

Monitor radioactivity
with this compact

GEIGER COUNTER

Are you are concerned by the Nuclear tests in the Pacific and in China? Worried about a possible increase in the amount of background radiation? Then check it out with this Geiger counter. It will detect alpha, beta and gamma radiation and has an audible output.

By JOHN CLARKE



Most people have never used a Geiger counter but they would probably have seen them in old war movies. These showed people in full protective suits sweeping an area with a rather large "high tech" contraption that produced loud clicking when a source of radiation was detected. Our Geiger counter does the same job and produces audible clicks at a rate dependent on the amount of radioactivity. However, it is much more compact and does not require the obliga-

tory carry handle used on the instruments of the past.

What is radioactivity?

Radioactivity is the emission of energy or particles due to the spontaneous decay of an unstable nucleus of an element to a lower energy state.

Atoms of all elements have a nucleus comprising one or more protons and neutrons plus outer shells of electrons. The number of protons in the nucleus is referred to as the Atomic

Number and this determines the basic element properties. While most atoms of an element will have a fixed number of neutrons, some can differ and these are called isotopes. Most isotopes are unstable and all isotopes above Bismuth (Bi) with an Atomic Number of 83 are unstable.

An unstable isotope will spontaneously decompose and emit radioactive energy which is far greater than the energy changes normally associated with chemical reactions. Radio-

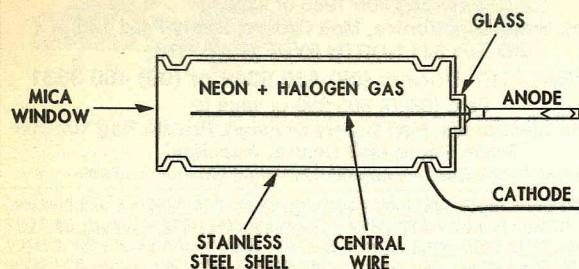
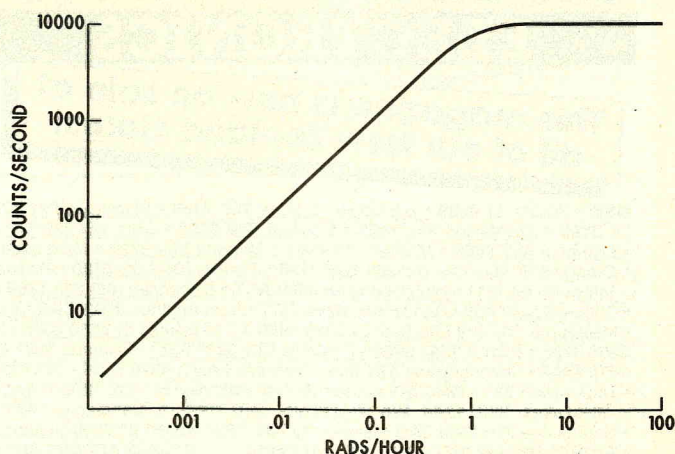
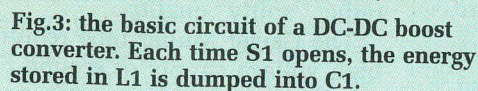


Fig.1 (above): cross section of the Geiger Muller tube. The passage of an alpha or beta particle or a gamma photon causes the tube gas to ionise and produces a brief discharge. Fig.2 at right shows the response characteristic of the Geiger tube to radiation. It is limited by the tube "dead time" to about 10,000 counts/second.





activity comprises alpha particles, beta particles, gamma rays, fast neutrons, positrons, photons or a combination of these.

Alpha particles are positively charged particles which are identical to Helium nuclei; ie, they comprise two protons and two neutrons. These particles can cause a large amount of tissue damage but fortunately they do not travel very far in air. In fact, alpha particles must have an energy of greater than 6MeV before they can travel 45mm. MeV stands for million electron volts and is a measure of the energy of the particle.

As an example, the Americium alpha particle source used in most smoke detectors only has a range of 20mm or so before all the particles are stopped by collisions with the air. The alpha particles are further restricted by the fine particles of smoke and this is the principle of operation of smoke detectors. We'll talk a little more about smoke detectors later but readers should note that provided a smoke detector is not disassembled it

emits no alpha particles at all; they are all confined within the metal chamber.

Beta particles are electrons. Electrons with energies over 1MeV lose a lot of energy by producing continuous X-rays.

Gamma rays are high energy photons (electromagnetic waves) with a very short wavelength (.0005nm to 0.1nm). These photons are difficult to stop unless very thick lead or concrete barriers are placed in their path.

The Positron is a positively charged particle with the same mass as an electron.

The total biological effect of radiation is measured in rems which stands for "Roentgen Equivalent in Man". This is found by multiplying the number of rads (absorption of .01 joules per kilogram of tissue) by a factor of 1 for beta, gamma and X radiation and by 10 for alpha and other high-energy neutron sources. Table 1 shows the effects of radiation

at varying exposures, measured in rems.

The heart of a Geiger counter is a Geiger Muller tube which is essentially an ionisation detector. Its cross section is shown in Fig.1. It comprises a metal case with a mica window at one end and a glass insulating seal at the other. A thin wire is located in the centre of the case and a high voltage of around 500V is applied between this (Anode) and the metal case (Cathode). When a radiation particle or photon enters the tube via the mica window, it ionises the gas and this creates a discharge.

After each discharge, the tube is not

This circuit includes a 500V supply which can cause an electric shock. Avoid contact with the circuit components when power is on.

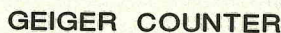
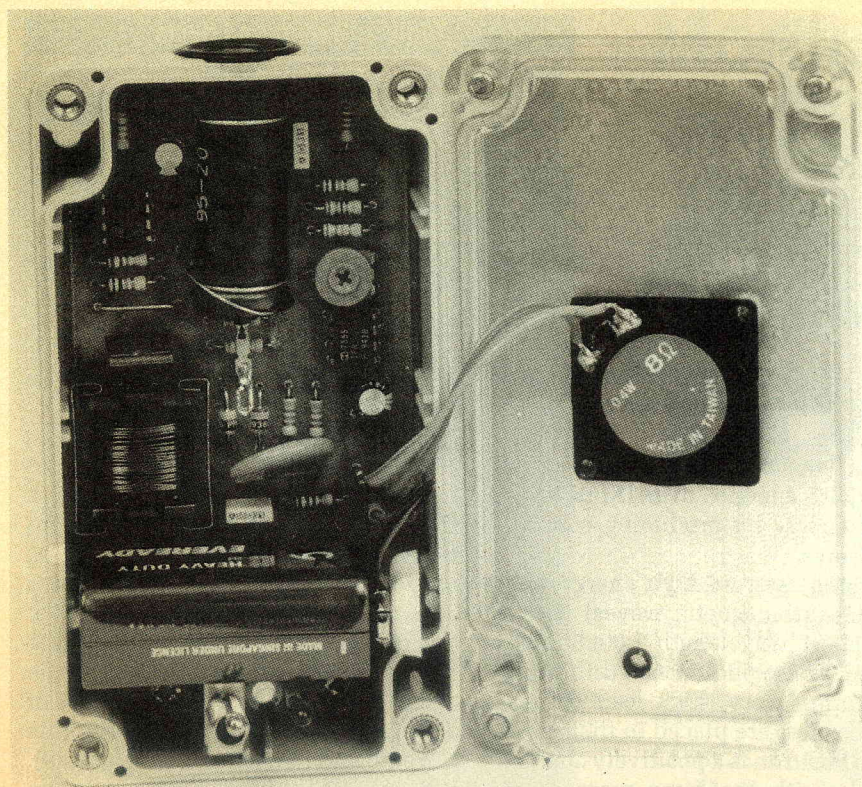


Fig.4 (below): the full circuit of the Geiger Counter. IC1 and Q1 step up the battery voltage to 500V DC for the Geiger tube. Each time the tube discharges due to the passage of a radioactive particle or photon, IC2 and Q2 produce a click in the loudspeaker.



Inside the case of the Geiger counter. Note that the corners of the PC board must be filed to fit it into the case. The 9V battery sits on top of a small foam cushion and is held in place when the lid of the case is attached.

immediately sensitive to further ionising radiation until the gases have reverted to their normal de-ionised state. This period of insensitivity is called dead time and it sets a limit on the number of discharges per second. In the Geiger Muller tube used in our circuit, the dead time is typically 90 microseconds and this limits the maximum number of detectable discharges to about 10,000 per second.

Fig.2 shows the radiation response of the tube. The horizontal axis shows the level of radiation while the vertical axis shows the number of discharges per second.

Note that radiation sources are typically random in nature, so the audible

Table 2: Typical Radiation Exposure

Natural Sources (Millrems/Year)	
Cosmic	50
Earth	47
Buildings	3
Air	5
Internal human tissue (potassium isotopes)	21
Man-Made Sources (Millrems/Year)	
X-ray machines	50
Radioisotopes	10
Luminous watch dials, TV tubes	2
Radioactive fallout during nuclear tests	4-30

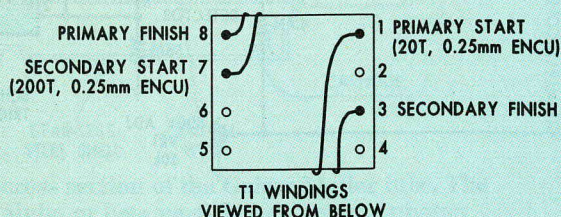


Fig.5: here are the winding details for the step-up transformer. Note that the two windings are both wound in the same direction.

output from the Geiger counter is just noise. At low radiation levels, it produces random clicks and as the radiation level is increased, the clicks become more rapid but still quite random. At much higher radiation levels, the clicks merge into noise with a rather "spitty" quality.

The Geiger Muller tube requires a high voltage supply of around 500V DC. To provide this we step up the supply from a 9V battery. Fig.3 shows how this is done using a boost converter.

Initially, S1 is closed and current builds up in inductor L1. The inductor current is i_1 . When S1 is opened, inductor current i_2 passes via diode D1 to charge capacitor C1. The actual voltage developed depends on the inductance of L1, the length of time that L1 is charged (ie, for the current to build up) and the load current drawn from C1. By the use of a feedback circuit, the voltage across C1 can be set to the required level.

Now refer to the full circuit for the Geiger counter in Fig.4. The step-up arrangement differs from that in Fig.3 in that the inductor is a transformer with two windings and a Mosfet transistor (Q1) is used as the switch. The advantage of using a transformer with a higher voltage secondary is that we can use a readily available 60V Mosfet rather than a more expensive 600V type.

Q1 is switched on and off at a rate of about 10kHz by op amp IC1b which is connected as a Schmitt trigger oscillator. IC1b operates by successively charging and discharging the .0015μF capacitor at its pin 2 via the 6.8kΩ resistor from its output at pin 1.

Each time Q1 switches off, it produces a high voltage (ie, many times the 9V supply) pulse across the primary of transformer T1. The transformer steps up the primary pulses by a factor of 10 in its secondary and the resultant output is fed via diodes D1 & D2 to a .01μF 2kV capacitor.

Regulating the output

While the circuit described so far will certainly develop a high DC output, the actual voltage will tend to vary widely, depending on the input DC voltage and the load current drawn by the Geiger Muller tube which will itself vary widely, depending on the amount of radiation present. To set the DC output close to 500V we need

a negative feedback circuit and this is provided by op amp IC1a which functions as an error amplifier.

IC1a monitors the DC output of the boost converter via a voltage divider consisting of two 4.7MΩ resistors in series, trimpot VR1 and the 100kΩ resistor to pin 6. IC1a compares the DC voltage at its pin 6 with the reference voltage at its pin 5, provided by the 1.8V voltage drop across light emitting diode LED1. IC1a amplifies the difference between the two and its output is used to vary the threshold voltage of the Schmitt trigger oscillator, at pin 3 of IC1b.

Hence, if the DC output voltage is higher than it should be, IC1a increases the voltage at pin 3 and the result is that the pulses fed to Q1 are slightly reduced. This reduces the output voltage. Conversely, if the DC output voltage is a little low, due to extra drain or a lower battery voltage, IC1a lowers the threshold voltage at pin 3, lengthening the pulses to Q1 and thereby increasing the output voltage to what it should be.

C1, the 100μF 16VW capacitor across LED1, is there to prevent overshoot of the high voltage DC at switch-on.

Two fast recovery diodes, D1 & D2, have been used in series at the secondary of T1 because the breakdown voltage for each diode is only 500V. By using two diodes in series we get an adequate safety margin. Normally though, to ensure equal voltage sharing, the diodes should each have a high voltage resistor (eg, 1MΩ) across them. However, in this circuit, the impedances are so high that we are relying on the internal leakage of the diodes to provide adequate voltage sharing.

The 500V supply is applied to the Geiger Muller tube via two 4.7MΩ resistors in series. When the tube de-

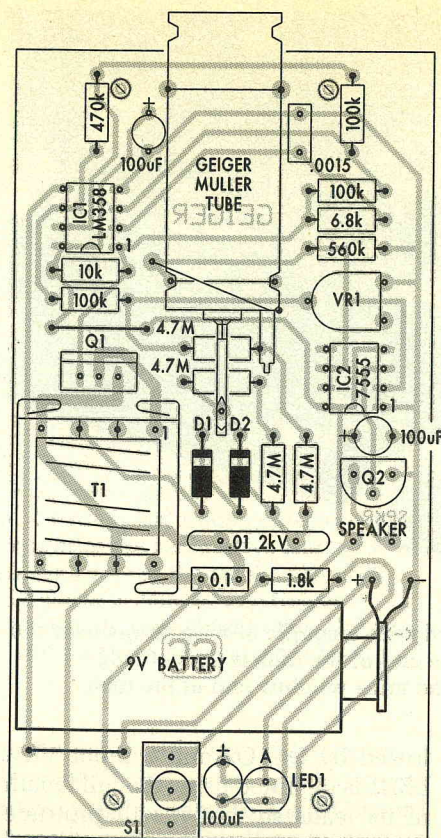


Fig.6: follow this component layout diagram when installing the parts on the PC board. The Geiger Muller tube is held in place with wire straps.

fects radiation, its impedance drops sharply and a brief pulse appears across the 560kΩ cathode resistor. This pulse is fed to IC2, a 7555 wired as a Schmitt trigger. It can be thought of as a pulse buffer, between the high impedance of the 560kΩ cathode resistor and the low impedance of the base of transistor Q2.

Thus each time the Geiger tube discharges, IC2 delivers a brief pulse to Q2 which drives the loudspeaker to produce an audible click.

Power for the circuit comes from a 9V battery via switch S1. When the

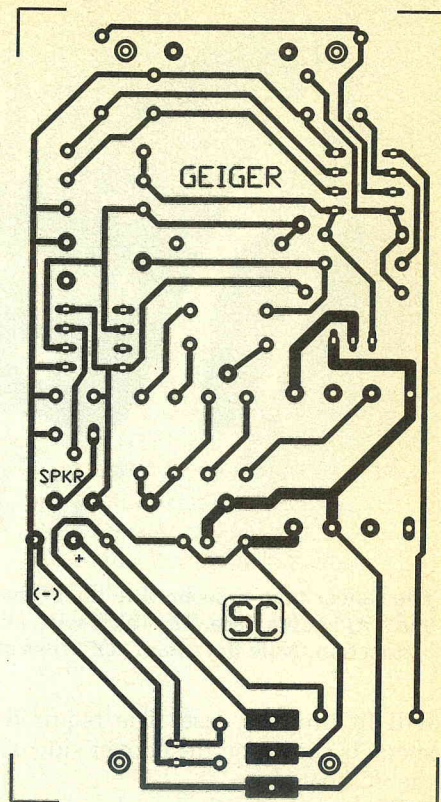


Fig.7: this is the full size etching pattern for the PC board. Check your board carefully before mounting any of the parts.

switch is off it connects the circuit's positive supply rail directly to the 0V rail. This discharges C1, the capacitor across LED1, so that the circuit will start slowly when power is reapplied.

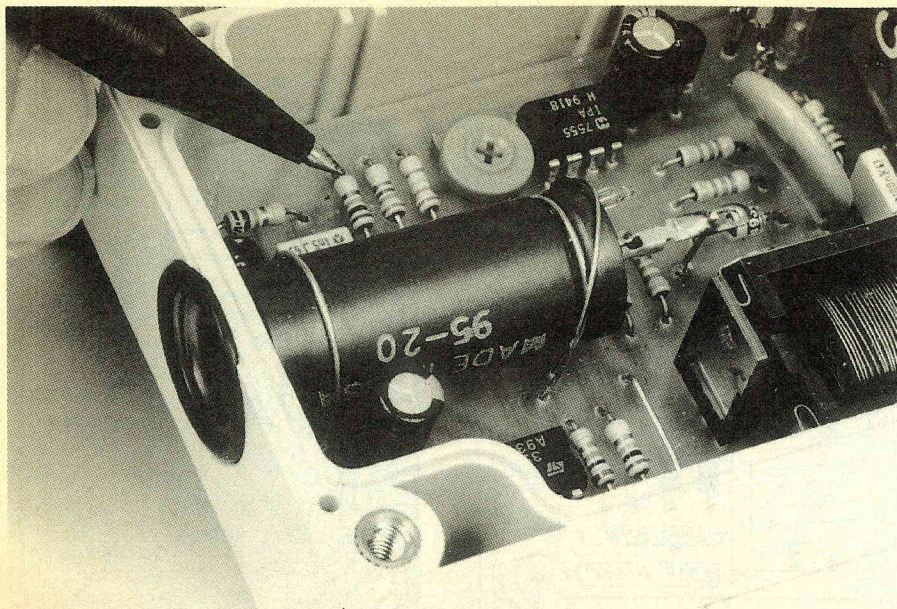
Assembly

All the components are mounted on a PC board coded 04310951 and measuring 56 x 104mm. The component overlay is shown in Fig.6.

Begin construction by checking the PC board for any breaks or shorts between tracks. Also the corners of the PC board will need filing so that it

TABLE 3: RESISTOR COLOUR CODES

	No.	Value	4-Band Code (1%)	5-Band Code (1%)
□	4	4.7MΩ	yellow violet green brown	yellow violet black yellow brown
□	1	560kΩ	green blue yellow brown	green blue black orange brown
□	1	470kΩ	yellow violet yellow brown	yellow violet black orange brown
□	3	100kΩ	brown black yellow brown	brown black black orange brown
□	1	10kΩ	brown black orange brown	brown black black red brown
□	1	6.8kΩ	blue grey red brown	blue grey black brown brown
□	1	1.8kΩ	brown grey red brown	brown grey black brown brown



The Geiger tube is secured to the PC board with a couple of wire straps over the body, as shown here. The third wire at the end of the tube is the cathode connection. Note the use of "O" rings at the mica window end of the tube.

will fit into the case. The required shape is shown on the copper side of the PC board.

This done, start the board assembly by installing the PC stakes. These are located at the + and (-) battery input points and the loudspeaker outputs. Three PC stakes are also placed in the holes for switch S1 so that it will be raised from the PC board.

Next, install the two wire links (one near Q1 and the other next to S1), then install all the resistors, using Table 3 to guide you with the colour codes. This done, insert the diodes and ICs, taking care with their orientation. The capacitors are next, fol-

lowed by Q1, Q2 and trimpot VR1. LED1 is mounted using the full length of its leads so that it will protrude through the front panel. It is a good idea to fit plastic sleeving over one of the leads, to prevent shorts. Switch S1 is soldered on the top of the PC stakes.

Do not attach the Geiger tube yet!

Transformer winding

Transformer T1 is wound with 0.25mm enamelled copper wire as shown in Fig.5. The secondary is wound first. Strip back the insulation on one end of the wire and terminate it on pin 7 of the bobbin. Now wind a

layer of turns side by side in the direction shown and wrap a layer of insulating tape around this. Make sure that the tape does not start or finish on the sides of the former since this will prevent the cores sliding onto the bobbin when winding is completed.

Continue winding and apply one thickness of insulating tape over each layer. After 200 turns, terminate the end of the winding into pin 3.

The primary is started on pin 1 and after 20 turns finished on pin 8. It must be wound in the direction shown. There will not be sufficient room for a layer of insulating tape on this primary winding.

The transformer is assembled by sliding the cores into each side of the bobbin and securing the clips. This done, solder the transformer to the PC board, making sure that it is oriented correctly.

Circuit testing

Wind trimpot VR1 fully anticlockwise, connect the battery leads and switch on. The LED should light and the transformer should emit a high pitched whistle. **Take care not to touch the circuit because of the high voltage it produces.**

Select the 1000VDC range on your multimeter. Attach the negative lead to the (-) battery terminal on the PC board and the positive lead to the cathode (striped end) of D2. Adjust VR1 for a reading of about 500V.

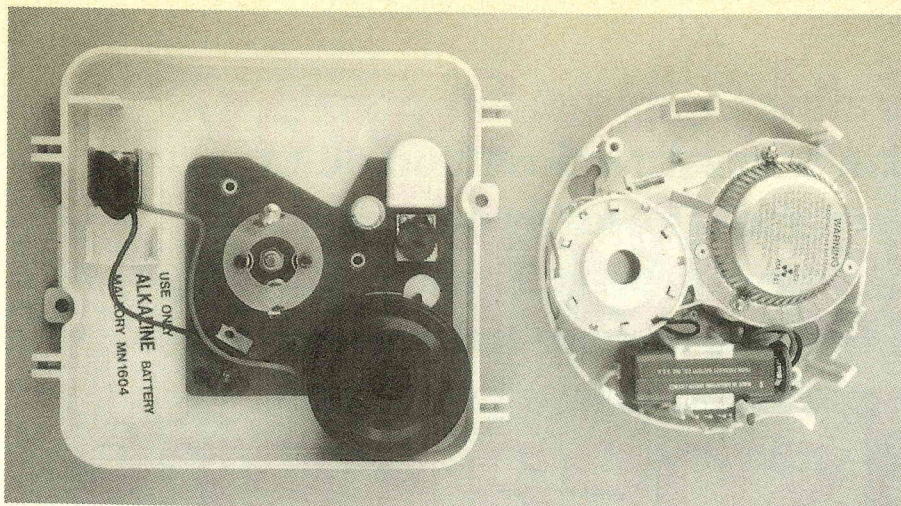
Disconnect the battery and connect the Geiger tube to the PC board. The tube is secured using tinned copper wire straps over the body, while its cathode lead is soldered to a pad adjacent to pin 1 of IC1. The anode connection is made using a short length of tinned copper wire to a pad near the cathodes of D1 & D2. Avoid using excess heat on the anode terminal when soldering.

Case

The unit is housed in a plastic case measuring 64 x 114 x 42mm. One end of the case needs a 19mm hole drilled for the Geiger tube. We used two 18mm OD "O" rings to support the tube and provide shock relief. One "O" ring is fitted over the groove at the mica window end. The other is placed over the section of the tube where it just protrudes from the end of case. The board is mounted in the case using four 3mm screws at the corners.

Tube Specifications

Gas content	Neon & halogen
Operating temperature	-40°C to +75°C
Window material	Mica
Recommended anode resistor	10M Ω
Starting voltage	325V
Recommended operating voltage	500V
Operating voltage range	450-600V
Minimum dead time	90 μ s
Minimum alpha particle energy for detection	2.5MeV
Minimum beta particle energy for 25% absorption in mica window	30MeV



This photo shows the internal construction of two typical smoke detectors. Both have a detection chamber with a minute amount of the radioactive isotope Americium 241. The detector on the left has the cover of the smoke chamber removed to reveal the centrally placed alpha particle source. The Geiger Counter will only detect radiation when it is brought very close to this alpha source. This is because the alpha particles will only penetrate a very short distance in air.

Fix the label onto the lid and drill holes for the switch and LED 1, plus mounting holes for the small loudspeaker. Holes are also drilled in the radiation symbol to let the sound from the loudspeaker escape.

Attach the loudspeaker with two small self-tapping screws and wire it

to the PC board using the twin rainbow cable. We used a small strip of foam plastic glued to the PC board directly under the battery to prevent it rattling in the case.

Finally, assemble the case and apply power. The Geiger tube should fire once every few seconds and sound the speaker. This is the background radiation. Any radiation greater than background will provide a much faster repetition sound.

Radiation source

If you want to test your Geiger counter with a much higher intensity than background radiation, you can use the radiation source inside a smoke detector. This consists of a small amount of the radioactive isotope Americium 241 (equivalent to 0.9 microcuries). This has a half-life of 400 years so it is pretty constant over a human lifetime.

To use the Americium alpha particle source, you need to remove the internal aluminium cover from the smoke detector's PC board. This needs to be done otherwise no alpha particles escape. With the central alpha particle source exposed, bring the window of the Geiger counter close to it. Virtually nothing happens until the Geiger tube window is within 20mm of the alpha source. Then as you bring it closer, it will begin to click rapidly and then produce more and more noise with a rising pitch as you place the source as close as possible to the

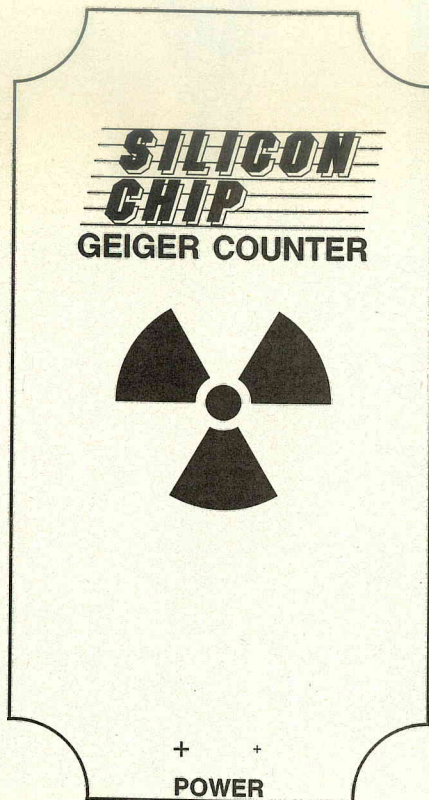


Fig.8: the full size artwork for the front panel label.

PARTS LIST

- 1 PC board, code 04310951, 56 x 104mm
- 1 plastic case, 64 x 114 x 42mm
- 1 Dynamark label, 55 x 103mm
- 1 LN712 Geiger Muller tube (from Jaycar Electronics)
- 1 square 30mm 8Ω loudspeaker (Altronics Cat. C-0606)
- 1 SPDT toggle switch (S1)
- 1 9V battery and battery clip
- 1 Philips EFD20 transformer assembly (T1):
- 2 4312 020 4108 1 cores
- 1 4322 021 3522 1 former
- 2 4322 021 3515 1 clips
- 1 8-metre length of 0.25mm enamelled copper wire
- 1 50mm length of twin rainbow cable
- 1 100mm length of 0.8mm tinned copper wire
- 7 PC stakes
- 4 3mm screws
- 2 self-tappers for loudspeaker
- 2 "O" rings 15mm ID x 18mm OD
- 1 50kΩ horizontal trimpot (VR1)

Semiconductors

- 1 LM358 dual op amp (IC1)
- 1 7555, TLC555, LMC555CN CMOS timer (IC2)
- 1 MTP3055E N-channel Mosfet (Q1)
- 1 BC328, BC327 PNP transistor (Q2)
- 1 3mm red LED (LED1)
- 2 1N4936 fast recovery diodes (D1,D2)

Capacitors

- 3 100μF 16VW PC electrolytic
- 1 0.1μF MKT polyester
- 1 .01μF 2kV ceramic
- 1 .0015μF MKT polyester

Resistors (0.25W 1%)

- 4 4.7MΩ 1 10kΩ
- 1 560kΩ 1 6.8kΩ
- 1 470kΩ 1 1.8kΩ
- 3 100kΩ

window. This highlights the fact that the alpha particles penetrate only very short distances in air.

After you have made the test, reassemble the smoke detector, test it and reinstall it so it can provide you with ongoing protection against fire. **SC**