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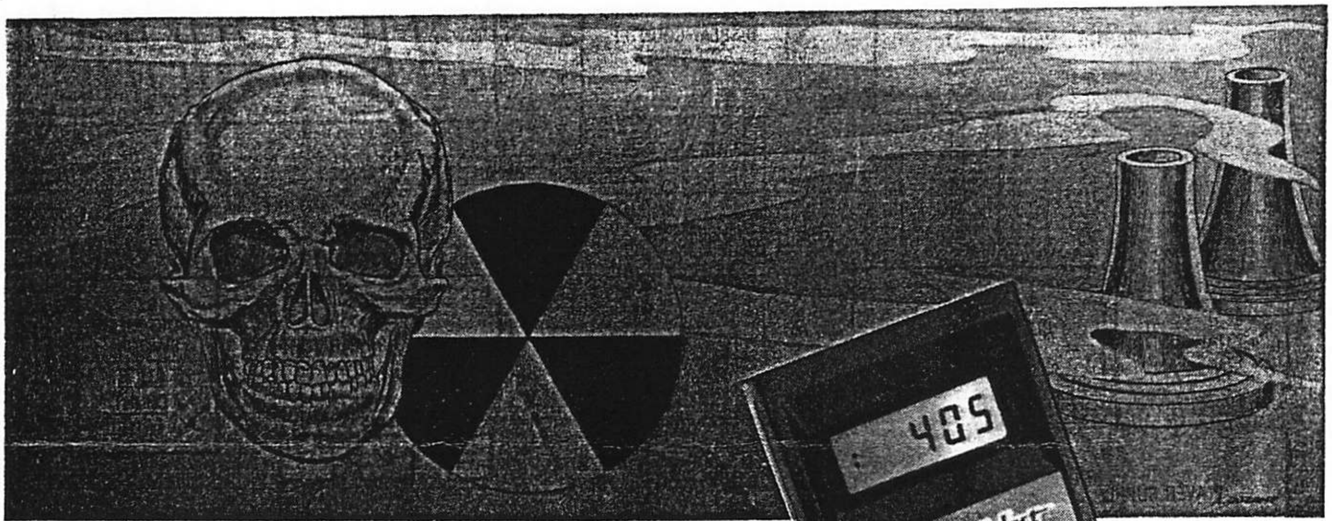

RADIATION MONITOR

This hand-sized Geiger counter is so sensitive it can measure the radiation from a ceramic drinking cup.

JOE JAFFE, DAN SYTHE, AND STEVE WEISS

HAVE YOU EVER DRIVEN PAST A NUCLEAR power generating plant and wondered whether it was leaking radiation? Is there radioactive radon in your basement? When the Chernobyl nuclear plant exploded in April, 1986, and the Three Mile Island plant almost had a meltdown in March, 1979, did you wonder if any of the radiation was coming your way? If you have a luminous watch dial that glows in the dark, is it giving off radiation? Did you know that common items found in a home emit small amounts of ionizing radiation?

Construct your own Geiger counter and you will find the answers to those questions and many more. With a Geiger counter you can reassure yourself that radiation levels in your area are normal. You can detect nuclear-plant radiation leaks by monitoring changes in radiation level, and even sound an alert if the level is abnormally high. You can network with your friends who have similar instruments to determine radiation patterns. You can identify items in your home that are radioactive. And you can explore for underground deposits of radioactive materials. In short, if you build a Geiger counter you will learn about radiation, where it comes from, and how it is detected.

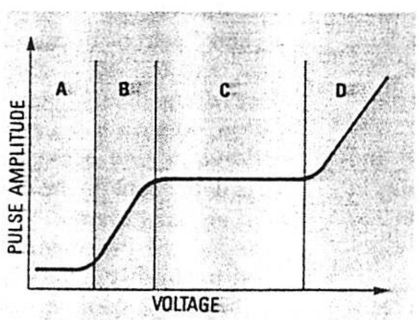

FIG. 1—THE RELATIONSHIP BETWEEN PULSE AMPLITUDE and the electrode voltage of a Geiger tube. Region c, which is the most sensitive to radiation, is called the *Geiger region*.

Measuring radiation

A common characteristic of alpha, beta, gamma, and X-rays is that they ionize the material that they strike or pass through. Therefore, it is possible to measure the amount of radiation by measuring the resulting degree of ionization. One of the first devices used to detect ionization was the electroscope, developed about 100 years ago. In that device, when a gold leaf and its metallic support are insulated from another metallic member and charged to a DC potential of several hundred volts, the gold leaf is repelled. With high-quality insulation, the charge leaks off slowly, but if any ionizing radiation is present the charge leaks off more quickly. Obviously, only relative-intensity measurements are possible.

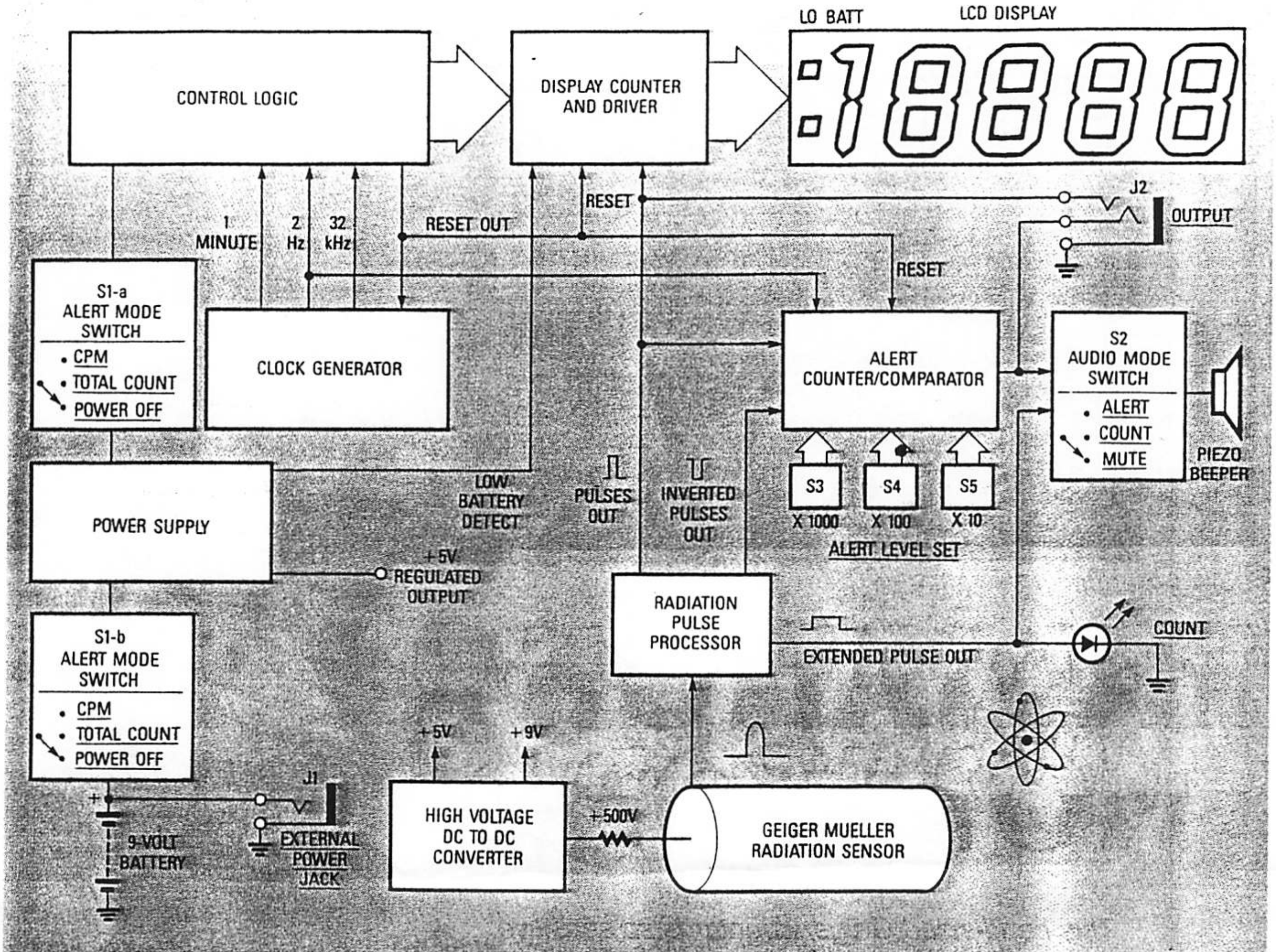

FIG. 2—BLOCK DIAGRAM OF THE RADALERT. The Alert Counter/Comparator can be programmed to sound a beeper when the pulse count exceeds a user-determined value.

The most common sensor used today to detect ionization is the Geiger tube, which consists of an enclosed anode and cathode separated by a mixture of argon, neon, and either chlorine or bromine gases. Usually, the cathode is a thin-wall metallic cylinder sealed at each end with an insulating disk so that the gas is contained. The anode is an axial wire in the cylinder that extends through an insulator. A DC voltage connected to the electrodes creates an electric field within the chamber. A pulse of current is generated when radiation passes through the container and ionizes the gas. The pulses are counted and electronically processed for display in a variety of ways. The relationship between pulse amplitude and electrode voltage is shown in Fig. 1.

A single positive ion and one electron are produced by the initial ionizing event: the collision of an alpha, beta, or gamma ray with a neon or argon gas molecule in the sensor. At low voltages, region A in Fig. 1, the electron moves at low velocity to the central anode and the positive ion moves more slowly to the cathode, where they are neutralized. The detector is rarely operated in that region as extremely small pulses are generated. As the voltage is increased, the velocity and energy of the electron increases. At a specific threshold voltage, the start of region B, there is sufficient energy to produce more ions and electrons by additional collisions, and the pulse amplitude increases dramatically due to gas amplification. Region B is called the *proportional region* because the pulse size is dependent on the energy of the initial ionizing event.

Specialized instruments operating region B can distinguish between alpha, beta, and gamma rays by measuring the pulse amplitudes.

Region C starts when the gas amplification reaches saturation. The pulse amplitudes due to alpha, beta, and gamma rays become essentially equal and increase only slightly with increasing voltage. Region C is the *Geiger region*; it has the highest sensitivity to incoming radiation. Most Geiger counters operate in region C.

When the voltage is increased beyond the Geiger region, the electric field becomes high enough to cause the gas to self-ionize. That occurs in region D and results in almost continuous discharge, which can only be stopped by turning off the voltage. Operation in region D can damage the tube.

The actual threshold voltages for each of the regions depend on the size and shape of the sensor and the configuration of the electrodes.

The thin wall of the Geiger tube allows high-energy beta and gamma rays to pass through and ionize the gas. However, alpha rays have considerably less energy and are blocked by the metallic tube. To detect alpha rays, a very thin mica disk or Mylar film that is transparent to alpha rays is used in some Geiger tubes to close off one end of the cylinder. That end is called an *alpha window*. The alpha window must point toward the radiation source to detect alpha rays. The range of alpha rays in air is only about 3 centimeters.

Radon

The primary emissions from radon are alpha particles that rapidly dissipate in air. Secondary emissions of beta particles and gamma rays from radon, and from its decay products known as radon "daughters" or "progeny," occur in sufficient quantity to be detected. The EPA has published a booklet on measurement protocols for radon. The simplest technique uses a carbon canister to adsorb radon from the air for weeks or months. At the end of the measurement period the canister is sealed and returned to a laboratory for analysis.

Build a radiation monitor

But waiting for the results of laboratory tests is time-consuming, and if the canister isn't placed in a "hot" spot, false low readings will result. You can do faster measurements by building our radiation monitor, which for simplicity we will henceforth refer to as the *Radalert*.

The Radalert, whose block diagram is shown in Fig. 2, is an extremely versatile Geiger counter that is sensitive to alpha, beta, gamma, and X-ray radiation. It is designed for ease of use by people who want to be better informed about the level of radiation that surrounds them. It also meets the needs of technical, medical, and public-service personnel who require accurate information involving the use, transportation, and storage of radioactive materials. A 4½-digit LCD display provides a direct reading of the number of ionizing events detected by the sensor. (A commercial version of Radalert is currently being tested at a major university laboratory to relate the total counts over extended time periods with calibrated radon levels to determine the time required to get useful results. Preliminary results indicate a 12-hour count may be necessary to detect the increase in background radiation due to low levels of radon and its decay products.)

Two switches allow you to select the operating mode and type of display desired. With switch S2 set to the MUTE position, the COUNT LED visually indicates each ionizing event. When S2 is set to the COUNT position, you will also hear a beep corresponding to each count.

Switch S1 gives you a choice of two display modes. In the CPM (*C*ounts *P*er *M*inute) mode, the number of counts detected each minute is displayed on the LCD until replaced by the next minute's count. No count is displayed during the first minute of operation, but the flashing LCD colon tells you that the count is in progress. In the TOTAL COUNT mode, the counts are accumulated and a running total is displayed.

A special feature of our monitor is a user-adjustable alert level. Using the CPM mode, the alert level can be set to a level greater than the normal background radiation. Using the TOTAL

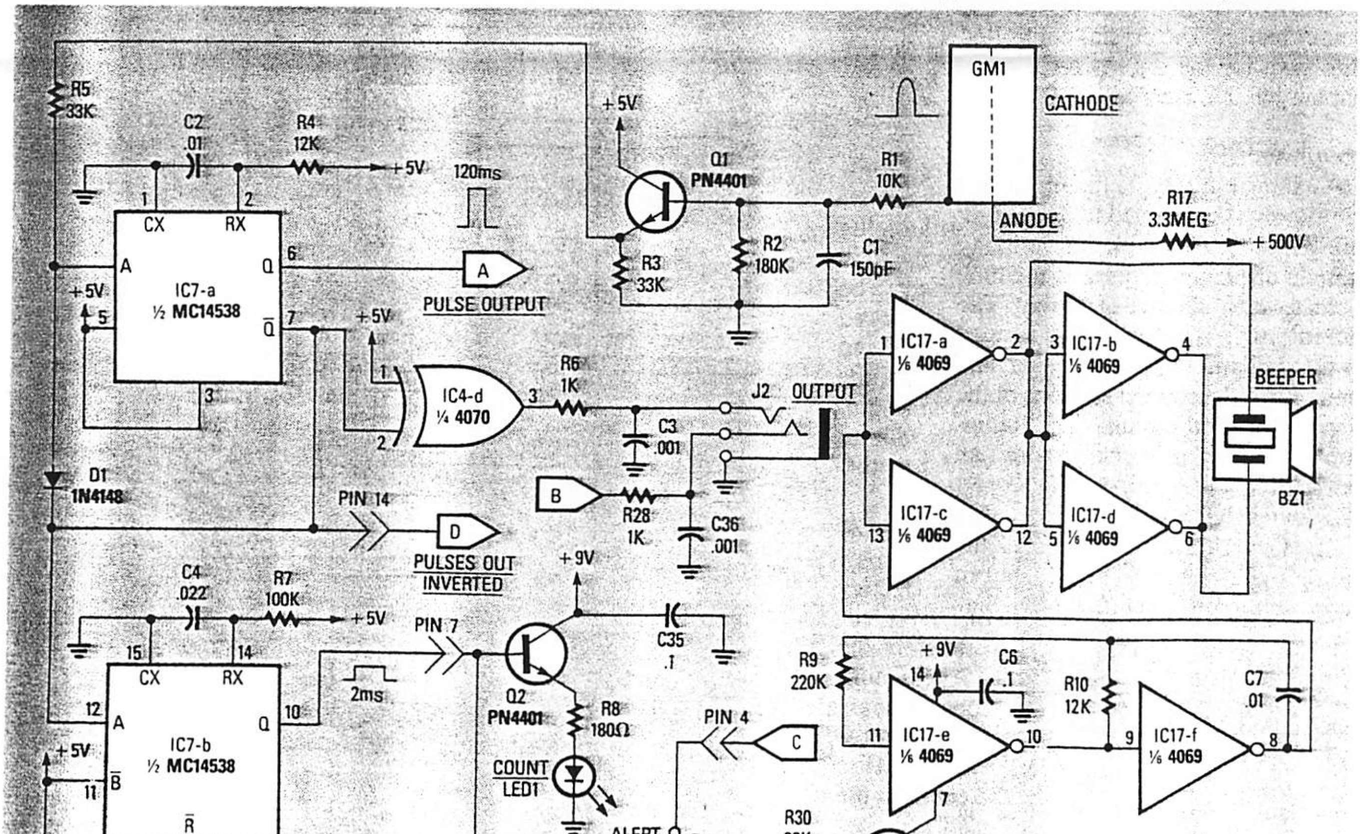

FIG. 3—THIS IS THE CIRCUIT FOR THE GEIGER TUBE and its pulse processor. LED1 blinks in step with each pulse. The beeper also can beep in step with each pulse, and can function as the alert alarm.

COUNT mode you can average the background radiation over long periods when testing for small changes in the background radiation. If S2 is set to its ALERT position, a pulsating beep lets you know when the count reaches the preset alert level.

Portable operation

The monitor is powered by a transistor-radio type 9-volt battery. Very low current drain allows up to 6 months operation before the LO BAT (low battery) indication appears on the LCD display. For continuous 24-hour operation over long periods, the Radalert can be powered by an optional AC adapter connected to EXTERNAL-POWER-jack J1. Notice from Fig. 2 that the battery is not disconnected when the AC adapter is connected to J1. That arrangement permits the battery to automatically take over if the AC powerline fails, thereby assuring uninterrupted measurements. A diode prevents the AC adapter's output voltage from being applied to the battery.

A 500-volt regulated power supply operates the radiation sensor in the Geiger region. The crystal-controlled time-base for the COUNTS PER MINUTE display has an accuracy of 0.005%.

How it works

As shown in Fig. 2, the high-voltage supply is connected to the Geiger tube's anode. Each time an ionizing particle or photon penetrates the tube it creates an avalanche of current. The current pulse is detected and shaped by the Radiation Pulse Processor, and then sent to the counter sections of the display and alert circuits. The Radiation Pulse Processor also provides an extended pulse to drive the COUNT LED and the Piezo Beeper.

The Clock Generator produces the timing signals required by the Control Logic section to operate the Display and the Display Counter/Driver circuits. Control Logic also resets the Clock Generator, and the Alert Counter/Comparator at the proper times.

The Alert Counter/Comparator section accumulates the radiation counts and compares the count to the setting on the binary-coded switches (S3, S4, and S5). When the level on the counter is equal to the BCD setting, the alert output pulsates at a 2-Hz rate to drive the Piezo Beeper when the Audio Mode Switch (S2) is in the ALERT position.

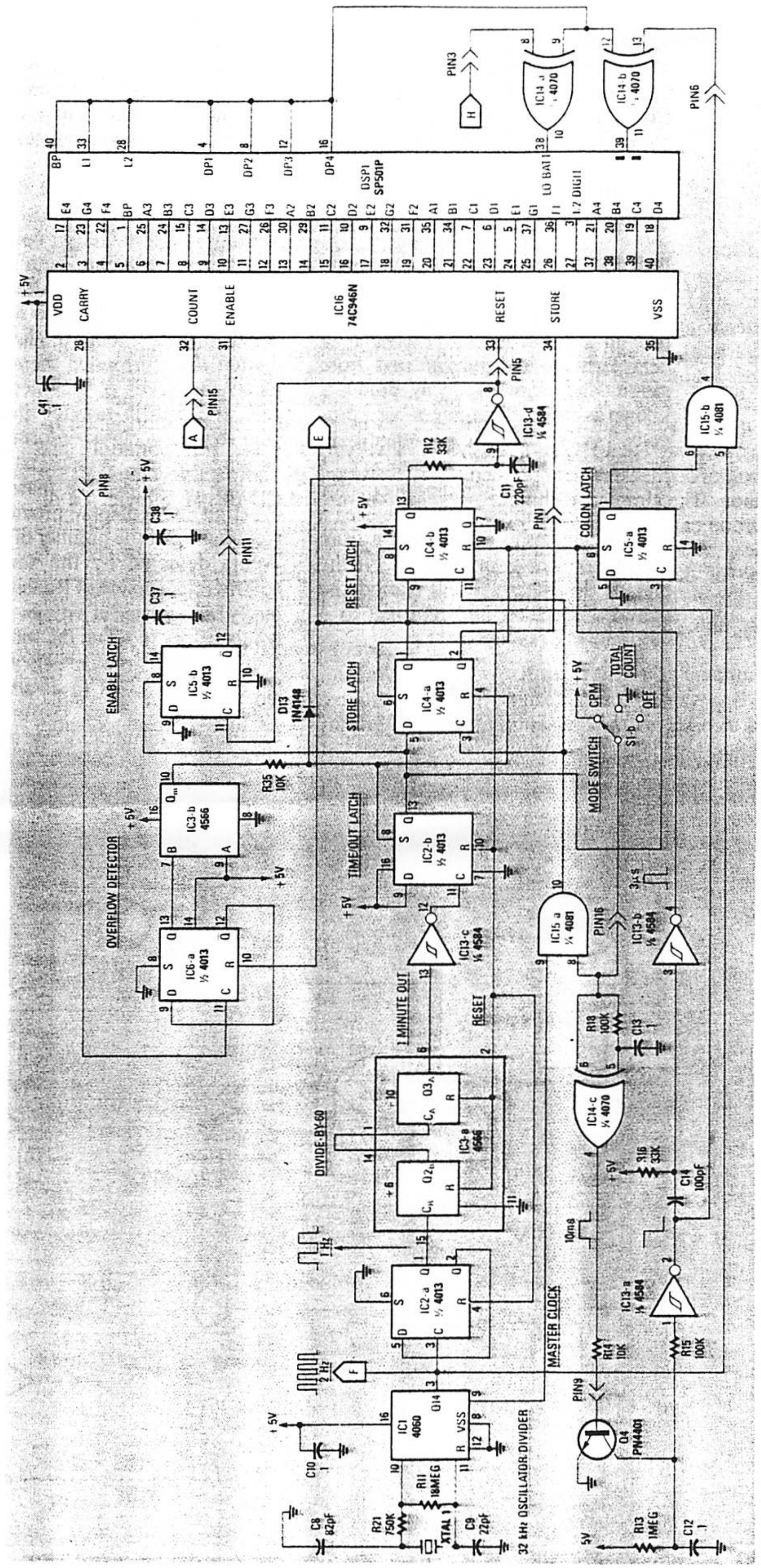

FIG. 4—THE CONTROL LOGIC. A 32-kHz master clock is divided down to provide the one-minute timing for the counts-per-minute function.

PARTS LIST

All resistors are 1/8-watt, 5%, unless otherwise noted.
R1, R14—10,000 ohms
R2—180,000 ohms
R9, R33—220,000 ohms
R3, R5, R12, R16, R30—33,000 ohms
R4, R10—12,000 ohms
R6—1000 ohms
R7, R15, R18—100,000 ohms
R8—180 ohms
R11—18 megohms
R13, R20—1 megohm
R17—3.3 megohms, ½ watt
R19—2.2 megohms
R34—47,000 ohms
R21—750,000 ohms
R31, R32—100 ohms
R22—4700 ohms
R23—1 ohm
R24—510,000 ohms
R25, R26—3.9 megohms
R27—390,000 ohms
R28—1000 ohms
R29—10 megohms
RN1, RN2—220,000 ohm × 6 resistor network
All capacitors rated at least 15 volts, unless otherwise noted
C1—150 pF, 5%, polyester
C1, C11—220 pF, 5%, polyester
C2—0.01 µF, ceramic disc, type X7R
C3, C10, C15, C19, C28, C33, C34, C36—0.001 µF, ceramic disc
C4—0.022 µF, ceramic disc, type X7R
C5, C25, C26, C30, C31—not used
C6, C10, C12, C13, C17, C28, C29, C35, C39, C41—0.1 µF, ceramic disc
C7, C29—0.01 µF, ceramic disc
C9—22 pF
C8—82 pF
C14—100 pF
C16—0.022 µF
C18, C37—47 µF, electrolytic
C20, C21, C22, C23, C24—0.0047 µF, 1KV, ceramic disc
C27—10 µF, tantalum
C32—0.0027 µF, ceramic disc
C38—10 µF, electrolytic
Semiconductors
IC1—4060 oscillator/counter
IC2, IC4, IC5, IC6—4013 dual D flip-flop
IC3—4566 time-base generator
IC7—4538 dual multivibrator
IC8, IC9, IC10—4585 4-bit comparator
IC11, IC12—4518 dual BCD counter
IC13—4584 hex Schmitt trigger
IC14—4070 quad exclusive OR
IC15—4081 quad AND
IC16—74C946 counter/decoder/driver
IC17—4069 hex inverter/buffer
IC18—MAX666 micropower regulator
DSP1—4½-digit LCD display, Seiko SP501P
Q1–Q5—PN4401 transistor
Q6, Q7—MPS6515 transistor
Q8—PN3906 transistor
D1, D10—1N4148 diode
D2—Not used
D3–D6, D12—1N4007 diode
D7–D9—1N5278B diode
D11—1N5819 diode
D13—1N4148 diode
LED1—Light-emitting diode
Other components
B1—9 volt battery
BZ1—piezo-electric beeper, Kyocera KBS-27DB-3T
GM1—Geiger tube, type LND 712
J1—miniature jack
J2—miniature 2-circuit jack
S1, S2—DPDT slide switch
S3, S4, S5—BCD rotary switch, right angle mount
T1—DC/DC blocking transformer
XTAL1—32.768 kHz crystal, watch type
Miscellaneous: Samtec 16-pin male and female connectors, cabinet, printed-circuit materials, wire, solder, cabinet, etc.
Note: The following components are available from International Medcom, 7497 Kennedy Rd., Sebastopol, CA, 95472:
T1, $3.75; DSP1, $10.00; set of two double-sided, plated through printed-circuit boards, $16; GM1, $45. Add $1.00 for shipping and handling for those components. California residents must add appropriate sales tax.
A complete kit, which includes the two printed-circuit boards, the plastic enclosure with custom modifications, labels, all components, hardware, assembly instructions and an operating manual, is available for $149.50 (without battery).
A completely assembled and tested Radalert with an operating manual is available for $225 (including battery).
Add $4.00 for shipping and handling to each Radalert or Radalert kit order. California residents must add appropriate sales tax.
To order the complete kit or the assembled Radalert by Visa or Mastercharge call toll free 1-800-257-3825. In California, call 1-800-255-3825. (Those numbers are for credit-card orders only. For technical information contact International Medcom at the above address.

The circuit

As shown in Fig. 3, the cathode of Geiger tube GM1 returns to ground through Q1's base. The current pulse created in the Geiger tube by a radiation event is about 50 to 75 microseconds long. It pulls up R1, thereby raising Q1's base voltage and turning Q1 on for the duration of the ionizing event. That, in turn, pulls up emitter resistor R3, bringing pin 4 of IC7-a high, which causes the Q output to go high, thereby producing a square wave about 120 microseconds long (the length is determined by the time-constant of R4/C2).

Since $\bar{Q}$, pin 7, is always the opposite of Q, it goes low, pulling the A input low again through D1. The $\bar{Q}$ output to A ensures that the circuitry will continue to count at extremely high radiation levels and not saturate or "jam." The Q output is connected to the display and alert counters. The $\bar{Q}$ output is used by the alert circuit and is also buffered through IC14-d and R6 to the Count Output port (J2's tip), which is the interface to a computer or other data logging device.

One section of IC7, IC7-b, is used as a pulse extender to drive LED1 and beeper BZ1. The pulse width, about 2 milliseconds, is determined by the time-constant of R7/C4.

Beeper BZ1 is driven in a push-pull configuration by two sets of paralleled buffer/inverter gates from IC17. The other two gates of the device are configured as a 3.3-kHz oscillator to match the resonant frequency of BZ1. The oscillator's frequency is determined by the values of resistors R9 and R10, and capacitor C7. The circuit is very efficient, providing a sound pressure level of about 75 dB at 12 inches, with a current drain of 2 mA.

Since the drain is only on for 2 milliseconds per count, that 2 mA averages out to only 1 µA at normal background radiation levels of about 15 counts per minute.

Although LED1 draws 15 mA when it is on, the average current drain is still in the low microampere range. Indicators LED1 and BZ1 are switched by Q2 and Q3, respectively.

LCD display

The 4½-digit liquid-crystal display, DSP1, is the non-multiplexed (direct drive) type. As shown in Fig. 4, it is driven by IC16, a National Semiconductor 74C946, which features 100-microwatt power consumption and leading-zero blanking. It has internal counters for each of the 4 digits and a flip-flop to drive the ½ digit.

The pulses from IC7-a, pin 6 (Fig. 3), are fed to IC16's COUNT INPUT, pin 32. Every negative-going transition clocks the internal counter chain. The STORE pin, pin 34 of IC16, controls the counter latches.

In the TOTAL COUNT mode, pin 34 is low, the latches are in a flow-through state, and counts are actively displayed as they are detected. In the COUNTS PER MINUTE mode, pin 34 is high, and the counter latch outputs are stored. Each minute, CONTROL LOGIC disables the counter, pin 31, while the prior minute count is displayed and stored (pin 34). The counter is then reset to zero (pin 33) to start the count for the next minute.

Clock generator

All timing waveforms are referenced to a 32.768 kHz crystal oscillator built into IC1. That IC has a 14-stage ripple-carry counter that divides the oscillator frequency by two 14 times to give a 2-Hz output at pin 3. The IC2-a flip-flop divides the 2 Hz by two again to furnish a 1-Hz signal to IC3, a 4566 industrial time-base generator that was described in detail in the January, 1988 issue of **Radio-Electronics** (see page 56). The time-base generator divides the 1 Hz, first

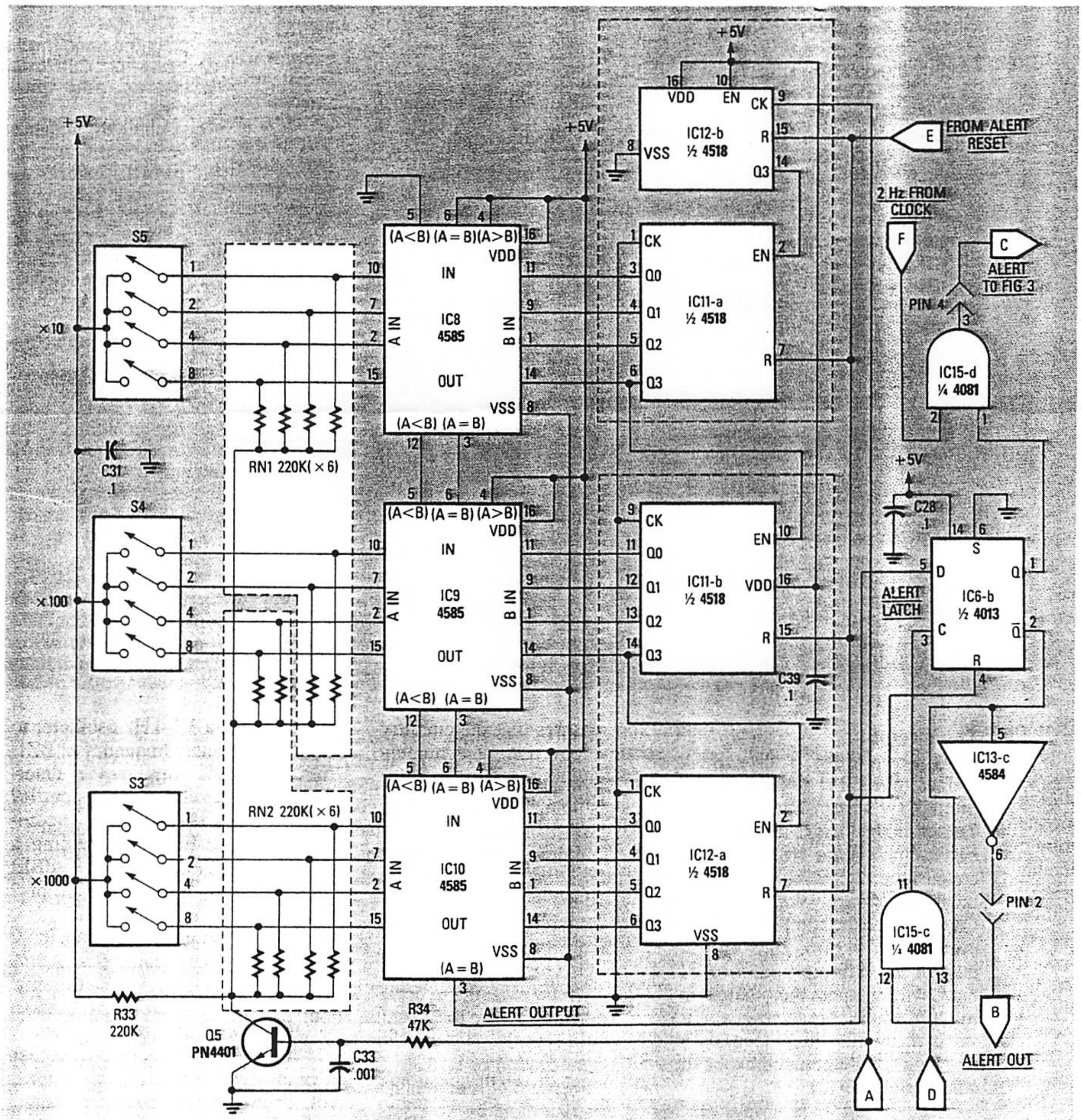

FIG. 5—THE ALERT COUNTER is user programmed through switches S3, S4, and S5.

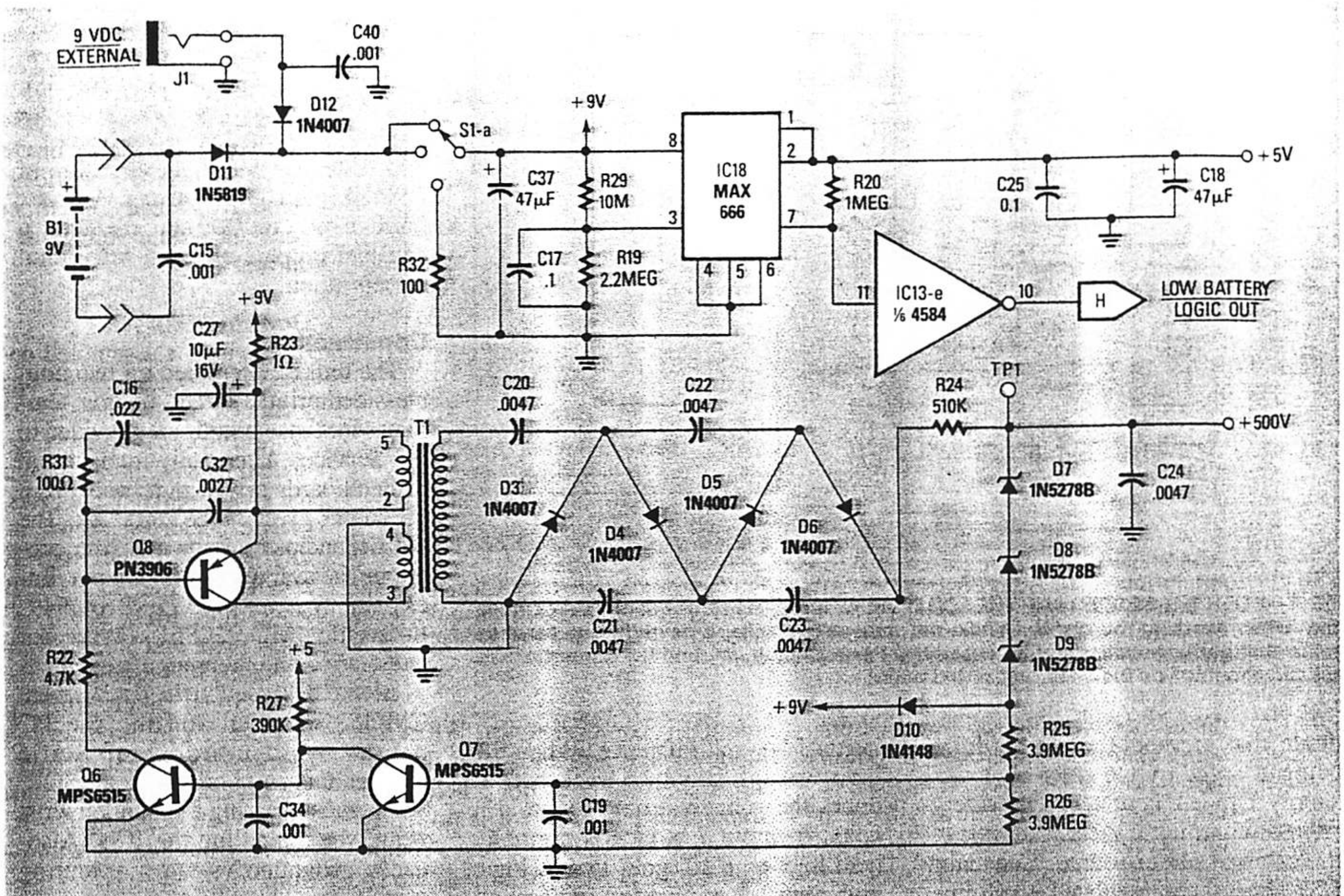

FIG. 6—THE 500 VOLTS DC for the Geiger tube is generated by the DC-to-DC converter circuit consisting of Q6, Q7, Q8, and their associated components.

by six and then by 10, to provide the 1-minute timing signal for the COUNTS PER MINUTE mode. One minute is up when pin 6 goes low; the transition is inverted by Schmitt trigger IC13-c.

Control logic

Refer to Fig. 4. The power up/reset sequence starts when the Radalert is turned on. Capacitor C12 charges through resistor R13, causing IC13-a, pin 2, to go low. Capacitor C14 is momentarily discharged, then recharged through R16. The recharge time is set by the R16/C14 time constant and creates a 3-microsecond power up/reset pulse at IC13-b, pin 4.

Whenever S1 is switched between COUNTS PER MINUTE and the TOTAL COUNT modes, IC14-c, pin 6, goes either positive or negative, with a time delay determined by R18/C13. That section of IC14 is configured as a one-shot that can be triggered on a positive or negative transition, and its output will be high when pin 5 and pin 6 are unequal. The R18/C13 time delay makes them unequal for a very short time, creating a 10-millisecond positive pulse at pin 4 that turns on Q4. The Q4 collector momentarily discharges C12 to re-initiate the power up/reset sequence.

In the COUNTS PER MINUTE mode, critical timing of the IC16 ENABLE, RESET, and STORE functions is implemented by four D flip-flops: IC2-b, the Time Out latch; IC4-a, the Store latch;, IC4-b, the Reset latch; IC5-b, the Enable latch. In the TOTAL COUNT mode, IC15-a inhibits the Master Clock, allowing the radiation count-data from the Pulse Processor to accumulate on the display.

A count of 19999 triggers the overflow detector, freezing the display at that value, and providing a time out signal in COUNTS PER MINUTE mode. In the TOTAL COUNT mode, the 19999 remains on the LCD until S1 is switched.

The colon at the left end of the LCD display flashes at a 2-Hz rate in the first minute of the COUNTS PER MINUTE mode. In the TOTAL COUNT mode, the colon continues to flash as counts are accumulated. A D flip-flop, IC15-a, controls those functions.

Alert counter and comparator

Refer to Fig. 5. Two 4518's, IC11 and IC12, form a chain of four BCD up-counters. Counts from the Pulse Processor feed the least significant digit of the chain, IC12-b, pin 9. The counts are incremented by the ×10, ×100, and ×1000 registers, IC11-a, IC11-b, and IC12-a. Register outputs are compared to the settings of the BCD ALERT LEVEL switches (S3, S4, S5) by IC8, IC9, and IC10. To conserve battery life, comparison is made only as each count is detected. When the alert level is reached, a true alert output is clocked into the Alert Latch IC6-b to energize the beeper at a 2-Hz rate (if S2-a is set to ALERT). The latch then disables any more pulses from clocking through IC15-c.

Power supply

As shown in Fig. 6, the Radalert operates from an internal 9-volt battery, or an external 9-volt power source. Capacitors C15 and C28 are RF-bypass capacitors. External power supply jack J1 does not disconnect the battery when external power is used so that the Radalert will continue to function on battery power if the AC power fails. Diode D11 is a Shottky

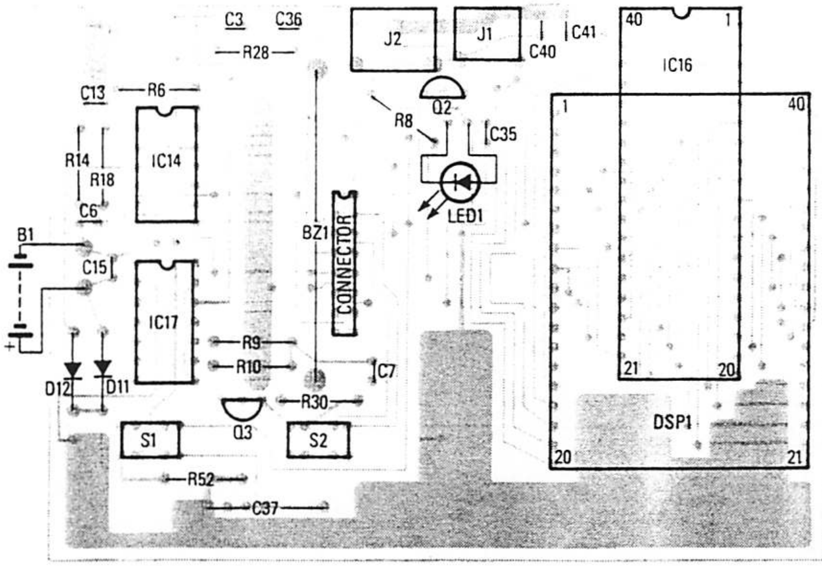

FIG. 7—BOTH THE BEEPER AND THE LCD DISPLAY are on the same board. Take extreme care when handling the display. While not unusually fragile, it nevertheless requires somewhat gentle handling during assembly. Parts IC16, J1, J2, and the connector are actually mounted on the underside of the board.

diode that prevents the battery from being charged by the external power supply. Diode D12 protects the battery from discharging if there is a short in the external power source. Capacitor C37 filters the unregulated 9-volt line that powers the high voltage power supply, LED1, and BZ1.

Switch S1 turns the Radalert on. A MAX666 regulator, IC18, provides regulated 5 volts to the LCD and all the other IC's. That regulator is unusual in that it contains a built-in low-battery detector. The threshold is set by the ratio of R29 and R19. The voltage at pin 3 is compared to an internal 1.3-volt reference. When the input voltage falls to a level that reduces the voltage at pin 3 below 1.3 volts, then pin 7, which is normally held high by R20, goes low. A logic high signal is required to indicate LO BAT on the LCD display, so the state of pin 7 is inverted by IC13-e, an inverting Schmitt trigger.

The high-voltage circuit provides regulated 500 volts at up to 50 microamps, as required by the Geiger tube. It uses a DC-to-DC blocking-oscillator design and closed-loop feedback regulation. Transistor Q8 oscillates at approximately 25 kHz.

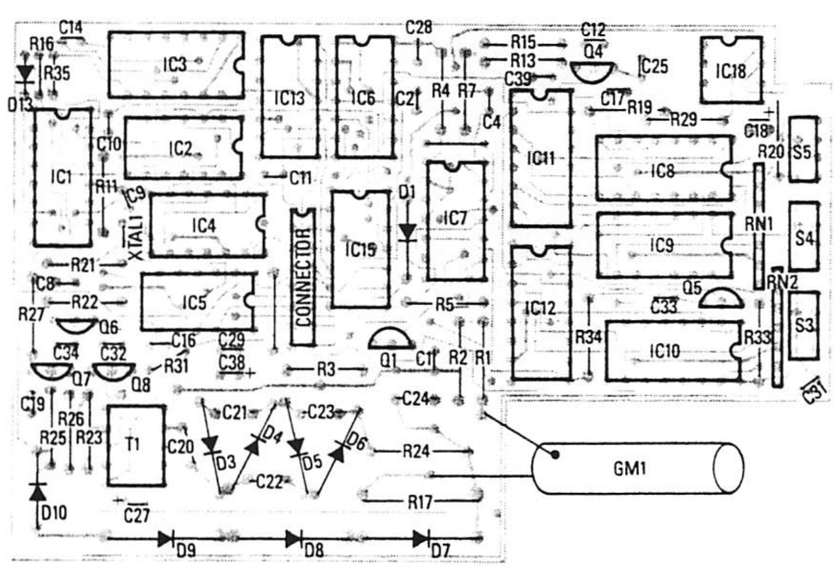

FIG. 8—NOTICE THAT THE BCD SWITCHES that set the alert level mount along the smaller edge of the printed-circuit board. To ensure that their adjustments align with their cabinet cutouts, be sure the switches are pressed against the printed circuit board when being soldered.

Transformer T1, in combination with the voltage multiplier formed by capacitors C20, C21, C22, and C23, and diodes D3, D4, D5, and D6, steps up the voltage to approximately 500 volts. The Zener diode chain of D7, D8, and D9 provides feedback through Q7 and Q6, to maintain a constant output-voltage at minimum current drain.

Construction

The unit is assembled on two double-sided printed-circuit boards; templates for those boards are provided in PC Service. Alternately, etched and drilled boards can be purchased from the source given in the Parts List. The plastic enclosure shown in the prototype is available from Bopla Enclosure Systems, P.O. Box 649, Rockville, MD. 20851. (Write for latest price and shipping charges.)

All the IC's used in the Radalert are CMOS, so when stuffing the PC boards avoid building up static charges that might damage the IC's. We suggest wearing a grounded wrist strap when handling the IC's. Also, use a grounded (3-wire) soldering iron.

The location of all components is silk-screened on the pre-drilled printed-circuit boards. If you make your own boards, refer to Figs. 7 and 8 for the parts-placement. Double check the placement and the polarity of diodes, electrolytic and tantalum capacitors, and the orientation of all transistors, IC's, and switches before soldering. Install the BCD ALERT switches, S3, S4, and S5, with their screwdriver slots facing away from the board. And because there is little clearance between the boards, make certain all components except the LCD display are pressed against its board before soldering.

The LCD display is mounted by pressing it against the window in the cabinet, not against the printed-circuit board. Like the IC's, the display is also static-sensitive, so handle it with care.

Because the high voltage section delivers 525 volts DC, do not handle the bottom (high-voltage) printed-circuit board during assembly and testing when the power is on. After testing, an anti-corona conformal coating (such as Dow Corning No. 1-2577) should be is applied to the components and both sides of the

continued on page 102

RADIATION MONITOR

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printed-circuit board in the high-voltage section. In addition to being a safety precaution, the coating protects against humidity that might cause leakage in the high-impedance regulator circuit.

The two printed-circuit boards mate together through a 16 pin connector. Make sure the high voltage capacitors, C20–C24, are bent over to provide at least a 0.2-inch clearance between them and the top board.

Short leads

Clip the component leads very close in the area of the top board that is adjacent to the Geiger tube. Use care when handling the Geiger tube because both the mica window and the glass evacuation bulb adjacent to the anode connector are delicate. Install the Geiger tube after all other components have been soldered to the bottom board. Connect the Geiger tube's anode—the terminal with the solder lug—to the printed-circuit board through a ¾-inch length of insulated wire. The wire already welded to the Geiger tube is the cathode. The tube is positioned in the cut-out space of the bottom board and is held in place by double-faced adhesive foam on the bottom of the case. Insulate the Geiger tube from the top board with a small piece of *fish paper* or other insulating material rated for at least 1000-volts DC insulation. Make sure the tube is insulated from all components and the PC board. If necessary, trim your cabinet so the boards and switches fit properly.

Testing

Make sure all leads are trimmed close to the printed-circuit board. Look for cold solder joints and solder bridges between traces before turning the power on. Measuring battery drain will usually reassure you that everything is connected properly; the current should be between 100 and 150 microamperes.

Check the regulated 5-volt supply at IC18 pin 2. Check the 525-volt regulated high-voltage supply at the Geiger tube's anode if you have a meter having an input resistance of at least 10 megohms. (A lower resistance will load down the power supply, causing a false voltage drop.)

After testing is complete and voltages are correct, apply the conformal coating previously described.

Using the Radalert

Now that you have the Radalert operating, it's time to put it to work. But that's another story, and it's found in the following article. R-E

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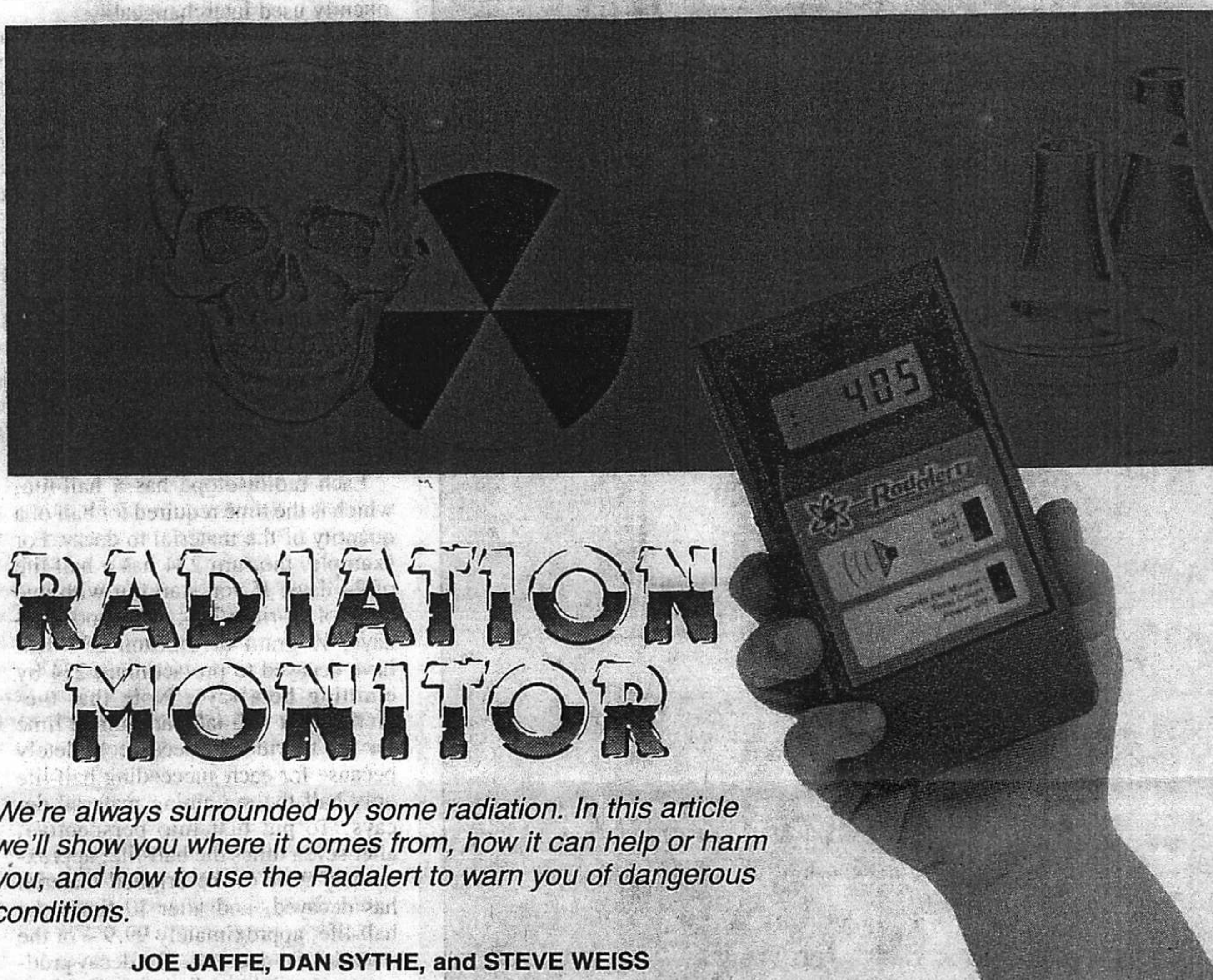


RADIATION MONITOR

We're always surrounded by some radiation. In this article we'll show you where it comes from, how it can help or harm you, and how to use the Radalert to warn you of dangerous conditions.

JOE JAFFE, DAN SYTHE, and STEVE WEISS

HUMAN BEINGS HAVE BEEN EXPOSED TO naturally occurring ionizing radiation for millions of years because nuclear reactions take place on our sun and on other stars continuously. Their emitted radiation travels through space, and a small fraction reaches the earth. Natural sources of ionizing radiation also exist in the ground, the most familiar and most common ground-source being uranium.

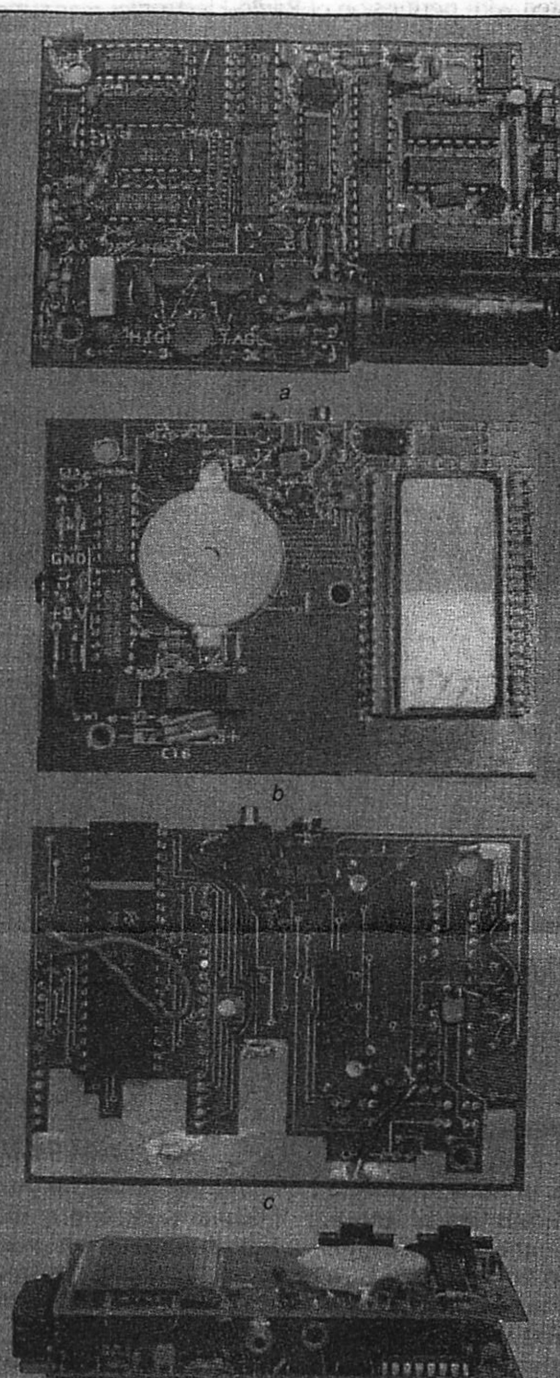
Last month we showed you how to build a nuclear radiation monitor—the Radalert. Now we'll show you how to use it, and how to interpret its readings.

Ionizing radiation

Ionizing radiation is radiation that has the ability to remove electrons (the process of ionization) when it strikes or passes through an electrically neutral atom. It was first discovered about 100 years ago and given the name *X-rays* because its nature was unknown. X-rays can be generated in a vacuum tube by connecting the tube's anode and cathode to a source of high voltage: anything from 25,000 to 250,000 volts. When the cathode is heated it emits electrons that travel at high speed to the anode. The bombardment of the metallic anode by the electrons produces the X-rays. The ability of X-rays to penetrate a variety of materials, including body tissue, makes them a powerful tool in the physical and medical sciences. We now know that X-rays are a quantum of electromagnetic energy, also called photons.

Soon after the discovery of X-rays, it was discovered that uranium salts spontaneously give off radiation that penetrates matter in the same fashion as X-rays. Other supposedly inert materials were found to emit similar radiation, forming a class of radioactive materials known as *radioisotopes*. Gamma rays, one type of radiation from those materials, are similar to X-rays. Other types of radiation from radioisotopes are alpha rays and beta rays.

The emission of a gamma ray, alpha ray, or beta ray causes the radioisotope to change from one type of atom to another. When the emission occurs, the atom is said to decay. The radioactive process is an electronic process in that it involves changes in the electrical charge configuration of the atom. A beta ray is actually a particle, an electron emitted by the atomic nucleus. A gamma ray is the photon emitted when an electron is added to the atomic nucleus. The alpha ray is a particle that consists of two protons and two neutrons, identical to the nucleus of the helium atom, emitted when the atom decays. In physics theory, particles sometimes



PUTTING IT ALL TOGETHER

The Radalert circuit uses two PC boards; these are the ones from the Radalert prototype. The PC-board templates shown in the PC Service section of the June issue, and the boards supplied in the kit, are slightly different from the photos so that user-assembly will be easier. Most important, jumpers are no longer required.

The main board (*a*) has all its components installed on one side. The display board (*b* and *c*) has components installed on both sides. The top of the display board (*b*), what is usually called the "component side," has the LCD display unit, the beeper, and the two operating switches. The "solder side" (*c*) of the display board has the remote power and alert jacks, IC16, and the Samtec connector.

When the case is assembled the main board is automatically connected to the display board through the 16-pin Samtec connectors, forming the circuit "sandwich" shown in *d* (case removed for clarity).

behave like rays, which travel in waves, so the terms are quite frequently used interchangeably.

Gamma rays behave in the same manner as light waves and radio waves although the wave lengths of gamma rays are extremely short, less than 0.1 billionth of a centimeter. However the energy of gamma radiation is millions of times greater than light and radio waves, giving it the ability to penetrate matter.

The energy of ionizing radiation is measured in millions of electron volts (mev). Beta particles have energy values ranging from almost zero up to 1 mev. Alpha particles have energy values from 0.1 mev up to 5 mev, and gamma rays have energy values as high as 100 mev.

Each radioisotope has a half-life, which is the time required for half of a quantity of the material to decay. For example, thorium 234 has a half-life of 24 days. If you start out with one gram of thorium 234, at the end of 24 days, ½ gram of thorium 234 will have decayed to protactinium 234 by emitting beta rays. Note that theoretically it will take an infinite time for the thorium to decay completely because for each succeeding half-life only half the remaining material decays. To put that into perspective, after seven times the half-life, approximately 99% of the original material has decayed, and after 10 times the half-life, approximately 99.9% of the material has decayed. The decay products may still be radioactive. Because the decay process actually occurs randomly, the half-life represents the average rate of emission.

The decay chain

Table 1 shows the complete radioactive decay chain for uranium starting with U238 and ending with a stable isotope of lead. You can see that the half-life of the atoms in this chain range from 4.5 billion years to 164 microseconds, an astonishing span. Only the primary type of ray emitted is shown, but since radioactive decay is a complex phenomena, secondary emission of the other rays may take place to a lesser degree.

Natural radiation

Uranium and its decay products are the most common radioactive materials in the ground. They are found everywhere. All the isotopes in the uranium decay chain are solids except

TABLE 1
RADIOACTIVE DECAY CHAIN

Isotope	Emits*	Half-life		Product
U238	alpha	4.5 billion years	Th234	Thorium
Th234	beta	24.1 days	Pa234	Protactinium
Pa234	beta	1.17 minutes	U234	Uranium
U234	alpha	250,000 years	Th230	Thorium
Th230	alpha	80,000 years	Ra226	Radium
Ra226	alpha	1602 years	Rn222	Radon
Rn222	alpha	3.8 days	Po218	Polonium
Po218	alpha	3 minutes	Pb214	Lead
Pb214	beta	26.8 minutes	Bi214	Bismuth
Bi214	beta	19.7 minutes	Po214	Polonium
Po214	alpha	164 microseconds	Pb210	Lead
Pb210	beta	21 years	Bi210	Bismuth
Bi210	beta	5 days	Po210	Polonium
Po210	alpha	138 days	Pb206	Lead

*Primary emission

for *radon*, the only radioactive gas. High concentrations of radon are found in soils and rock containing uranium, granite, shale, and phosphate. Trace amounts of radon are widely distributed in the earth's crust. As a gas, radon migrates through the ground to enter the atmosphere. Radon is colorless, odorless, and tasteless; it does not burn or glow. In recent years, it has been discovered that radon is a serious problem in many homes.

According to the Environmental Protection Agency (which is more generally referred to as the EPA), radon was first noticed in the late 60's in homes that had been built with materials contaminated by waste from uranium mines. Only recently they have learned that houses in various parts of the U.S. may have high indoor radon levels caused by infiltration from the soil. The EPA has published booklets for the public on that topic; they are titled *A Citizen's Guide to Radon* and *Radon Reduction Methods*.

Phosphate deposits throughout the world contain relatively high concentrations of the uranium decay chain. In the U.S., about half the mined phosphate is converted to fertilizer; the rest is used to produce chemicals and gypsum building materials. Mining and processing phosphate ores distributes uranium and its decay products in the environment. The use of phosphate fertilizers with high levels of radioactivity may contaminate food crops.

Man-made radiation

The development of nuclear weapons, their use at Hiroshima and Nagasaki, and subsequent atmospheric testing, significantly increased radioactive elements in the environment. The finding of high concentrations of radioactive strontium in milk and other food products led to a world-wide treaty to end atmospheric testing in 1963.

The use of nuclear reactors to generate electricity is a major contributor to man-made increases in radiation levels. The nuclear fuel cycle consists of mining and milling uranium and its conversion to fuel material, fabrication of fuel rods, use of the fuel in the reactor, reprocessing of spent fuel, transportation and storage of contaminated materials such as tools, filters, chemicals, and clothing (so-called "low-level" wastes), and transportation and storage of high-level wastes from the reprocessing of fuel rods. Each of those steps may add radioactivity to the environment.

Operation of a nuclear reactor may be accompanied by controlled small releases of radiation. There are frequent reports of uncontrolled releases, aside from major accidents such as those at Three Mile Island and Chernobyl. Unfortunately, data on radiation levels near nuclear plants are not generally available. Following the Three Mile Island accident, the people living in the area successfully sued the operator of the plant to provide funds for setting up a permanent monitoring system to give an early warning of any future releases, however, the monitoring system has yet to be implemented.

Luminous dials on watches and instrument panels incorporate radioactive materials; hence, they also generate man-made radiation. Also, some early color TV sets were found to emit X-rays in excess of recommended limits, although more stringent regulations have largely eliminated that problem.

If you have ever taken a mantle-type gas lantern on a camping trip you should know that the mantle contains radioactive thorium. Although the package for replacement mantles has a warning not to keep mantles or its ash near the skin for prolonged periods, nowhere does it say that the mantles are radioactive.

Compounds containing radioactive uranium and cerium are incorporated in porcelains used in restorative and prosthetic dentistry to simulate the fluorescence of natural teeth. The amount of these radioactive materials in dental porcelain powders and artificial teeth is limited by law.

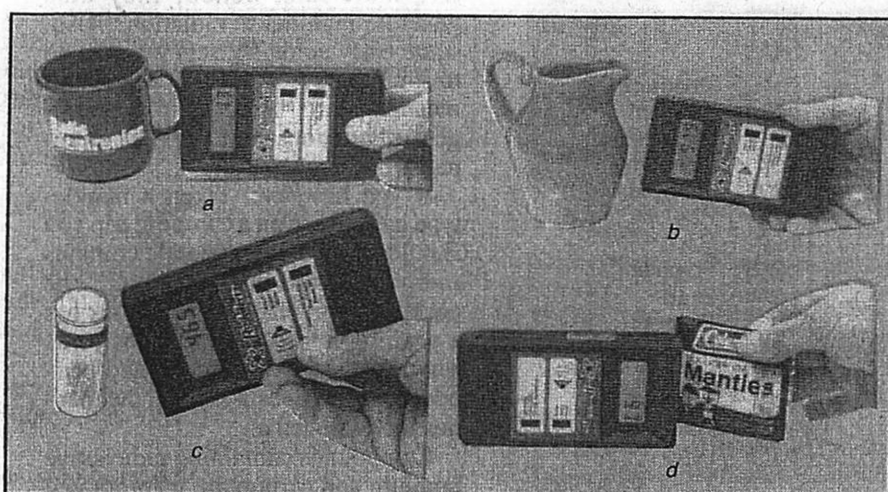
Ceramic pottery and its glazes may contain small amounts of radioactive uranium and thorium, depending on the source of the clay.

Beneficial radiation

The first, and best known, use of radiation is the X-ray. Almost every one of us has at some time been exposed to diagnostic X-rays. It is hard to imagine the practice of orthopedics or dentistry without the use of X-rays. Some uses of X-rays—such as measuring the fit of shoes in shoe stores—have been long abandoned because of health risks.

Radioisotopes behave the same way in chemical reactions as the stable isotope. That makes them useful in diagnosing and treating disease. If a sample of material containing a radioisotope of a chemical involved in a specific disease or physiological process is injected or ingested, doctors can follow the activity of that chemical within the body with appropriate instrumentation. Much of the knowledge of thyroid function and thyroid disease has come from the use of radioactive iodine, I^{131}. Tumors can be localized with radioactive phosphorus, P^{32}, and radioactive chromium, Cr^{51}, is used in blood studies. Vitamin B_{12} made with radioactive cobalt, Co60, makes it possible to identify diseases associated with poor absorption of that vitamin.

Business Week magazine has reported an interesting side-effect of using radioactive isotopes in medi-



SOME COMMON RADIATION READINGS found around the office. In *a*, the Radalert's reading from a plastic drinking cup is the background radiation level, which means the cup is radiation-free. But *b* shows that the orange clay or glaze used in making the pitcher obviously is radioactive; more so than the tube of Uranium-235 samples shown in *c*. Also radioactive—but to a smaller degree—are the camping-lamp mantles shown in *d*.

cine. On two separate occasions, the Secret Service asked women visiting the White House to step out of the visitors line. A sensitive radiation detector had picked up radiation from the women. After questioning it was discovered that both women had recently had injections of radioisotope material for medical purposes, and enough of the isotope remained in their bodies to trigger a radiation alarm.

The uses of X-rays are not limited to medicine and dentistry. Industrial applications include the familiar baggage examination at airports, engineering studies of integrated circuits, and flaw detection in metals, including welded joints. Non-contact thickness measurements on moving extrusions of rubber and plastic is a common industrial application of beta and gamma rays.

Harmful radiation

In general, the biological effects of ionizing radiation are destructive. As alpha, beta, or gamma radiation passes through the body, it interacts with the body's cells. Atoms in the cells may be ionized, or electrons in orbit about the nucleus can be displaced from one energy state to another. In either case the cells are changed from their original form to new forms, and the information contained in them is modified.

The changes that occur may cause some cells to stop reproducing; other cells may undergo mutation, or the control mechanism in cells that limits cellular reproduction may fail, causing cancer.

It may take years before the effects of radiation become manifest, so it is almost impossible to prove on an individual basis whether there is a relationship between radiation exposure and a subsequent disease. However, two studies on large populations indicate a statistical relationship. One study involved the survivors of the Hiroshima and Nagasaki atomic bomb blasts. Another study followed children of mothers who had diagnostic X-ray procedures during pregnancy. As a result of the latter study, the use of X-rays on pregnant women has been considerably reduced.

Many experts used to think that if radiation exposure was under a certain threshold, a person would not have any harmful effects. Although some still believe in the theory, the evidence is establishing that there is no minimum radiation level that can be considered safe. *Radiation and Human Health*, by John W. Gofman, M.D., Ph.D., is a comprehensive investigation of the evidence relating low-level radiation to disease. *The Wall Street Journal* reported in February, 1988, that the National Institutes of Health has launched "...a large-scale evaluation of cancer deaths occurring among persons living near the over 100 reactors operating in the United States."

The amount of energy received from ionizing radiation by sensitive biological tissues is a determining factor in causing harmful effects. Energy is measured in *ergs*. If 100 ergs of ionizing radiation are received by 1 gram of body tissue, the tissue has received 1 rad of radiation, a unit of exposure. The *Roentgen* is another measurement of exposure, originally used for X-ray machines. One roentgen equals 93 ergs per gram of tissue, almost the same as a rad. For some purposes it is useful to speak of rads per unit of time such as per minute, per hour, or even per year, while sometimes just the total accumulated exposure is of interest.

To assess the potential damaging effect of radiation from radioactive materials, we need to know the number of emissions per unit of time and the amount of energy of each emission. While a Geiger counter can easily measure the emission rate in counts per minute, it can only measure the energy level in rads if the specific source of radiation is known. To get around that problem, some Geiger counters are calibrated in terms of *millirads*, or *milliroentgens*, per hour (mr/hr) for a specific source such as Cesium-137; then, comparisons can be made for other materials. The Radalert display is in counts per minute, or total counts, as its main purpose is to indicate changes in background radiation without the need to know what the radiation source is, a task for more expensive equipment. An Operating Manual for the Radalert supplied with the parts kit includes conversion charts between counts per minute and mr/hr for common isotopes.

Further information on radiation can be found in IEEE *Spectrum*, November, 1979, and in *Report of United Nations Scientific Committee on the Effects of Atomic Radiation*,' 1982.

Using the Radalert

As mentioned earlier, we are always exposed to naturally occurring background radiation from outer space and from the earth. After you finish assembling and testing the Radalert you can determine the background radiation level in your area. Do that outdoors first so it can be compared with the level inside your home. Notice—by watching the count light or listening to the beeper—that background radiation occurs randomly. In a northern California labotenuated by collisions with air molecules so the radiation at sea level is normally lower than at higher elevations. Figure 2 shows the relationship between CPM and altitude based on 15-minute average readings taken in California from the top of the ski lift at Heavenly Valley (10,000 feet) to sea level.

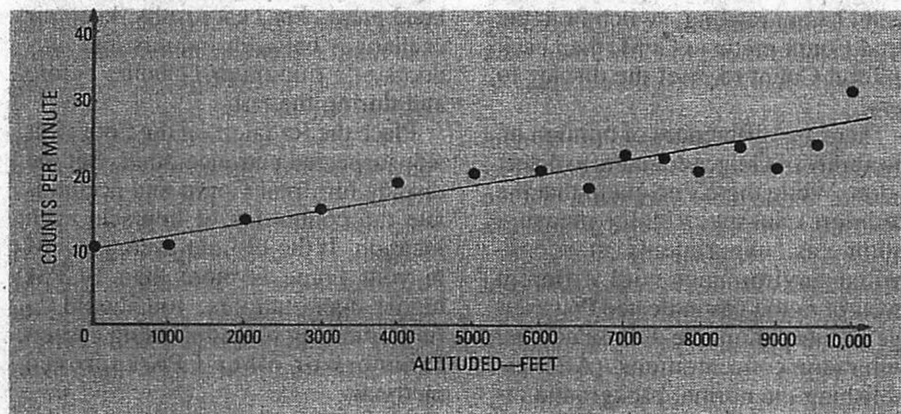


FIG. 2—THE BACKGROUND RADIATION at various altitudes, measured from a ski-lift.

The altitude effect is particularly noticeable when traveling by air at 35,000 to 40,000 feet. Radiation levels 30 to 50 times higher than on the ground have been measured at these altitudes.

At times of solar flares the radiation level may go considerably higher, so supersonic aircraft, which fly as high as 60,000 feet, have radiation-monitoring equipment to alert the pilot to move the plane to lower altitudes if the radiation reaches a predetermined level. Make some radiation measurements with your Radalert on your next flight, with the beeper *off* so that you don't disturb any of the other passengers.

You can establish a baseline of background radiation if you live, or frequently drive, near a nuclear power plant; then you can observe changes from the baseline due to controlled or uncontrolled releases of radioactivity. A baseline of 12–14 CPM for a local nuclear plant was established during drive-bys on a number of occasions. But on one occasion the CPM increased to 22, an increase of over 50%.

Use your Radalert in your car. You may be able to detect vehicles transporting radioactive materials, or discover you are passing a phosphate mining region, or other radioactive deposits. With the sound-selector switch set for the *Count* position the audible beeps will help you recognize short-time radiation increases that might be masked by averaging.

Exploring for underground radioactive materials can be an interesting hobby. Gemstones may be found together with, or may contain, radioactive materials; also, high radon concentrations are present in some caves, so be careful if your Radalert indicates higher than normal radiation levels while exploring. Radioactive materials can be hazardous if inhaled or handled carelessly.

In-home tests

As mentioned earlier, ordinary common household items produce a slight—though not necessarily unsafe—radioactivity. The photographs on page 54 show the readings attained when the Radalert was used to check some of those items.

If you work in the nuclear industry, or in a hospital or laboratory that uses radioisotopes, you may want to convert Radalert readings to mr/hr. For Cobalt-60, divide the CPM reading by 958 to obtain mr/hr. For Cesium-137, divide by 982. This relationship for the LND 712 Geiger tube was obtained at Battelle Laboratories using sources traceable to the National Bureau of Standards. If you have access to calibrated sources of other isotopes, you can determine the appropriate conversion factor for your isotopes.

What should you do if the Radalert shows abnormally high radiation levels in the CPM mode? First, you should seek confirmation of your readings. Public Health Departments, hospital health physics or nuclear medicine departments, civil defense offices, EPA offices, police or fire departments, are possible places with radiation-monitoring equipment. Before you start doing your own measurements, you might want to find a contact you could call for confirmation if the Radalert gives an alert signal, or other indication of unusual radiation activity. Should there be confirmation, keep in touch with your local authorities and follow their instructions. Be aware that radiation from airborne radioactive particles will be less in a closed house or inside a building.

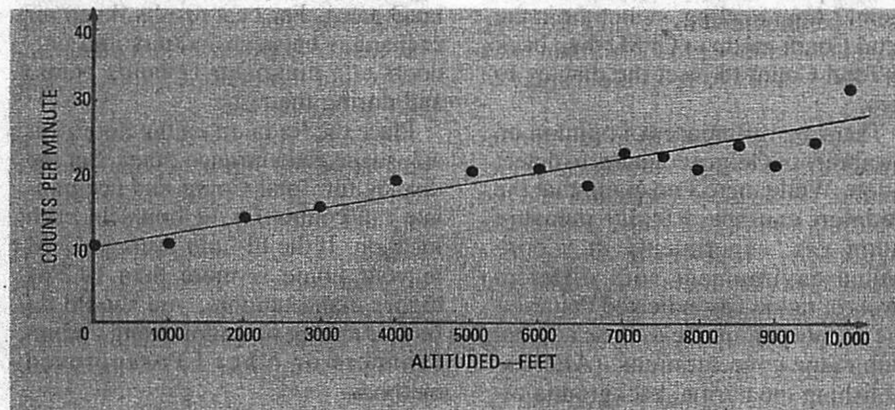
SOURCE

A complete kit of Radalert parts which includes assembly instructions and an operating manual is available for $153.50 postpaid. The Geiger tube, the LCD display, and a set of PC boards with plated-through holes are individually available.

A completely assembled and tested Radalert including an operating manual is priced at $229 postpaid.

From: International Medcom, 7497 Kennedy Rd., Sebastapol, CA 95472. Or call toll-free, 1-800-257-3825. In CA 1-800-255-3825. For technical information contact International Medcom at the above address.

If you don't have (or can't get) confirmation of a general increase in radiation, you should try to identify a localized source: a parked truck with radioactive materials, an excavation that has uncovered radioactive deposits, or even a container of radioactive material that has been disposed of illegally. The radiation level from such a source will decrease by the inverse square law; that is, if you move around with the Radalert and the level decreases by a factor of four, you will be twice the distance from the source. Or conversely, if the level goes up by a factor of four, you are only half the distance to the source. If you see evidence of a localized source, notify the authorities and get as far away as you can. Up to now, there has not been a large scale use of Geiger counters outside of laboratories and nuclear plants, which has limited our knowledge of the potential existence of localized "hot spots" of naturally occurring and man-made radiation. The dispersion of man-made radiation throughout the environment is still generally unknown. We hope the use of the Radalert to collect and disseminate radiation data will contribute to better understanding of these important subjects. **R-E** tenuated by collisions with air molecules so the radiation at sea level is normally lower than at higher elevations. Figure 2 shows the relationship between CPM and altitude based on 15-minute average readings taken in California from the top of the ski lift at Heavenly Valley (10,000 feet) to sea level.



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