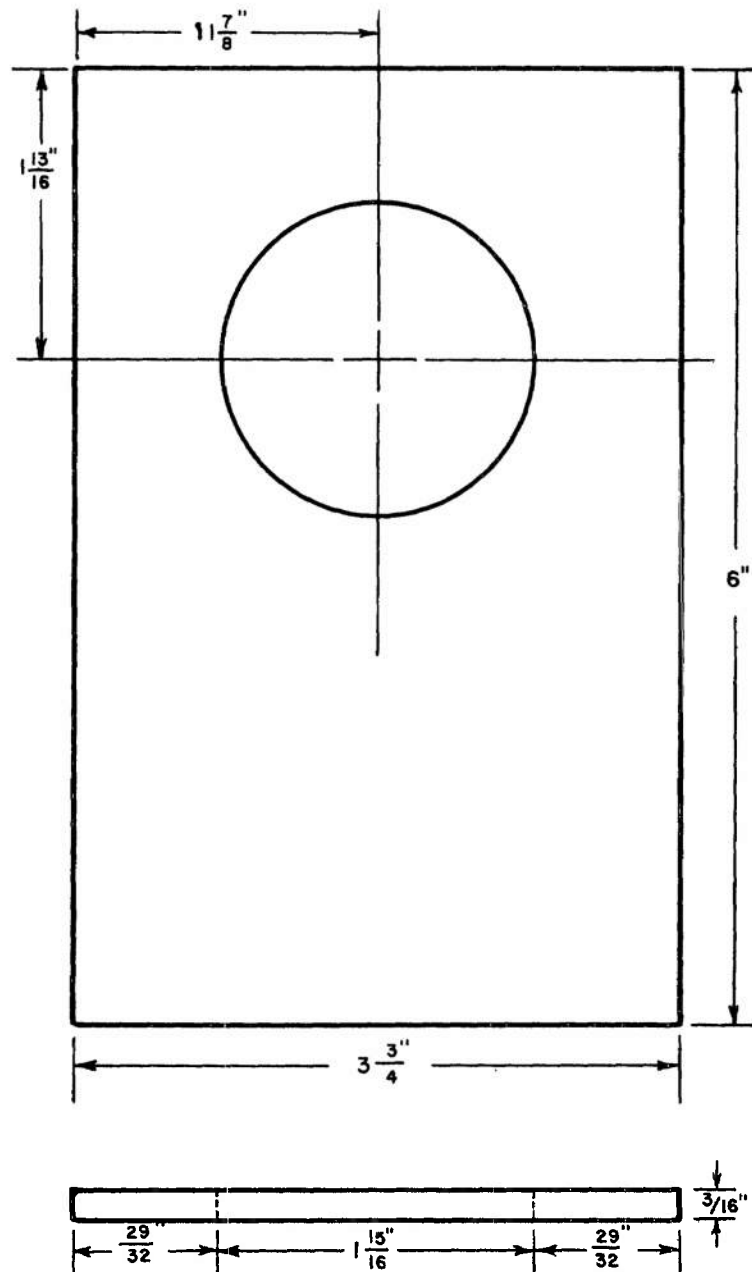
5. NAVSHIPS 389-0266 Article 222.6, January 1964.
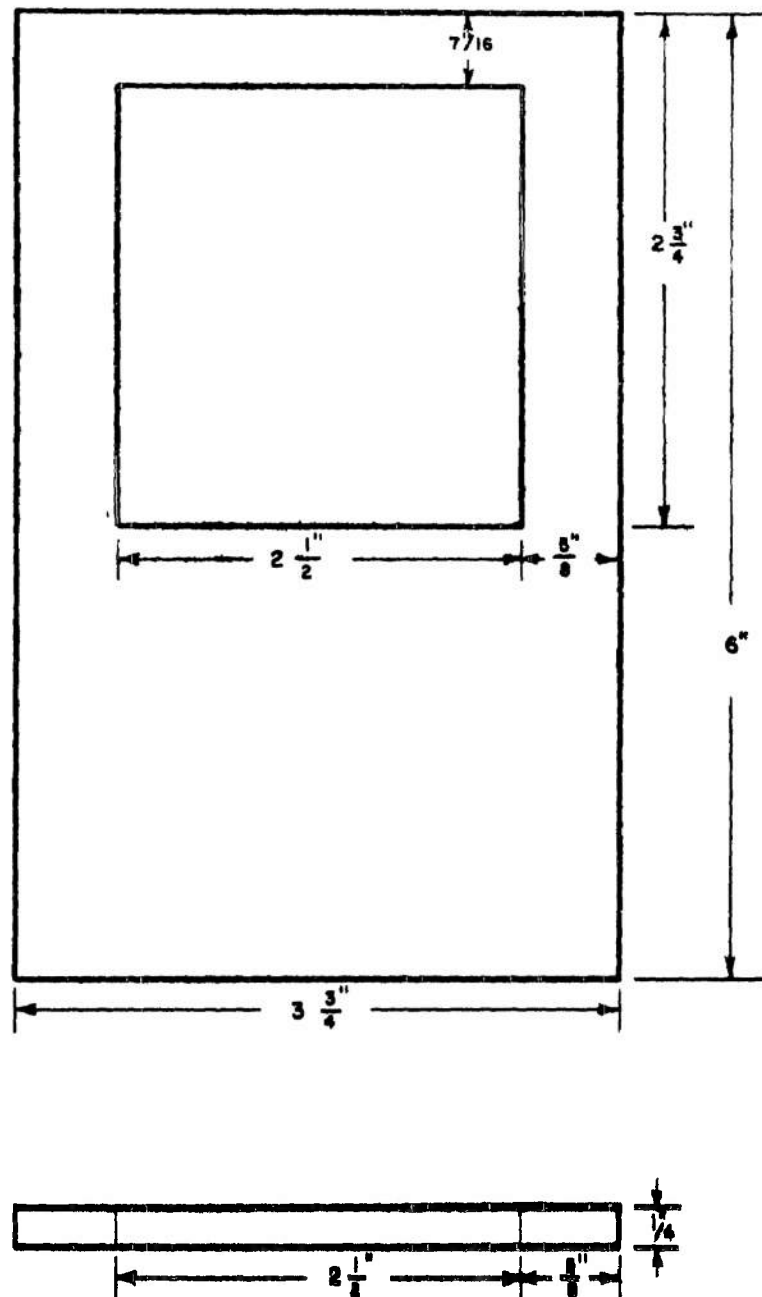
Figure 1 - Expanded view of assembly

6"

$3 \frac{3}{4}$"

$1 \frac{5}{16}$"

Base Block
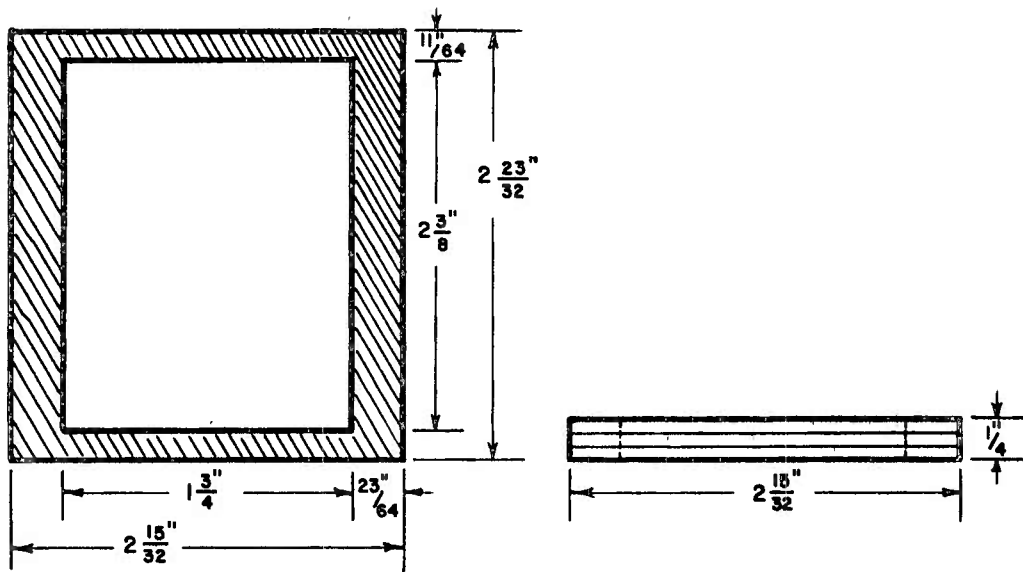
Figure 2 – Base Block

Planchet Holder

Figure 3 - Planchet Holder

Detector Holder Insert

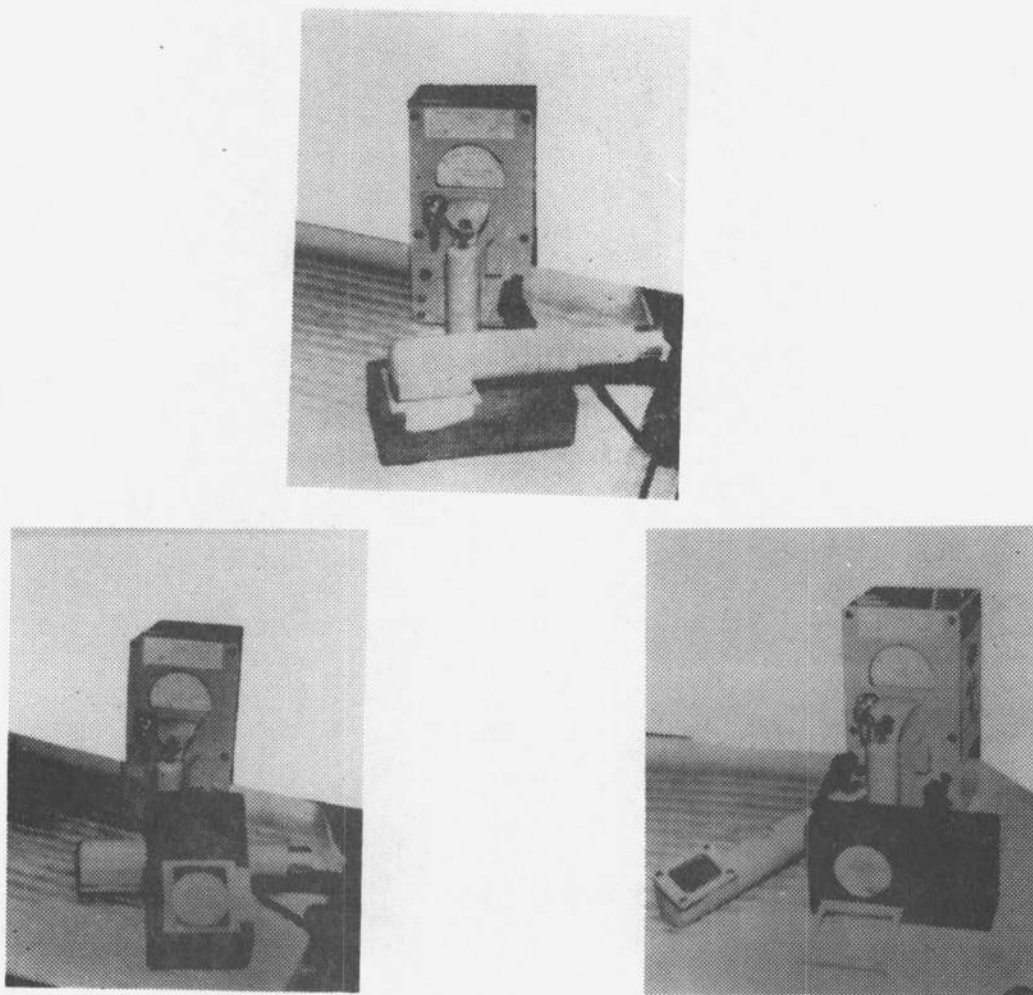Figure 4 - Detector Holder Insert

Detector   Holder

Figure 5 – Detector Holder

Figure 6 - Three views of Geometry Device