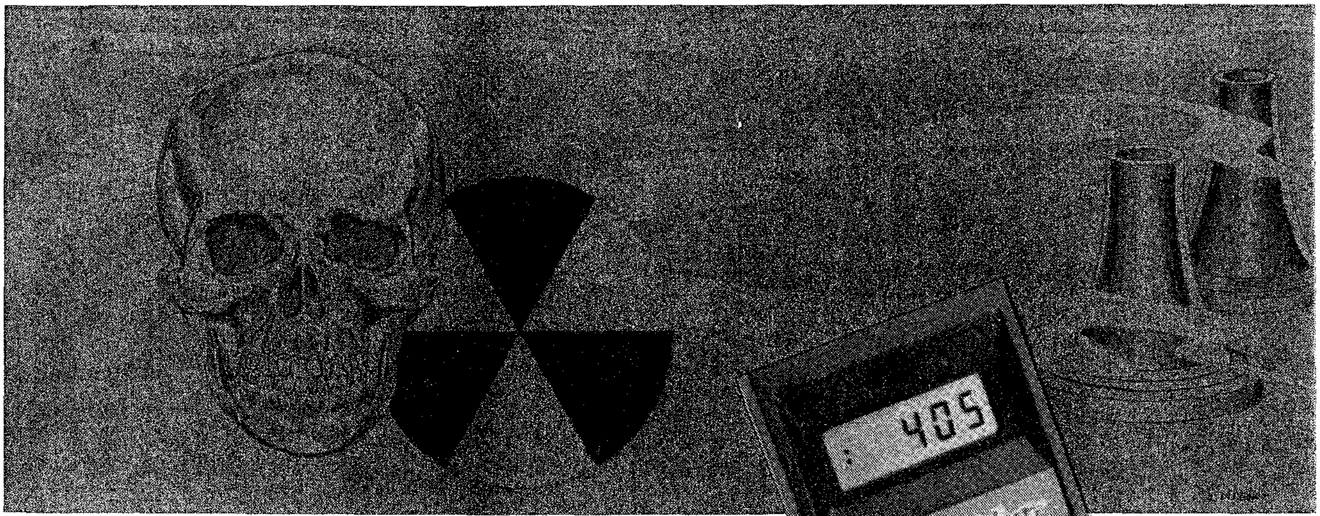
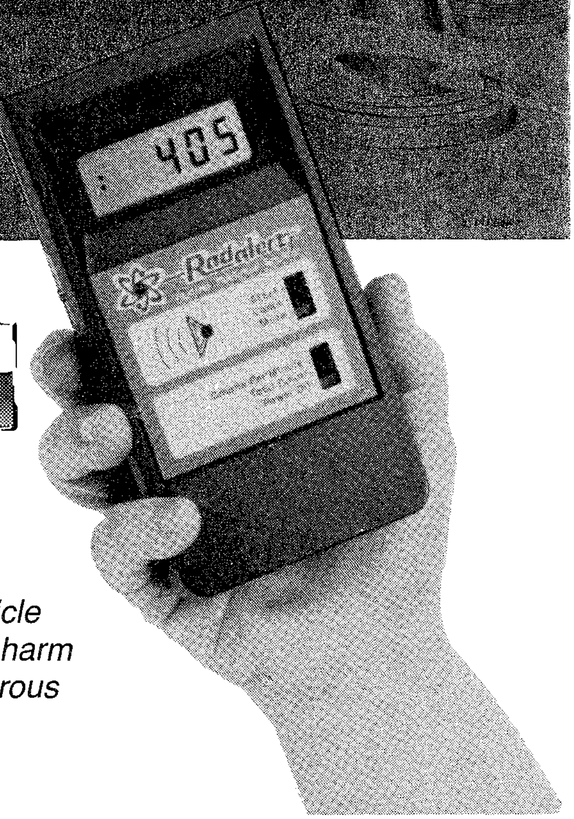


RADIATION MONITOR



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.

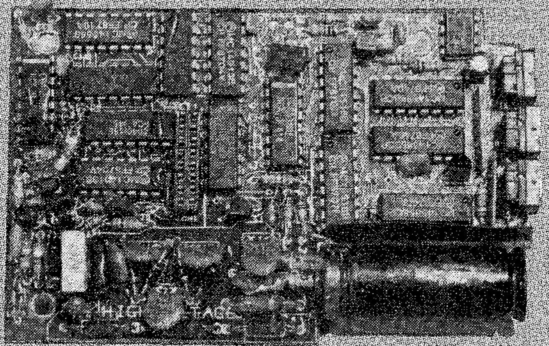
Last month we showed you how to build a nuclear radiation monitor—the Radalert. Now we'll show you how to use it, and how to interpret its readings.

Ionizing radiation

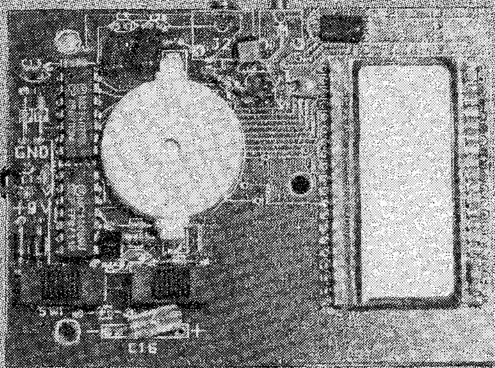
Ionizing radiation is radiation that has the ability to remove electrons (the process of ionization) when it strikes or passes through an electrically neutral atom. It was first discovered about 100 years ago and given the name *X-rays* because its nature was unknown. X-rays can be generated in a vacuum 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



a



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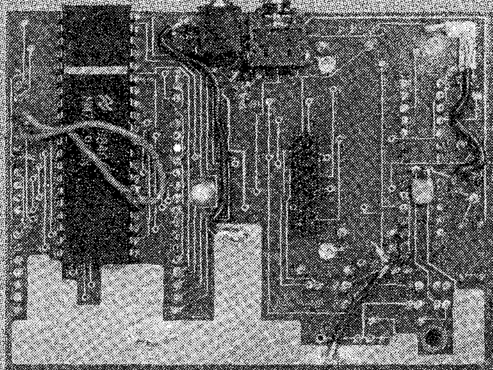


c

d

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.

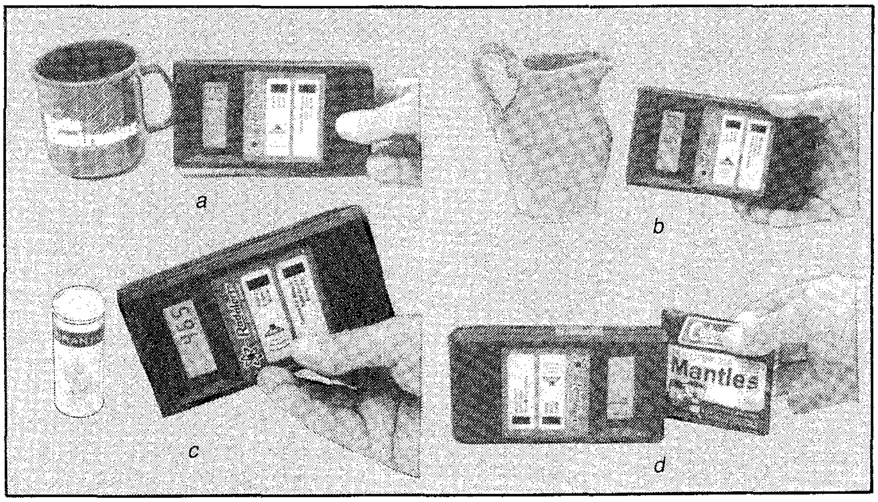
Ceramic pottery and its glazes may contain small amounts of radioactive uranium and thorium, depending on the source of the clay.

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 laboratory, an average CPM (*C*ount *P*er *M*inute) is 12.5, but a one minute count as low as 5 or as high as 25 is not unusual. Because of the possibility for a large CPM variation, you need to collect two sets of data: one for use in setting the Alert level (which warns you if the count in any minute is higher than would be normally expected); the other to help you detect small changes that might result from radon or other sources of radiation in your home.

We suggest you set the Alert level at a value that rarely sounds a false alarm, but one that still warns you when the radiation is unusually high. To determine that value you must first find the normal variation in background level. Standard deviation is a descriptive statistical measure of the variability of a set of data.

To calculate the standard deviation, use your Radalert in the CPM mode to measure 30 or more consecutive one-minute readings. Sum the readings and divide the sum by the number of readings to get the average value. Then take the difference between each CPM value and the average, square each of those numbers, and sum them. Divide the sum by 29 (if you have taken 30 readings, otherwise by the number of readings minus one). The square root of that number is the standard deviation. A hand calculator, or a computer, will help you do the calculations quickly.

A typical set of data has an average of 12.8 counts per minute, and a standard deviation of 4.3. $3 \times 4.3 + 12.8$ equals 25.7. Set the Alert level at 30, the next higher increment.

Use the Radalert's Total Count mode to check for small differences in radiation (for example, between outdoors and indoors). Obtain the total count for a 12-hour period in each location. When you take the count outdoors, place the Radalert on the ground in an unpaved area for one set of counts, then get another set of counts with the instrument about 4 to 6 feet above the ground. That procedure helps you detect alpha particle radiation from the earth, which rapidly dissipates in air.

Differences in radiation level as low as 1 CPM can be detected by comparing total counts for 12-hour periods. The differences might result from radon or concentrations of radioisotopes in the earth. Solar flares, low-level leaks from nearby nuclear plants, or higher-level leaks from distant plants can cause small changes in the 12-hour count. If you keep your Radalert operating continuously in the Total Count mode and take readings every 12 hours, say at 7 am and 7 pm, you will know when those events take place. For comparison purposes, it is best to convert the total count to counts per minute. After you take each 12-hour reading, switch from the Total Count mode to CPM, then back to Total Count to reset the display to zero.

There are differences of opinion on the ability of Geiger counters to detect radon. While there's no claim that the Radalert can specifically measure radon gas, experiments in a controlled environment with different levels of radon gas indicated that average counts per minute did rise and fall with radon concentrations. (After establishing the normal background radiation for a controlled-environment test site, the background radiation was subtracted from the total counts.) Preliminary results are shown in Fig. 1. The radiation detected is a combination of the emissions from radon and its "daughters," or "progeny."

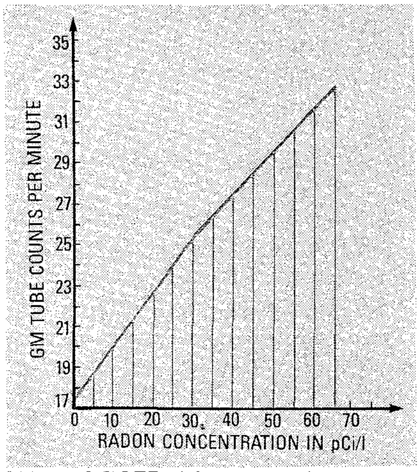


FIG. 1—GEIGER TUBE COUNTS vs. radon concentration. The CPM scale starts at 17 CPM, which was the background radiation at the testing station. The radon concentration at the test station is assumed to be between 1 and 5 picocuries per liter.

The Radon Technical Information Service of the Research Triangle Institute prepared a Cumulative Proficiency Report for the EPA in July, 1987. The report describes the approved radon testing methods, and the advantages and disadvantages of each method. The use of the Radalert in conjunction with the EPA methods reduces the possibilities of error.

Radon entrance

The most likely entrance points for radon in homes or other buildings are cracks or openings in the floor around pipes or conduit, unsealed wall-floor joints, and underground hollow block walls. Dirt floors in basements are particularly vulnerable. Unventilated basements or closets normally have higher levels of radon than well-ventilated areas. For best results, keep air exchanges between indoors and outdoors at a minimum 12 hours before and during the test.

Place the Radalert on the floor near any suspected entrance point. Set the display for Total Count and accumulate the counts for 12 hours in each location. If the 12-hour average CPM in your home is more than 1-CPM higher than outdoors, you should do further testing for radon using carbon canisters or other EPA-approved methods.

Common radiation

You may find that you have radioactive items in your home. Pottery and glazed dinnerware are potential sources of radiation if they are made from uranium-bearing clays or uranium oxides. If you have any ceramicware with orange glazes, check it carefully for higher radiation levels. Also, static eliminators for records and photographic film may contain polonium, an alpha emitter. Use the Radalert in the CPM mode with the beeper *on* to identify those items.

Some commercial gemstones used in jewelry may have had their color enhanced by neutron bombardment, thereby making them radioactive. Also, gold jewelry has been made from reprocessed gold that was previously used in radiation therapy. Check those products with your Radalert in the CPM mode.

Do you have a watch, clock, or other instrument with a luminescent dial? Place its face as close as possible to the alpha window on the Radalert and see if there is an increase in radioactivity. Observe the change in CPM for different distances between the Radalert and the dial, and you can see how much of the count was due to alpha rays, compared to beta or gamma rays. Repeat these experiment with a replacement mantle for a gas lantern. You may be surprised by the results. Do not handle the mantle directly; keep it in its plastic bag.

Radiation from outer space is attenuated 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.

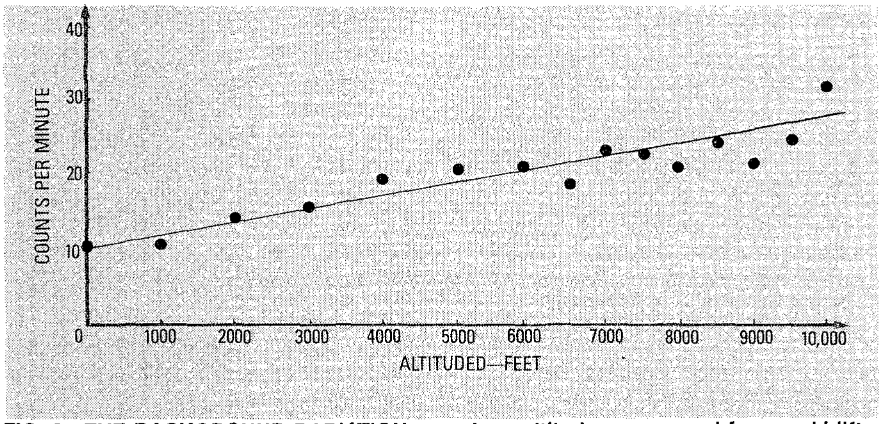


FIG. 2—THE BACKGROUND RADIATION at various altitudes, measured from a ski-lift.

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.

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**