CHAPTER 6

INSTRUMENTS

INTRODUCTION

You cannot hear, see, feel, smell or taste ionising radiation. Therefore, the only way you can detect and measure radiation is to use instruments. This chapter will give you a basic understanding of how instruments work and some of their limitations. We'll start with some general features of radiation instruments, and then we'll deal with the specific types of instruments we have at Point Lepreau.

CHARACTERISTICS OF RADIATION MEASUREMENT

In Chapter 2 we described some of the ways in which radiation interacts with matter. We will be using some of that information in this chapter, so I hope that you still retain a few clues.

All instruments require that radiation must deposit some of its energy in sensitive material that forms part of the instrument. This sensitive material is called the **detector.** The energy given to the detector then leads to events which we are able to observe and measure.

For example, in some cases these useful events are the formation of ion pairs in a gas. Separating the positive and negative ions with an electric field produces an electronic signal which can be amplified and recorded. In other designs, radiation can be made to produce light pulses in the detector — these light pulses are then processed electronically.

The effects of radiation on a detector can be measured in two ways. First, we can measure the **rate** at which events occur within the detector, and this will be related to the intensity of the radiation. For example, an instrument of this type used for measuring gamma radiation would give a high count rate for intense gamma radiation (i.e., lots of gamma photons interacting in the detector every second) and a lower count rate for less intense gamma radiation. Such an instrument would display the gamma dose rate in mSv/h or μSv/h.

Alternatively, some instruments are designed to operate in an **integrating** mode. In this case, the instrument records the total amount of radiation it receives in a given time rather than the rate at which it receives it. The personal dosimeters you wear in the station are an example of this type. They store the effects produced by radiation, so that when they are read out, they indicate the total radiation dose you received while wearing them. They read out in mSv.

Whatever effect is used to detect the radiation must be **reproducible.** In other words, the instrument response to radiation must remain constant and not vary from day to day.

An ideal instrument would be accurate over a wide **range** of intensity. For example, an instrument measuring gamma radiation intensities from μSv/h to tens of Sv/h, i.e., over seven decades, would be pretty nice to have. In practice, there is usually a limit to the range of intensity a single instrument can measure. Instruments that are accurate at low intensities are often useless for measuring high intensities, and vice versa.

IDENTIFICATION OF RADIATION TYPE

We have to know what type of radiation an instrument can measure. For instance, an instrument may indicate that the radiation field in a work location is 1 mSv/h. This is not enough information.

For example, if the radiation being measured is gamma radiation, we would be exposed to a deep dose rate of 1 mSv/h to the whole body, and a shallow dose rate of 1 mSv/h to the first cm of tissue. If the radiation were pure beta radiation, we would also be exposed to 1 mSv/h, but would only get shallow dose, not deep dose. It is relatively easy to shield against beta radiation, so we might want to do that. If the radiation being measured is pure alpha radiation, there is no external hazard at all since alpha particles cannot even penetrate the outer dead layer of skin. However, we would very definitely want to know the source of the alpha radiation, so that we could make sure that we didn't take the alpha emitter into the body where it could be a serious internal hazard.

Unfortunately, all radiation detectors respond to more than one type of radiation. It is therefore necessary to design an instrument so that by the use of shielding and/or electronic circuitry the effects of only one kind of radiation are measured. Then, when we work in mixed radiation fields (i.e., those made up of more than one kind of radiation), we will have to use a number of different instruments to sort out how much of each radiation is present. This sounds more complicated than it is; we will be returning to this topic later on. For the time being, it is enough to say that you must use the correct instruments for the job, and know how to use them.

RADIATION MEASUREMENTS

In and around Point Lepreau we use a variety of instruments for the following measurements:

1. External Radiation Dose Rates
2. External Radiation Doses Received
3. Airborne and Surface Contamination
4. Internal Radiation Doses Received
5. Effluent Wastes
6. Radioactivity in the Environment

Gamma, beta and neutron dose rate measurements are made to assess the hazard of a work location. Instruments used for this are known as **dose rate meters** (a gamma dose rate meter is just known as a **gamma meter** for short). The dose rate multiplied by the working time gives an estimate of your dose for the job. This estimate normally is used only for planning purposes — it is not assigned to your dose records. For that we use the personal dosimeters you wear, which integrate the dose received.

Internal radiation comes from sources inside the body. These usually enter the body as a result of breathing contaminated air. The actual amount of radioactivity taken into the body can only be measured reliably **after the intake.** In practice, we assess the hazard by measuring the airborne concentration of activity in the working area. Radioactive material that has been dispersed on exposed surfaces or suspended in the air or water supply is normally called **contamination.** Instruments that measure the amount of contamination on surfaces are called **contamination meters.** The results of such measurements will normally indicate what precautions or protective action should be taken — they are not used in your dose records.

If you do take some radioactive material into your body, we can estimate the dose from it if we can find out the quantity and identity of the material in your body. One way of doing this is to look at the rate at which such materials are eliminated from the body. Analysis of excretion samples (urine, faeces, mucus and other good things) is known as **bioassay.** Urine samples are collected routinely from people working at Point Lepreau and are analysed for internal contamination. The information obtained from bioassay is then used in your dose records.

Effluent monitors are instruments that are used to monitor continuously contamination in air and liquids discharged from the station. This gives us a measurement of the amount of radioactive material released from the plant to the environment and ultimately to the general public. The land, air and water surrounding the station are also monitored for possible contamination. This is called **environmental monitoring**. It is done to confirm that the operation of Point Lepreau has not caused a significant increase in the natural background radiation levels.

Measurements made by station staff are summarised below:

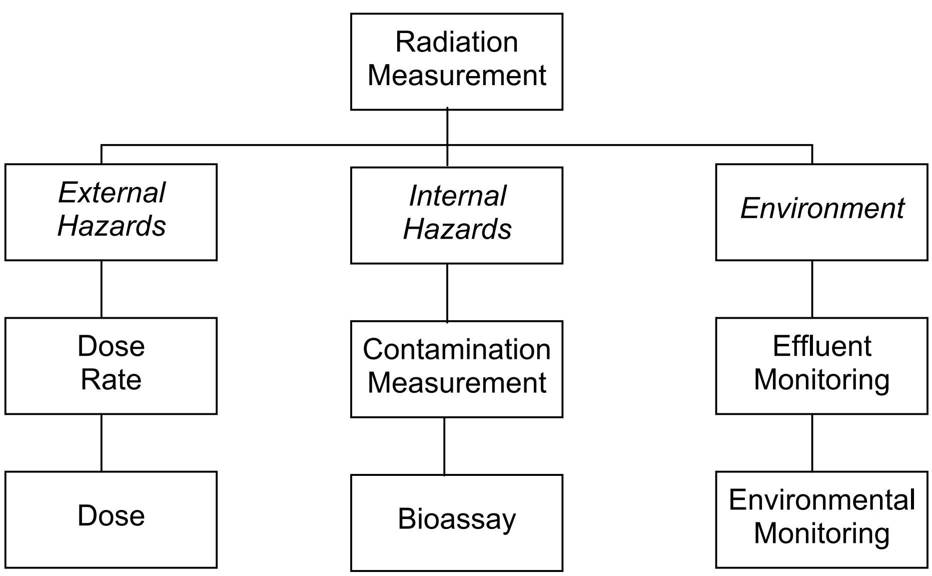


Fig. 6.1. Measurements Made by Station Staff

The operating staff of our station must ensure that:

1) there is an adequate supply of the required types of instruments,
2) they know how to use them,
3) they know what to do with the information they get from the instruments.

IONISATION CHAMBERS

When radiation interacts with matter, it always produces ionisation. A common method of measuring radiation is to collect the ions it produces in a gas. The more ions we collect, the more radiation we have. There are three types of instruments that operate along these lines: they are known as **ionisation chambers, proportional counters** and **Geiger counters.** We'll describe ionisation chambers first.

Imagine that radiation has produced several ion pairs in a volume of gas between two metal plates as shown in Fig. 6.2. What is going to happen? Well, not much. The electrons and the positively charged ions will just drift about and eventually recombine until there are no ion pairs left. However, if we made one plate positively charged and the other negatively charged (by connecting a battery between them, for example), then the electrons will be attracted to the positive electrode and the positive ions to the negative electrode. Will we collect all the ion pairs on the electrodes?

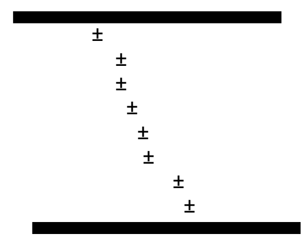


Fig. 6.2. Ion Pairs

That depends on the battery. If the voltage is low, the attractive force is small and many of the ions will recombine before they have a chance to reach their electrode. If the voltage is increased, we'll collect more and more, and eventually we'll be able to grab almost all of them before they have a chance to recombine. Further increases in voltage beyond this should have no effect. This behaviour is shown in Fig. 6.3.

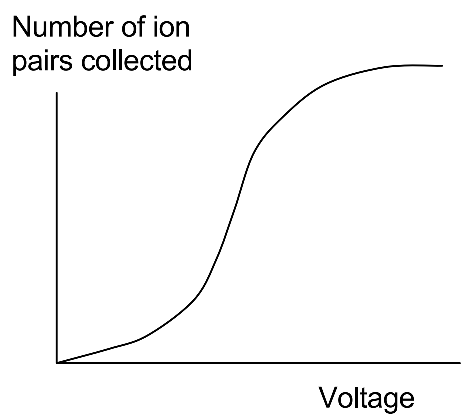


Fig. 6.3. Ion Collection

Ionisation chambers — often called ion chambers for short — work on the principle that if the voltage is high enough (perhaps 100 - 200 V) we can collect all the ions that radiation produces in a gas.

A practical ion chamber circuit is shown in Fig. 6.4. The chamber is normally a sealed cylindrical arrangement of two electrodes that are electrically insulated from each other. A battery connected across the chamber makes the centre wire electrode positive (the **anode)** and the outer cylindrical electrode negative (the **cathode)**.

Radiation striking the gas in the chamber will produce ion pairs. For example, a charged particle passing through the chamber will leave a trail of electrons and positive ions behind it. The electrons will be attracted to the anode, and the heavier positive ions will drift more slowly to the cathode. With the circuit shown here, the electrons reaching the anode will flow through the resistor R back to the battery.

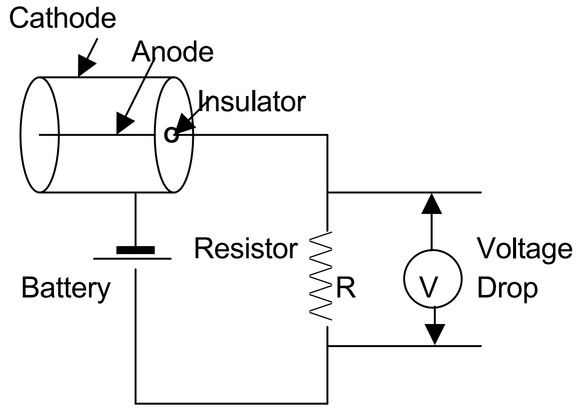


Fig. 6.4. Ion Chamber Circuit

When radiation strikes the detector at a steady rate, ion pairs will be produced at a steady rate, and electrons will flow through R at the same rate at which they are being released in the gas of the detector. In other words we have an electric current through R to indicate the rate at which ionisation occurs in the detector. These currents are normally very tiny and hence hard to measure. They do, however, generate a voltage drop across R, and if R is made large enough (a billion ohms or more), this voltage drop can be measured with clever electronics. The voltage across R will indicate the rate at which radiation is producing ionisation in the detector.

In their many different versions, ion chambers are widely used radiation instruments. Normally, they are designed to respond to gamma radiation, but they can also be designed to detect beta radiation or thermal neutrons. For example, the Reactor Regulating System at Point Lepreau uses ion chambers to measure the neutron levels in the core at low power.

ION CHAMBER GAMMA SURVEY METERS

An ion chamber gamma survey meter is a portable instrument that gives continuous readings of gamma field intensities. Fig. 6.5 shows one of our **Emergency Gamma Survey Meters**.

The detector of this instrument is fairly small (about 60 mL). It consists of a Lucite cathode (easy to machine), a wire anode and a dry nitrogen gas filling. Gamma photons will interact mainly with the lucite walls of the detector and release electrons by the weird and wonderful mechanisms we met on pages 23 and 24. Of these electrons, those produced in the walls with sufficient energy to reach the gas, and those produced in the gas itself will travel through the chamber to create ion pairs. The electron current through resistor R develops a voltage across it, and this voltage is applied to appropriate electronics to drive a meter movement calibrated in mGy/h.

This instrument has a range 1 mGy/min to 2 Gy/min. Yes, that's right, *per minute*. Let's hope you never need to use one.

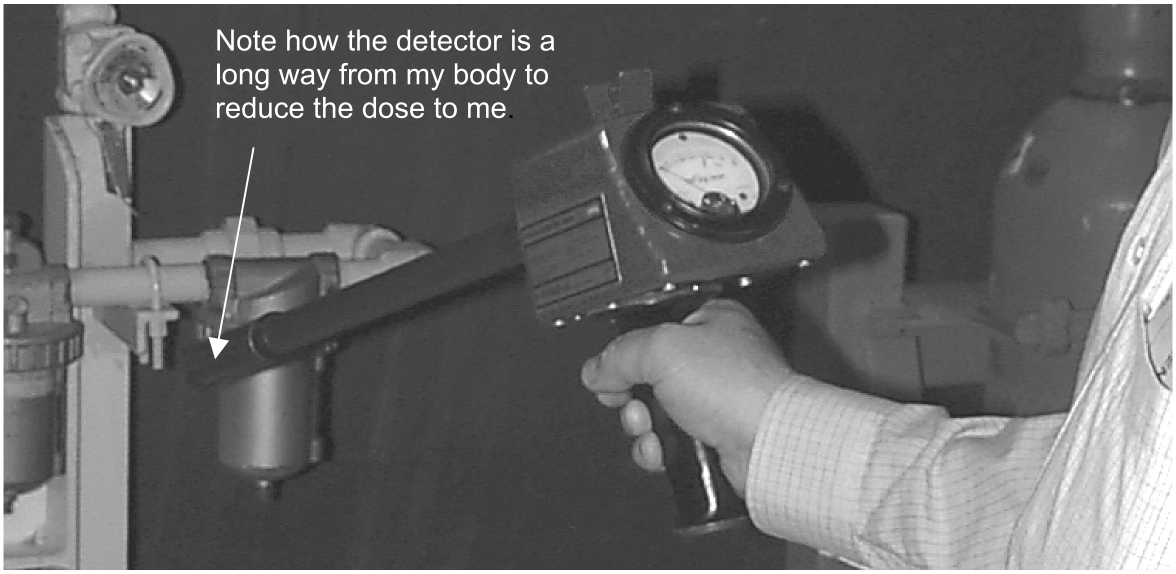


Fig. 6.5. Emergency Gamma Survey Meter

ION CHAMBER TRITIUM-IN-AIR MONITORS

The measurement of tritium in the air presents special problems because the average energy of the beta particles is so low (5.7 keV), that it is not possible to design a detector whose walls they can penetrate. Instead, we pump the tritium-contaminated air right through an ion chamber, so that all of the energy of the beta particles can be usefully converted to producing ion pairs inside the chamber.

Fig. 6.6. Tritium Ion Chamber

Since such a detector obviously would have ion pairs created in it by external gamma radiation as well, a practical monitor is designed with two ion chambers of equivalent size. One is used to collect the ions produced by tritium and gamma, and the second chamber is sealed, so that it sees only the gamma ionisation.

The electronics is designed to measure the difference in the currents from the two chambers, which should then indicate the tritium concentration in the first chamber.

Although this all sounds very plausible, in practice the instrument has a number of limitations. For example, any radioactive gas present in the air will be measured as tritium, and will lead to false high readings, because the number of ion pairs produced by a higher energy beta particle from the gas will be much larger than those produced by a tritium beta particle. Also, the gamma compensation is adequate only in relatively low gamma fields of less than about 100 μSv/h.

We have a few of these instruments — they are useful for detecting tritium if there is no significant gamma background. We'll have more on the various methods of tritium-in-air measurement later on in Chapter 9.

PROPORTIONAL COUNTERS

In proportional counters, the applied voltage is kept constant at such a value that the final number of electrons collected by the anode will be much greater than, but **proportional** to, the original number of primary ions produced in the tube. This is a subtle, but important difference between ion chambers and proportional counters.

An ion chamber will produce a current that is proportional to the number of electrons collected each second. This current is averaged and is used to drive a display reading in μSv/h or mSv/h. Proportional counters do not work in this way. Instead, they amplify each of the individual bursts of ionisation so that each ionising event is detected separately. They therefore measure the *number of ionising events* (which is why they are called **counters),** whereas ion chambers measure the *amount of ionisation produced by these events.*

GAS AMPLIFICATION

Let us assume that a beta particle ionises the gas in a detector to produce 100 primary ion pairs. If the detector is operated as an ion chamber, 100 electrons will be collected to the anode, i.e., the voltage on the electrodes is high enough to collect all the electrons before they have a chance to recombine. What happens if we increase the voltage?

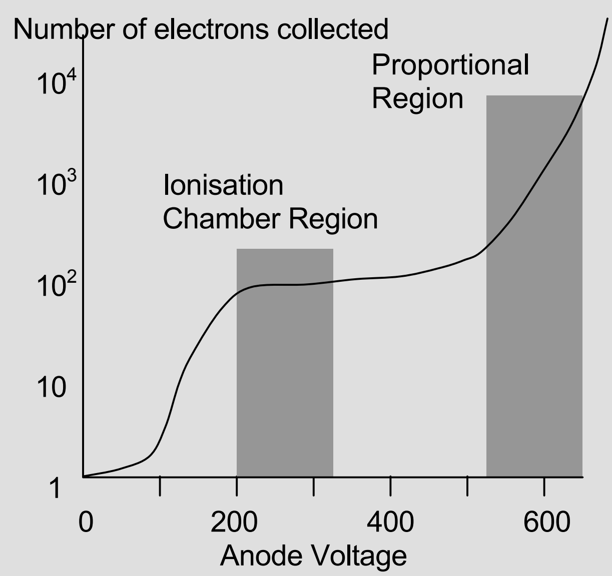


Fig. 6.7. Electron Collection versus Voltage

As the voltage is increased beyond C, we seem to be collecting more electrons than the beta particles produced. Believe it or not, that's correct. What is happening is that the primary electrons are accelerated in their rush to the anode to such an extent that they themselves produce further ionisation in the gas. In fact, with a sufficiently high applied voltage, the secondary electrons produced in this way can also cause further ionisation. This effect is called **gas amplification** and results in an avalanche of secondary electrons being created. Figure 6.7 shows how the number of electrons that are collected increases as the voltage is raised.

The pulses produced by a proportional counter provide us with two useful pieces of information:

1) the *number of pulses counted* gives us a measure of the **intensity** (i.e., rate) of the radiation.
2) the *size of the pulses* gives us a measure of the amount of ionisation produced in the detector, which is proportional to the **amount of primary ionisation produced by the radiation.**

PROPORTIONAL COUNTERS FOR β,γ CONTAMINATION

We have several Hand & Shoe Monitors of this type (see Fig. 6.8) made by the Herfurth Company in Germany. They have large area, gas-flow proportional detectors, and they are used in various locations in the station to detect beta-gamma contamination on hands, shoes and clothing.

These large area detectors have thin Mylar *windows* to allow low-energy beta particles to enter the detector. For example, they can easily detect the low energy beta particles emitted by carbon-14 (E_{max} = 156 keV).

Although such detectors are very sensitive, their drawback is that the windows are punctured quite easily by misuse. The detector is then dead until its window is repaired. The detector for the right hand on the Herfurth monitors is removable so that clothing (or other objects) can be monitored separately.

We also have four Full-Body Monitors from Herfurth of similar design. You use one of them every time you leave the Service Building to go to the Administration Building. These monitors contain 27 large area, gas-flow proportional detectors, and they will monitor most of your body surface.

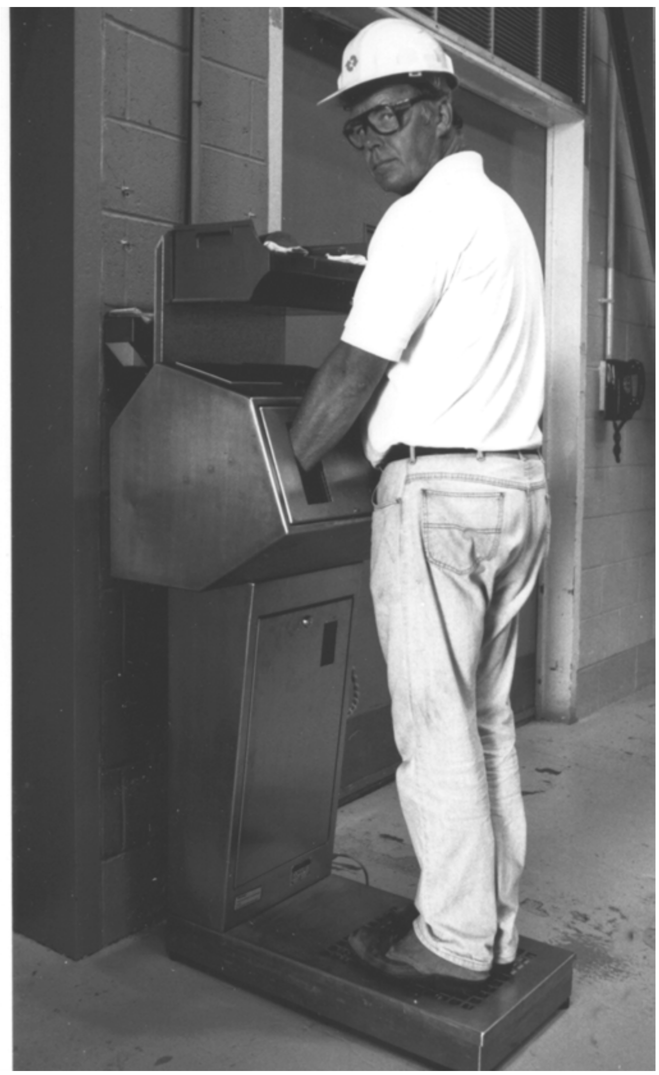


Fig. 6.8.That's me at the Hand & Shoe Monitor

These monitors (see Fig. 6.9) require a two-step measurement. First you face the detectors; when they've done their thing, you turn around to monitor your back. Proximity sensors check that you are standing in the right position for the measurement — if not, the monitor actually talks to you and tells you what to do. Its conversation is limited, though.

Fig. 6.9. Hanging Around in the Full-Body Monitors

We have another Herfurth monitor with large area, gas-flow proportional detectors. It is used during shutdowns, when we often remove a lot of material from the Reactor Building. Much of this material is clean (= not contaminated), and we can check that very quickly by passing the stuff slowly through the monitor.

PROPORTIONAL COUNTERS FOR α MEASUREMENTS

In general, a beta particle, or a photoelectron or Compton electron from a gamma interaction will produce relatively few primary ion pairs in the chamber of a proportional counter (or any other counter, if you want to be picky). If an alpha particle passes through the chamber, it will create many more primary ion pairs and the resulting output pulse will be much larger, although still in proportion to the original number of ion pairs. This property, exploited by suitable electronics, lets us identify and measure radiation of high ionisation (alpha) in the presence of others with lower ionisation (beta and gamma).

If alpha radiation is to be measured, the electronics is designed so that the relatively small pulses from beta and gamma radiation can be distinguished from the large pulses caused by alpha radiation. The Herfurth Hand & Shoe Monitors have an internal switch enabling them to do this, and two of them (outside the Spent Fuel Bay and outside the Decontamination Centre) are set up in this way so that both α and β,γ can be recognised.

The main drawback to using proportional counters in portable instruments is that they require a very stable power supply and amplifier to ensure constant operating conditions (in the middle of the proportional region in Fig. 6.7). This is difficult to provide in a portable instrument, and that is why proportional counters tend to be used more in fixed or lab instruments.

One such fixed instrument for alpha measurements is a Nuclear Enterprises **Contamination Monitor** located at the exit from the Service Building to the Administration Building. This proportional counter has a large area, thin window detector similar to the Herfurth monitors. The electronics sorts the alpha and the beta-gamma pulses and displays both in a bar-type display (see Fig. 6.10).

Fig. 6.10. Alpha/Beta-Gamma Contamination Meter

One of the main uses of this monitor is to detect natural radon daughters on the clothing of those of you who have been in the tunnel connecting the Turbine Building with the Seawater Pumphouse. Since radon daughters emit alpha and beta radiation, the presence of both is generally a sign of radon daughter contamination.

PROPORTIONAL COUNTERS FOR NEUTRONS

Actually, despite what I said before, we do have a portable proportional counter: see Fig. 6.11.

The detector is a proportional chamber at the centre of a 23-cm diameter cadmium-loaded polyethylene sphere. The chamber is filled with boron trifluoride gas (BF_3). The boron-10 isotopes in the BF_3 gas absorb neutrons and emit alpha particles (we met this reaction on page 50).

The alpha particles produce intense ionisation, and these "alpha" pulses caused by neutrons can easily be counted while the much smaller "gamma" pulses from any gamma background radiation are rejected.

You will remember that neutrons have a quality factor ranging from 5 to 20 depending on their energy. The cadmium-loaded polyethylene sphere corrects the response of the instrument so that it can read directly in mSv/h rather than mGy/h.

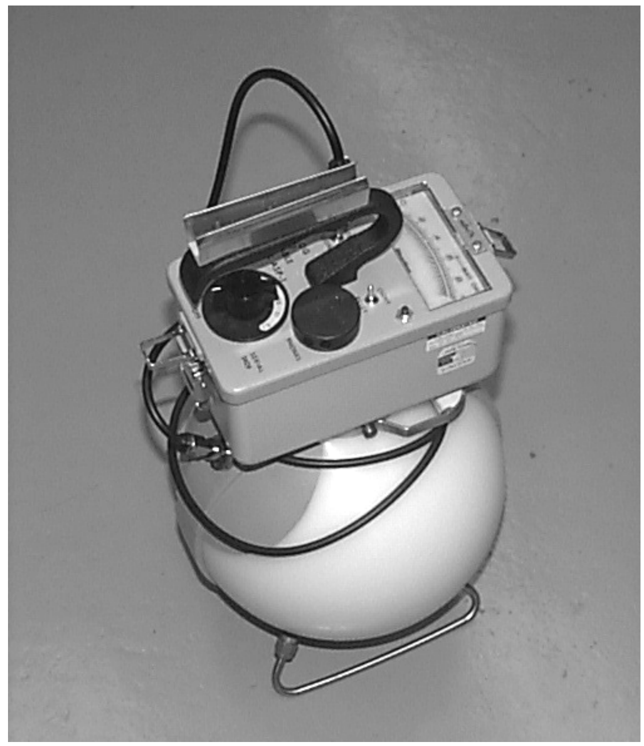


Fig. 6.11. Our Neutron Meter

We have modified this instrument by adding an integrating circuit, which can be selected to display the total neutron dose equivalent received since the instrument has been switched on. With this feature, the neutron meter can be used as a neutron survey meter and also provide neutron dosimetry for the person doing the survey. Its official name is the Neutron Meter/Integrator, but its friends just call it the Neutron Meter.

GEIGER COUNTERS

If we turn the voltage up quite a bit on a proportional counter, a strange thing happens. The voltage pulses from the ionising events in the detector tube become pretty well constant, regardless of how much ionisation was produced by the original event. Also, the voltage pulses are relatively large (a few volts) so that they can easily be managed without any fancy electronics. Instruments using the Geiger region of operation are therefore fairly simple, yet sensitive to low levels of ionisation, because we need only one primary ion pair to give us a large pulse.

If we crank up the anode voltage of Fig. 6.7 some more, the number of electrons collected increases as shown in Fig. 6.12. Gas amplification increases until eventually the number of electrons remains pretty well constant. This occurs in the so-called Geiger-Müller region (after the discoverers) and is commonly called the "GM" or "Geiger" region.

What is happening here is that the electrons produced in secondary ionisation gain so much energy that they in turn produce more ion pairs, which lead to further ion pairs again, and so on, until the detector tube is delivering the maximum number of electrons it can produce. The pulse of charge collected is constant, regardless of whether one, or a hundred or a thousand ion pairs were produced in the tube originally.

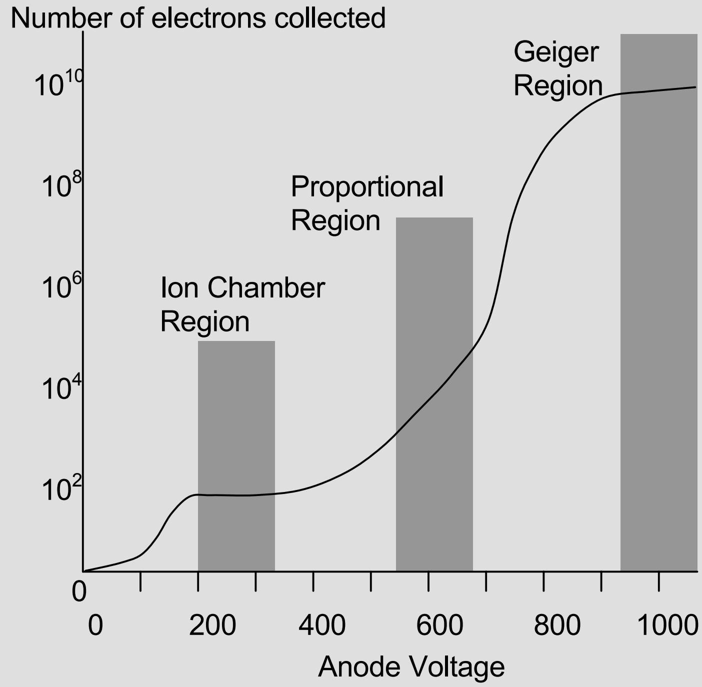


Fig. 6.12. Gas-Filled Detector Characteristics

If the voltage is increased much beyond the Geiger region, the breakdown region is reached where continuous arcing occurs across the counter electrodes. This happens because the voltage is high enough to cause ionisation by itself; no initial radiation is needed. Counters must not be operated in the breakdown region, because that's what happens to the detector.

GEIGER COUNTER PARTICLE DETECTORS

The Geiger counter delivers a pulse each time a particle produces ionisation in its detector. This makes it really useful for detecting individual particles.

If a Geiger counter is to detect beta radiation as well as gamma radiation, the detector tube must have walls thin enough to allow the beta particles to penetrate them. Such tubes are called **thin-walled** tubes, and they are often used in portable contamination meters. The windows we met earlier in our discussion of proportional counters do the same thing.

Figure 6.13 shows our Portable Contamination Meter with its probe. This detector is a flat Geiger tube with a thin mica window of 15 cm² area. Flat Geiger tubes like this are known as "pancake" tubes. Such tubes are fitted with a wire screen to protect them.

Fig. 6.13. Portable Contamination Meter with Pancake Geiger Detector

These meters have a scale reading in counts per second because that's what they measure. They are not designed to measure anything else, just the number of ionising events occurring in the tube each second. They are used for monitoring surfaces (walls, floors, clothing, hands, shoes, etc.) for contamination.

GEIGER COUNTER GAMMA SURVEY METERS

Although the major use of Geiger counters is probably in individual particle detection, they are also found in gamma survey meters. A gamma survey meter has a suitable thickness of shielding cunningly arranged around the Geiger tube to eliminate any response from beta particles. Even more important, such shielding also ensures that the instrument reads a gamma radiation field correctly in units of μGy/h or mGy/h. We'll come back to this point in a minute. For the time being, look at Fig. 6.14; this shows one of our low-range gamma survey meters.

Fig. 6.14. Low-Range Gamma Survey Meter

The meter has two log scales; a low range from 10 to 1000 μGy/h and a high range from 1 to 100 mGy/h. The unit contains two Geiger tubes, a small one for the high range and a larger one for the low range. When you switch ranges on the instrument, it automatically connects the correct tube to the counting circuits.

PRACTICAL CONSIDERATIONS

So far in this chapter, we have told you about the mechanisms that cause the detector of a radiation instrument to respond. We have also introduced you to a couple of practical instruments, while probably leaving a few questions hanging in the air. We will now consider those features of radiation instruments that you should bear in mind in order to have a practical understanding of their use.

IDENTIFICATION OF RADIATION TYPE

We said earlier that a practical radiation instrument must be able to measure one type of radiation in the presence of others. There are three ways of achieving this:

1) mechanical design,
2) special operating techniques,
3) electronic design.

We'll give an example of each.

Mechanical Design

Consider the gamma survey meter just described. We want to be sure that the reading on the scale is due to gamma radiation and nothing else. Therefore the instrument must be so designed that alpha and beta radiation cannot penetrate to the Geiger tubes inside the casing. Using a relatively thick casing around the Geiger tube does this. In addition, the Geiger tubes themselves are surrounded by thin tin and lead shields to allow for *energy dependence*. This means that the instrument responds correctly to low-energy gamma radiation instead of reading too high. (Energy dependence is explained in the box on the next page).

The problem of energy dependence was taken into consideration when we bought instruments for Point Lepreau. They have a flat (i.e., correct) response for the energies normally found in a nuclear power plant. So, as far as practical use is concerned, if your gamma survey meter tells you the radiation field is 50 μGy/h, believe it. You are looking at 50 μGy/h of gamma radiation.

I've said that the gamma survey meter doesn't respond to beta radiation. This is as it should be, but there is an exception. If you bring a very powerful beta source in contact with the instrument, you will get a reading if the beta particles are energetic enough (i.e., greater than 2 MeV or so). The indication on the meter is the result of some bremsstrahlung being detected. The bremsstrahlung is basically low-energy X-rays produced when high-energy beta particles are absorbed in the metal of the case and the shielding surrounding the Geiger tubes.

In practical use, the amount of bremsstrahlung that would be produced when surveying mixed beta and gamma radiation is negligible. It only becomes a problem if you hold the instrument against powerful high-energy beta sources; these conditions are rarely found in the field. However, we do take advantage of this in our three Portable Instrument Check Sources, which are equipped with a high-energy beta source. The bremsstrahlung from the beta source is much easier to shield, and so is less of a hazard, than a gamma source capable of giving similar dose rates. You can see one of these devices in Fig. 6.28 on page 151.

ENERGY DEPENDENCE

Almost all detectors are energy dependent. This means that a detector capable of measuring the dose or dose rates from radiation with a specific energy may overestimate or underestimate the dose or dose rate from a different energy.

In practice, the response of a Geiger tube would actually be something like that shown by the dotted curve in Fig. 6.15. The dose rate for 100 keV gamma radiation is overestimated by a factor of six or so. (It is a log-log scale.) This is corrected with shielding around the tube to absorb some of this low energy radiation.

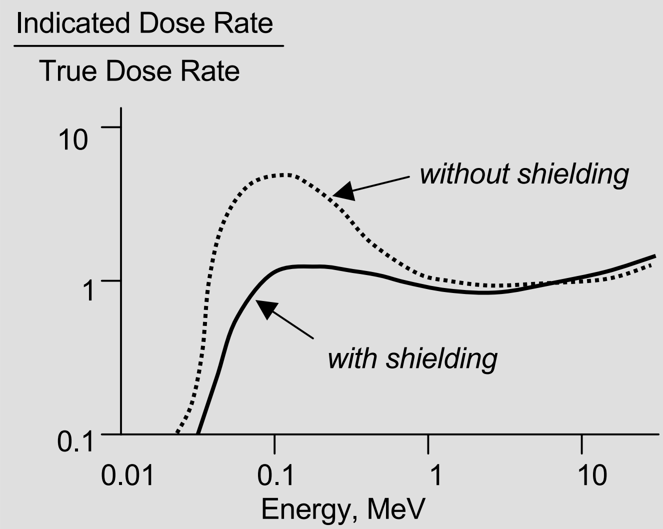


Fig. 6.15. Energy Dependence

Suitable shielding and tube wall design can produce the solid line of Fig. 6.15. You can see that one of the drawbacks of this is that the shielding has pretty well eliminated the response to low energy photons below 50 keV, because very few of them are now able to reach the tube.

Practical Geiger gamma survey meters are quite good from about 50 keV to 3 MeV. By that, I mean that they are going to read within 25% of the true dose rate. Above 3 MeV they will read a bit high, which is no problem because it overestimates the risk.

Special Operating Techniques

As far as I know, nobody has yet been able to design an instrument that responds to beta radiation, but not to gamma radiation. Our Beta Survey Meter responds to both. It is shown in Figures 6.17 and 6.18.

The detector is an ion chamber with a very thin Mylar window covered by a sliding beta shield on the bottom of the instrument. To get an accurate beta measurement, you have to subtract the gamma radiation that is always associated with beta radiation. Basically, the procedure is:

1) Take a reading with the shield open
(the instrument will then read beta plus gamma radiation);

2) Close the shield and take the reading again: this time no betas will get through to the detector and the instrument will respond to gamma only;

3) Subtract the lower reading from the higher: the result is a measurement of the beta radiation.

Fig. 6.16. Low-Range Beta Survey Meter (Top View)

We've calibrated these instruments to measure gamma radiation correctly. In practical use, we have found that it still gives us a beta measurement (step 3) that is quite adequate for most purposes (within 25% of the true value). Therefore, you can use this instrument to make both beta and gamma survey measurements. This feature of responding fairly accurately to both beta and gamma radiation is very useful. It is not available on any other beta survey meters that I know of; i.e., they would not give a reading in step 2 that could be used as a gamma measurement.

Fig. 6.17. Low-Range Beta Survey Meter (Bottom View)

Electronic Design

The Alpha/Beta-Gamma Contamination Monitor of Fig. 6.10 is a good example of how radiation is identified by electronic means. The monitor is designed to measure both alpha and beta radiation and tell them apart. The detector tube (shown in Fig. 6.18) has an extremely thin Mylar window to allow alpha radiation to penetrate; of course beta and gamma radiation will also enter the tube.

An alpha particle entering the tubes will produce many more ion pairs than a beta particle or a photoelectron from gamma radiation. The tubes are operated in the proportional region; this produces much larger voltage pulses for alpha radiation than for beta or gamma radiation. These pulses are amplified (to make them easier to handle), and then passed to an electronic circuit called a **discriminator** which sorts them out according to size.

Fig.6.18. Thin-Window Detector Tube

If they are large enough to be alpha pulses, they are routed to the alpha counting circuit, and if they are not large enough, they are sent to the beta-gamma counting circuit instead. If the monitor alarms, it will tell you whether the alpha count or the beta-gamma count (or perhaps both) are above pre-set limits.

A similar discriminator circuit is used in the neutron meter to distinguish the large pulses from alpha ionisation (neutron absorption in the detector produces alpha particles) from the much smaller ones that would be caused by gamma photons.

Electronic discrimination works well. It is used in several of our radiation instruments, both portable and lab equipment.

SCALERS AND RATE METERS

A SCALER is a device that displays the total number of pulses or counts received from a radiation detector.

A RATE METER is a device that displays the rate at which pulses or counts are received from a radiation detector.

Common examples of a scaler and a rate meter are the odometer and speedometer on your car. One tells you total kilometres travelled, and the other tells you the rate at which you are travelling them.

Figs. 6.19 and 6.20 show a scaler and a rate meter, both of which can be used with the same detector, in this case a pancake Geiger tube.

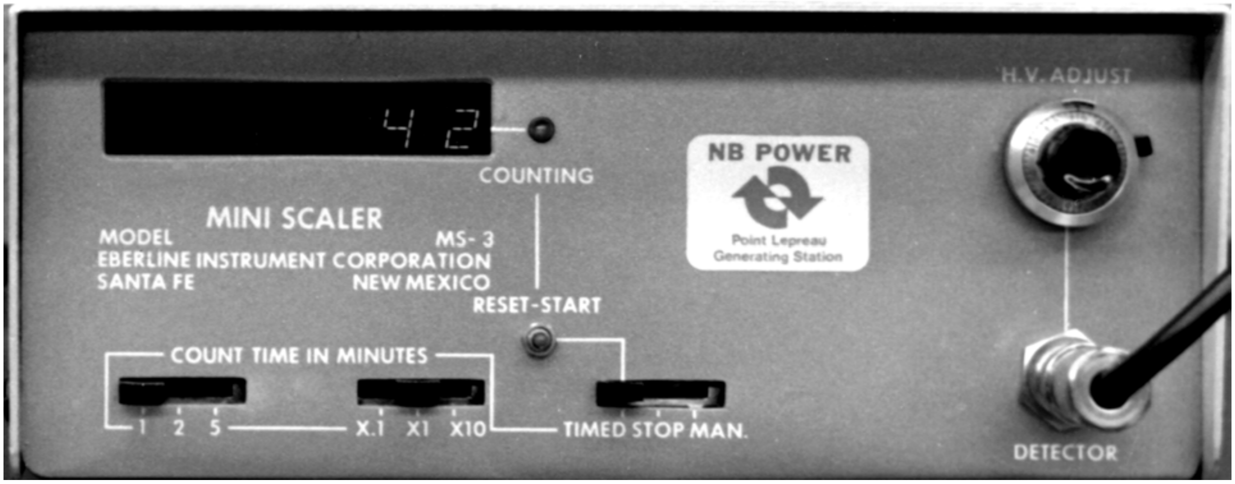


Fig. 6.19. A Scaler

Scalers are generally quite a bit more expensive than rate meters. We use them when we want to know the total number of counts registered. Scalers are useful when the count rate is so low that a count rate meter would not be able to give a steady reading. Scalers are often used in laboratory applications when accurate measurements are needed.

Of course, count rates can be obtained from scalers. For example, if a scaler accumulated 180 counts in 1 minute, the average count rate was 3 counts per second. However, if you wanted immediate information on the count rate, you would choose an instrument fitted with a rate meter rather than a scaler.

Fig. 6.20. A Rate Meter

Portable instruments usually have rate meters. Fig. 6.20 shows the rate meter used in a semi-portable instrument. We have a lot of these scattered throughout the station.

You must not confuse a scaler, which indicates total counts or dose received, with a digital rate meter. We have a (Geiger) low range gamma survey meter with both digital and analog displays of dose rate. It is shown in Fig. 6.21.

It is generally known as the “FAG Meter”, so named after the German company that makes it. It is a more modern instrument than that shown in Fig. 6.14, which we call the “5016” (the model number the manufacturer gave it).

For gamma surveys in the station, you have the choice of either instrument. Although the FAG meter is preferred by many, it does have a much slower response time than the 5016. Before we get into that topic, I just want to mention another feature of the FAG meter.

We have a telescopic version that extends up to twelve feet. It uses a standard FAG meter inserted into its housing as shown below. The cable from the telescoping unit is plugged into the FAG meter, and you’re in business. The entire rig is shown in Fig. 6.23.

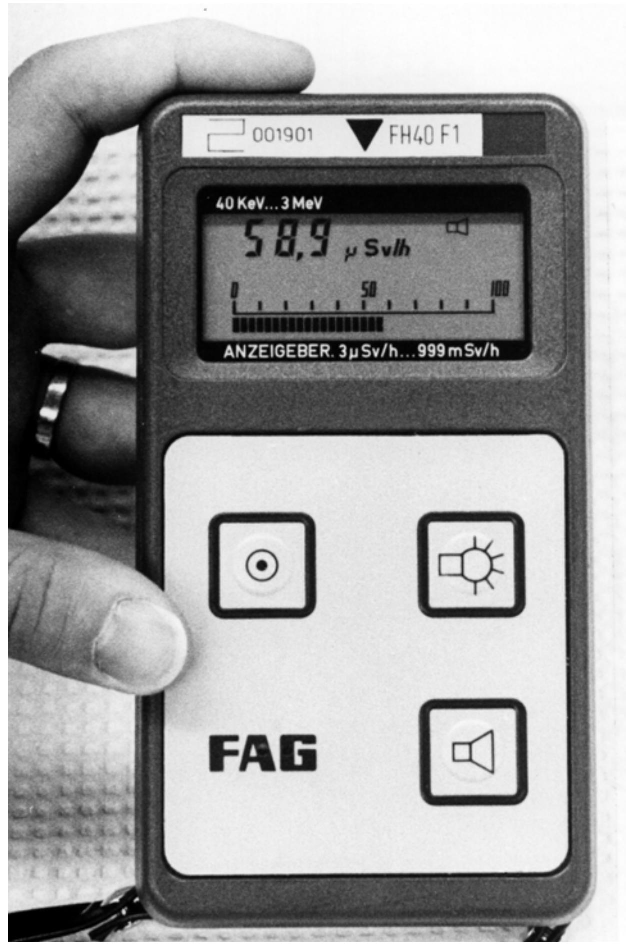


Fig. 6.21. The FAG Gamma Survey Meter with Analogue and Digital Displays

Fig. 6.22. FAG Meter in Telescopic Unit

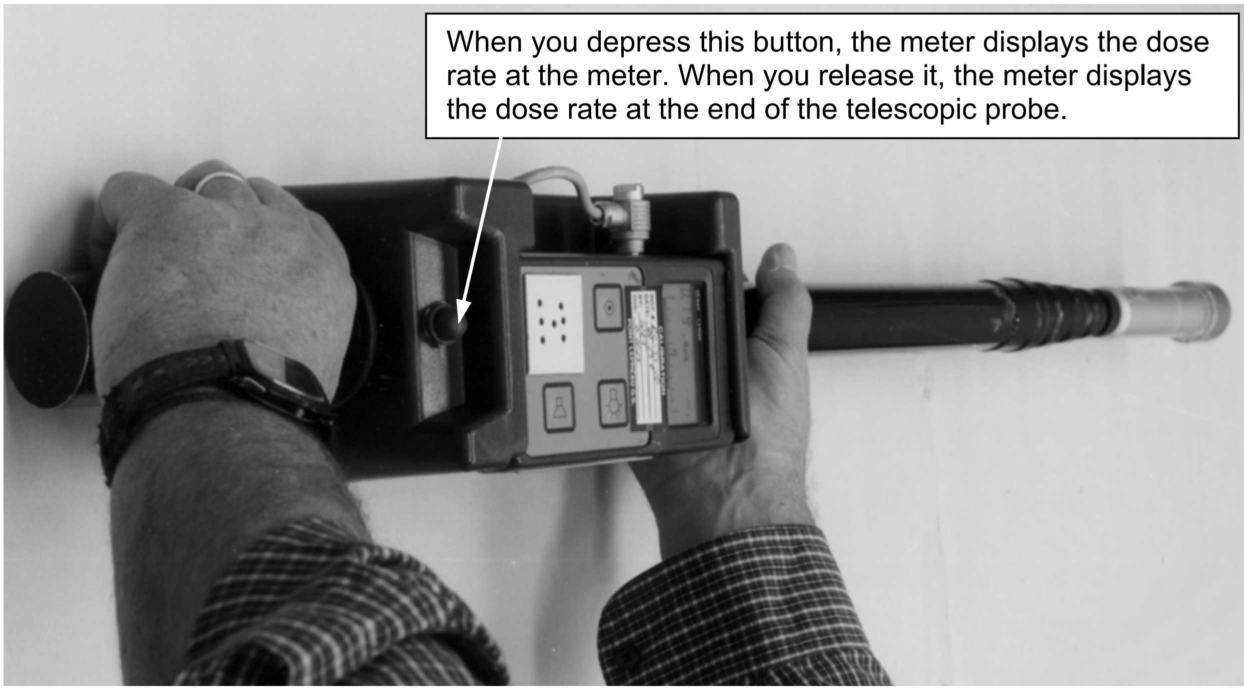


Fig. 6.23. The Telescopic Unit Shown with its Extension

RATEMETER RESPONSE TIME

The most important characteristic of a ratemeter is its **response time.** It takes a certain length of time for a ratemeter to reach its true reading. Fig.6.24 indicates the response of a ratemeter that had been receiving 100 counts per second (cps), and then suddenly was asked to accept 200 cps. It takes a while before the meter reading reaches its final value.

The RESPONSE TIME is the length of time it takes for a ratemeter to indicate 90% of a change in true reading.

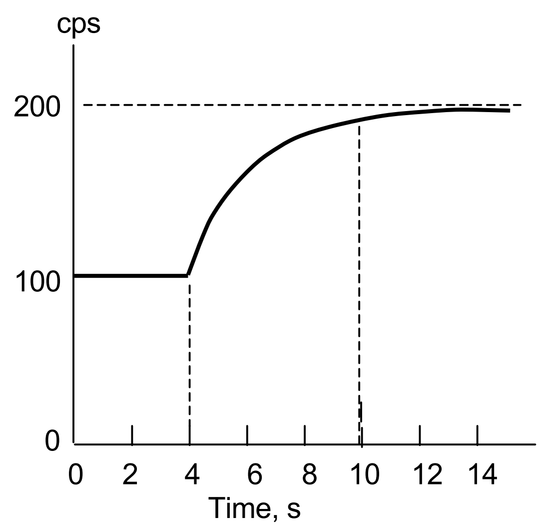


Fig. 6.24. Rate Meter Response

The response time in Fig. 6.24 is about 6 seconds. Some ratemeters are equipped with a control that permits you to select a response time convenient to you. Long response times give a steadier reading, but you have to wait for it. Short response times may result in the meter needle being jiggly, but you see changes more quickly.

To get an accurate estimate of low levels of radiation, you would select a long response time if the instrument lets you do that. This will smooth out the random rate at which pulses are arriving. For high levels of radiation this is not a problem, and you can use a short response time. So now that you are a big name in ratemeters, remember this:

Instruments with ratemeters can have response times of up to tens of seconds. You must give the instrument enough time to reach its final reading.

INSTRUMENT EFFICIENCY

No instrument is able to detect every particle or gamma photon emitted by a source. The fraction that will interact with the detector depends on all of the following factors:

a) The relative position of the detector and the radiation source:

Obviously, the closer the detector is to the source, the greater is the number of particles or photons that will be detected (see Fig. 6.25).

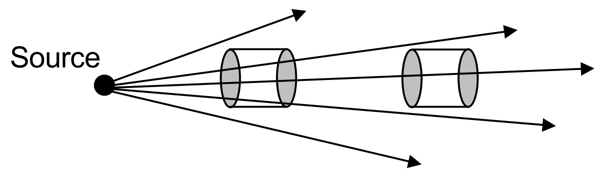


Fig. 6.25. Closer is Better

b) The size of the detector:

A large detector will be able to intercept more radiation than a small one (see Fig. 6.26). This is used to advantage in the 5016 meters, which have two Geiger tubes. The larger tube is used to measure low radiation fields and the smaller tube can measure radiation fields about 100 times bigger without going off-scale.

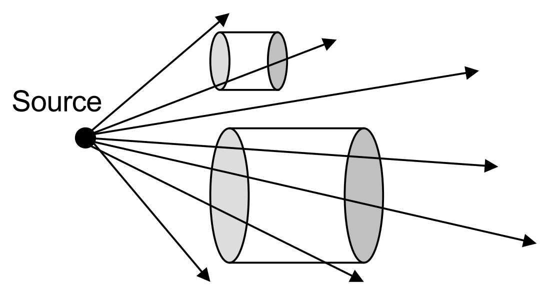


Fig. 6.26. Bigger is Better

c) The type of radiation being detected:

A gas-filled thin-walled Geiger tube will detect beta particles much more efficiently than gamma photons, because gammas will usually zip right through the tube without interacting at all. As a general rule, you can say that a Geiger tube will give a pulse for every beta particle entering it, but will only see about 1% of the gamma photons passing through it.

d) Detector construction:

A Geiger tube with a thin Mylar window will detect beta particles much more efficiently than one with thin aluminum walls that many of the betas wouldn't be able to penetrate. For gamma photons, the situation is reversed. Aluminum walls will be better than thin Mylar windows, because many more photons would interact in the aluminum walls. The photo-electrons released there could well have enough energy to reach the gas and then cause ionisation in the gas.

With all these variables, practical detector efficiencies can range from almost 50% down to fractions of a percent.

The EFFICIENCY of a detector is the percentage of the source disintegrations that it will detect.

DEAD-TIME

More stuff that can affect instruments. For example, while a Geiger detector is "processing" one pulse, it is unable to cope with another one.

What happens is that the electrons produced by the ionising event are very quickly accelerated to the anode, but it takes a lot longer for the remaining positive ions to trundle off to the cathode — and the detector is paralysed until they are out of the way. This time is called the **Dead-Time.** Typically it has a value of about100 μs for Geiger counters (for proportional counters it is much less), and so after each ionising event a Geiger tube is basically switched off for 100 μs.

For example, if the dead time of a Geiger counter is 100 μs, and the counter is indicating 3000 counts a second (a very high rate!), it will have been dead for 3000 x 100 μs = 0.3 s in each second.

So you actually got 3000 counts in 0.7 seconds. This means with no dead-time losses, you should have got 4300 cps.

In other words, at very high count rates, Geiger counters (and also some other instruments) will read low because they are unable to detect all of the events.

You can now appreciate the main reason for having the large and small Geiger tubes in the 5016 gamma survey meters. In low radiation fields, the larger, more sensitive tube sees lots of counts and its response time is good. For radiation fields greater than 1 mGy/h, dead time losses start to become significant in the larger tube. Its range ends at 1 mGy/h, and for fields greater than this you have to switch over to use the smaller tube. Switching the range does it for you.

The FAG meter has only one Geiger tube. It has to be small so that it doesn't suffer from dead-time losses at its upper range (1 Sv/h). This means that in low radiation fields, it sees very few counts per second, and the response time becomes very long. In fact, Gerry Black told me that at the bottom of its range (3 μSv/h), the response time can approach 60 seconds. That's why I like using the 5016.

What happens when the radiation field becomes so high that dead-time losses become significant? All our gamma survey meters will continue to read off-scale until the radiation field is reduced again. In other words, the design of the electronics keeps the display locked off-scale high for very high fields. You might say "big deal, so what?" Well, some older type of Geiger counters will give low on-scale readings when dead-time losses are huge. Not nice. We don't have any of these.

In general, it is true to say that if the instrument is on-scale, it is reading correctly because either dead time losses are negligible or else they have been allowed for by suitable design of the scale.

If an instrument reads off-scale high, BELIEVE IT.

If it is off-scale, it tells you that the radiation level is above a certain value, but that is all it tells you. You must select a high-range instrument to measure the radiation level. This can't be overemphasised. There have been many incidents when people who should have known better have said, "this thing can't be reading right, so I'll ignore it". As a result they exposed themselves needlessly and stupidly to high radiation levels. Way to go, Homer.

INSTRUMENT CHECKS

All of our various radiation instruments are checked periodically to ensure that they are operating correctly. These checks consist of pre-operational checks and calibration checks.

Pre-operational checks are those that you should do **every time** before surveying radiation hazards. They are:

1. **Calibration Check**

   check that the DUE date on the calibration sticker is not exceeded.

2. **Battery check**

   used to check that the battery power supply is adequate.

3. **Source check**

   used to check that the instrument correctly indicates actual radiation fields.

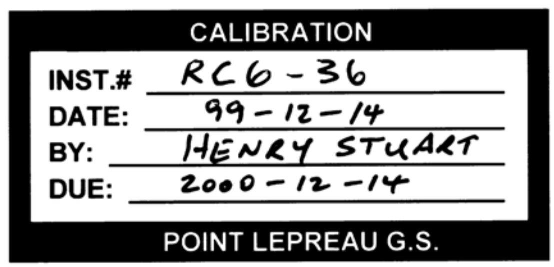


Fig. 6.27. Example of a Calibration Sticker on each Instrument

Portable contamination meters have their own sources mounted on the side of the instrument. Gamma and beta survey meters are checked in an Instrument Check Source (opposite), which is designed to fit all the different types that we use. There are three of these Check Sources; outside Stores, outside the Equipment Airlock and outside the Personnel Airlock. Fig. 6.28 shows the FAG and 5016 meters in position for a source check.

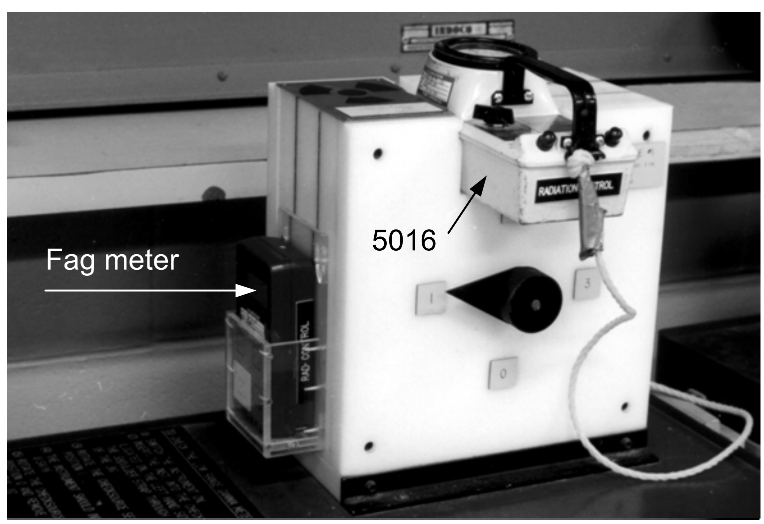


Fig. 6.28. Instrument Check Source

If you find that an instrument fails any of the checks, it should be **removed from service.** Behind the check source outside Stores, there is a shelf for defective instruments (you can see it in the picture). Fill out a Defective Instrument Tag, briefly stating what appears to be wrong, attach it to the instrument and put the instrument on the shelf.

Service Maintenance will then pick it up and take it to the Instrument Shop to be fixed. Once that's done, Service Maintenance returns the instrument to Stores or whatever tools cribs it came from originally.

Calibration is an operational test done in the Instrument Shop. It is done routinely on a call-up basis for each instrument; the instrument is checked for accuracy across its entire range, and not just at one point of the range as is the case for a source check. If it turns out to be operating less well than it should, it is tuned up, i.e., calibrated. Once we know that the meter works properly, it is given a new calibration sticker and returned to service.

PECULIAR READINGS

Finally, let me emphasise again that if an instrument you are using gives an unexpected or even off-scale reading, believe what it says and take appropriate action until you can prove (which you usually can't!) that the instrument is wrong.

SCINTILLATION COUNTERS

The three detectors we have described so far (ion chambers, proportional counters and Geiger counters) all collect or amplify the ionisation produced by radiation in a gas. The **Scintillation Counter** works on quite a different principle; it measures radiation by detecting tiny flashes of light that radiation produces in certain materials. We are going to describe only the major features of scintillation counters, because the subject is complicated and beyond the scope of this course.

When supported by suitable accessories, scintillation counters can discriminate between different types of radiation and, more importantly, even between different energies of the same radiation.

There are several types of scintillation counters, but their detector systems always consist of two components.

The first is a **scintillator.** This is a solid or liquid **phosphor**, which emits a tiny flash of light when ionising radiation strikes it. The second part of the detector system is the **Photomultiplier Tube** or **Phototube** for short, which converts the flash of light to a current pulse.

The Phosphor

There are several suitable materials; the choice depends on the type of radiation to be detected.

Fig. 6.29 shows a 50 mm x 50 mm cylindrical crystal of sodium iodide (NaI), a typical phosphor for gamma radiation. The iodine provides most of the stopping power in sodium iodide (since it has a high Z = 53). In the diagram, a gamma photon has been stopped in the crystal by the photo-electric effect. It has lost all its energy to ionise the atoms in the crystal, and this produces the scintillation or light.

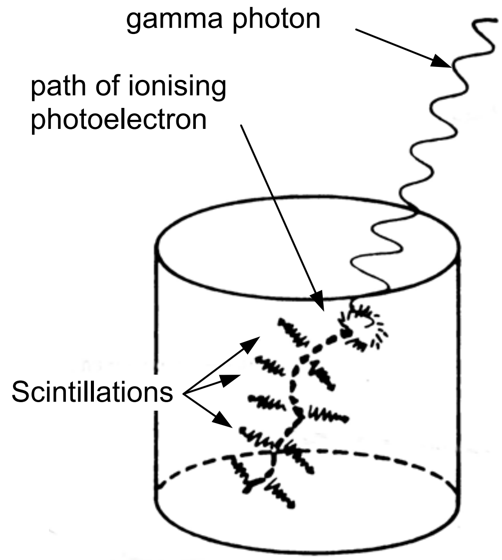


Fig. 6.29. Gamma Absorption in the Phosphor

A "scintillation" is in reality a very brief shower of extremely tiny blue, violet, and UV light flashes; each flash results from the resettlement of the electrons in an ionised atom. In a sodium iodide crystal, the whole process is completed in less than a millionth of a second, so that the shower would look like a single flash (if we could see it, which normally we can't because it isn't bright enough).

With this picture in mind, then, you can see that the more energetic the absorbed photon is, the greater will be the number of ionised atoms in the crystal, and therefore the more intense the scintillation. In other words, *we can measure the energy of the gamma photon by measuring the intensity of the scintillation.*

The Phototube

Its function is to convert the tiny flashes of light into an electronic pulse that we can deal with. A transparent grease such as silicone cement is used to attach the phosphor to the light-sensitive end of a phototube called a **photocathode**. It emits electrons when struck by light. *The number of electrons it emits is proportional to the intensity of the scintillation striking it.*

The phototube (Fig. 6.30) contains maybe ten internal electrodes called “dynodes”. Each dynode is at a potential of about 100 volts more positive than that of the previous dynode. With such an arrangement, electrons released by the photocathode are promptly accelerated to the first dynode, which they strike so forcibly that more electrons are splattered out of its surface. These are now accelerated to the second dynode, where they release more electrons. The number of electrons released by a dynode is about 3 to 5 times the number striking it. The multiplication by a string of dynodes can therefore be enormous to give us a measurable pulse at the phototube’s anode output.

The end effect of all this is that we get an output pulse, *whose height is exactly proportional to the total number of electrons collected by the anode.*

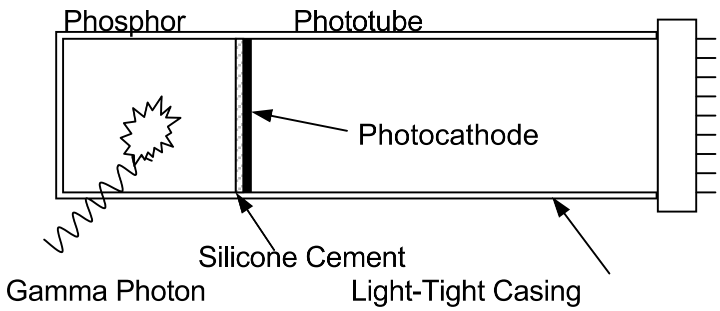


Fig. 6. 30. The Phosphor-Phototube Assembly

A 1 MeV gamma photon that is completely absorbed in the phosphor will produce about 4E4 light photons, each of ~ 3 eV. These in turn will produce about 8E3 electrons at the photocathode. Ten dynodes with a gain by a factor of 4 at each dynode will result in an overall amplification of $4^{10} \ll$ E6. The phototube's output pulse will contain 8E3 x 1E6 = 8E9 electrons, a useful size for electronic amplification and processing

This is a very important aspect of the detector, because it means that we will obtain a voltage pulse whose height is proportional to the energy deposited in the phosphor by the gamma ray. The reason for this becomes obvious when we retrace our steps at the right.

The height of the phototube voltage pulse

↓

is proportional to the number of electrons collected at the anode,

↓

which is proportional to the number emitted by the photocathode,

↓

which is proportional to the intensity of the scintillation striking it,

↓

which is proportional to the number of ions formed in the phosphor,

↓

which is proportional to the gamma energy deposited there.

Two electronic components are still needed for a working scintillation counter; they are an **amplifier** and a **discriminator.**

The Amplifier

The pulses delivered by the phototube are typically only a few millivolts in height. The purpose of the amplifier is to increase the pulse heights proportionally. For instance, we might prefer to adjust the amplifier so that it gives us a pulse exactly 10 volts high for a 1000 keV gamma ray totally absorbed in the scintillator. If our next pulse were to be 3.6 volts high, then we would know that 360 keV had been absorbed in the phosphor.

The Discriminator

The pulses have now been blown up to a useful size and are sent to a discriminator. This is the same circuit we came across before on pages 138 and 139 when we described proportional counters for α/β, and neutron measurements. The discriminator blocks pulses below a certain height, which is called the **discriminator level** or **discriminator threshold,** and it can normally be adjusted by twiddling the appropriate knob.

For every pulse fed into it from the amplifier, the discriminator gives an output pulse (of fixed size) if, and only if, the pulse height is above the threshold. Fig. 6.31 shows how a discriminator rejects the numerous but tiny pulses caused by electrical hum and noise in the amplifier and phototube.

The discriminator output pulses are fed into a scaler or ratemeter. A scaler will register the total number of interactions in the phosphor, which released sufficient energy to trigger the discriminator, whereas a ratemeter tells us at what rate these events occur.

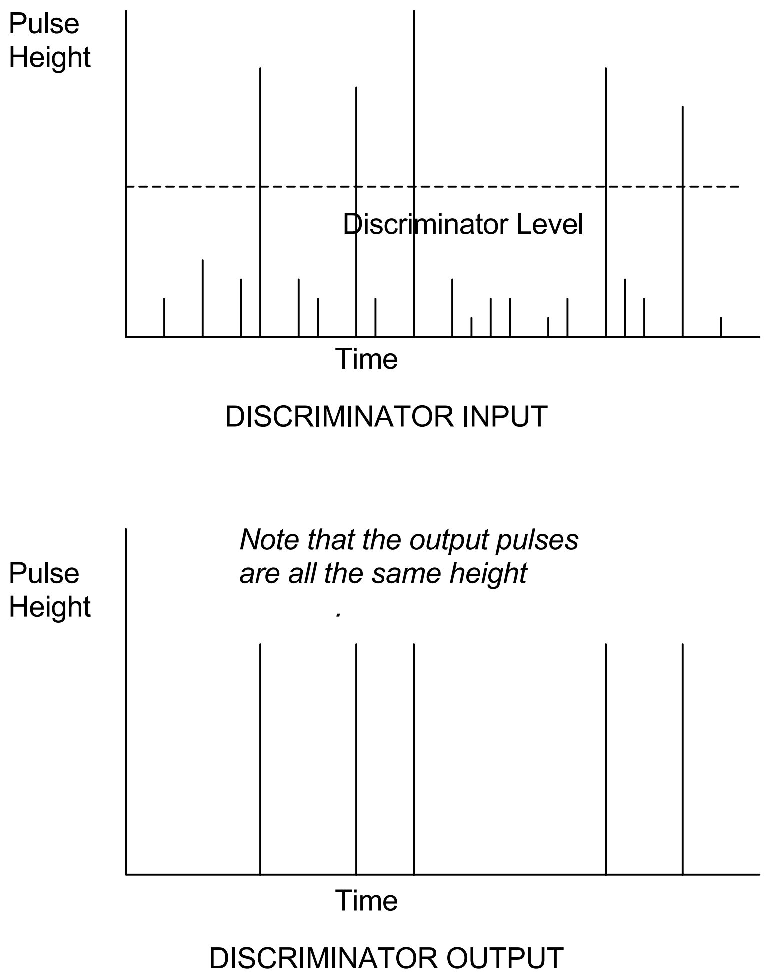


Fig. 6.31. The Discriminator Action

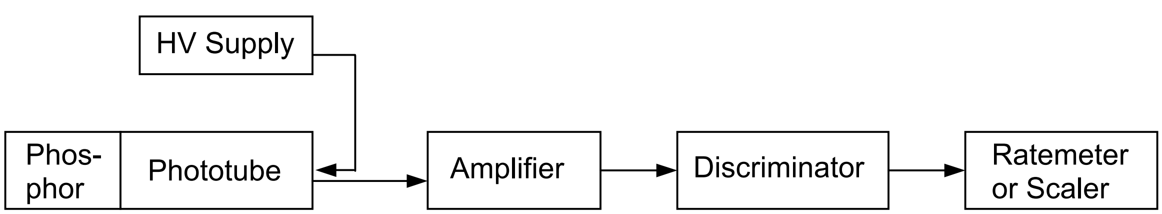


Fig. 6.32. A Complete Scintillation Counter

The whole nine yards as shown in Fig. 6.32, consisting of phosphor, phototube, high-voltage supply, amplifier, discriminator and scaler or ratemeter, is a complete scintillation counter. Next we'll introduce you to a portable scintillation counter.

Alpha Scintillation Counter

You've probably already figured out that if alpha or beta particles interact in the phosphor, they will also produce scintillations. A scintillation counter as described so far can be used to detect alpha particles only (in the presence of other radiations), as long as a very thin scintillator replaces the large sodium iodide phosphor. We have an **Alpha Contamination Meter** like this (shown below).

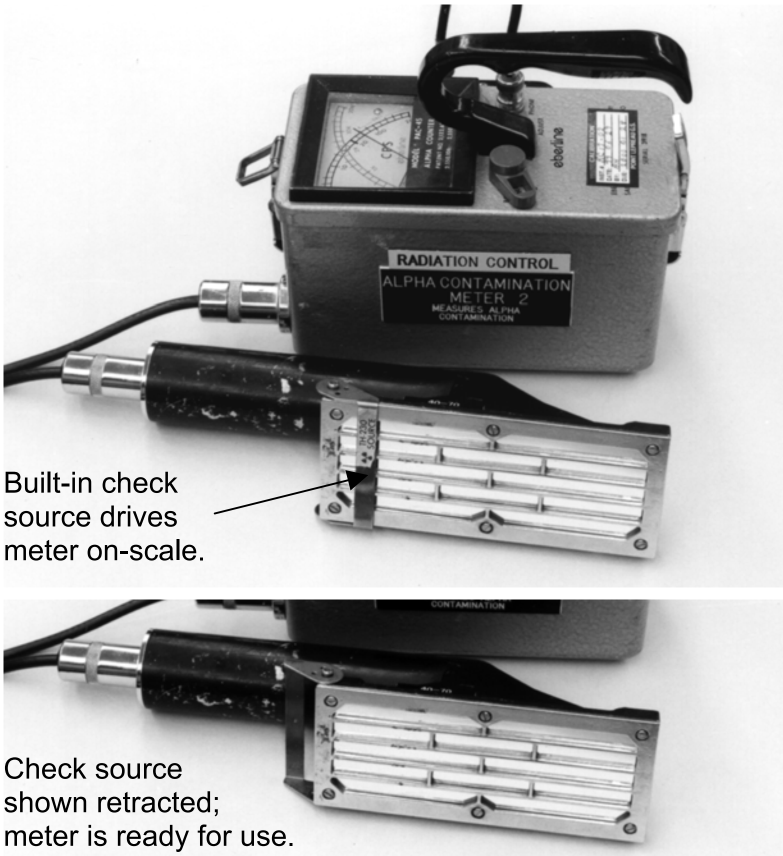


Fig. 6. 33. Alpha Contamination Meter

The scintillator is zinc sulphide embedded in tape and optically coupled to the photocathode. To allow alpha particles to penetrate to the zinc sulphide, a very thin Mylar foil is used. It also makes the detector light-tight.

Because of their low penetrating power, alpha particles are stopped in the scintillator and so deposit most of their energy there. Beta will lose only a small fraction of their energy in the scintillator. Can you explain why? (Please answer this before looking at the footnote).

The output pulses resulting from the interactions of alpha particles will be much greater than those from beta particles or gamma photons. The discriminator rejects the beta-gamma pulses and ensures that only alpha pulses reach the rate meter. The Radiation Control guys use this instrument for detecting alpha contamination alone, even when beta-gamma contamination is present as well (which it always will be).

One last note – should you puncture the Mylar foil in this instrument, you will immediately see off-scale high readings. The instrument would be flooded with zillions of ordinary light photons. Please take care not to do this. The phototube doesn't like it any more than Henry Stuart does.

Beta particles passing through the thin detector will produce far fewer ion pairs than alpha particles, because betas produce much less dense ionisation tracks (just as in air, see page 23). So the beta particles will deposit less energy in the detector. Most gamma photons will pass right through the detector without interacting, but if they do, the photoelectrons produced will deposit only small amounts of energy before leaving the scintillator (just like the beta particles).

Wide Range Gamma Survey Meter

The instrument shown on the right is a scintillation counter with a 2” x 2” sodium iodide phosphor. This makes it an extremely sensitive gamma survey meter.

It is used by Security Guards to monitor vehicles leaving the inner fence: Hart Eichmann is checking the forks of a forklift truck for any activity. The count rate of 143 cps shown here is typical of the background outside the Admin Building, and represents about 0.2 μSv/h.

Fig. 6.34. Wide Range Gamma Survey Meter

Vehicle Monitor

The Vehicle Monitor at the outer Guard House is designed to detect extremely low levels of radioactivity leaving the site. This monitor has four large plastic scintillation detectors. They will detect a source that produces a radiation field of only 0.01 μSv/h at the outside of the vehicle. It doesn’t get any better than this! If a source is detected, audible and visual alarms alert the Security Guard in the Guard House.

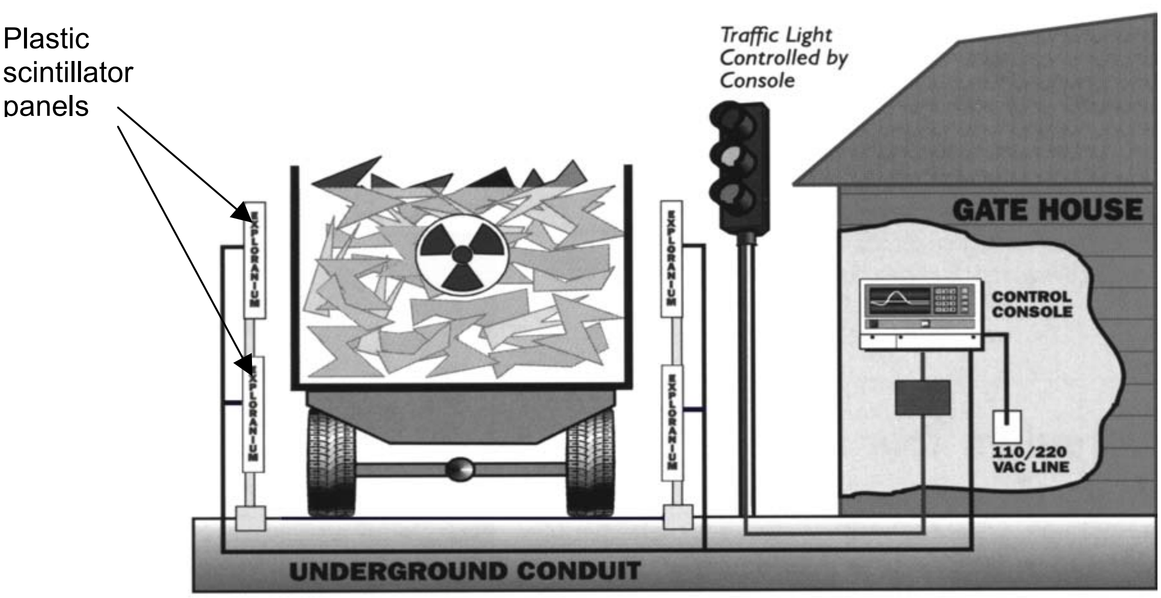


Fig. 6.35. The Vehicle Monitor

PULSE HEIGHT ANALYSIS

We've learned that in a scintillation counter the pulse heights leaving the amplifier are proportional to the energy the gamma photons deposit in the crystal. Accordingly, if we sort these pulses in terms of their heights, we will be doing the equivalent of sorting the gamma photons according to their energies. This is called **Pulse Height Analysis**.

The electronic circuitry that does this for us is called a **Pulse Height Analyser (PHA).** The PHA replaces the discriminator; it permits us to plot the gamma energies emitted by a source by individually counting the various pulse heights associated with them.

Fig. 6.36 shows such a plot for cobalt-60, it is called a **gamma spectrum.** If you go back to page 35 and look at the decay scheme of cobalt-60 (Fig. 2.21), you will appreciate where the peaks in this spectrum come from. The resolution of NaI detectors isn't great — you can imagine that if we had many gamma peaks, it would be very difficult to sort out what's what.

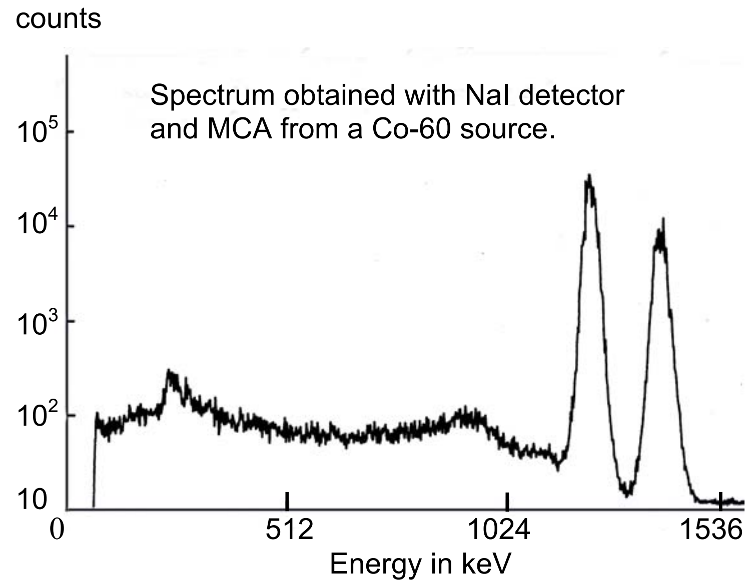


Fig. 6.36. Co-60 Spectrum with NaI

Fig. 6.37 shows a spectrum obtained with a Ge(Li) detector, pronounced "jelly". It is basically a very small solid-state ion chamber. It has far better resolution than the NaI detector, but the efficiency is much lower. Ge(Li) detectors are used in lab instruments. Each gamma-emitting radioisotope has a characteristic spectrum (a kind of fingerprint pattern) and this can be used to identify an unknown or uncertain source.

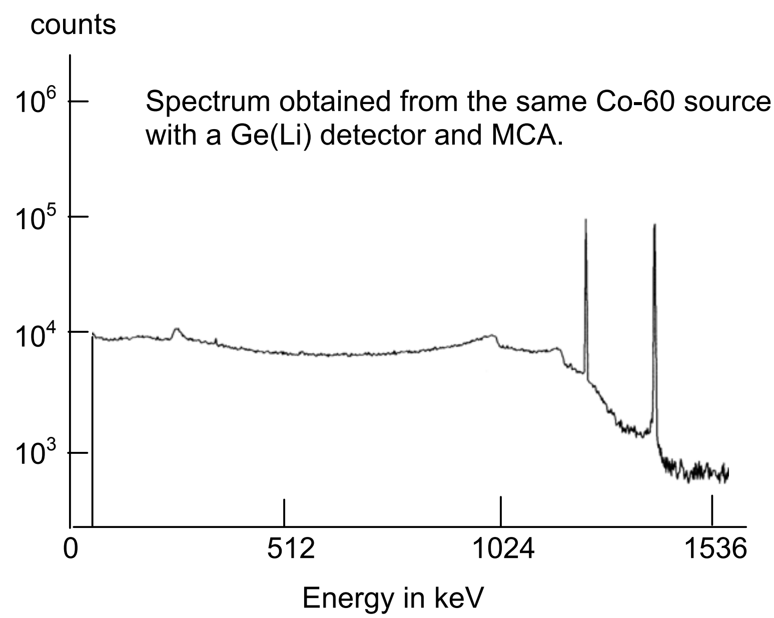


Fig. 6.37. Co-60 Spectrum with Ge(Li)

You will notice the counts at energies below the 1.17 and 1.33 MeV peaks. These are due to Compton scattering (page 24), where the incoming photons have transferred only part of their energy to an electron. The residual gamma escapes, and so we end up with ionisation that is less than that from the photoelectric effect.

Pulse height analysers are of two types: single-channel and multi-channel.

Single-Channel PHA

A single-channel PHA can only look at one range of gamma energies (called a channel) at a time. It is fitted with two important controls, **threshold level** and **channel width**. For example, if we wished to single out I-131 (gamma energy of 364 keV) in the presence of other gamma emitters, we could set the level control to 350 keV and the width control to 30 keV. The effect of this would be that only those pulses resulting from 350 keV to 380 keV of energy deposited in the crystal would be registered. These would be due to I-131.

At Point Lepreau, we use a single-channel PHA set up in this way as a **Self-Serve Thyroid Monitor** (located in the corridor outside the Health Physics Lab). A large section in Chapter 8 is devoted to radioiodine exposures and uptakes. For the time being, it is enough to know that you can walk up to this monitor and check for yourself whether you have taken radioiodine into your thyroid. The instrument detects I-131, and if the result exceeds a certain level, you would make arrangements for an accurate analysis to be made in the Health Physics Lab. If not, you are OK, and you don't have to do anything else.

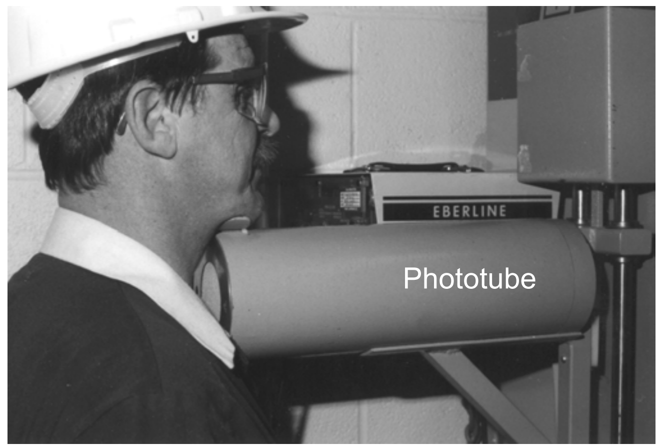


Fig. 6.38. Tony Harris at the Thyroid Monitor

Multi-Channel PHA

A multi-channel PHA (usually called multi-channel analyser or MCA) is a more sophisticated version of the single-channel type. Unlike the single-channel PHA, it can sort out and display what is going on in all channels (i.e., all gamma energies) simultaneously. It usually feeds a cathode ray tube (CRT) display, on which the spectrum is displayed and built up as the individual pulses arrive. The Co-60 spectra on the opposite page were obtained by dumping such a display to a printer. An MCA is very complex and expensive, especially if the number of channels capable of being counted simultaneously is very large, e.g., several thousand.

Whole-Body Counter

A Whole-Body Counter is a lab instrument that measures the amounts of gamma-emitting radionuclides in the body. To reduce the background and thereby increase measurement sensitivity, these counters are surrounded by large quantities of lead shielding. Our whole-body counter consists of a stand-up booth with two large-area NaI detectors The upper one looks at your lungs, the lower one at your gut. Each detector is a 4” x 5” x 16” crystal; this means we can normally tell in a one-minute count whether there is any activity in you. We’ll have more on this in Chapter 8.

Fig. 6.39. Chris Nicolau in the Whole-Body **Counter**

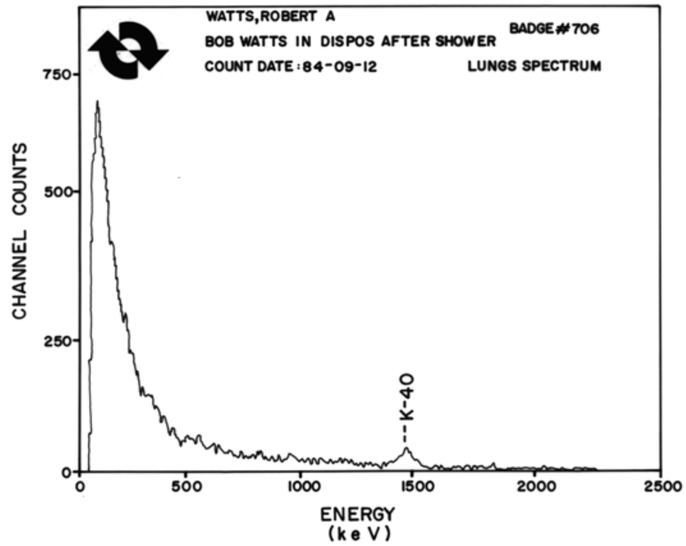


Fig. 6.40. A typical Spectrum obtained with the Whole-Body Counter

Liquid Scintillation Counters

Certain liquid solutions of organic compounds can be used as scintillation detectors. When coupled to appropriate phototubes and all the electronics that goes with them, they are known as **Liquid Scintillation Counters (LSC)**. We have two types of LSC at Point Lepreau.

LSC for Analysing Tritium Concentration in Liquids

We have a need for analysing tritium concentrations in water and urine samples. The samples to be analysed are mixed with liquid scintillator for maximum detecting efficiency.

Measurements of tritium-in-urine are known as **bioassay.** Fig. 6.41 shows an automatic LSC used to process your urine samples. The liquid scintillator is mixed with the sample in a small transparent bottle. The machine measures the tritium activity in a large number of such bottles automatically by transporting them to the phototube one at a time for counting. The results are fed directly to our Lab computer.

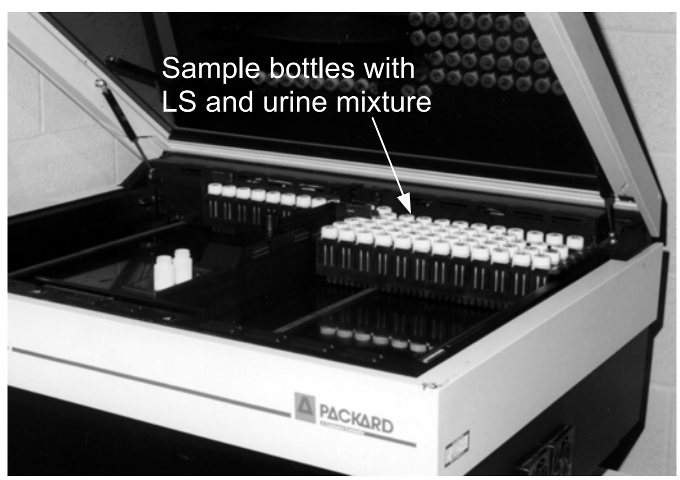


Fig. 6.41. LSC for Bioassay Measurements

Portal Monitor

The function of the Portal Monitor is to prevent the passage of radioactive materials into the Administration Building or off-site. It is our last line of defence against contaminated people and equipment leaving the station. The Portal Monitor at Point Lepreau is shown in Fig. 6.42. It is at the entrance to the bridge from the Service Building to the Administration Building. It is a "walk-through" monitor.

In order to be able to detect the passage of low levels of gamma activity, large and sensitive detectors are required. These consist of two columns of liquid scintillator, which are just over 2 m high and 1 m apart.

The high sensitivity of these detectors allows 100 kBq of Co-60 activity to be detected when it passes between the columns at a speed of 1 m/s. Indeed, our tests show that 10 kBq are detected more than 50% of the time.

Of course the same performance could be achieved by stacking sodium iodide crystals 2 m high, but then the monitor would have been prohibitively expensive.

This monitor alarms locally and in the Main Control Room when it sees activity above its set-point.

Fig. 6.42. The Portal Monitor

DOSIMETRY

By law, NB Power is required to provide an adequate program for measuring and recording the radiation dose any person receives from ionising radiation at our station. Here we'll describe how the dose is measured, and in Chapter 10 we'll tell you about dose records. We had the option of using a dosimetry service available from Health Canada, or of developing our own. We chose to go the in-house rather than the out-house route, because we knew that our service would be faster (turn-around time) and better suited to our specific needs than the one available from the Feds. The technique we use is called **Thermoluminescent Dosimetry.**

THERMOLUMINESCENCE

By definition, ionising radiation absorbed in matter produces ionisation. In some materials, a tiny fraction of this ionisation energy is stored by electrons caught in electron traps. If the material is heated at some later time, these electrons (in what are called *metastable states*) return to their ground state, releasing the stored energy as visible light.

This is known as **thermoluminescence**: "thermo" for the heat required to release the trapped electrons, and "luminescence" for the light emitted when the electrons get rid of their surplus energy.

The total amount of light emitted when the electrons return to their ground state is proportional to the number of electrons that were trapped, and this is proportional to the radiation dose absorbed by the material. Therefore, the amount of light emitted when thermoluminescent material is heated is proportional to the total radiation dose absorbed.

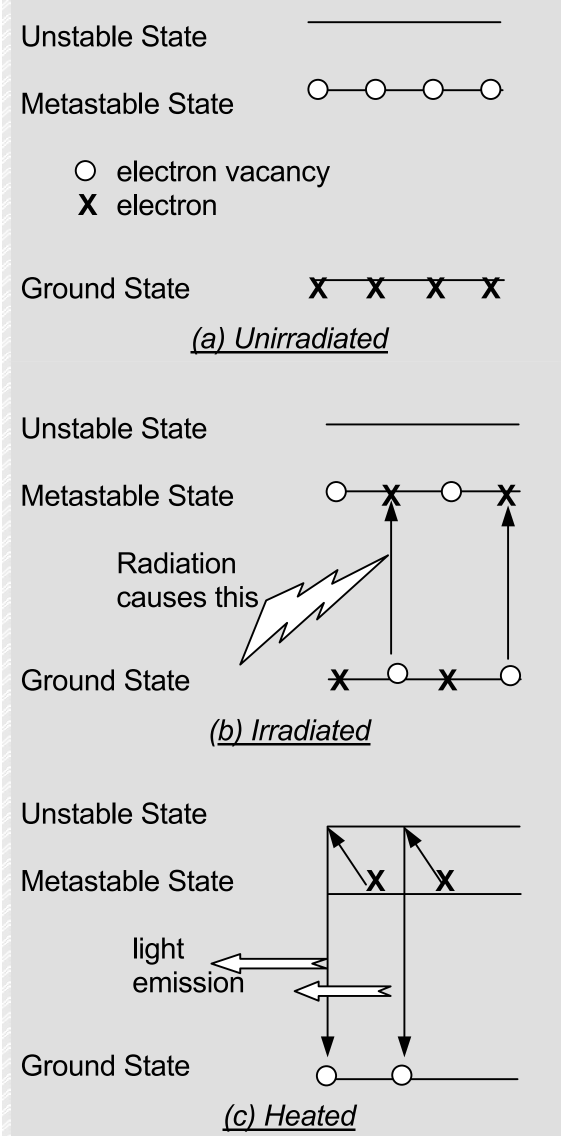


Fig. 6.43. Thermoluminescence

OUR TLD SYSTEM

TLD stands for Thermoluminescent Dosimeter. Our TLD system is made by Panasonic and consists of zillions of dosimeters and two TLD readers. We have a manual TLD reader at the station and an automatic TLD reader in our Fredericton lab.

The Dosimeters

The exterior of the dosimetry badge or TLD badge is shown on the right. The badge is clipped to the front of your torso, usually on your clothing — it's less painful that way. Inside the badge is the TLD, which consists of a holder and a removable insert on which are mounted four separate TLD elements.

The TL material used in the four elements is lithium borate ($Li_2B_4O_7$). The main advantage of lithium borate is that it has an effective atomic number (Z = 7.4) very close to that of soft tissue (Z= 7.7). Therefore, the energy absorption is very similar to that of soft tissue, and no corrections have to be applied for different responses at different energies. In other words, we don't have an energy dependence problem of the kind discussed on page 143.

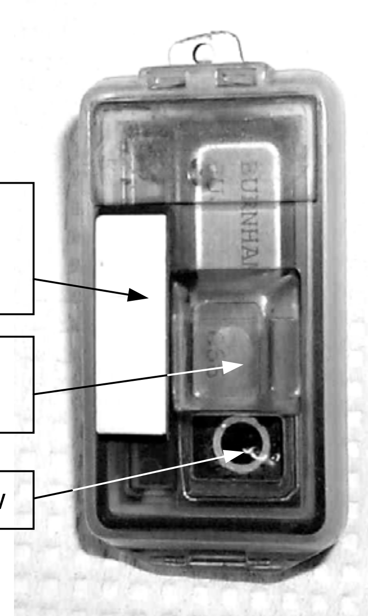


Fig. 6.44. TLD Badge

One of the four elements has a very thin window in front of it to allow the penetration of beta radiation. This element is used to measure the shallow dose H_S. The next two elements are behind a filter, which simulates the thickness of 1 cm of tissue. They are used to measure deep dose H_D from gamma dose. The fourth element may be used to indicate exposure to neutrons — we'll describe this later.

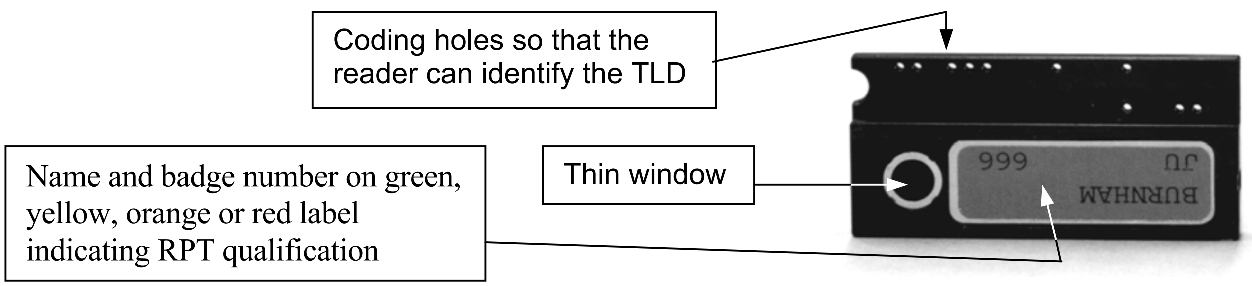


Fig. 6.45. TLD Holder: Front View

Fig. 6.46. TLD Holder: Rear View

TLD Reader

We have two readers: one automatic, and one manual for back-up. The difference in the two is that the automatic reader has a transport mechanism permitting 500 badges to be read out automatically, whereas the manual reader requires that the TLD badges be fed in by hand one at a time.

The automatic TLD reader is a lot more complicated than you might expect. For those of you who are throbbing to know more, the sequence of readout operations is summarised below:

1. The TLD element holders are stacked in the automatic badge transport mechanism.
2. The reader advances the holders one at a time to the readout position.
3. The identification coding is read.
4. The inner plastic card with the four TLD elements is removed from the holder and the four TLD elements are rapidly heated, one at a time, by exposing them to focussed infrared radiation.
5. The light emitted from each TLD element as a result of this heating is conducted through a light pipe to a photomultiplier tube.
6. The output of the photomultiplier tube in units of dose is printed out along with the identification number.
7. After all four elements have been processed, the card is shoved back into the holder, and the reader gets ready to accept the next holder.

The total cycle, including positioning, readout, and advance of a single holder with four elements takes about 20 seconds.

Performance Of Our TLD System

Before TLDs arrived on the scene, photographic films were used for personnel dosimetry. TLDs were first used on an experimental basis in the early 1950's, and by the late 1960's, adequate commercial systems were available. The state of the art has been improving very rapidly since then, and we have tried to take advantage of this by buying one of the most recently developed systems.

We have been very satisfied with its performance (details are given in the box on the next page). There are only two significant disadvantages, and you should be aware of both.

Neutron Response

Natural lithium borate contains the isotopes Li-6, Li-7, B-10 and B-11. Li-7 and B-11 are insensitive to neutrons, and Li-6 and B-10 are very sensitive to neutrons. A natural lithium borate TLD exposed to a neutron dose of 1 mSv can indicate anywhere from 0.3 to 3 mSv of dose on the TLD, depending on the neutron energy spectrum. This is obviously no good, because if the badge has been exposed to neutrons, the readout won't tell us the neutron dose or the gamma dose with any kind of accuracy.

Although some of our TLDs do use natural lithium borate, the TLDs assigned to Green and Yellow qualified people (who may be exposed to neutrons) have special features. Their shallow element and the two deep dose elements are enriched in Li-7 and B-11, but depleted in Li-6 and B-10. This makes these elements insensitive to neutrons: now the gamma dose (plus the beta dose in the case of the shallow element) can be read out directly. The fourth element is enriched in Li-6 and B-10; this makes it extremely neutron sensitive.

If you've been working in even a low level neutron field for any length of time, this last element will give a positive reading. Unfortunately, that's all it does. The response depends on the neutron energy spectrum and this is different in various locations in the station. As a result, element 4 (that's what we usually call it) only tells us that a neutron exposure has occurred; it can't tell us what the actual dose was.

For this reason, a neutron meter (p. 137) must be used to measure dose whenever you are exposed to neutrons. If you are green qualified and supervising red or orange people working in areas with neutrons, you must exchange their regular (neutron-sensitive) TLDs for the neutron-insensitive type.

TABLE 6.1. TLD SYSTEM SPECIFICATION

Range	Personnel TLDs: 0.2 mGy – 10 Gy Environmental TLDs: 10 μGy – 2 Gy
Accuracy	About ± 10%
Stability	Negligible loss of stored dose when read out one month after exposure.
Linearity	Light output is directly proportional to dose up to 100 mGy. This is the range of interest to us, and makes calibration very simple.
Environ-mental Effects	We've tested our TLDs by storing them at temperatures from -20 °C to +50 °C for 15 days in relative humidity ranging from 10 to 99%. There were no significant changes in performance due to humidity or temperatures below 30 °C. At 50 °C, the TLD will lose its stored reading at a rate of about 50%/month.
Re-Use	Panasonic guaranteed the performance of our TLDs for 300 readout cycles. Our tests show that they last a lot longer than this.
Tritium	No response to tritium
Neutrons	The shallow element and the two deep elements are neutron insensitive. The fourth element provides an indication of neutron exposure.

The Procedure calls for such an exchange of TLDs if you expect the people to get a neutron dose greater than 0.2 mSv. The replacement TLDs are kept at Work Control. It's hard to go wrong here; the neutron-insensitive badges are a disgusting shade of pink. Chapter 10 explains how the neutron dose registered by the neutron meter is recorded.

You might ask, "why go to this trouble when we could give everyone the neutron-insensitive TLDs?" Good question. Neutron-insensitive TLDs are a lot more expensive. We use many TLDs for people who will hardly ever be exposed to neutrons (admin staff, attached staff, and visitors) so we saved a lot of money by giving them the cheaper badges.

Dose Information Is Erased During Readout

This applies to all TL materials, and is of course the advantage that makes TLDs re-useable. But it does demand a very reliable reader. It would be most irritating, to say the least, if, for example, the reader erased several badges during the heating cycle after its phototube had failed. Our reader automatically checks for the correct operation of the heating and readout circuits before it processes each badge. If it sees a problem, it stops and blares at you. At worst, we would lose dose information from only one badge.

Accuracy of Dose Assessment Using TLDs

The TLD gives us a measurement of dose absorbed in the TLD (in mGy) with an accuracy of about ±10%. However, what we need to know is not the absorbed dose in the badge, but the deep dose, H_D (in mSv), in tissue. Remember that H_D is the dose at a depth of 1 cm of tissue.

There are many uncertainties involved in this assessment, and when these are allowed for, we can expect an accuracy of about ±30% in assessing H_D from a measurement of the absorbed dose in the TLD. Although this uncertainty seems quite large, it is the best we can do without surgically implanting a bunch of TLDs in your body. In any case, the uncertainty of our measurement is still smaller than the uncertainty of predicting the biological effects from a given dose equivalent.

Outline of Operational Procedures

TLDs are issued to all individuals who enter the Reactor, Service, and Turbine Buildings of Point Lepreau. These include:

a) station staff,
b) attached staff (AECB, AECL, Head Office, etc.),
c) casual visitors.

Station and attached staff will be assigned two TLD badges for alternate one-month monitoring periods. One TLD will be read in our Fredericton laboratory while the other is being worn. The badge has a blue or white stripe to indicate the wear period (see the photo on page 163). If yours has a blue stripe when everyone else has a white stripe, don't assume that they are all doing it wrong.

Each TLD badge is labelled with an individual's name and badge number. The labels are colour-coded red, orange, yellow or green to indicate the wearer's radiation protection qualification. The current period TLD badge, when not being worn by the individual, is stored in portable wall cases (shown at right) in the Service Building Foyer near the Portal Monitor.

Fig. 6.47. An Old Health Physicist Picking up his Badge

The cases are used to transfer TLD badges to and from the station. Each wall case contains ten unirradiated control badges that are used to subtract the background dose received while in the case during the one-month monitoring period. This gives a better estimate of the dose received while the TLDs are worn. There are also another ten irradiated control badges in each case; they are used to correct for any loss of TLD dose caused by fading (i.e., any loss of dose from storage at too high a temperature).

A manual reader is available in the station Health Physics Lab, so that the TLDs can be read at the station, if necessary. Also, the manual reader is used if the automatic reader is unavailable.

The manual reader is also used to read out extremity TLDs. These are used to measure the dose received by your hands or feet, if the dose rate there is expected to be much greater than at your chest where you wear your TLD badge. Extremity TLDs are not used all that often (and we've rarely used them for feet) — the procedure will be explained to you in the Applications course.

In fact, all the dosimetry procedures will be covered there. Until you've gone though that course, you should know this:

If you have lost your badge (i.e., either you can't find it in the badge rack where it is supposed to be, or you lost it somewhere while working in the station), go to Security and they'll walk you through the procedure for issuing you a new one.

PERSONAL ALARMING DOSIMETERS (PADs)

We also have some Personal Alarming Dosimeters, known as PADs. This is really a dosimetry system, consisting of PADs and one or more Readers. Its purpose is to provide:

1) immediate readout of gamma dose received,
2) dose control by means of alarm set-points,
3) back-up information for dose records if the TLD result is not available,
4) dose accounting for specific jobs.

PAD System Description

Our PADs have solid state detectors that respond to gamma radiation. They weigh 134 g, and are powered by a single AA battery that last six months.

The PADs have a top mounted display to make them easy to read when they are clipped to your breast pocket. The digital display gives both dose and dose rate information in mSv and mSv/h. The PAD has a dose rate alarm, and a dose alarm. These alarms are programmable. Health Physics sets the alarms. The ranges are:

1) dose rate alarm: 10 μSv/h up to 1 Sv/h,
2) dose alarm: 10 μSv to 10 Sv.

If an alarm set point is reached, the relevant display flashes along with a red light, and quite a piercing noise is generated. You can clear the dose rate alarm by retreating to a lower radiation field, but you cannot clear the dose alarm until you get to a PAD reader.

There is another nice feature of our PAD: it gives a bleep for every 10 μSv it registers. This gives you an audible indication of the radiation fields. For example, how many seconds between bleeps at 2 mGy/h and at 20 mGy/h?

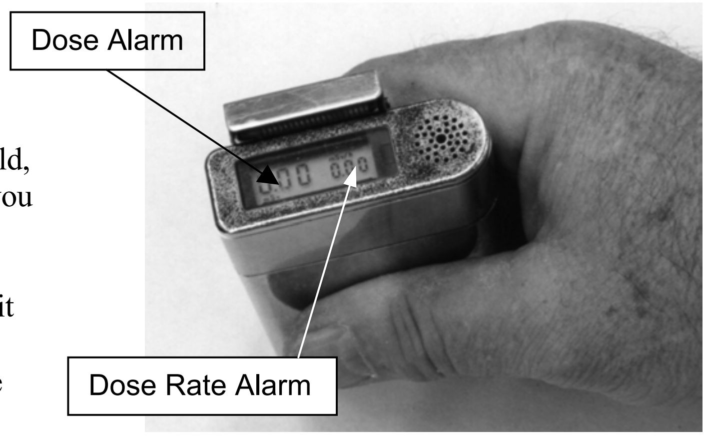


Fig. 6.48. PAD

Outline of Operational Procedures

You have to wear a PAD whenever you enter a Zone 3 area. You wear it beside your TLD. We have lots of PADs in a rack outside the Health Physics Lab. Pick any one, check for a valid calibration sticker, and source check it.

Fig. 6.49. PAD Source Checker

On the left is the PAD Checker. Insert the PAD as I'm doing here for a source check before using it. The source check takes about ten seconds. If the PAD is OK, the display will show "Resp. Check Passed".

If the PAD fails the source check, tag it as defective, and place it in the bin nearby. Get another PAD, and start again.

Next you have to prepare the PAD for use. Insert it into the PAD Reader (Fig. 6.50). At the prompt, use the keypad to enter your badge number and the job code. The job codes are listed beside the Reader. It will display your name, badge number, and the job description. Each job has dose and dose rate alarms assigned to it and the Reader will display these.

The PAD is now activated, and you remove it from the Reader. In the field, check your PAD often to keep track of your accumulated dose.

If the dose rate alarm sounds, check your gamma survey meter (the PAD does not replace a survey meter) and leave the area. The alarm will stop once the dose rate drops below the set point.

If the dose alarm sounds, leave the area, read out your PAD, and inform your supervisor. The alarm will continue to sound until the PAD is read out.

When your work is done, you read out the PAD by inserting it in the Reader and entering your badge number at the prompt. The Reader will display your dose and the highest dose rate the PAD registered during your work. While you're putting the PAD back in the rack, the Reader sends info it sucked out of the PAD to the Health Physics computer.

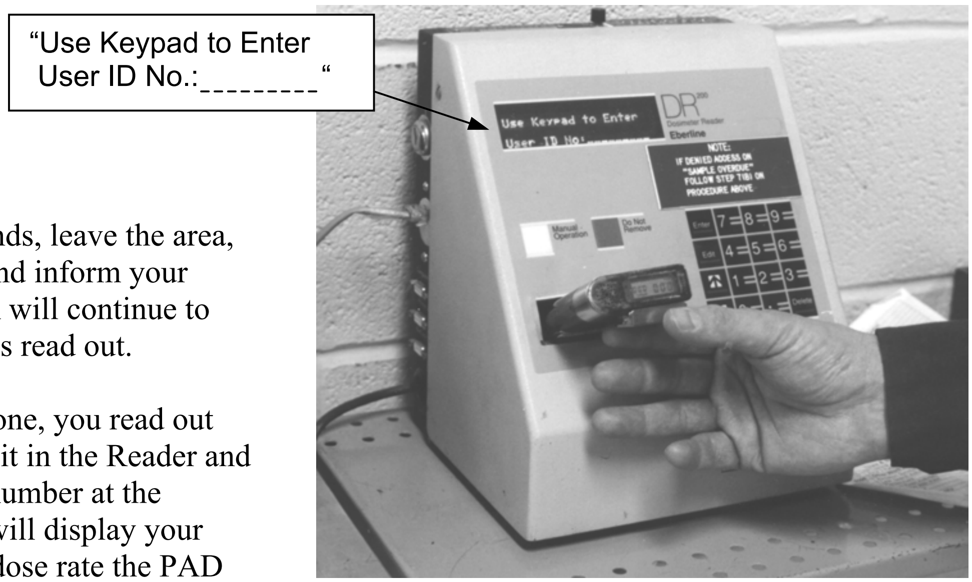


Fig. 6.50. PAD Reader

The computer stores in your file the date/time when the PAD was logged in/out, the dose, the highest dose rate, PAD #, job code, work group, and company. It keeps track of your accumulated dose during the current Monitoring Period, and this gives us the back-up we need if your TLD result at the end of the period should be unavailable.

Reports can be generated to give a history of PAD dose for particular jobs, work groups, and contractors. This is very useful when the time comes to plan similar work. It also lets us track those jobs that consume a lot of dose, so that we can think about doing them differently, or perhaps less often.

The only serious problem we've experienced with our PADs is that they read high when used very close to electric power tools like drills or grinders. Put your PAD in your pants pocket while you're doing this. If you get irrational high readings, inform Health Physics.

Finally, if you do not read out your PAD, it will alarm 15 hours after it was activated. (We sometimes have to investigate a high-pitched whine coming from somebody's locker — don't let this embarrassment happen to you; the PADs should be kept in their rack.)

DIFFERENCE IN TLD AND PAD MEASUREMENTS

The approved personnel dosimeter used by N.B. Power for official dose records purposes is the TLD. All TLD results are reported in mSv. PADs can give immediate dose information for dose control purposes. PAD results are not used in the official dose records system unless approved by Health Physics. They will be used if the TLD results are unavailable (lost or faulty TLD).

Differences in doses measured by a TLD and a PAD are inevitable. Some possible reasons are:

1. A hundred PADs exposed to an identical radiation dose (i.e., same field for same time) will give a range of results. The same applies to TLDs. Therefore, identical results from any one PAD and any one TLD are quite rare.

2. Our TLDs and PADs have different energy responses, although both are fairly close to that of tissue. Therefore, you can't expect them to give exactly the same readings, even when exposed side by side to the same gamma field.

3. The TLD isn’t all that accurate below 0.2 mSv. If your TLD deep dose is less than 0.20 mSv, deep and shallow are assigned based on your PAD total for the month. The minimum reporting level is 0.05 mSv.

If you wear your PAD beside your TLD all the time, the results should agree quite well. We’ve found that for dose greater than 0.5 mSv, the results are within 20% of each other 95% of the time, and within 10% two-thirds of the time. Curt Nason and his troops in Health Physics monitor the differences between PAD and TLD results quite closely, and they will correct any problems by taking shaky PADs or TLDs out of service.

There, aren’t you glad that this chapter is finally over? Still want you to do the problems, though.

SUMMARY

The only way we can detect and measure radiation is by using instruments; all work on the principle that radiation deposits energy in a detector, which leads to reproducible and measurable effects.

Ion chambers measure the ionisation produced in a gas- filled chamber. Ion chambers are found in the Emergency Gamma Survey Meter, the Beta Survey Meter, and the Tritium-in-Air Monitor.

Proportional counters can be designed to distinguish between radiation types producing large or small amounts of ionisation in the detector. This feature is used in our alpha/beta-gamma Hand and Shoe Monitors, Full-Body Monitors, some alpha Contamination Monitors, and the Neutron Survey Meter.

Geiger counters operate at such a high voltage that the size of the output pulse is always the same, regardless of how many ion pairs were created in the detector. This makes Geiger counters very sensitive and well suited to the detection of contamination, although they can be designed to measure gamma dose rate as well. We use them in beta-gamma Contamination Meters and Gamma Survey Meters (5016 and FAG).

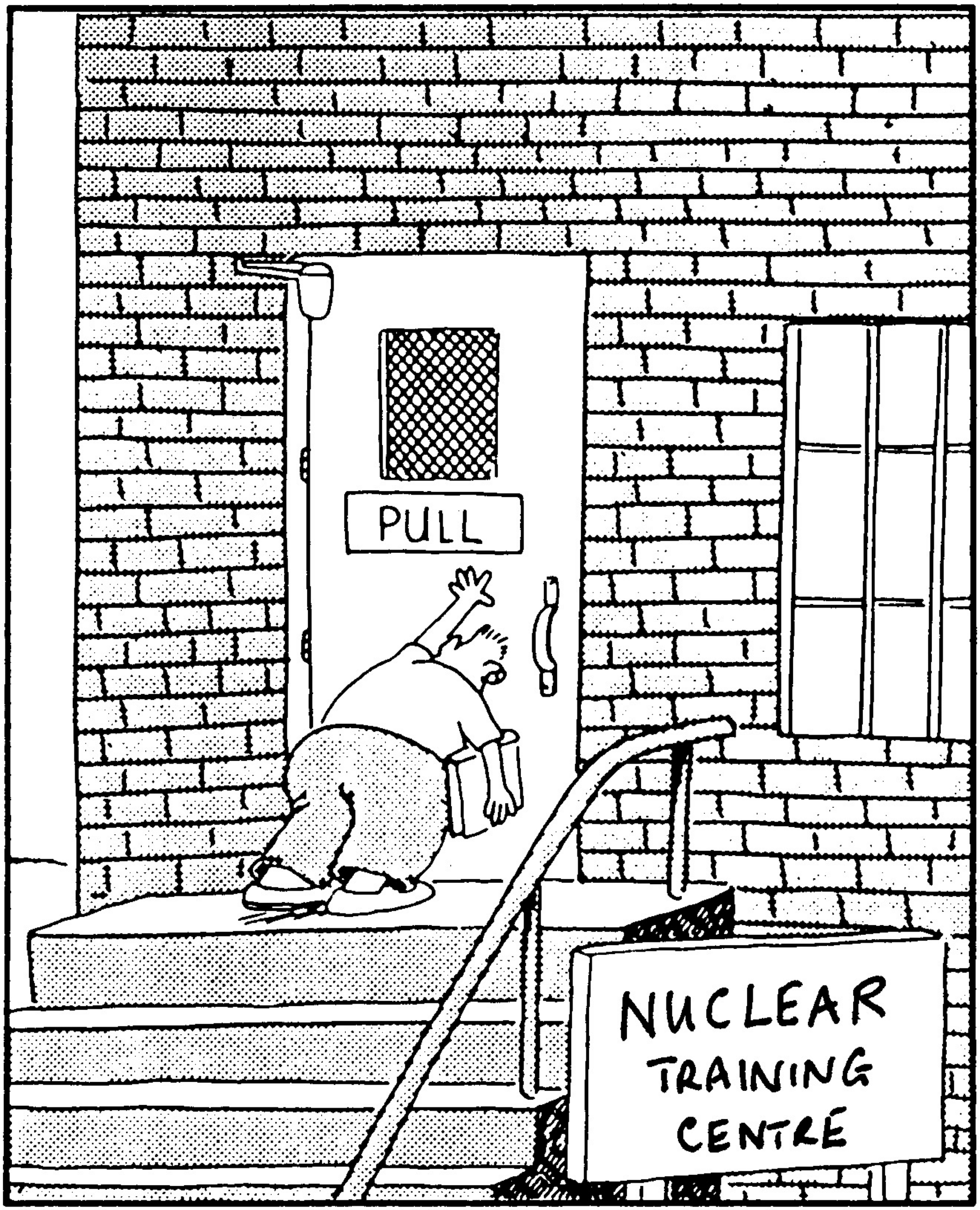
An instrument must identify the type of radiation it detects. Detector design, electronic discrimination or special operating techniques can do this.

All instruments have a ratemeter or scaler to display the results. Before you use any instrument, you should do three checks (valid calibration sticker, battery check, and source check).

Scintillation counters detect radiation by measuring tiny flashes of light produced in their detectors. When coupled to Pulse Height Analysers, they can identify gamma-emitting radionuclides. At Point Lepreau, scintillation counters are used in an alpha Contamination Meter, a Wide Range Gamma Survey Meter used by Security, the Vehicle Monitor, the Self-Serve Thyroid Monitor, the Whole Body Counter, the Portal Monitor, and the tritium-in-urine bioassay program.

TLDs measure absorbed dose by measuring the amount of light emitted from thermoluminescent material when it is heated rapidly. They are the official dosimeters for dose records purposes for external beta and gamma radiation. A neutron meter must be used to measure neutron dose received. Although element 4 of the TLD badge will indicate whether a neutron exposure has occurred, it won't indicate the actual dose received.

PADs form a back-up dosimetry system. The difference in gamma dose recorded by PADs and TLDs is less than 10% most of the time.


PULL
NUCLEAR
TRAINING
CENTRE

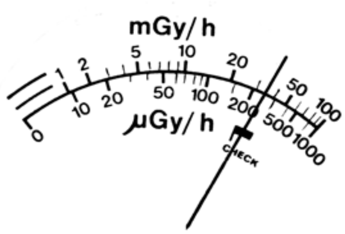
PROBLEMS

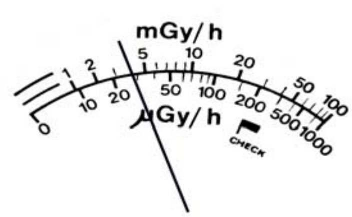
1. We use radiation instruments because:
   (a) we cannot taste or feel radiation,
   (b) we can't see, hear, or smell radiation,
   (c) they can help us to minimise radiation exposure,
   (d) all of the above.

2. If an instrument is reading off-scale, you should:
   (a) bang it against the wall until it reads what you think it should read,
   (b) change the battery and try again,
   (c) get another instrument,
   (d) believe it and retreat.

3. Imagine that you had to purchase 100 gamma survey meters for Point Lepreau. What are all the desirable features you would like to have if you could get them?

4. The diagrams show the scale of the 5016 Low Range Gamma Survey Meter. For the needle position shown, what gamma field is indicated on the low and high ranges in each diagram?





5. This chapter gives four examples of instruments used at PLGS that operate as proportional counters. Name them, and indicate which radiations they are designed to detect.

6. We have three instruments operating as Geiger counters. Which are they, and what are they used for?

7. We also have three instruments operating as ion chambers. Which are they, and what are they used for?

8. PLGS has seven different types of scintillation counter. What are they used for?

9. One instrument uses a solid-state detector. Which one?

10. Which of the instruments mentioned in this chapter would you select to measure:
    (a) gamma fields ranging from 20 to 200 mGy/h,
    (b) gamma fields ranging from 0.2 to 2 mGy/h,
    (c) beta fields ranging from 1 to 500 mGy/h.

(d) alpha contamination
(e) beta-gamma contamination
(f) gamma dose
(g) beta dose
(h) neutron dose rate
(i) neutron dose

11. (a) What pre-operational checks should you make before using any radiation instrument?
(b) While checking out a beta/gamma Contamination Meter (Fig. 6.13), you find a fairly steady reading of 8 to 9 cps. Give three possible causes.

12. A radiation survey indicates 60 mGy/h beta and 4 mGy/h gamma radiation at a work location, where you spend one hour.
(a) What shallow and deep doses should your TLD indicate (from this exposure)?
(b) What would you expect your PAD to indicate?
(c) How would you expect the answers to (a) and (b) to change if a neutron field of 1 mSv/h were present as well?

13. The alpha/beta-gamma Hand and Shoe Monitor produces the following pulse heights in one second from the detector of the left hand:

12, 600, 17, 540, 16, 18, 22, 712, 890, 20, 24, 42, 380, 640, 79, 50, and 520 mV.

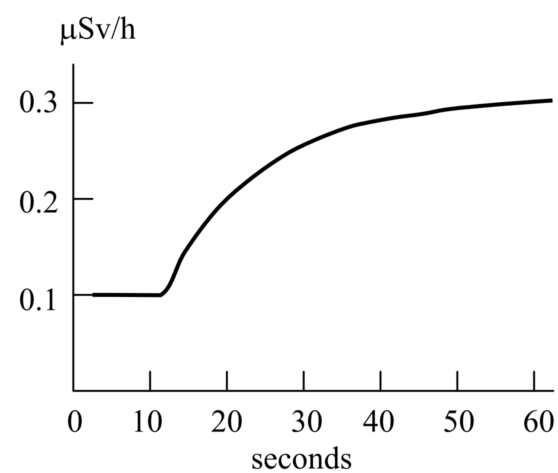
(a) With the discriminator set to 250 mV, what is the alpha and beta/gamma count rate the instrument will register?
(b) The efficiency of the detector is 15% for alphas and 20% for betas. What is the level of alpha and beta contamination on your left hand?

14. Why does the Low Range Gamma Survey Meter contain two Geiger tubes? How is it prevented from responding to beta radiation? Why is this necessary?

15. The FAG gamma survey meter shown in Fig. 6.21 has a delayed response as shown opposite when trying to measure low dose rates.

What is its Response Time?

Note: At higher does rates its response time improves. After 10 μSv/h it is down to 3 s, and above 10 mSv/h it is only 2 s.



16. What happens if you puncture the light-tight cover of a scintillation counter?

17. A radioactive source was counted with a scaler as shown in Fig. 6.19. It gave 2500 counts in a ten minute counting period. The background count rate (i.e., no source) was 750 counts in a five minute period. A week later the same source was counted again in the identical set-up. This gave 1750 counts in ten minutes. The background count rate this time was 125 counts per minute. What was the half-life of the source?

18. What should you do if you cannot find your TLD in the Badge Rack when you come to work?

19. If you are green-qualified and supervising red or orange people working in neutron fields, what must you do to ensure that their exposure will be tracked accurately?

20. What are "extremity TLDs" and what are they used for?

21. You are wearing a PAD and it is beeping at the rate of about one beep a second. What dose rate do you expect to see on the display? How come you haven't left yet?

22. Give three reasons why PAD and TLD results may be different? How close do you expect them to be?

23. Here are some True/False questions to test your knowledge of this chapter.

a	T	F	Geiger counters are designed to distinguish between different types of radiation that produce large or small amounts of ionisation in the detector.
b	T	F	Ion chambers measure the amount of ionisation produced in a gas-filled chamber.
c	T	F	Proportional counters can be designed to distinguish between different types of radiation that produce large or small amounts of ionisation in the detector.
d	T	F	The range of the 5016 gamma survey meter is 10 μSv/h to 100 mSv/h.
e	T	F	The reaction used in the neutron meter to detect neutrons is $B^{10}(n,\alpha)Li^7$.
f	T	F	The portal monitor uses liquid scintillation detectors.
g	T	F	The portal monitor is more sensitive to gamma radiation than the whole-body monitors at the bridge to the Admin Building.
h	T	F	None of the elements of the TLD badge respond to neutrons.
i	T	F	TLD results of less than 0.2 mSv are reported as zero.
j	T	F	The neutron meter uses a discriminator to reject the lower voltage pulses produced by gamma radiation.
k	T	F	One of the disadvantages of Geiger counters is that at high count rates they may saturate and are unable to indicate the true count rate.
l	T	F	A thin-walled Geiger tube will detect beta particles much more efficiently than gamma photons.
m	T	F	The time taken by an instrument to register 63% of the change when asked to respond to a higher radiation level is its response time.
n	T	F	Doing these T/F questions is the most fun you can have with your clothes on.