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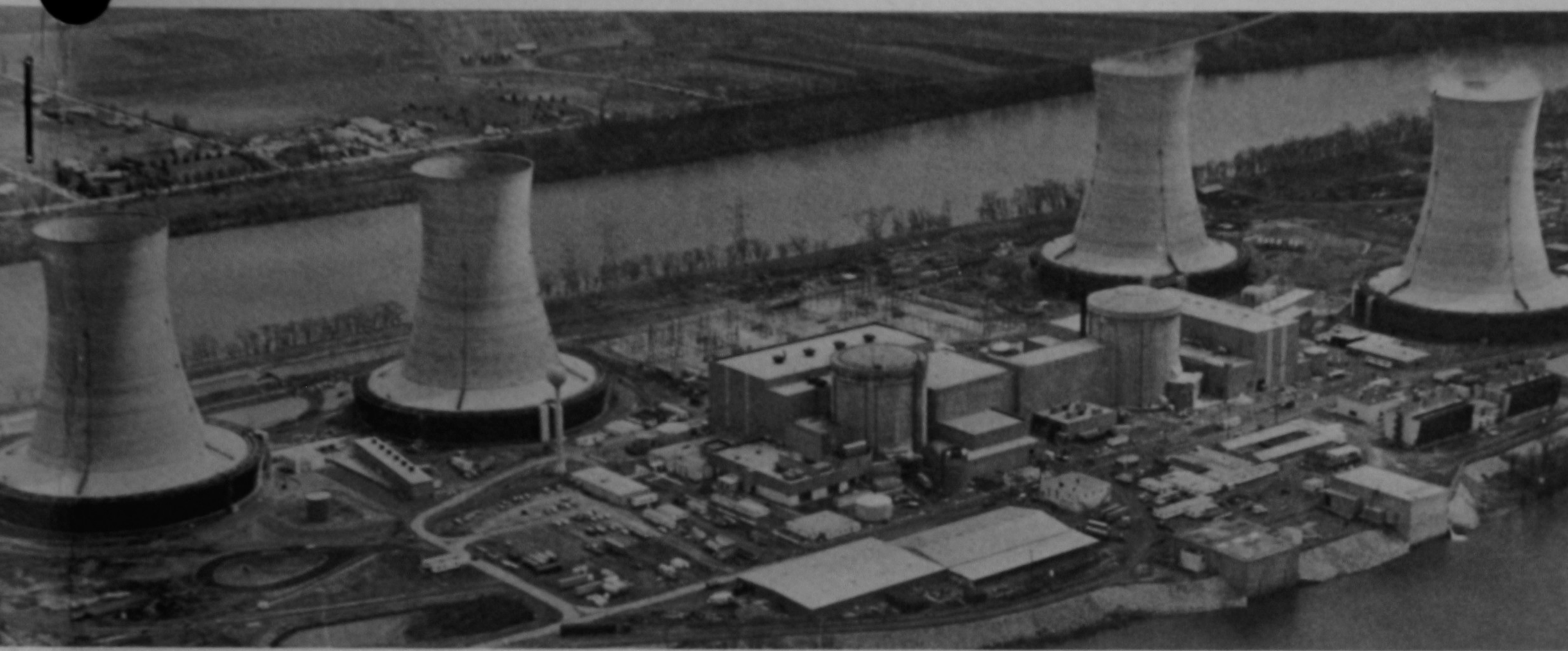

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QUICK LOOK REPORT ON HP-RT-0211 MULTIVALUED BEHAVIOR

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Prepared for the
U.S. Department of Energy
Three Mile Island Operations Office
Under DOE Contract No. DE-AC07-76ID01570

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ABSTRACT

Area Radiation Monitor, HP-RT-0211, was one of several Geiger-Müller (GM) detectors located within the Three Mile Island (TMI) Unit 2 containment. The monitor was intended for normal plant operation. During the accident on March 28, 1979, the unit appeared to operate for a short time. Following what might have been the initiation of the reactor building pressure transient and subsequent building spray, the monitor signal disappeared from the strip chart, but reappeared later. The recorder chart drive appears to have jammed and stopped driving the chart. For a period of time, no data were obtained. Manual data collection was resumed later and continued until the instrument was removed for examination. During the examination, the detector exhibited a multivalued behavior when exposed to very high radiation levels.

SUMMARY

HP-RT-0211, an area radiation monitor, was installed at the 350-ft elevation of the TMI Unit 2 reactor building. The monitor is a GM detector, Model 857-2, made by Victoreen Instruments, Inc. The unit failed and eventually was removed from the containment for examination. Sandia National Laboratory (SNL) performed the examination.[1] One peculiar behavior observed during the examination was the decrease and rise of the detector output as the unit was exposed to increasing radiation levels (see Figure 1). This phenomenon was observed only when an RG-58 coaxial cable connected the detector output and the associated Victoreen Model 856-2 ratemeter.

To eliminate uncertainties about whether or not the observed behavior is peculiar to HP-RT-0211, three new units in addition to the SNL test unit were also exposed to the high radiation level condition with the long coaxial cable. The test was carried out at Sandia's Gamma Irradiation Facility with the participation of representatives from EG&G Idaho, Victoreen Instruments, and Sandia.

All four detectors exhibited idosyncratic behavior when exposed to very high radiation fields. The degree of depression, however, was not as pronounced as on the HP-RT-0211. The Sandia test unit, because it had been exposed earlier to some appreciable dose, exhibited a lower depression than did the three new and previously unexposed units.

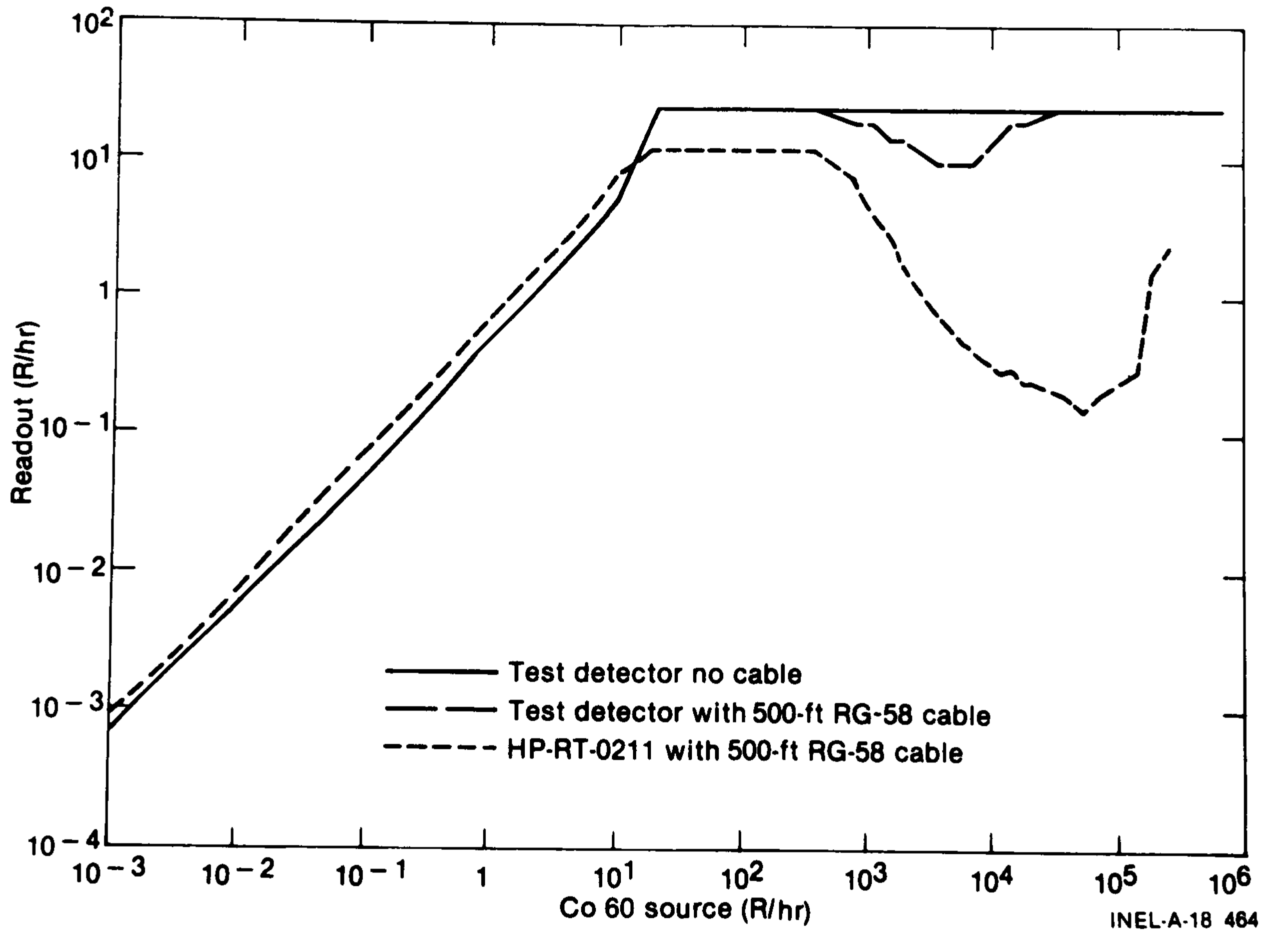

Figure 1. Multivalued radiation measurement for three detector conditions.

ACKNOWLEDGMENTS

M. B. Murphy of SNL provided the technical supervision for technician G. F. Müeller. Bob Ulman of Victoreen Instruments also provided technical support for the examination.

Thanks to Paul A. Amperex for the technical information he furnished about the GM tube.

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QUICK LOOK REPORT ON HP-RT-0211
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INTRODUCTION

The HP-RT-0211 was one of the area radiation monitors in the Three Mile Island (TMI) Unit 2 containment. During the accident on March 28, 1979, the monitor indicated a steep rise in radiation level approximately six hours into the accident. The reading peaked to approximately 180 mR/hr followed by a rapid drop until it went down below scale. An in situ test performed on the unit indicated a bad output drive transistor. This finding was later confirmed when the detector was removed from the containment and examined. A new transistor (identical to the original) was installed; and an extensive test was performed on the detector at Sandia National Laboratories. During the examination, the detector exhibited a multivalued behavior when subjected to a very high radiation level.

This report describes the testing and results, and the causes for the multivalued behavior. Recommendations are presented for correcting deficiencies and improving design.

PRELIMINARY EVALUATIONS

Five identical radiation monitors, (three new units, one Sandia test unit, and HP-PT-0211) exhibited a depression past the saturation level when subjected to a very high radiation field. This inherent characteristic of the GM detectors constitutes a dangerous condition as the monitors could indicate low radiation reading where an intense radiation level may exist.[2,3]

The three new detectors (serial numbers 1340, 1370, and 1377) exhibited a slight depression in their output while HP-RT-0211 had the lowest depression. Tests to determine the cause of the magnitude of the depression indicated that the phenomenon is directly related to the degree of degradation exhibited by the GM tube in HP-RT-0211.

The multivalued behavior of the Victoreen GM monitors was determined to be the result of two factors not recognized in the design:

1. The impedance mismatch between the detector output circuit and the coaxial cable attached to it

2. The GM tube/circuit interactions above the antijam point.

Objectives

The supplementary test on HP-RT-0211 met two objectives:

1. To determine the cause of the detector's multivalued behavior

2. To evaluate the effect of the radiation dose on the overall characteristic of the Victoreen GM detector.

Equipment and Instruments

1. Oscilloscope

2. Ionization Counter, Victoreen

3. Brush recorder

4. Ratemeter, Victoreen model 856-2

5. New GM detectors--Victoreen model 857-2, serial numbers 1340, 1370 and 1377.

ANALYSIS RESULTS

Impedance mismatch between the detector ouput drive and the transmission cable was determined to be one cause of the multivalued behavior of the Victoreen GM radiation monitors. The output drive resistors R20 and R21 (see Figure 2) are 100 ohms while the cable characteristic impedance is 50 ohms.[4] At low frequencies the mismatch did not affect the detector output; however, at very high radiation rates, the frequency approached 100 kHz and hence, the output.

The ratemeter input appeared as an open circuit for the steady-state signal from the detector. This open circuit, combined with the mismatched driver, set up reflections in the cable that produced the same effect as filtering the signal. Since the ratemeter circuit is a linear log pump, both the amplitude and the frequency of the signal affect readout accuracy. Figure 3 illustrates the effects of the mismatch on the waveform. Mathematically, for a voltage, Va, propagating down a coaxial cable of characteristic impedance, Zo, the voltage across the load resistor, R_L, is equal to (1 + R) Va. R is the reflection constant and is equal to

$$R = \frac{Z - Zo}{Z + Zo} \tag{1}$$

where Z is the termination impedance. A voltage, RVa, is reflected back down the cable. With a value of $R_L = \infty$, R is equal to 1, and Va is reflected. This voltage travels the length of the cable and impinges at the detector end where it is only partially reflected due to the improper termination. The process continues, and for a voltage step at the detector end, the resultant waveform at the ratemeter shows a series of upward (or downward) steps. The width of each step is equal to $2T_D$ where T_D is the time required for the signal to propagate the length of the 500 feet of cable. If the detector output square wave reaches a frequency high enough to have a period that is of the same order of magnitude as T_D, a substantial rolloff of the waveform will result. Figure 4 shows an oscilloscope picture of this condition.

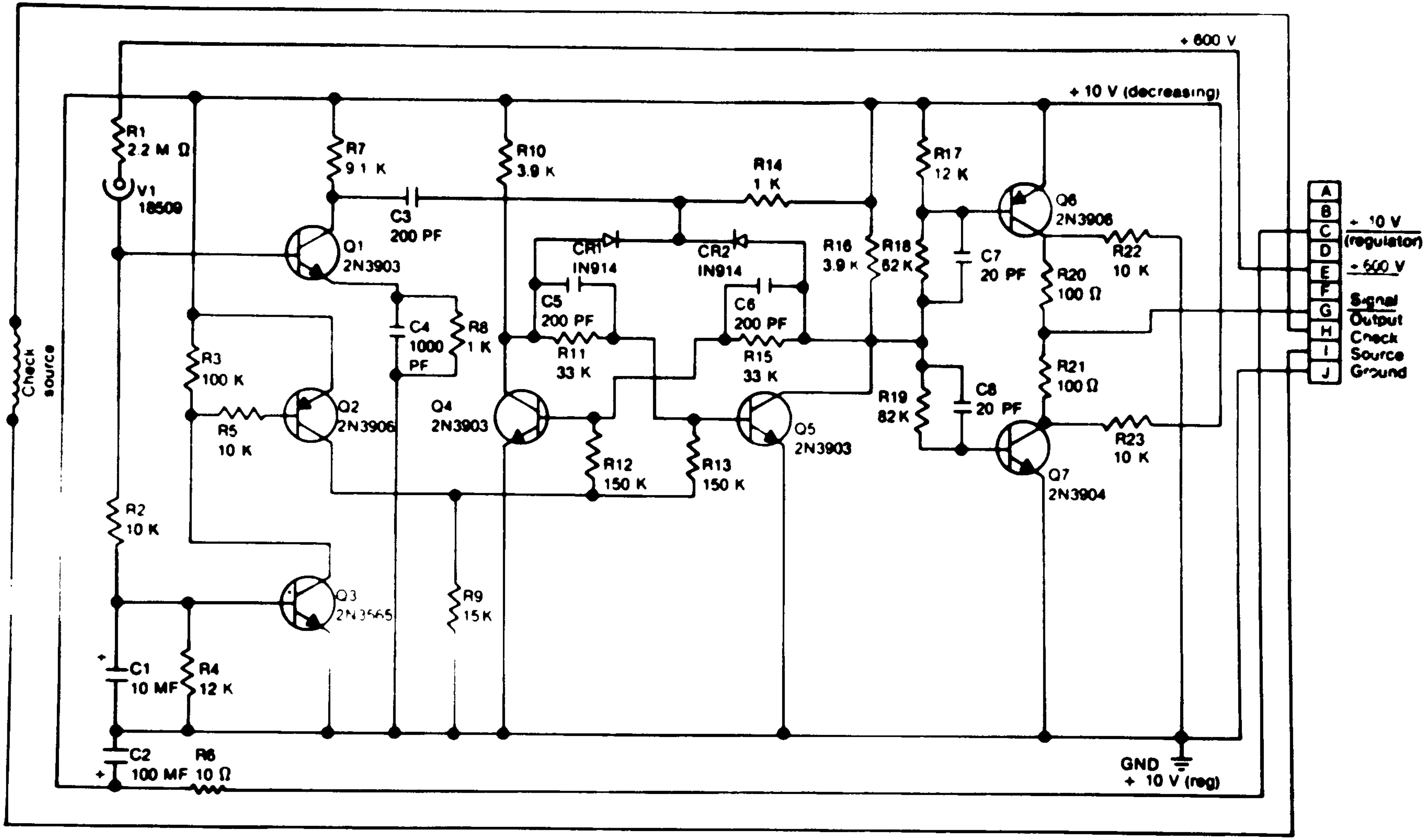

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Figure 2. Detector schematic--GM tube and antijam circuits on the left, flip-flop in the center, and the output driver on the right.[5]

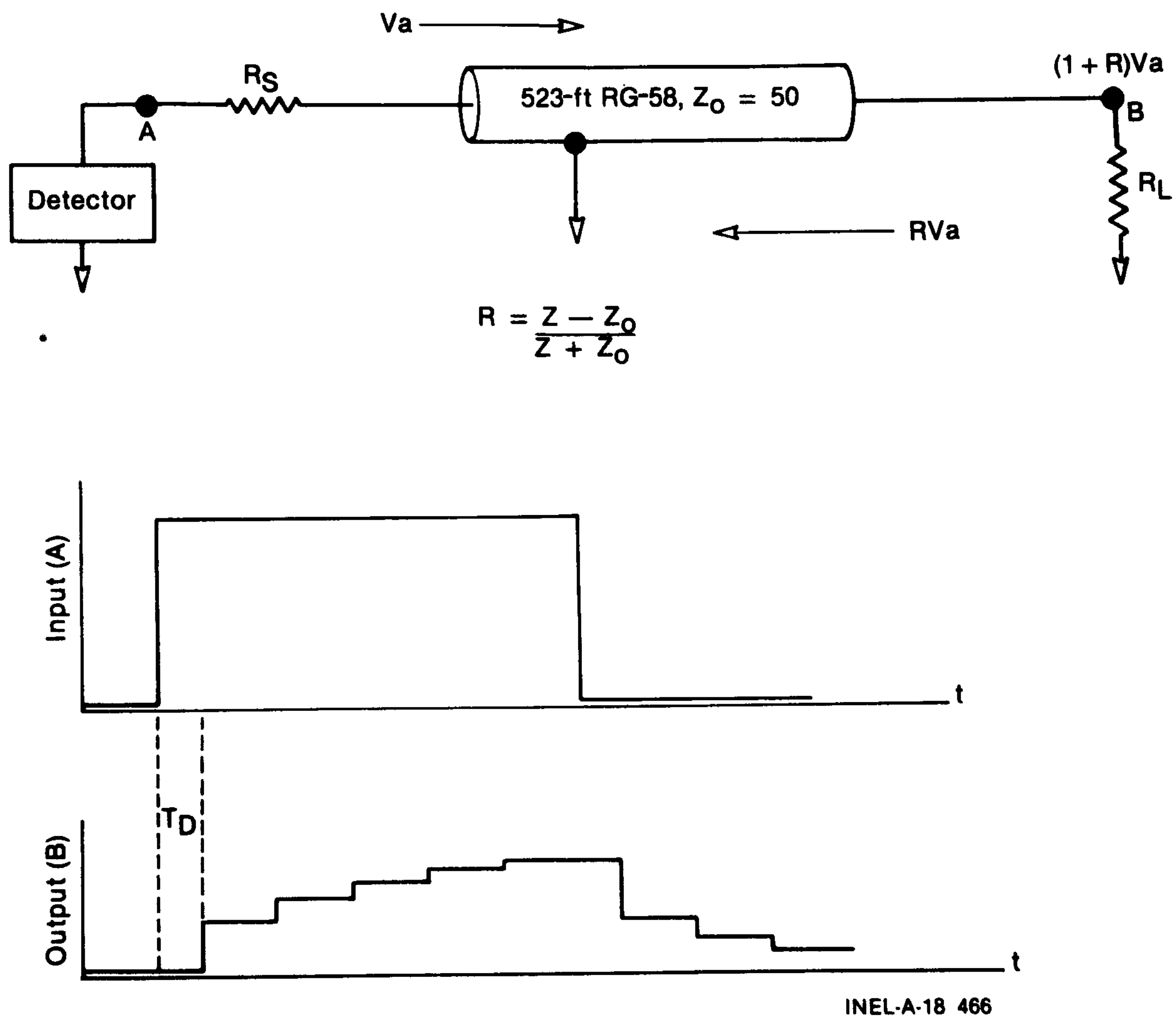

Figure 3. Input and output waveforms for a mismatched transmission line ($R_L = \infty$).

Figure 4. Mismatch filtering: Top trace of both photos in the transmission line input; bottom trace is the output voltage. Input frequencies: 50 kHz for left photo; 100 kHz right photo. R_S = 250 ohms and R_L = ∞ for both photos.

HP-RT-0211's lower depression is attributed to decreased transistor gain. Transistor gains are degraded when exposed to gamma radiation. Consequently, less output current will result from a specific base current. This condition is similar to a circuit in which the load impedance is increased. In the case of the HP-RT-0211, because the Q6 and Q7 transistors had been degraded, the output current decreased. The cumulative effect was equivalent to approximately 270 ohms source impedance. This has the effect of further impedance mismatches and more pronounced reflections.

The second major cause of the anomaly as described was continued GM tube pulsing of the multivibrator circuit even after the antijam circuit had begun to control the multivibrator frequency. The antijam circuit did not disable pulse amplifier Q1, and allowed GM tube output interference. This pulsing increased the detector square wave frequency until the reflection time T_D became a significant factor. More "filtering" or rounding of the signal waveform was thus produced. The TMI detector GM tube behaved differently from the one in the new test detector as tubes were interchanged. The TMI GM tube apparently had been changed or degraded by the radiation exposure. This degradation was expected since some of the quenching gas in the tube is dissociated at each discharge;[6] consequently, after exposure to high radiation doses, quenching will become erratic. The precise GM tube mechanism for causing the observed interaction has not been pinpointed, although an attempt was made to monitor several internal circuit nodes.

The approach toward recovery shown above 100,000 R/hr in Curve C of Figure 1 was presumably due to fewer GM tube interactions, and a lowering of output frequency. The frequency stabilized at a value determined by the antijam/free-running multivibrator combination. The cable drive was still inadequate and reflections still occurred; however, the lowered frequency signal was not "filtered" as much.

RECOMMENDATIONS

As discussed above, the causes of the multivalued behavior of the Victoreen GM detector 857-2 are (a) impedance mismatch between the detector and the cable, and (b) interaction between the GM tube pulse amplifier and the antijam circuit. The deficiencies noted can be rectified by some relatively simple changes in the circuit design. Specifically, the following changes would improve the detector characteristics:

1. Reduce R20 and R21 to approximately 50 ohms to properly match the 50-ohm coaxial cable

2. Employ higher radiation-tolerant transistors in the Q6 and Q7 transistor slots

3. Increase the base drives to Q6 and Q7

4. Disable the GM tube pulse output to the multivibrator when the antijam circuit is operational.

Although they are not necessary to correct this problem, two improvements in circuit design could be made in the ratemeter:

1. Terminate the coaxial cable in 50 ohms to prevent reflections. (This would require gain changes in the ratemeter differential amplifier.)

2. Employ a zero-crossing comparator circuit to reconstruct the detector square wave and thus make the ratemeter input amplitude insensitive. (A new P.C. board layout would be required.)

Although the problem was discovered on a Victoreen model, similar problems could exist in other makes of GM detectors. In view of the discovery made on the Victoreen GM detector, it is strongly recommended that an action be initiated to have ANSI N42.3-1969/IEEE Std. 309-1970 (Standard Test Procedure for Geiger-Müller Counters) revised to incorporate a new test requirement. The test should involve subjecting all untested GM detector models to high radiation (approximately 100,000% overload) with a conservative length-of-signal transmission cable attached.

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