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HIGH ENERGY GAMMA RAY DETECTOR
WITH A FAST, VARIABLE DISCRIMINATOR

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A FAST, VARIABLE DISCRIMINATOR*

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ABSTRACT

A high energy (5-10 MeV) gamma ray detector with a variable, fast discriminator was developed. The discriminator circuitry employs a variably biased tunnel diode monostable multivibrator and is housed in a case mounted to the base of the photomultiplier tube for portability. The detector is designed to operate in a wide spectrum gamma field of about 200 mR/hr. The signal is taken from the PM tube anode with the low energy background field acting as a constant current and the high energy pulses superimposed. The signal from the discriminator is fed to a standard rate meter for evaluation. The detector was used successfully to measure high energy gammas streaming from the face and in the working areas of two production reactors operated by Douglas United Nuclear, Inc. From the data, calculations were made to estimate the exposure problems extant in these areas due to high energy gammas.

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I. INTRODUCTION

Since production reactors have been in operation, radiation protection engineers have been concerned about the exposures to personnel as a result of high energy gammas (5-10 MeV) from activated materials within the reactors. In past years, estimates of exposures have been made from personnel film exposures using filtration techniques.¹ In 1966, gamma spectra were taken in suspected areas around the reactors and indicated that the vast majority of the high energy gammas came from the $^{15}\text{N}(n,\beta,\gamma)^{16}\text{O}$ reaction, which primarily yields gammas of 6.13 and 7.12 MeV.² Additional studies were made in the summer of 1968,^{3,4} which confirmed the earlier report.

Studies made during the operation of the reactors^{2,3,5} indicate that the high energy gammas stream out of the bore patterns of the core as well as being contained in the effluent air and water.

The project discussed here was oriented toward the development of a portable instrument which could be used to readily identify areas of high energy gamma exposure and which could be used to readily determine the high energy gamma exposure rate.

II. INSTRUMENT DEVELOPMENT

Reasonable criteria for such an instrument are:⁴

- a. The instrument should be portable;
- b. It should be capable of operation in radiation fields of up to 50 mR/hr.
- c. It should be capable of energy discrimination for photons in the 5-10 MeV range.

d. The discriminator used must be fast.

A tunnel diode monostable multivibrator provides a simple, sensitive amplifier discriminator capable of operation at count rates in excess of the maximum available from the NaI(Tl) scintillation crystal. By connecting a sensitive discriminator directly to the multiplier phototube anode circuit, it is not necessary to amplify and process the pulses below the discrimination level. This application requires only determining the count rate of the detected high energy photons and thus the principle problem was determining if pulse pile-up from low energy high count rates would cause unacceptable error. An experimental approach was used to study this problem.

The tunnel diode monostable multivibrator circuit was designed (see Figure 1) and tested using a 3 in. x 3 in. NaI(Tl) crystal,⁶ a rate meter and standard 10 μ Ci sources of ^{60}Co and ^{54}Mn (see Figure 2). An output pulse width of approximately 0.5 microseconds was selected to be compatible with portable instrument count rate meters readily available.

The tunnel diode bias level was adjusted to pass pulses from ^{60}Co photon (average energy of 1.25 MeV) interactions but not those from ^{54}Mn photons (energy of 0.84 MeV). With the ^{60}Co and ^{54}Mn sources on the crystal, an additional 30 μ Ci of sources emitting photons of energy less than 1 MeV were placed on the crystal with no change in the counting rate. A second test was conducted using an old radium gamma source which has daughters emitting gammas up to about 2.5 MeV. The discriminator was again adjusted to pass everything over 1 MeV. Tests were conducted in fields of 1 to 4 mR/hr and using various voltages on the photomultiplier tube. The results

indicated that a 1 in. x 3 in. NaI(Tl) crystal should operate satisfactorily in a 35 mR/hr field without excessive anode current or pulse pile-up.

To quickly verify this conclusion, the system was modified by using a 1 in. x 2-1/4 in. NaI(Tl) crystal which was on hand. To extend the operational limits, shielding was provided by a sheet of 1/8 in. x 48 in. x 12 in. lead wrapped around the crystal and photomultiplier tube^{7,8} so that the crystal was four inches from the end of the tube (see Figure 3).

To evaluate the rate meter readings, it is necessary to know the full-energy peak efficiency of the detector. Preliminary efficiency was determined by using three calibrated sources and three (p, γ) sources from reactions initiated by a 2 MeV positive ion Van de Graaff accelerator. The sources and yields are listed in Table 1.⁹⁻¹⁷

To determine the full-energy peak yields, the detector was connected through a preamplifier and amplifier to a multichannel analyzer system. The sources were arranged to simulate streaming photons (near normal incidence on the crystal). To assure good statistics, sufficient times were used to accumulate several thousand counts per peak. The full-energy peak efficiency is roughly constant for the interval 5-8 MeV.¹⁸ Therefore, if the discriminator is set at about 5 MeV, the detection is due primarily to full-energy peak contributing interactions and remains roughly constant over the range of interest (6-7 MeV). The results indicated a full-energy peak efficiency for near normal incident photons in the 6-7 MeV range of about 0.10 percent^{6,7,19} (see Figure 4).

With the tunnel diode biased at a stable point, adjustment of the high voltage on the photomultiplier tube can determine the level of discrimination.

Using a multichannel analyzer and a ^{60}Co source, the discrimination level was set at about 5 MeV. The discrimination level was checked with 6 and 7 MeV photons from the $^{19}\text{F}(\text{p},\alpha,\gamma)$ reaction and 5.3 MeV photons from the $^{26}\text{Mg}(\text{p},\gamma)$ reaction.

Several twenty-minute counts were made with the system using a scaler in place of the rate meter. The results are shown in Table 2.

The cosmic radiation background in this area has been determined to be about 20 counts/minute.

To determine the possible range of discrimination for this circuit, a table was made of tunnel diode bias voltage, V_{Bias} , versus mercury pulser settings for an operating voltage of -4.989 volts D.C. (see Table 3). The charge sensitivity under these conditions was 15 picocoulombs and the pulser setting of 100 corresponded to 1 MeV. Thus, by varying bias level, the tunnel diode has the capability to discriminate at any energy level within the range of interest.

A study was made of the stability of the tunnel diode²⁰ and the results indicate that the peak voltage shift and the peak current shift are on the order of 0.1 percent/ $^{\circ}\text{C}$. Discrimination level error due to temperature variation was therefore considered acceptable under normal ambient conditions.

III. FIELD EXPERIENCE

Two surveys were made around reactors using the high energy gamma rate meter and a cutie-pie. The first survey was conducted in the 105-KW Bldg., and was a check as to the location and direction of the high energy photons and to determine the strength of gamma fields in which the instrument could

be used (see Table 4). The cutie-pie was calibrated with a radium gamma source. An auxiliary ^{60}Co source which gave about 3 R/hr exposure rate on the surface of the cutie-pie was used for comparison during the surveys. The high energy gamma flux indicated by the rate meter was converted to an exposure rate using a standard conversion.²¹

The second survey was conducted in the 105-KE Bldg. after the system was made a little more portable and other reactor operation areas were questioned in regard to high energy photons. The two buildings and operations were identical and would yield information applicable to both. The data are shown in Table 5.

Measurements made in the work area in front of the operating reactors indicated a 4 percent increase in exposure rate due to high energy gammas. The response of the detector was not directionally dependent in this area. On the elevator at the center of the core, the response was highly directional indicating the streaming nature of the high energy gammas. The response was also highly dependent on the area of the face being surveyed. The highest count rates were measured at the ends of the process tubes. Between the tubes, the count rates were 98 percent lower. The response was reduced more than half when the detector-shield was placed orthogonal to the end of a process tube. At the back rail of the elevator, the directional dependence increased to more than a factor of three. In the gamma monitoring room where there is considerable shielding material and scattering of gammas, the response of the detector was again direction independent.

Experiments conducted in the past have shown that the cutie-pie response in some reactor areas would about double when as much as five centimeters of plastic was placed in front of the ion chamber.^{3,4} In the surveys described in this paper, the cutie-pie/rate meter ratios varied from 0.006 between the process tubes to 2.5 in front of the sampling trough in the gamma monitoring room. These ratios are reasonable build-up factors for 7 MeV gammas in equilibrium.²²

IV. CONCLUSIONS

An instrument has been devised to measure high energy photon radiation streaming from a directional source. The instrument will operate in fields of about 200 mR/hr of lower energy photon radiation (⁶⁰Co, radium gamma and activation background) without appreciable pile-up. The instrument will discriminate against these lower energies and still show high count rates (test 8.0×10^6 /min) for photons of energies above a preset level (about 5 MeV during field testing).

The initial criteria set for the instrument have been met with the exception of total portability. This criterion can be attained with a conventional portable power supply.

V. RECOMMENDATIONS

It is recommended that a prototype instrument be assembled using the following additional criteria:

- a. The detector to be a 1 in. x 4 in. CsI(Tl) cylindrical crystal.

The 1 in. diameter helps to limit the total photon flux incident on the crystal, and, therefore, makes possible the use of the

crystal in high background photon fields without excessive anode current from the photomultiplier tube. The long crystal will increase the efficiency of the detector for high energy photons by increasing the probability of an interaction of an incident photon with the crystal. The use of a CsI(Tl) crystal will increase the efficiency of the detector by increasing the electron density in the crystal. Consideration must be taken of the decay time of the CsI(Tl) crystal if the detector is to be used in high energy high count rate photon fields. The decay time for CsI(Tl) is 1.1 microseconds while NaI(Tl) has a 0.25 microsecond decay time.

- b. Additional points on the efficiency curve need to be provided from sources such as ^{24}Na and $^{13}\text{C}(p,\gamma)$. Additional points in the 3-5 MeV range would provide a more solid basis for extending the curve by the relative yield method.

TABLESTABLE 1FULL-ENERGY PEAK EFFICIENCY SOURCES

<u>Source</u>	<u>Energies (MeV)</u>	<u>% Per Disintegration or Relative Yield</u>
^{22}Na	0.511, 1.274	179.7, 99.95
^{88}Y	0.898, 1.836, 2.734	91.4, 99.4, 0.62
^{60}Co	1.17, 1.33	99.74, 99.85
$^{26}\text{Mg}(\text{p}, \gamma)$ $E_p = 661 \text{ keV}$	2.75, 5.32, 5.86, 7.84	1:1:1.3:2.4
$^{27}\text{Al}(\text{p}, \gamma)$ $E_p = 992 \text{ keV}$	1.78, 10.76	1:1
$^{19}\text{F}(\text{p}, \alpha, \gamma)$ $E_p = 598 \text{ keV}$	6.13, 7.12	---

TABLE 2RESPONSE OF DETECTOR-DISCRIMINATE
SYSTEM IN RADIATION FIELDS

<u>Run</u>	<u>Source</u>	<u>Counts/Minute</u>
3	$^{19}\text{F}(\text{p}, \alpha, \gamma)$, 6-7 MeV + 50 mR/hr ^{60}Co	42.1
4	$^{19}\text{F}(\text{p}, \alpha, \gamma)$, 6-7 MeV + 30 mR/hr ^{60}Co	34.3
5	$^{19}\text{F}(\text{p}, \alpha, \gamma)$, 6-7 MeV + 50 mR/hr ^{60}Co	39.7
6	$^{19}\text{F}(\text{p}, \alpha, \gamma)$, 6-7 MeV only	31.7
7	50 mR/hr ^{60}Co only	21.7
8	30 mR/hr ^{60}Co only	21.5
9	Background only (934 min.)	21.4

TABLE 3

CALIBRATION OF TUNNEL DIODE

<u>V_{Bias}</u>	<u>Pulser Setting</u>
-0.0591	100.5
-0.0543	192
-0.0498	310
-0.0468	411
-0.0441	514
-0.0421	601
-0.0398	704
-0.0377	809
-0.0357	910
-0.0341	1000

TABLE 4

SURVEY OF 105-KW BUILDING WITH A CUTIE-PIE
AND HIGH ENERGY GAMMA RATE METER

<u>Position</u>	<u>CP</u>	<u>Rate Meter</u>	
	<u>(mR/hr)</u>	<u>(c/m)</u>	<u>(mR/hr)*</u>
On floor - center of face	5	3.0×10^2	0.2
Middle of Row 11 on elevator front rail	20	7.50×10^2	0.5
End of tube	25	2.6×10^4	18.3
Center of elevator	10	1.2×10^4	8.4
Back rail	7	8.0×10^2	0.6
Back rail	7	5.0×10^3	4.1
Between tubes	50	4.0×10^2	0.3

*Interpreted from c/m using relationships from the Radiological Health Handbook.

TABLE 5

SURVEY OF 105-KE BUILDING WITH A CUTIE-PIE
AND HIGH ENERGY GAMMA RATE METER

<u>Position</u>	<u>CP</u>	<u>Rate Meter</u>	
	<u>(mR/hr)</u>	<u>(c/m)</u>	<u>(mR/hr)*</u>
In front of first tube bundle back wall	6	2.0×10^4	14.0
Next to tube bundle	170	3.8×10^5	270
By east gate of monitoring room	6	1.4×10^4	9.8
In front of 3L	7	5.4×10^3	3.8
Wall in front of 3L	2	7.0×10^3	4.9

*Interpreted from c/m using relationships from the Radiological Health Handbook.

FIGURE 1. FAST DISCRIMINATOR

FIGURE 2. DETECTOR SYSTEM

FIGURE 3. DETECTOR

FIGURE 4. FULL-ENERGY PEAK EFFICIENCY OF A 1" X 2-1/4" NaI(Tl) CRYSTAL

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