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AEC RESEARCH AND DEVELOPMENT REPORT

A HIGH LEVEL GAMMA ALARM FOR CRITICALITY MONITORING

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Savannah River Laboratory

Aiken, South Carolina

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Instruments
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A HIGH LEVEL GAMMA ALARM FOR CRITICALITY MONITORING

by

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October 1964

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ABSTRACT

A monitor was developed that detects the gamma radiation from a nuclear accident and gives visible and audible alarms when the radiation exceeds a predetermined level. The instrument also gives a failure alarm when certain common internal malfunctions occur. Auxiliary alarm contacts are available for use with external alarm systems. The instrument is battery powered and, consequently, is unaffected by short-term power outages. A charger maintains the alarm battery at full power.

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A HIGH LEVEL GAMMA ALARM FOR CRITICALITY MONITORING

INTRODUCTION

A monitor that will adequately detect a criticality incident must meet stringent requirements of simplicity, positiveness of operation, freedom from false alarms, reliability, and versatility. The monitor normally will be unattended and subject only to occasional routine checks. The inclusion of automatic failure indication minimizes the time the monitor is not operating properly by indicating an immediate need for maintenance. Additional desirable features of a criticality monitor are operability during power failures, easy maintenance, and portability.

The instrument (Figure 1) was designed to incorporate these features. It is composed of five distinct units: detector, measuring circuit, alarm circuit, battery charger, and battery (Figure 2).

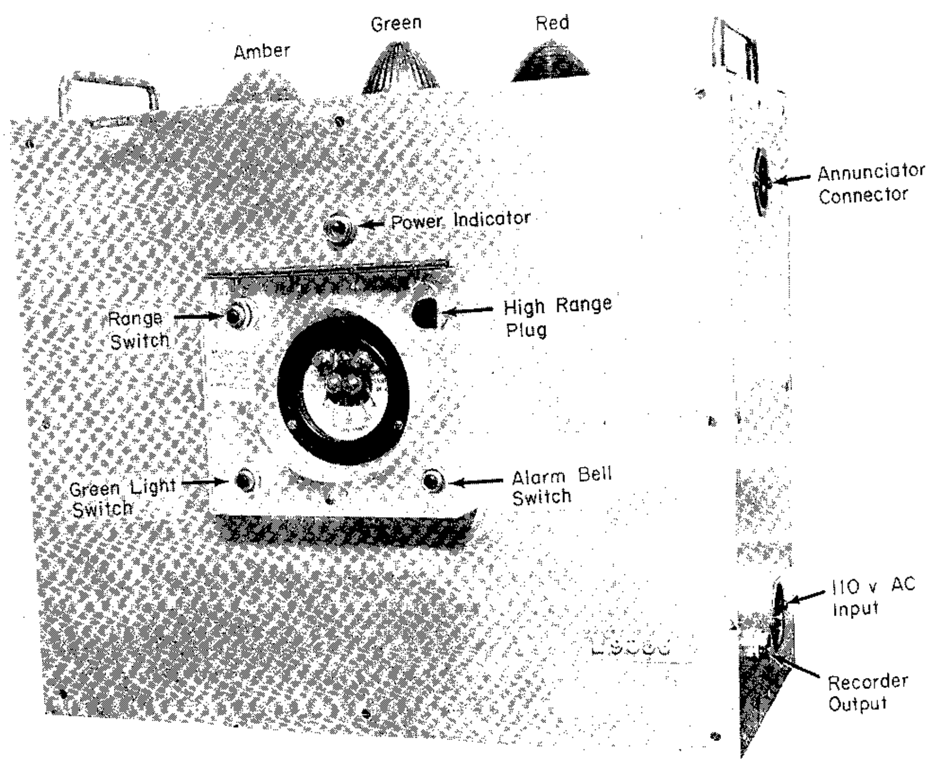

FIG. 1 CRITICALITY MONITOR

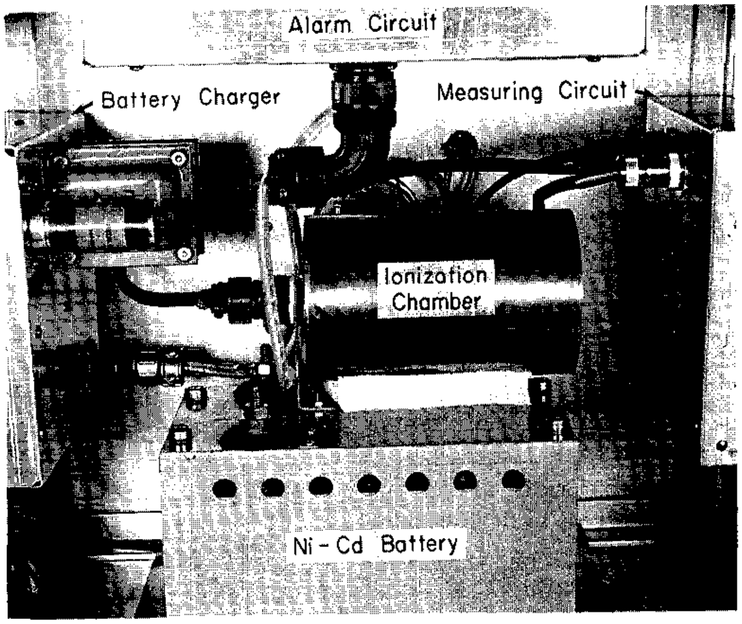

FIG. 2 INTERIOR CONSTRUCTION

DETECTOR

The detector is an ionization chamber of the Neher-White design (Figure 3). The chamber is filled with dry air at atmospheric pressure. The collector electrode and the electrometer tube control grid are connected together and are electrically floating. Polarizing voltages are such that the collector receives the positive ions in the chamber gas. Radiation at the chamber will cause an increase in positive ion current and the electrometer tube grid will stabilize itself at a potential to balance the ion current. The plate current - grid current characteristic of the electrometer tube is such that the plate current is proportional to the logarithm of the radiation field at the chamber.

The lead from the collector electrode to the electrometer tube control grid is the only high impedance lead, and leakage resistance to ground or to other electrodes must be of the order of 10^{15} ohms for proper operation. It is therefore convenient to mount the electrometer tube inside the chamber, which allows a very short, well-insulated connection between the control grid and collector electrode. The probe construction is shown in Figure 4. Several insulator materials were used to support the collector, but polystyrene gave most reliable results. The collector is aluminum foil and is connected to the control grid. Potting compound is used to anchor the tube and collector support.

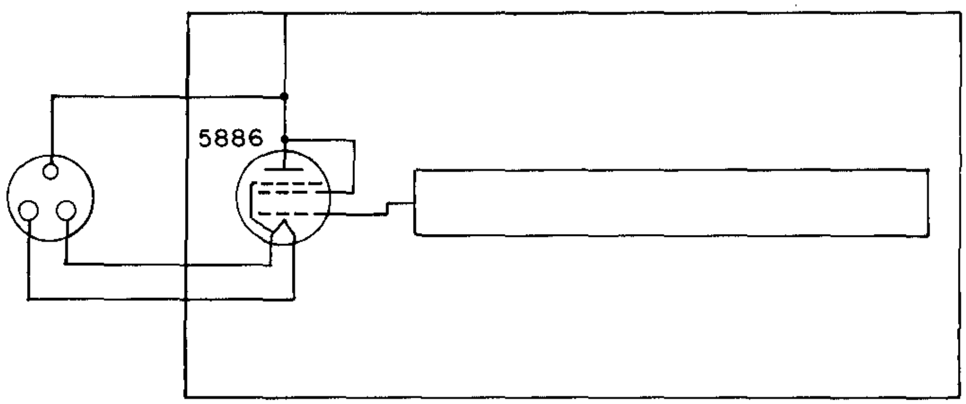

FIG. 3 CHAMBER CIRCUIT

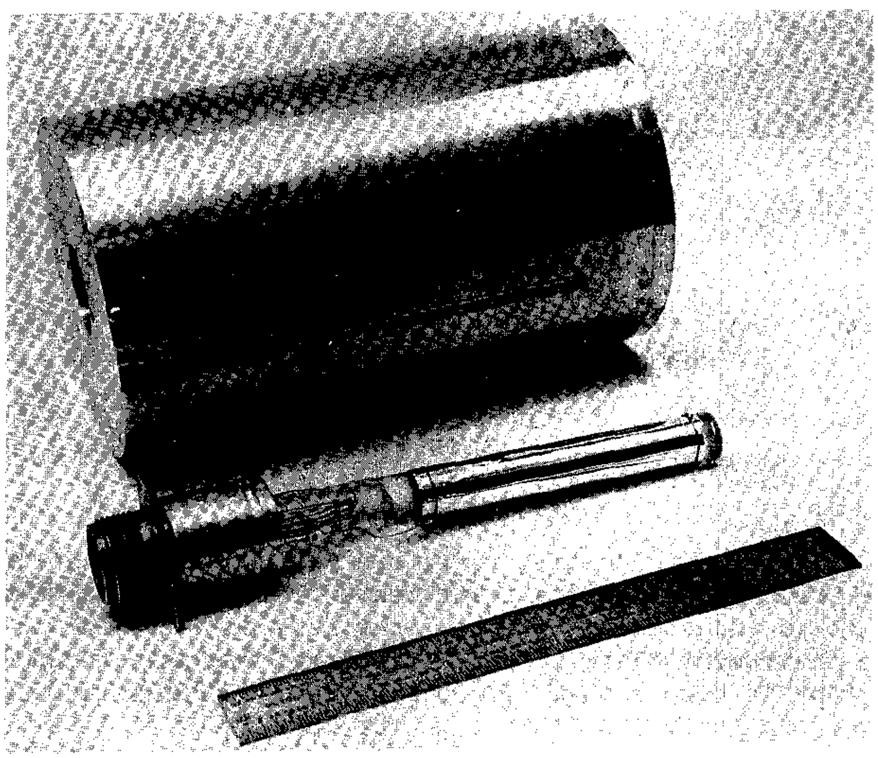

FIG. 4 CHAMBER CONSTRUCTION

The internal parts of the chamber (electrometer tube, collector electrode, and supporting parts) can be replaced if a tube fails. There is sufficient variation in tube parameters that each instrument must be calibrated to match its individual chamber and electrometer tube characteristics.

MEASURING CIRCUIT

A 50-microampere meter measures the plate current, which is an indication of the radiation level (Figure 5). This current will develop signal voltages to operate potentiometer-type recorders and auxiliary alarm units. A recorder output voltage is developed across potentiometer R_3, which is in series with the meter movement. Adjustment of R_3 provides an output voltage up to 25 millivolts for full deflection of the meter.

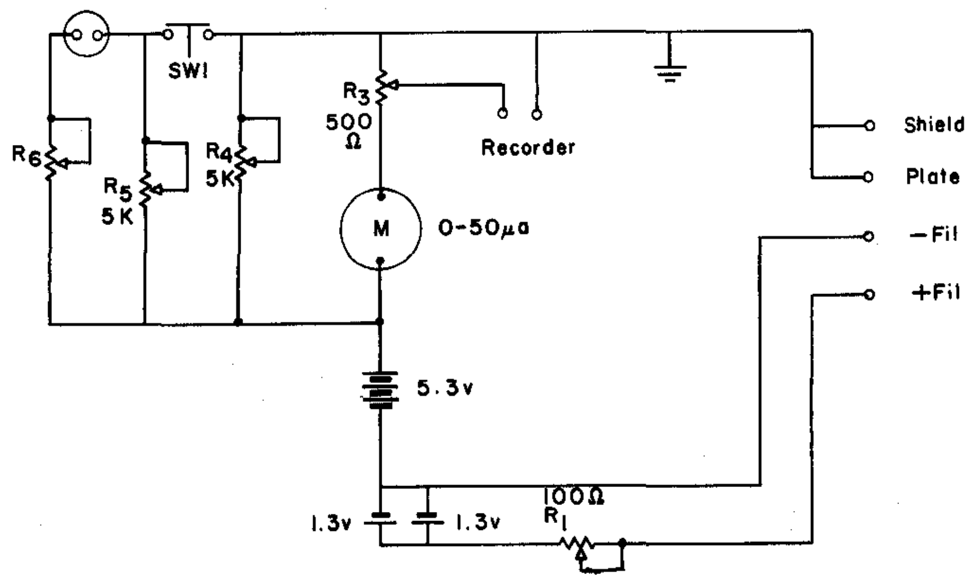

FIG. 5 RADIATION MEASURING CIRCUIT

The range-adjusting resistors R_4, R_5, and R_6 calibrate the three ranges of the instrument. The midrange or operating range is adjusted by R_5 to 10 r/hr full scale, which is also the instrument alarm point. This level was selected because 10 r/hr is high enough to provide freedom from false alarms caused by radiation sources in the instrument vicinity, and low enough so the radiation from a criticality event will be detected easily and rapidly.

One monitor at the Savannah River Laboratory is required to operate in a location where the radiation field is normally high and requires a 50 r/hr alarm point. This high range is adjusted by R_6 (Figure 5). A receptacle is mounted under the meter door so a high range plug will connect R_6 into the circuit. The high range plug is clearly visible through the meter door (Figure 1) and is identified by the yellow color of the insert. The normal 10 r/hr range plug is green in color and does not connect R_6 into the circuit. The high range is included in all monitors so they will be interchangeable.

A low range of 10 mr/hr for full-scale meter deflection is obtained by the adjustment of R_4 with the switch SW_1 open. This low range is desirable for testing purposes. A radiation source of this magnitude will not expose personnel to unnecessarily large amounts of radiation during routine testing. The range switch, SW_1 (Figure 5), is automatically operated when the meter cover (Figure 1) is opened. Opening this cover also disconnects the alarm bell and is part of the standard procedure for performing routine tests on instrument operation.

The measuring circuit is shown in Figure 5. The voltages necessary for electrometer tube and chamber operation are supplied by mercury batteries. Their long life and constant voltage characteristic are necessary to maintain measurement accuracy.

The tube filament power is supplied by two batteries in parallel, which provide stable operation for approximately four months. The life expectancy of the tube is increased by operating the filament at one volt. The filament voltage adjustment, potentiometer R_1, is shown in Figure 5.

The plate and chamber polarizing potential of 5.3 volts is supplied by four mercury cells in series. The battery current is less than 100 microamperes, so shelf life of six to twelve months is expected.

ALARM CIRCUIT

The alarm circuit shown in Figure 6 is controlled by the contacts on the meter relay. The meter relay signal coil is connected into the measuring circuit, and the meter deflection is an indication of the radiation level. The high and low current contacts on the meter relay provide the control function for the alarm circuit. The high level contact is set to close when the meter deflection is full scale, and the low level contact will close when the meter drops to 12 microamperes.

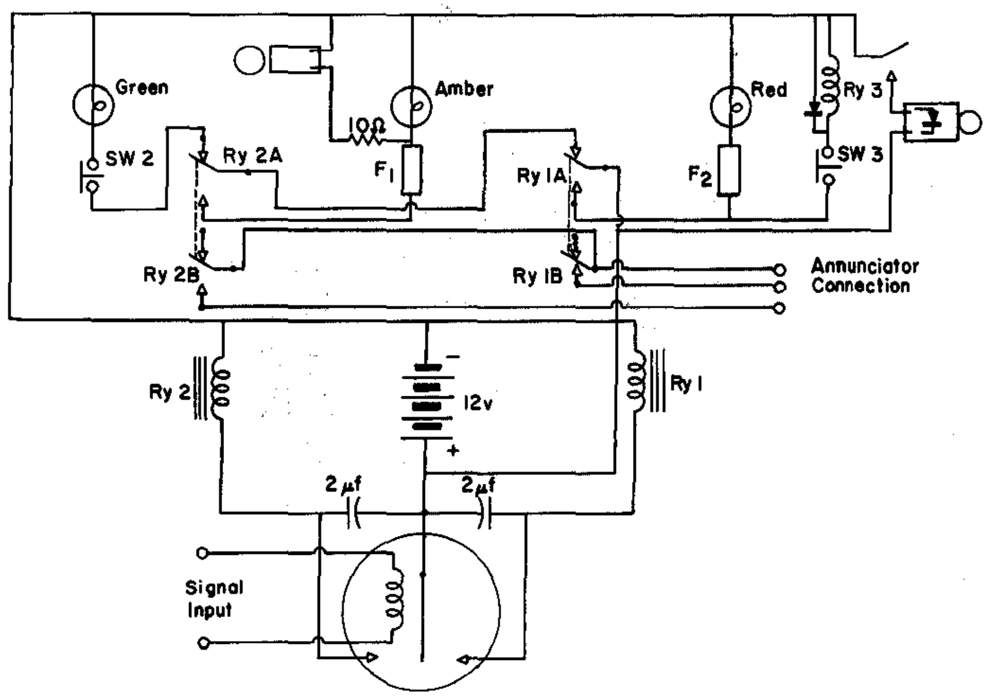

FIG. 6 ALARM CIRCUIT

If the radiation rises to 10 r/hr, the predetermined alarm level, the high level contacts on the meter relay close and lock magnetically. This contact closure energizes the high level alarm relay, Ry 1. Operation of Ry 1 extinguishes the green operation light and energizes the red alarm light and alarm bell. A flasher, F_2, is used in series with the light to turn it on and off. The alarm bell (Figure 7) is sounded continuously. When the radiation has dropped below 10 r/hr, the instrument is returned to normal operation by unlocking the meter relay contacts manually.

The instrument also indicates certain common internal malfunctions. Faults, such as a failure of the electrometer tube, the batteries or the meter coil, cause a downscale indication of the meter relay. A decrease in current from the normal operating level of approximately 25 microamperes closes the low level contacts on the meter relay. Closing these contacts energizes the low level alarm relay, Ry 2 (Figure 6). Operation of Ry 2 extinguishes the green normal operation light and actuates a flashing amber light. In addition a small bell is sounded intermittently. The flashing light and intermittent bell are controlled by the flasher, F_1. After the malfunction has been corrected, the instrument is reset by unlocking the low level contacts manually.

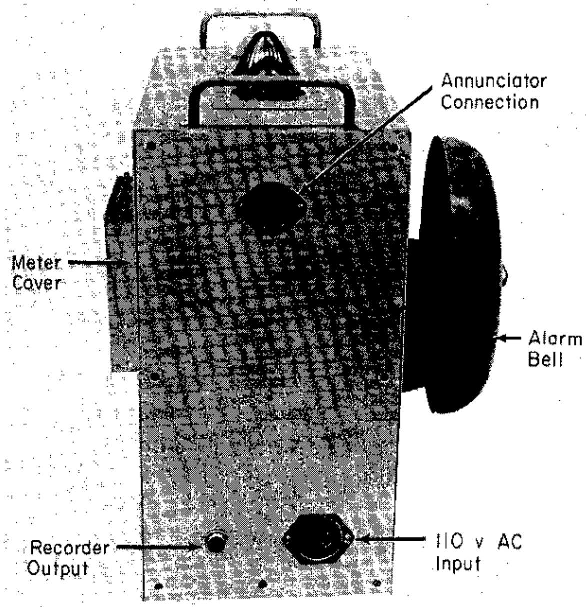

FIG. 7 SIDE VIEW OF CRITICALITY MONITOR

There is a second set of contacts on alarm relays, Ry 1 and Ry 2; these normally open contacts can be used to control remote alarms, indicators, or other devices that may be desirable.

The three indicator lights (Figure 1) give a visual indication of the instrument operating condition. The green light indicates the instrument is in the normal state of operation. A flashing red light indicates the preset radiation level has been exceeded. A loud, continuous bell alarm accompanies the red light. The flashing amber light indicates a malfunction within the instrument. A small intermittent bell is sounded with the amber light. The difference in the sound of the two alarm bells is quite distinctive.

Transients generated in the alarm circuit plagued the development of the monitor. These transients were reflected into the measuring circuit and paralyzed the detector. A radiation field applied to the chamber discharges these potentials through ionization current and returns the chamber to operation in a shorter period of time. The two 2-microfarad capacitors in the alarm circuit, shown in Figure 6, reduce the transients generated when the alarm circuit is reset. Diodes were used to reduce the transients generated in the bell circuit. The bell was dismantled to make the connection directly across the actuating coils. A diode was also connected acrcss the power relay, Ry 3. All the diodes are reverse-connected to suppress the transients generated by the collapsing fields.

BATTERY CHARGER

A nickel-cadmium battery powers the alarm circuit (Figure 8). The nominal voltage is 12 volts. This battery does not evolve gas when charged at the prescribed rate. The battery requires no maintenance; it is filled with electrolyte and sealed by the manufacturer. It delivers high peak currents and can be maintained in a fully charged state for long periods with a small charging current. It also has a very long life with many charge-discharge cycles.

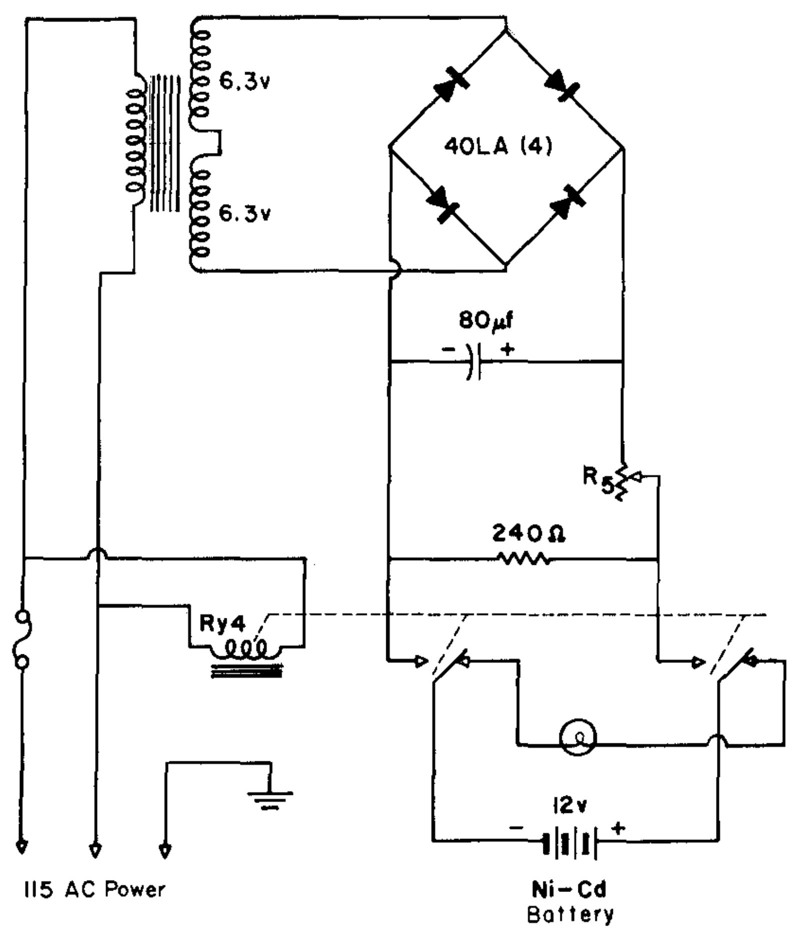

FIG. 8 BATTERY CHARGER CIRCUIT

The battery charger (Figure 8) is designed to conform to the manufacturer's battery charging specifications. A filament transformer is used with the secondaries connected in series. The AC power is rectified and filtered. The adjustable resistor, R_s, is set to provide 13.5 volts output with a load current of 0.420 ampere. The rectifier will supply 0.4 ampere to the green operational light and 0.02 ampere charging current to maintain the battery at full charge.

If power fails, the battery is of sufficient capacity to power the monitor for 12 hours. A power failure de-energizes Ry 4. The action of Ry 4 disconnects the battery from the charger and connects a small signal light to the battery. The "Power Off" signal light is located on the front panel directly over the meter, as shown in Figure 1.

OPERATION AND PERFORMANCE

Routine tests are made by opening the meter cover (Figure 1). This action automatically switches the range to 10 mr/hr, extinguishes the green operational light, and disconnects the large alarm bell. A gamma radiation source of sufficient strength to cause a 10 mr/hr field intensity at the chamber is needed to test the alarm relays. The high level contacts will lock magnetically and must be reset before the door is closed and secured. The second set of contacts on the alarm relays will also be actuated and any external connection must be considered before the instrument is tested.

The instrument performance and stability have been excellent. The drift of the recorded radiation level was approximately ±0.25 millivolt, which is equivalent to ±0.05 mr/hr. This drift occurred in recordings taken over a period of five weeks and includes the normal shifts in background radiation. A small chip of uranium mounted inside the chamber establishes a small residual ion current and suppresses the effects of background fluctuations.

The chamber was placed outside the laboratory and the fluctuations due to temperature were recorded. During the observation period, the outside temperature varied from 55 to 107°F. The variation of the recordings was approximately 0.5 mr/hr over this temperature range.

The instrument alarms in 0.8 second when subjected to a 10 r/hr radiation field; however, when subjected to a field of 100 r/hr, the alarm time is 0.3 second. Higher fields resulted in slightly faster response. The curves in Figure 9 show the time response to various radiation levels. The time constant for the chamber is given in the following table.

Radiation Level, r/hr	Time Constant, seconds
1.0	0.59
1.7	0.31
3.5	0.19
6.8	0.19
12.8	0.15
20.0	0.09
30.0	0.08

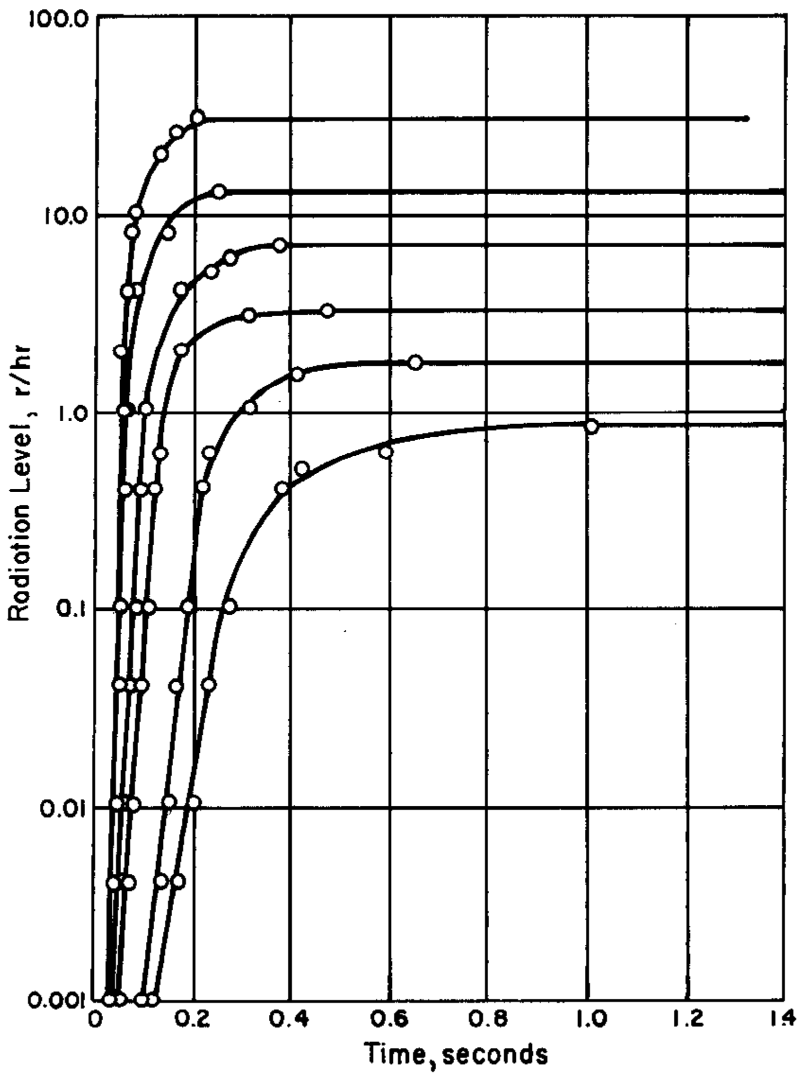

FIG. 9 TIME RESPONSE CHARACTERISTIC

INSTALLATION

The monitor installation in the laboratory provides two areas of alarm: the bell on the monitor gives the local alarm in the immediate vicinity; and an area alarm is sounded over a public address system throughout the building. The area alarm is connected to the second set of alarm contacts. These contacts are normally open, and close to complete either one of two circuits when the alarm relays are actuated. If an instrument failure alarm occurs, the circuit is closed that signals the control room of the failure and identifies the monitor that failed. If the high level contacts close to signal a nuclear accident, the circuit is closed that energizes the public address system. After a 5-second delay, the alarm is sounded throughout the building to initiate evacuation. An annunciator panel also identifies the location of the monitor that sounded the alarm. The building public address system is equipped with an "over-ride" control so that announcements may be made during alarm. After a 5-minute alarm, the public address system is automatically returned to normal control room operation.

A recorder output is provided for potentiometer-type instruments. An adjustable output signal voltage up to 25 millivolts is available for full-scale deflection of the meter relay. Since any criticality accident will create a radiation field that greatly exceeds the alarm level of 10 r/hr, a recorder that has a range extending well above the alarm level is used. The recorder has a span of 50 millivolts and will indicate the alarm level at midscale. The instrument response is logarithmic and the recorder span will cover radiation levels to approximately 10^8 r/hr. Normal background radiation and quiescent plate current in the electrometer tube will cause the recorder to indicate approximately 1/4 scale. The chamber response deviates slightly from a logarithmic response at the higher levels.

Ten monitors have been fabricated and installed in various locations throughout the Savannah River Laboratory.

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