Sensor and Simulation Note No. 10

Description of Gamma Anisotropy Sensor (Beatle)

by

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1. Purpose of Instrument

It is important that a method be found to measure the percentage of anisotropy, (or directionality), of high intensity, time dependent gamma radiation fields. The instrument herein described is capable of yielding both the percentage of anisotropic radiation present and the direction of the anisotropy. Such an instrument is urgently needed for research in nuclear weapon environments.

2. Description of Instrument

The instrument consists of six parallel plate, pancake type, gamma sensitive, semirad diodes, one on each face of a heavy, aluminum encased, lead cube. The lead cube should be large enough to antennuate gammas by a factor of approximately e^4. With this requirement met, the back to front sensitivity ratio should be less than 1% for any individual semirad element of the system.

The outputs of the semirads on opposite faces are tied together in such a manner as to make their responses cancel each other. If their sensitivities are sufficiently close, a net current from a pair of such elements indicates that there is an anisotropic component to the γ radiation field. We will, show that three such pairs of elements, together with a normally operated 4π semirad diode completely define the radiation field to first order. The instrument will henceforth be referred to as the "Beatle," so named (by an entomologically minded co-worker) because of its "six legged" nature.

3. Theory of Operation

a. Response of semirad pancake vs. angle.

A semirad pancake diode consists of three conducting plates wired as shown in Fig. 1, mounted in an evacuated chamber. A potential difference is maintained between the center plate and the two outer plates.

When a high energy γ ray passes through a semirad plate, it may produce Compton electrons in it, which in turn liberate low energy secondary electrons. If these secondary electrons are ejected from the appropriate surface, they will be collected by the potential. The current produced by the collection constitutes the semirad output.

In order to ascertain the dependence of the semirad output on the angle between the incoming γ flux and the normal to the surface, we must first take a closer look at the process of secondary electron emission. Present theories maintain that secondary electrons can only be emitted from the "escape layer". This is a region extending from the surface of a metal to about 10^{-8} cm into the metal. The theory also states that the number of secondaries produced should be governed by the track length of the ionizing particle <u>in the escape layer</u>. If the range of the particle is much larger than this distance, the number of secondaries is given by

$$Y = k \frac{dE}{dx} \Delta \ell \sec \theta = \frac{\text{no secondaries}}{\text{no primaries}}$$

In our case the ionizing particle is a high energy gamma-produced electron. These should be produced mainly in the forward direction of the scattering γ ray, so that the angle θ in the preceding formula is approximately the angle between the normal to the surface and the direction of the incoming γ ray. In the design of the Beatle it is essential that this dependence be eliminated when a large <u>flux</u> of γ's is incident. This is accomplished by roughing the surface, e.g. sanding to randomize the angle of incidence of individual γ rays.

If the incoming γ flux Γ is uniform over the semirad face area, the response should be given by

$$I(\text{amp}) = S_o \, \Gamma \cos \theta$$

where S_o is now no longer a function of the angle θ.

b. <u>Operation of a pair of semirads in Beatle</u>.

In the Beatle, semirads on opposite faces of the aluminum encased lead block will be wired together as shown in Fig. 2.

As can be seen from Fig. 2a, the response of semirads A and B will be exactly opposite for the same γ dose rate. If the γ field is isotropic over the entire instrument, the net signal should be zero. To understand the operation of the entire instrument, we will consider the following example.

Operation of the complete Beatle

Assume a gamma flux of strength Γ and direction given by direction cosines l, m, n, with respect to a set of axes (x y z) as shown in Fig. 3.

The semirad elements on faces perpendicular to the x axis are wired so that if a γ comes <u>from</u> -x the response will be negative (see Fig. 2). Similar statements can be made for the semirad pairs in the y and z direction.

If the radiation flux makes an angle e_x with the semirad $\perp$ to the x axis, the output should be according to equation 1.

$I_x = S_0\Gamma \cos e_1$. Similarly for the semirad pairs in the y and Z direction $I_y = S_0\Gamma \cos e_y$ and $I_z = S_0 \Gamma \cos e_z$

But $\cos e_1$, $\cos e_2$ and $\cos e_3$ are just the direction cosines l, m, n which define the direction of the radiation field.

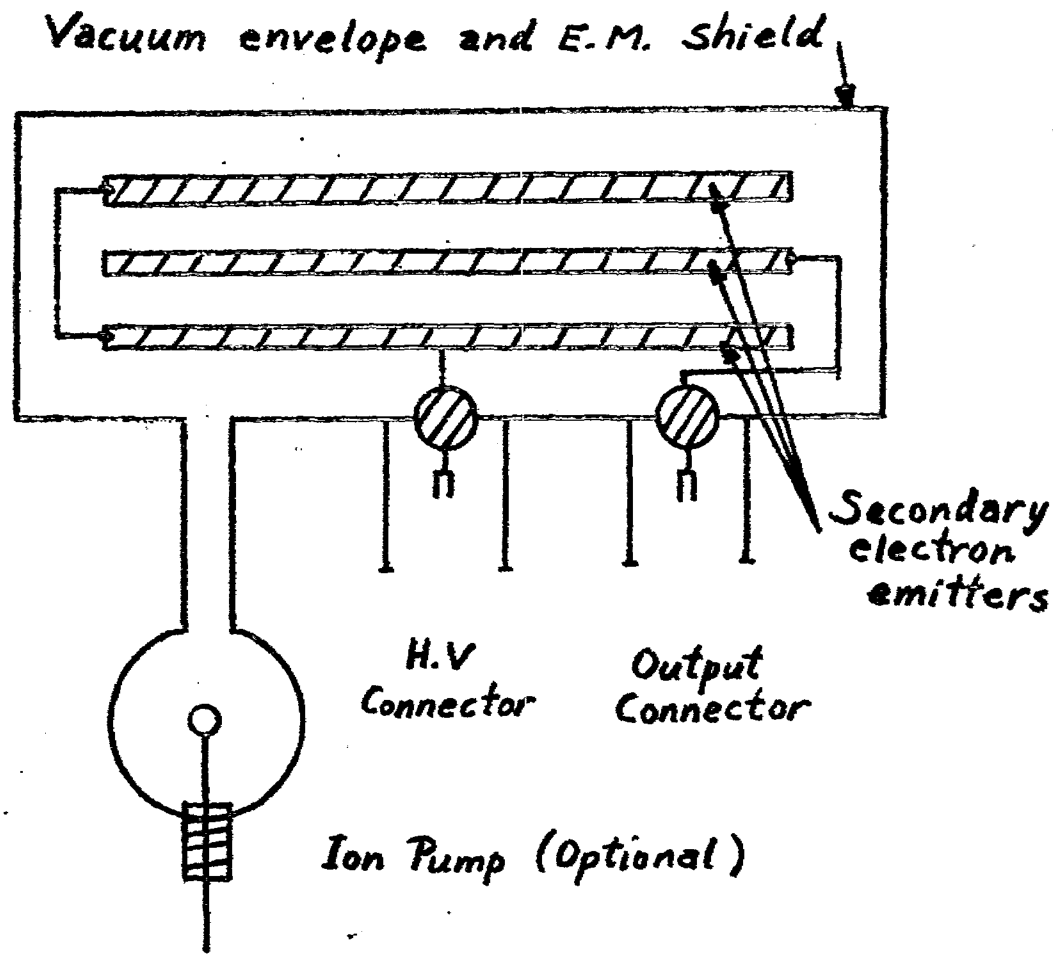
So that, given (I_x I_y I_z) and I_o (the response of a 4π semirad dose rate measurement), one can define the radiation field completely to first order.

The percentage of anisotropy is given by

$$\frac{(I_x^2 + I_y^2 + I_z^2)^{\frac{1}{2}}}{S_o \times I_o} \times 100\ \% = \text{percent anisotropy.}$$

The direction cosines of anisotropic radiations are

$$\ell = \frac{I_x}{(I_x^2 + I_y^2 + I_z^2)^{\frac{1}{2}}} \qquad m = \frac{I_y}{(I_x^2 + I_y^2 + I_z^2)^{\frac{1}{2}}} \qquad n = \frac{I_z}{(I_x^2 + I_y^2 + I_z^2)^{\frac{1}{2}}}$$



Vacuum envelope and E.M. shield
Secondary electron emitters
H.V Connector
Output Connector
Ion Pump (Optional)

Figure 1

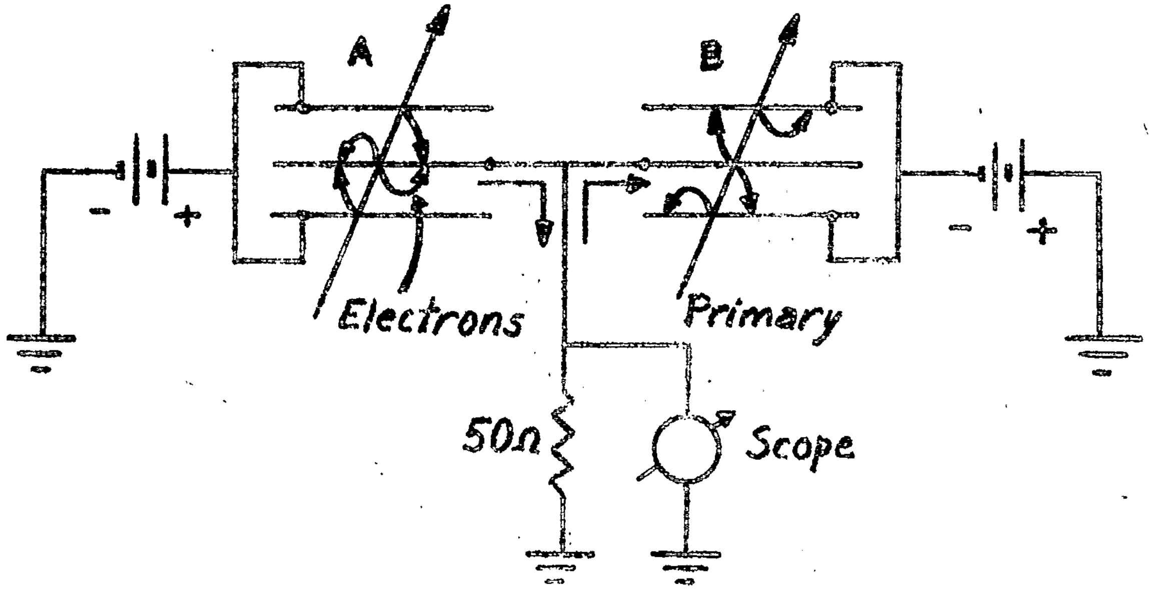


Figure 2a

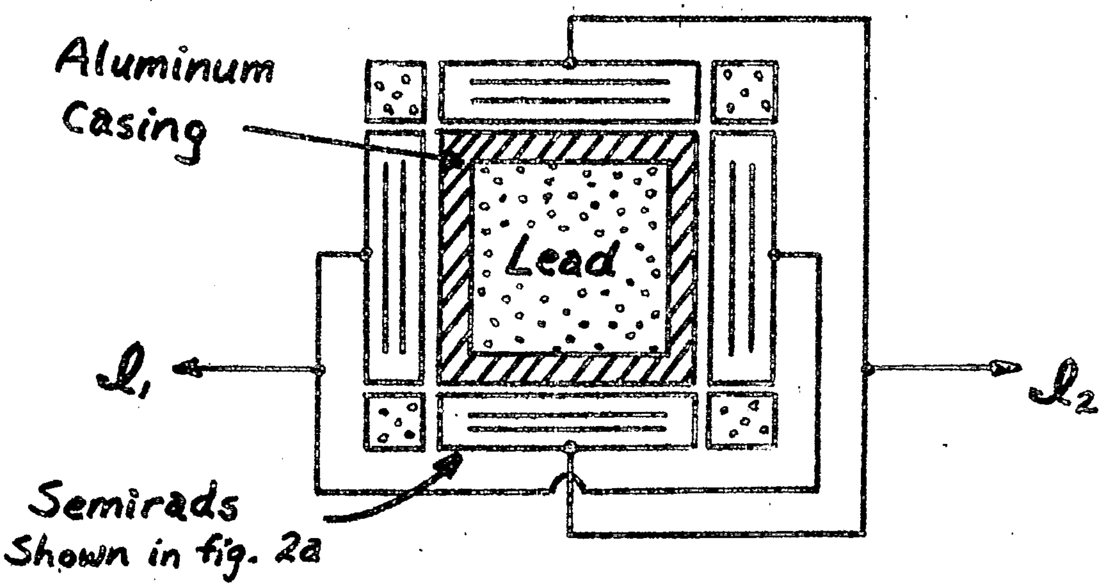


Figure 2b

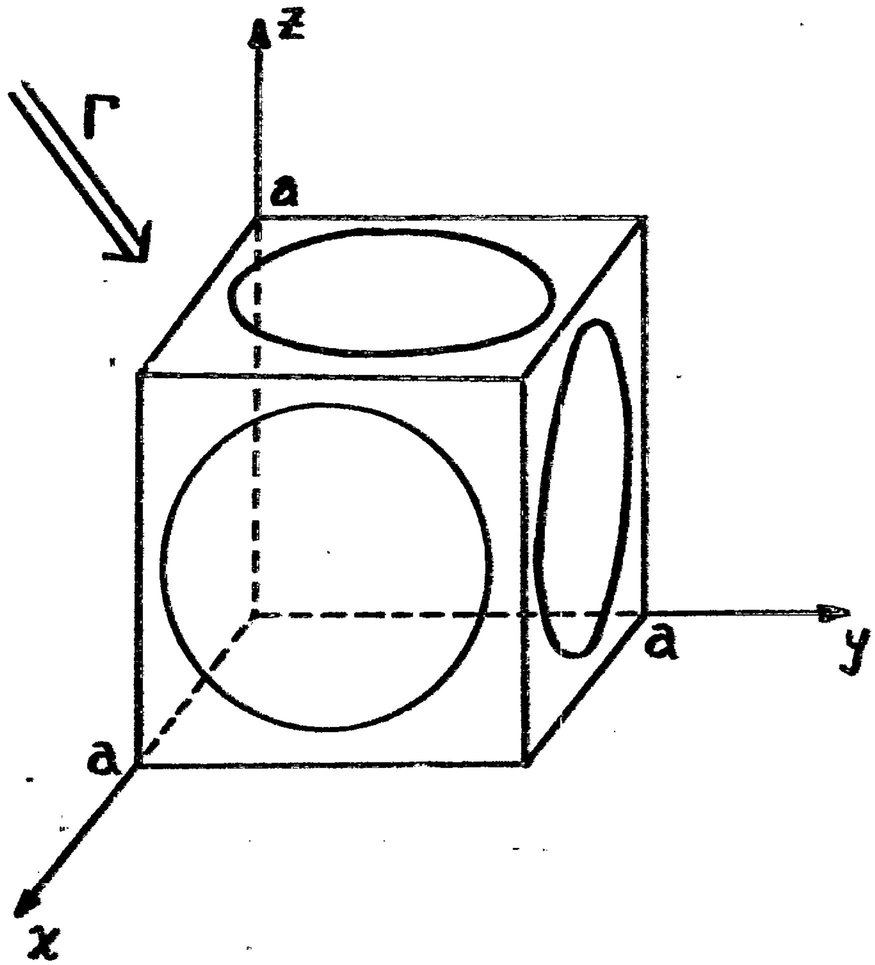


Figure 3