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by

P.C. East and M.A. Periard

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Nuclear Effects Section
NBC Defence Division

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ABSTRACT

A plug-in module and detector are described which extend the range of the AN/FDR-502 Remote Reading Radiation Monitor and Alarm System from 100 mR/h down to background (10 to 15 μR/h).

The detector, an 18504 Geiger-Mueller tube, is connected to the control console by a single-core screened cable which can be up to 500 feet in length. (U)

RÉSUMÉ

Nous décrivons ici un panneau de contrôle et un détecteur qui étendent la portée du radiac, détecteur à distance AN/FDR-502 avec alarme, de 100 mR/h jusqu'au fond naturel de rayonnement (10 à 15 μR/h).

Le détecteur, un tube Geiger-Mueller 18504, est branché au panneau de contrôle par un câble avec âme et treillis métallique. Ce câble peut avoir jusqu'à 500 pieds de longeur. (NC)

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INTRODUCTION

The AN/FDR-502 is a high-level remote-reading gamma-radiation monitor and alarm system (1) that has been accepted for service in the Canadian Forces. This instrument has been designed for fixed installations, such as airfields and it has also been accepted for use on board ships.

The control console is built on a modular basis and ten channels can be accommodated in a 4½-inch-high standard 19-inch rack. In applications where ten high-level channels are not required front-panel space is available for alternative functions, such as an integrator (2), or a low-level channel as described in this note.

The addition of a low-level channel to a land installation offers a number of advantages:

1. It can be seen to measure radiation. This should enhance the interest of operating personnel in the equipment and could therefore be considered as a training aid.

2. When in operational use, that is monitoring radiation from fallout, the low-level detector could be used to monitor levels inside the headquarters building and to provide a warning if contaminated personnel enter the building.

3. During peace time it enables the equipment to be used as an environmental monitor. This will make its installation acceptable to a larger number of people and if the installation is near a nuclear power station it may be of some practical value.

For the installation on board ship, where lower levels of radiation from fallout can be expected, there is a direct application and a stated requirement (3) for a low-level detector to monitor the water intake and to warn of an increase in radiation at low levels.

GENERAL DESCRIPTION

The detector for the low-level channel is an 18504 Geiger-Mueller (G-M) tube. For this to be compatible with the AN/FDR-502 the signal to the digital readout must be an analogue voltage. To minimise fluctuations in the readout due to the normal statistical variations in the G-M-tube output, the

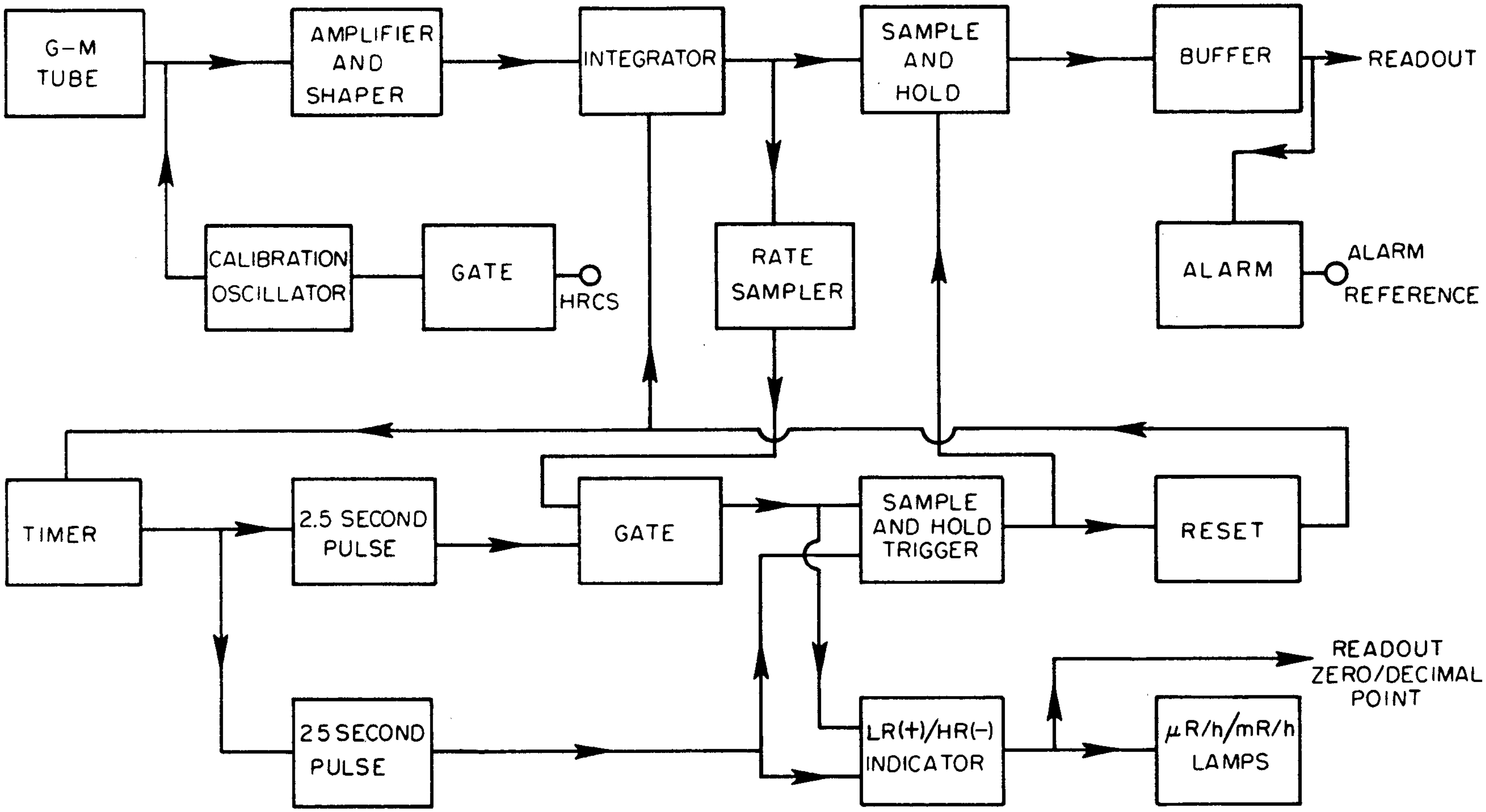


Figure 1. Block Diagram.

G-M-tube pulses are integrated for a fixed period and this voltage displayed during the following period. On the high range (HR) 2.0 - 99.9 mR/h, the integrating period is 2.5 seconds and on the low range (LR) 0 - 9,990 μR/h, the integrating period is 25 seconds. The 18504 tube gives 2,000 counts per second at 100 mR/h, so that these integrating periods give a statistical accuracy, one standard deviation, of 10% at 2 mR/h and 200 μR/h. The 2.5-second cycle gives a relatively fast response time on the HR and on the LR 25 seconds is acceptable. These times could be increased to extend the range, but since the readout accuracy is ±1 digit, ±5% at 2 mR/h and 200 μR/h, any further increase in the cycle time offers only a marginal increase in accuracy. However, for low-level or background monitoring where radiation conditions are relatively constant the better statistics of a longer cycle time makes it easier to detect small changes. A front-panel switch enables the cycle time to be increased by a factor of 10, to 250 seconds, on the LR and this permits consistent readings to be made down to 20 μR/h.

The system is illustrated in the block diagram of Figure 1. The G-M-tube pulses are amplified, shaped to a fixed amplitude and duration and fed to an integrator. At the end of each time interval or cycle the integrator output is sampled and held for display during the following cycle.

The integrator output is monitored by a rate-sampler and for exposure-rates below full scale deflection (FSD) on the LR a gate blocks the 2.5-second pulse and the cycle is controlled by the 25-second pulse. For exposure-rates above FSD of the LR the gate is open and the cycle is controlled by the 2.5-second pulse and the circuit is automatically switched to the HR.

The timing pulses also control the HR/LR indicator circuit which switches on or off the decimal point and fixed zero on the readout and illuminates the appropriate μR/h or mR/h indicator lamp.

DETECTOR

The detector is a Philips 18504 Geiger-Mueller (G-M) tube which, with a 550-volt dc-to-dc converter and an amplifier, is mounted in a 1¼-inch-diameter aluminum housing. A photograph of this unit is shown in Figure 2. The housing is fitted with a removable end cap so that β particles can be detected.

The detector is connected to the control console by a single-core screened cable. The length of the cable is limited by its capacity. For cable such as Alpha 1704 50/SP, with a capacity of 25 pF/foot, up to 500 feet can be used.

At the control console the cable is connected to the +20-volt supply via a 220-ohm resistor and to the signal terminal via a capacitor. At the detector (as shown in the detector circuit diagram of Figure 3) the cable is connected through a 220-ohm resistor to a voltage regulator MC7812 which provides a regulated 12-volt supply for the converter and amplifier.

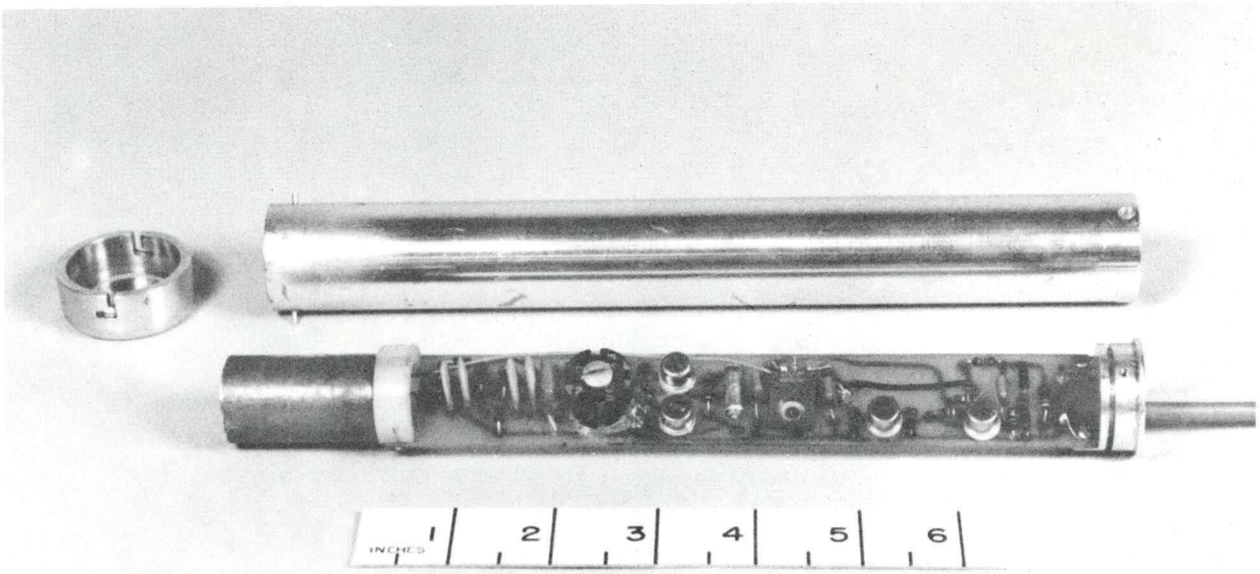
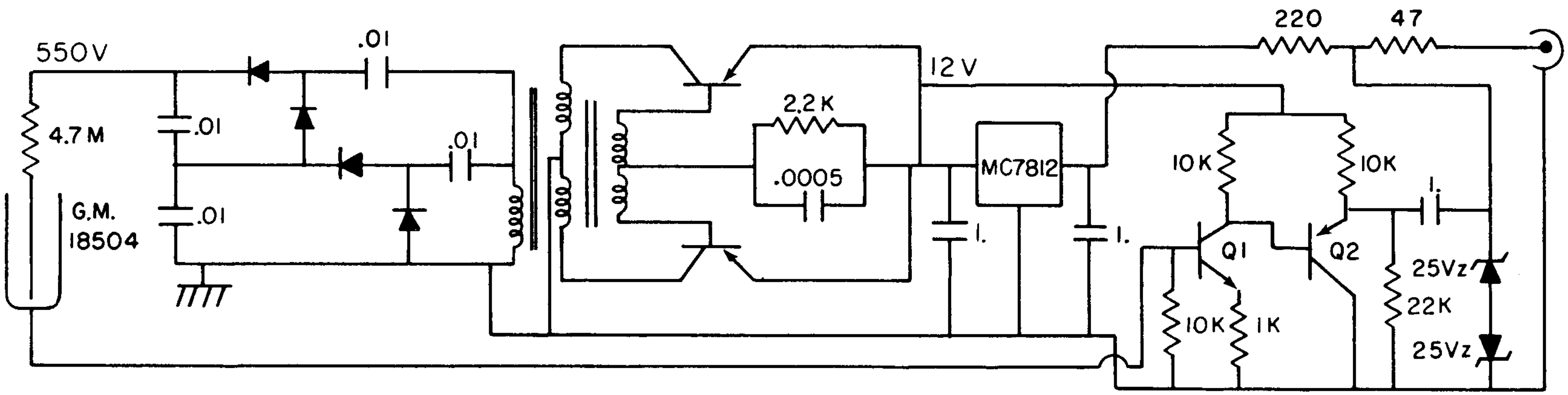


Figure 2. Detector.



RESISTANCE IN OHMS
CAPACITANCE IN MICRO FARADS

Figure 3. Detector circuit diagram.

Transistors Q1 and Q2 amplify and shape the G-M tube pulses. Q1 saturates, squaring the top of each pulse and the reverse bias on Q2 blocks the long tail of each pulse so that a 6-volt 2-microsecond square pulse is fed into the cable via a capacitor.

The circuit is protected against high-voltage transients by a 47-ohm resistor and Zener diodes.

CONTROL CIRCUIT

The circuit diagram is shown in Figure 4. In this diagram all resistance values are in ohms and all capacitance values in microfarads. Unmarked diodes are general purpose silicon diodes. All NPN transistors are 2N2219's, all PNP transistors are 2N2905's and the operational amplifiers are 741's. The circled numbers are the pin connections to be AN/FDR-502 connector.

Each G-M tube pulse is amplified by Q4 and Q5 and turns on Q6 which discharges C1, triggering a "one shot" switching circuit, using complementary MOS NOR gates, G1 and G2. This produces a negative pulse, effectively equal to the negative (-9 volt) supply in amplitude and approximately 40 microseconds in duration, at the output of G1. The output of G1 is connected to integrator A1 which has a time constant R3C3 so that each pulse increases the voltage across C3 by about 2 millivolts. With an average 2,000 counts per second at 100 mR/h, from the 18504 G-M tube, in 2.5 seconds C3 will be charged to 10 volts.

The timing is controlled by integrator A3 and comparators A4 and A5. Capacitor C4 is charged via R4 from the -9-volt supply to about 10 volts in 25 seconds. Comparators A4 and A5 are set to switch when the A3 output is 1 volt and 10 volts respectively.

The outputs of A4 and A5 are taken to a monostable multivibrator A6; A5 directly and A4 via a NOR gate G3. When A6 is triggered by either A4 or A5 its output goes negative, turning on Q7, for approximately 10 milliseconds and C5 is charged to the output of A1. The voltage across C5 is monitored by A8, a high-input-resistance voltage follower, and inverted by A9 which is connected to the DVM in the readout unit. All the operational amplifiers in this circuit are 741's, however A1, A3 and A8 have dual FET's, 2N5909's, connected as source followers to provide high-input resistances. In its off state Q7 must have a high resistance. A 2N4065 insulated-gate FET is used and since the source may be either negative or positive with respect to the drain, the substrate must be isolated from both source and drain.

When A6 goes positive, returning to its normal state, A10 is triggered turning on Q8 and Q9 and discharging C3 and C4 and the cycle repeats.

The NOR gate G3 is controlled by comparator A2. If the output of A1 is less than 1 volt, A2 is positive and G3 is off. If G3 is off when A4

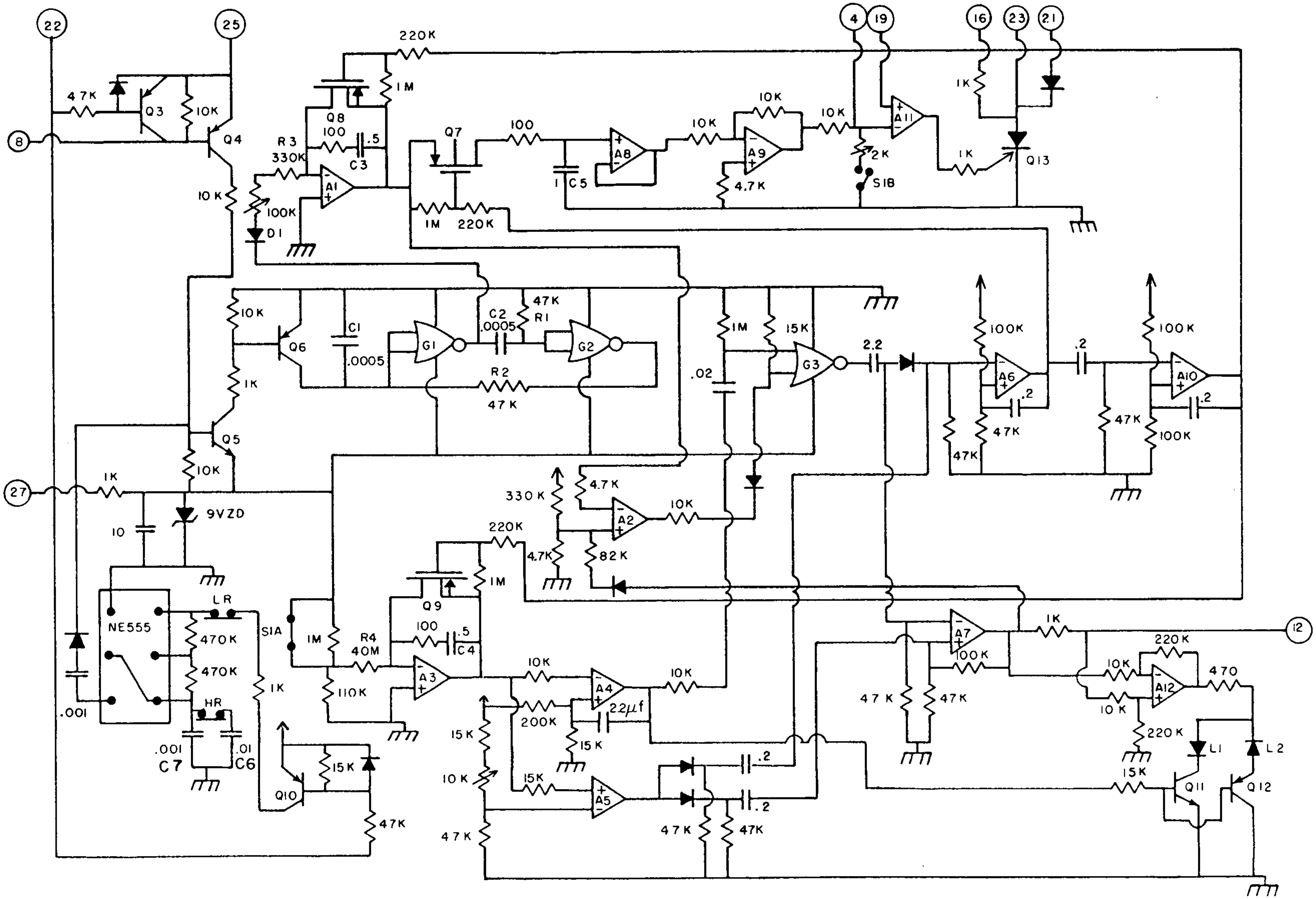


Figure 4. Circuit diagram.

switches at 2.5 seconds, the pulse from A4 is blocked and the cycle will continue until A5 switches at 25 seconds.

When A5 switches it also triggers a bistable circuit A7 to make the A7 output positive. The A7 output connects to the readout panel and when it is positive the fixed zero on the readout is on and the decimal point is off. The output current from A7 also controls comparator A12 which supplies power for two light-emitting diodes L1 and L2. These diodes are connected in series with Q11 and Q12 respectively. When A7 is positive A12 is negative and L2, which illuminates the μR/h sign, is lit when Q12 is on. Q12 is on when A4 is negative. During the 25-second cycle A4 is positive for the first 2.5 seconds and negative for 22.5 seconds. Thus L2 is off for 2.5 seconds and on for 22.5 seconds.

For exposure-rates about 10 mR/h (FSD on the LR) A2 will be negative and G3 open when A4 switches so that A6 and A7 are triggered by A4. The cycle time is 2.5 seconds and with A7 output negative the fixed zero on the readout is off and decimal point on. A12 output is positive and L1, which illuminates the mR/h sign, is lit when Q11 is turned on by A4. At the end of each cycle A4 is held negative for about 100 milliseconds, by positive feedback through a capacitor, so that L1 can be seen to blink at the end of each cycle. When A7 is negative the reference voltage to A2 is reduced so that the readout will continue indicating on the HR until the exposure-rate falls to 2 mR/h or lower.

When changing from the LR to the HR, the range-change pulse, from A4, comes at the end of the 2.5-second period. The readout indicates, on the HR, the charge accumulated over the previous 2.5 seconds, which is correct. However, when changing from the HR to LR there is no 2.5-second pulse and the readout indicates the previous 2.5-second exposure-rate for 25 seconds. Since A7 is negative L2 is off, and after 2.5 seconds A4 is negative so that L1 is also off. Thus the operator is warned that the channel is changing from the HR to LR by both indicator lights being off.

An NE555 oscillator is included which enables an electrical calibration check to be made on both the LR and the HR. The oscillator is connected to the +15-volt supply via Q10 which is biased by the high-range chamber supply (HRCS). When the Function switch on the readout panel is in the "Operate" position the HRCS, +30 volts, is on and Q10 is biased off. In any other position of the Function switch the HRCS is grounded and Q10 is on. The HRCS also biases Q3 in the same way so that when the HRCS is at ground potential Q3 is on, shorting the input to Q4 and the circuit is insensitive to G-M-tube pulses. The oscillator frequency is set to give a reading near FSD on the LR. Push buttons, on the front panel, enable the frequency to be increased or decreased so that the circuit can be made to switch up to the HR or back to the LR.

An alarm system, triggered by comparator A11, can be set to operate at any exposure-rate on the LR or the HR.

The cycle time can be increase to 250 seconds on the LR by a front-panel-mounted switch, S1, which reduces the input current to A3 by a factor of 10. Switch S1 also connects a 10:1 attenuator to the output of A9 so that the output reads correctly without the necessity to apply a scale factor. With the switch in this position it should be noted that the maximum exposure-rates are limited to 1 mR/h on the LR and 10 mR/h on the HR. Above these levels A1, A8 and A9 will be driven into saturation. This mode of operation is intended only for low-level monitoring, exposure-rates well below 1 mR/h, and the alarm can be set to warn the operator that these levels are being approached.

CALIBRATION ACCURACY

The circuit is calibrated on the HR by adjusting R3. The tolerances of the components used with A3 and A4 give a HR cycle time of 2.5 second ±5%. The 18504 G-M tube has a dead time of around 60 microseconds so that if the circuit is calibrated at 100 mR/h, with an average count of 2,000 counts per second, about 12% of the counts are lost. Thus at 50 mR/h the dead time will result in the readout indicating about 6% high and for exposure-rates below 10 mR/h, where dead time can be neglected, the readout will indicate about 12% high.

The LR is calibrated using the internal-calibration oscillator which has a frequency around 150 pulses per second and should not vary more than ±1% over the full temperature range. With the Function switch on the readout panel set to the "CAL" position the reading on the HR is noted. The circuit is then switched to the LR and the same indication on the readout obtained by adjusting the trigger level of A5. The LR now reads 10 to 12% high relative to ^{60}Co. This error could be reduced by calibrating the HR at a lower exposure-rate but, as discussed in the section on energy dependence, this calibration offset limits the maximum error to lower-energy radiation.

The 250-second mode is calibrated by switching the circuit to the HR then setting the 250-second switch to the "250 second" position. The circuit will now operate on a 25-second cycle, and the output attenuator on A9 is adjusted to give the same HR "CAL" reading.

The G-M tube is relatively insensitive to temperature and allowing for a small variation in the 550-volt supply voltage the detector output should not vary more than ±2% over the useful life of the tube.

The main sources of error in this circuit are variations in the timing cycle and the output of A1.

The output of integrator A1 (Figure 3) is given by:

$$e_0 = -\frac{t}{C_3}\left\{I_{in} + I_L + \frac{V_{off}}{R_3 + R_D}\right\}$$

where t is the integrating time, 2.5, 25 or 250 seconds, I_{in} the input signal current to A1, I_L the input leakage current of A1, V_{off} the input offset voltage of A1, and R_D the leakage resistance of diode D1. For a 2N5909 the leakage current (I_L) should be less than 10^{-11}A even at 52°C the highest operating temperature, however the current due to the offset voltage V_{off}/R_3 could be several orders of magnitude higher. The effect of the offset voltage can be made comparable to or less than I_L by addition of a low-leakage diode in series with R3. In this circuit D1 is a 2N2219 strapped as a diode and V_{off}/R_D should always be less than 10^{-12}A for $V_{off} \leq 10$ mV.

With C3 = 0.25 microfarad or greater the effect of leakage current can be neglected and

$$e_0 = \frac{NE_-(1 - \frac{V_D}{E_-})\tau t}{R_3C_3} ,$$

where N is the number of pulses per second, τ is the width of the input pulse to the integrator and E_- is the negative supply voltage and effectively the amplitude of the input pulse.

The integrating time is given by

$$t = \frac{E_R R_4 C_4}{E_-}$$

where E_R is the reference voltage to comparator A4 or A5; therefore

$$e_0 = \frac{NE_R(1 - \frac{V_D}{E_-})\tau R_4 C_4}{R_3 C_3} ,$$

and if $C_3 = C_4$,

$$e_0 = NE_R(1 - \frac{V_D}{E_-})\tau\frac{R_4}{R_3} .$$

E_R is derived from the +15-volt regulated supply and will vary less than ±1%. V_D/E_- will change less than ±½% and τ should vary less than ±2% so that the output should change less than ±3% over the operating temperature range -20°C to +52°C.

Measurements confirm these estimates. The probe sensitivity is virtually independent of temperature over the range -40°C to +65°C and the output changes less than 3% when the control circuit is exposed to temperatures from -20°C to +52°C.

The indication on the readout represents the number of counts obtained during the preceding integrating period or cycle time. The indications for a constant exposure-rate will fluctuate due to statistical variations in the number of counts in a given period.

At 2 mR/h, the lowest exposure-rate on the HR, an 18504 G-M tube gives on the average 40 counts per second or 100 counts per cycle time on the HR. Thus the statistical accuracy, one standard deviation, over the HR is ±10% or better. Similarly on the LR above 200 μR/h the statistical accuracy is ±10% or better. Switching to the 250-second cycle time extends this down to 20 μR/h. However at 20 μR/h ±1 digit represents an error of ±50% so that the longer cycle time has a limited advantage in reading accuracy. It should be noted that any offset voltage in A1 will be transferred to A8 and add to or subtract from the offset voltage of A8 and this will add to or subtract from the signal, thus on the 25-second cycle the accuracy is limited to ±20 μR/h. On the 250-second cycle the offset voltage can be neglected so that with the improved statistics it enables the alarm level to be set more accurately and to detect a smaller increase in radiation intensity.

If a push-button switch is used to disconnect the A9 attenuator, and the indication on the readout divided by 10 to give the true exposure-rate when the switch is depressed, then the scale accuracy of ±20% is extended down to 20 μR/h by the 250-second cycle. When measuring background radiation, typically 10 to 15 μR/h, the statistical accuracy can be improved by averaging a number of readings.

RESPONSE TIME

The response time, the time taken for the instrument to indicate 90% of the final exposure-rate for an increase in radiation or to 10% of the initial exposure-rate for a decrease in radiation, is for all practical purposes two cycle times. That is, 5 seconds on the HR and 50 seconds on the LR or 27 seconds if the increase or decrease results in a range change.

Similarly, with the cycle time set to 250 seconds the response time is 500 seconds. However, the 250-second cycle will be used only for monitoring background, or exposure-rates below 1 mR/h, and large or rapid changes are unlikely and the readout will not be monitored continuously by the operator. Thus the long time constant is unimportant and paradoxically saves time since the exposure-rate, to a statistical accuracy of ±10%, is continuously displayed.

The spring-loaded level switch, marked "Select HR", used to switch the electrical calibration signal to the HR could have a third position, not spring loaded. In this third position operation would be limited to the mR/h range. This could be used for exposure-rates above 0.5 mR/h where a fast response time is essential, e.g. if the detector is used as a frisking probe or used to monitor personnel passing through a doorway.

ENERGY DEPENDENCE

The energy response of the 18504 G-M tube, filtered by 0.015 in. of tin and 0.007 in. of lead, is shown in Figure 5. These measurements were made with the axis of the detector at right angles to the incident radiation using the X-ray spectra described in Ref. 4.

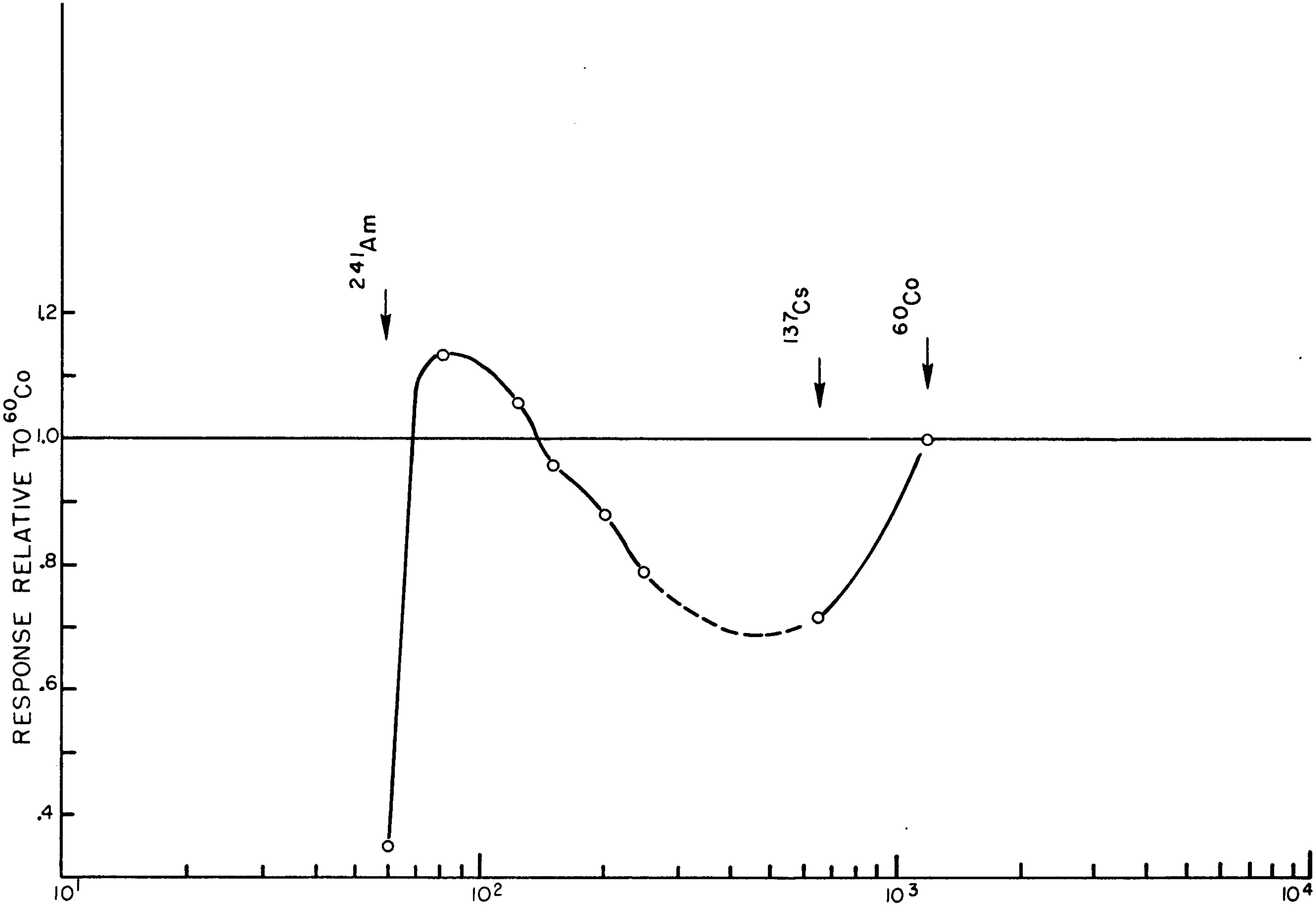


Figure 5. Energy Response.

This shows that errors due to the G-M-tube energy dependence can exceed all other system errors. By calibrating the instrument to read correctly in a ^{60}Co field of 100 mR/h, where the tube dead time causes a 10% loss in sensitivity, energy-dependence errors will be limited to ±25% over most of the scale. When measuring a broad spectrum of energies, such as in a fallout field, these errors will tend to cancel and be much less than this maximum value.

DIRECTIONAL RESPONSE

The directional response of the detector was measured, using ^{60}Co gammas and 100-keV X-rays, in a plane through the axis of the detector. The results are shown in Figure 6. The response to both energies is shown with the end cap in place and with the end cap removed. The end cap included a lead and tin filter. The curves indicate that the low-energy response would be improved with a thinner lead filter in the end cap.

The detector response is effectively independent of direction in the plane at right angles to the axis of the detector.

CONCLUSIONS

A plug-in unit is described which extends the range of the AN/FDR-502 from 100 mR/h down to background. Within the limitations of the detector energy response, characteristic of G-M tubes, this unit provides a very satisfactory low-level radiation monitor which will meet the military characteristics for this type of equipment.

The unit is relatively low cost and can be used without any modifications being made to the AN/FDR-502. However, if, as is desirable, the mR/h and μR/h indicator lamps are mounted on the readout panel, then three additional connections must be made between the readout panel and the low-level channel.

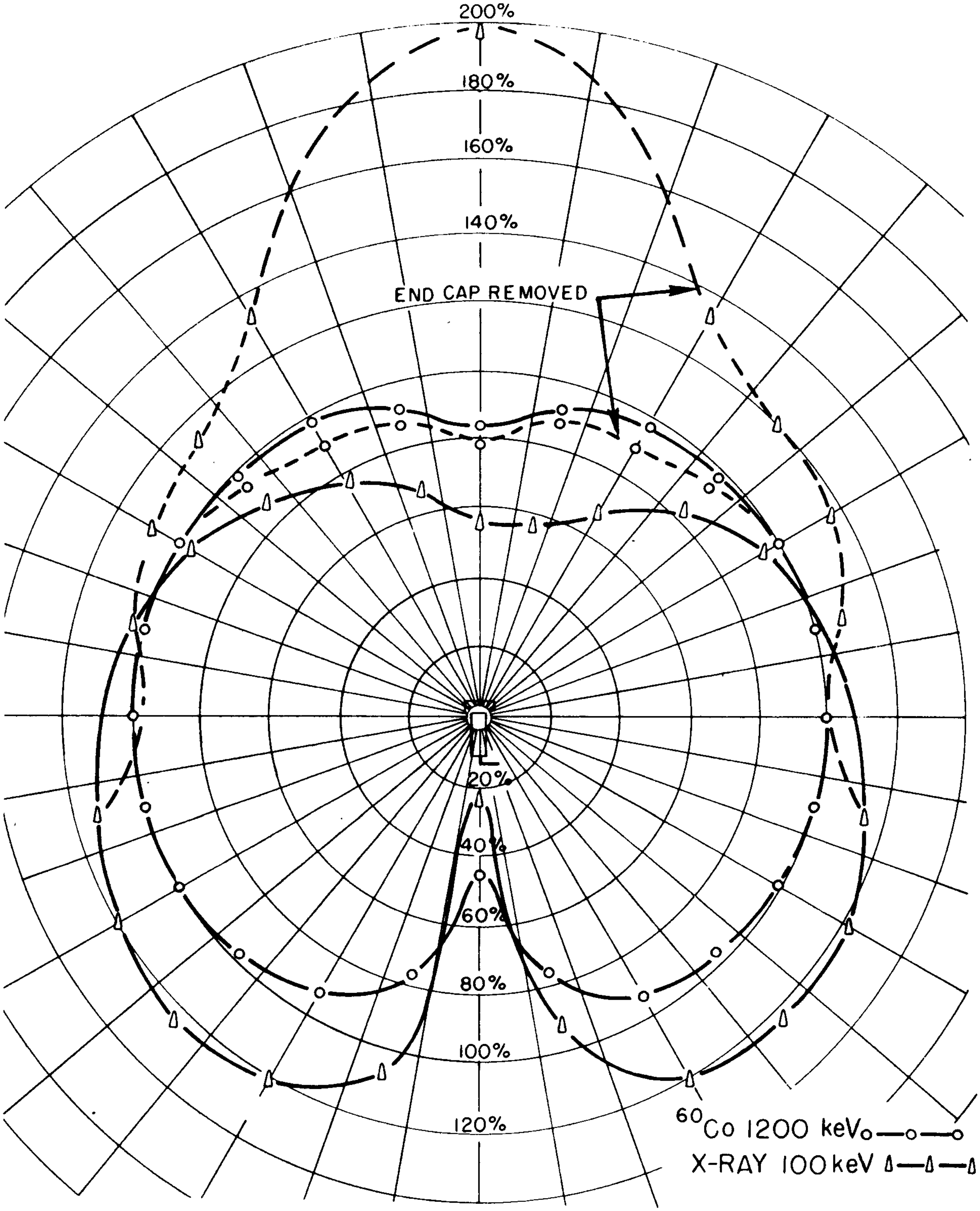


Figure 6. Directional Response.

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