# CHAPTER 7

# PROTECTION FROM EXTERNAL EXPOSURE

## INTRODUCTION

During your work at Point Lepreau, you will be exposed to radiation. If the radiation source is outside your body, we call it **External Exposure**. An example would be working near a pump that emits gamma radiation. If the source is inside your body, it is **Internal Exposure**. An example of this is when you have inhaled some tritium, whose beta particles will be absorbed by your body tissues.

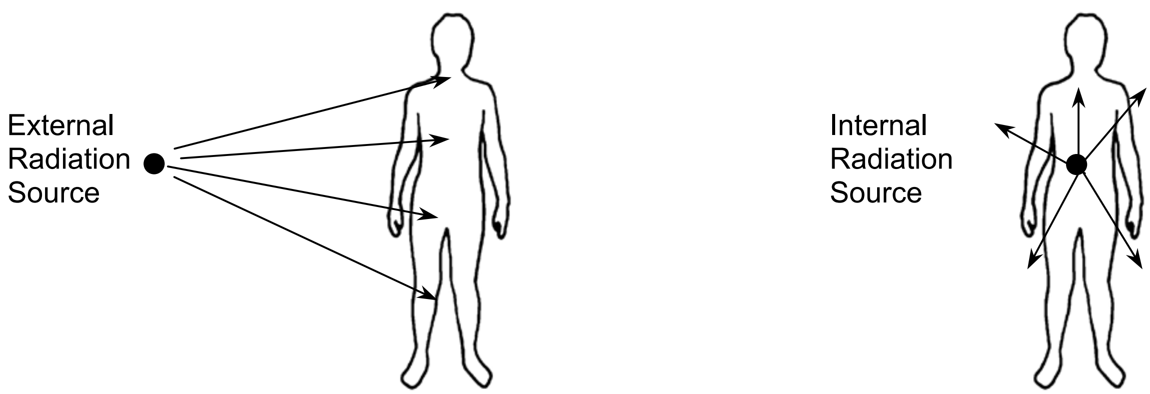


*Fig. 7.1. External and Internal Exposure*

The general biological effects of ionising radiation from external and internal sources are the same. However, as we progress it will become clear that precautions taken against the one hazard are of little use in protecting against the other. In this chapter, we'll look at how you protect yourself from external exposures. A good way to introduce you to this topic is via the "Safety Precedence Sequence".

## SAFETY PRECEDENCE SEQUENCE

The following sequence indicates, in order of decreasing effectiveness, what you can do to minimise hazards:

1. Eliminate the hazard
2. Minimise the hazard
3. Install physical barriers
4. Install warning devices
5. Minimise human error potential
6. Establish procedures
7. Train, motivate and supervise personnel
8. Accept the hazard as it exists

Let us look at this sequence with respect to the hazards of external radiation at Point Lepreau.

**1. Eliminate the Hazards**

The Safety Precedence Sequence tells us that the most effective way of reducing a hazard is to eliminate it completely. The only way to eliminate the gamma radiation hazards of Point Lepreau is not to have built it in the first place. So this is not an option. If you want to have nuclear power, you can't eliminate the hazards completely.

**2. Minimise the Hazards**

There are four ways of reducing the radiation exposure from external radiation. In the sections to follow we are going to talk about all four of them:

- Minimise the source.
- Reduce the exposure time to the source.
- Increase the distance from the source.
- Put shielding between you and the source.

**3. Install Physical Barriers**

Barriers which physically prevent people entering hazardous areas are very effective, e.g., locked doors. The Access Control System at Point Lepreau is based on this Physical Barriers approach and we'll deal with it in this chapter.

**4. Install Warning Devices**

Warning devices are not as effective as physical barriers, because some morons will ignore them. We have an electronic warning system, which alarms when exposed to high gamma fields, and I'll tell you all about it in a while.

**5. Minimise Human Error Potential**

Methods we use to control the hazard should be chosen so that the chances of human error are minimised. Make it easy for people to do it right, and make it hard for them to do it wrong. If you don't know what I mean, take a look at the control panel for the Equipment Airlock doors next time you're there.

**6. Establish Procedures**

Procedures for controlling the hazard should be established, written down and followed. Again, to be effective, the procedures should be designed with the people, equipment and work environment in mind: if you ask people to do things in an awkward way, they tend not to do them.

**7. Train, Motivate, and Supervise Personnel**

This means selecting suitable people to do the work, training them, motivating them and supervising them.

**8. Accept the Residual Hazards**

This just means that you and management should clearly understand what remaining hazards you've chosen to accept after you've done all the other things.

The Safety Precedence Sequence will tell you that this training course (will it ever end?) is one of the least effective of all our techniques for controlling hazards. Minimising hazards is better than training people to avoid them. However, if you follow the Radiation Protection Procedures all the time, you should never have a problem.

This brings us back to item 7 — if you don't understand the hazards and the procedures (training), or the need for the procedures (motivation), you won't have much incentive for following them. Physical barriers and warning devices are there to stop you and warn you in case you haven't followed the procedures — or if the procedures are inadequate or wrong, which would be our fault, not yours. With this background in mind, let us now start at Step 2 of the Safety Precedence Sequence and find out what we can do about protecting ourselves from external hazards.

## MINIMISE THE HAZARDS

### 1. Minimise the Source

There is not normally a lot you can do about this other than removing the source from the work site or letting it decay. We use both methods.

**Decontamination**

We bought an ice-blast machine in 1995. It uses cold water and compressed air to make ice chips that it fires out through a wand at high pressure. We use it to decontaminate large components before we need to work on them.

The 1995 outage involved lots of work in all four boilers. The Table opposite shows you how successful the ice-blast machine was in removing radioactive crap from the boilers and reducing the radiation fields.

TABLE 7.1. ICE-BLAST DECONTAMINATION

| *Location* | *Dose Rate (mSv/h)* | |
|---|---|---|
| Hot Leg | Before | After |
| Tube sheet contact $\beta$ | 5.2 | 0.3 |
| Tube sheet contact $\gamma$ | 2.8 | 0.8 |
| General beta | 2.4 | 0.6 |
| General gamma | 2.1 | 0.5 |
| Cold Leg | | |
| Tube sheet contact $\beta$ | 9.1 | 0.9 |
| Tube sheet contact $\gamma$ | 6.8 | 2.2 |
| General beta | 2.6 | 0.6 |
| General gamma | 4.6 | 0.6 |

Table 7.2 lists the work done on our four boilers and the dose resulting from it (after decontamination).

We think the ice-blast decontamination saved us about 1150 man-mSv in whole-body gamma dose alone.

TABLE 7.2. DOSE USED IN BOILER WORK

| *Activity* | *Man-mSv* |
|---|---|
| Boiler Modification | 12 |
| Primary-side tube sheet inspection | 81 |
| Boiler tube plugging | 9 |
| Divider plate inspection | 22 |
| Divider plate replacement | 204 |
| Total | 328 |

**Decay**

A second way of reducing exposure is to wait for the source to decay before you start work. The radiation field will drop by a factor of 2 for every half-life you wait. This is a good approach when work has to be done in a radiation field that will decrease very quickly with time (half-lives of minutes or hours).

If there is no need for the work to be done immediately, then waiting for a day or so will reduce the dose rate quite appreciably. This is always considered when planning work for a shutdown, because many radiation fields drop considerably during the first 24 hours.

***Example:***

You have to work for one hour near the snout of the fuelling machine. The gamma radiation field is 3.2 mSv/h and the activation products causing this field have an apparent half-life of 6 h. How long should you wait before doing the job, so that the your dose will be 0.1 mSv or less?

Initially, the dose rate will be 3.2 mSv/h, so you would get 3.2 mSv for an hour's work. The dose rate will decrease by a factor of 2 for every 6 hours delay because the activation products decay. So, after 6 hours the dose received will be 1.6 mSv; after 12 hours 0.8 mSv; after 18 hours 0.4 mSv; and after 24 hours 0.2 mSv. So if you first wait a day, you will receive only 0.2 mSv in an hour.

Incidentally, this problem assumed a constant half-life of 6 hours. In practice, the effective half-life might well increase because the short-lived activation products would decay faster than the longer-lived. This means that you might get less decay than you would expect. Therefore, before you start the job, you must check the radiation field again.

You can see the effect of an apparently increasing half-life in Fig. 7.2 showing how the gamma fields in the vault decrease with time after we shut down.

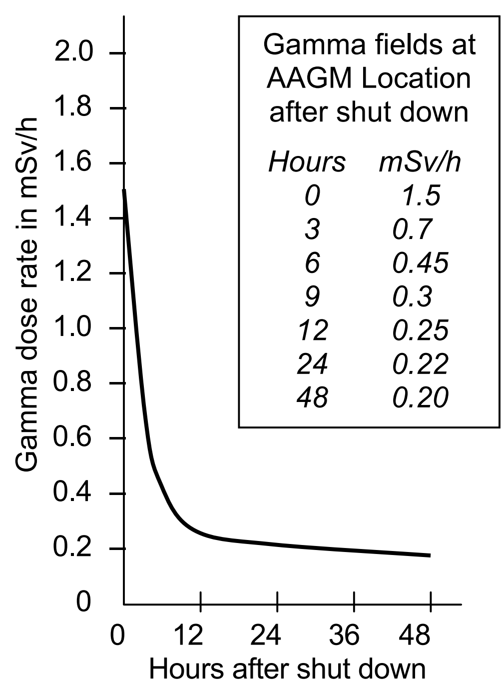


*Fig. 7.2. Gamma Fields in FM Vault*

Figure 2.24 on page 41 shows how the activity (and hence the radiation fields) will decrease as more and more half-lives elapse. You can see that waiting for three half-lives will drop radiation levels considerably. Waiting for seven half-lives will reduce radiation levels to less than 1%. A useful rule of thumb:

**Radiation fields will drop by a factor of just over 100 after 7 half-lives.**

## 2. Reduce the Time Spent Exposed to the Source

Estimating external dose is very simple. All you need is an instrument to tell you the dose rate where you are working. For example, if an instrument tells you that the radiation level in an area is 150 μSv/h and it takes 6 hours to complete a job, the dose received would be

$$150\ \mu\text{Sv/h} \times 6\text{h} = 900\ \mu\text{Sv}.$$

You can reduce the dose by simply limiting the time you spend near the source. No different from sunburn: if you don't want one, don't stay out too long in the sun. Proper job planning may reduce the time spent on the job site from 6 hours to 4 hours — in this case the absorbed radiation dose would be

$$150\ \mu\text{Sv/h} \times 4\text{h} = 600\ \mu\text{Sv}.$$

If you wish to limit the dose you are going to get to a certain value, and you know the radiation dose rate, you may calculate the maximum exposure time by using the formula:

$$\textbf{Time} = \frac{\textbf{Dose}}{\textbf{Dose Rate}}$$

If you want to limit your dose to 750 μSv, how long can you work in a dose rate of 500 μSv/h? Easy:

$$\text{Time} = \frac{\text{Dose}}{\text{Dose Rate}} = \frac{750\ \mu\text{ Sv}}{500\ \mu\text{ Sv/h}} = 1.5\text{ h}.$$

*The Units Must Be Consistent***.** For example, how long can you stay in a radiation field of 2 mSv/h if you are to be limited to a total dose of 100 μSv?

$$\text{Time} = \frac{\text{Dose}}{\text{Dose Rate}} = \frac{100\ \mu\text{ Sv}}{2\text{ mSv/h}} = \frac{100\ \mu\text{ Sv}}{2000\ \mu\text{ Sv/h}} = \frac{1}{20}\text{h} = 3\text{ min}.$$

You should complete work in radiation fields in a safe manner as quickly as possible. The job should be planned before it is started. A good plan results in an efficient work process and the lowest possible exposure.

Obviously, the dose you receive is proportional to the length of time you spend in the radiation field. You can reduce the time (and your dose) in any of the following ways:

- Use a mock-up of the work to analyse and rehearse the job to find the most efficient way of doing it. A good example of this occurred during the 1984 shutdown, for which a boiler mock-up was built. The mechanics practised entering and leaving it dressed in plastic suits before they did their thing in the real boiler with gamma fields of up to 30 mSv/h. Being smarter than most people, they kept the mock-up, and have used it ever since.
- Consider the ergonomics. Will better light, better access at the work site shorten the job?
- Detailed pre-job briefings will identify who is needed where and when. If people aren't needed, keep them out of there. Check that your procedures are going to work as planned.
- Review previous job reports to identify where you might be able to improve things and save time.
- Make sure all needed tools and equipment are at the job site before work starts, and that they are assembled and tested as necessary.
- If there are time limitations because of radiation, make sure that your PAD dose alarms are set appropriately. (HP can set the PAD dose and dose-rate alarms at any level.)
- Use experienced people for the work if you can. They will do it more quickly than those who haven't done it before.
- You can reduce the dose to individuals by using a team of workers. If you do this, you need good communications between the team members.
- Don't hang around in a radiation field while waiting for things to happen. Retreat to a low dose area. (It is surprising how many people forget this.)

### 3. Increase Your Distance from the Source

If you increase your distance from a small radiation source, there will be a marked reduction in the radiation field. Figure 7.3 shows why.

A small (point) gamma source emits photons equally in all directions. If you stand at A, you will intercept ten gamma photons every second, but if. you move out to B, only four photons hit you each second. Therefore, as you move away from the source, the gamma radiation field decreases. This is entirely due to the spreading out of the emitted photons.

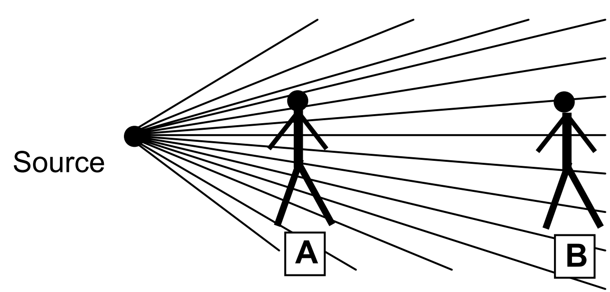


*Fig. 7.3. The Radiation Field Decreases with Distance*

The **Inverse Square Law** describes the drop-off in gamma fields with distance.

> **The gamma field varies inversely with the square of the distance from the source; that is, doubling the distance drops the field to 1/4, tripling it drops it to 1/9, and so on.**

Why is this so? Imagine a small light bulb at the centre of a balloon with a 1 m radius. The light will be spread over the entire surface of the balloon, which is $4\pi r^2$. If we blow the balloon up to have a 2 m radius, its area will be four times as big. The amount of light emitted by the bulb hasn't changed, so any piece of the balloon's surface will receive only one quarter the amount of light it received before. So doubling the distance reduces the intensity to one quarter. It is exactly the same with gamma radiation, because the same number of gamma photons will be spread over four times the area.

You have to realise that the inverse square law applies to gamma radiation only, and then only for point sources and not for beams. **In practice, we consider a point source to be one whose largest dimension is smaller than 1/5th of the distance from it to you.**

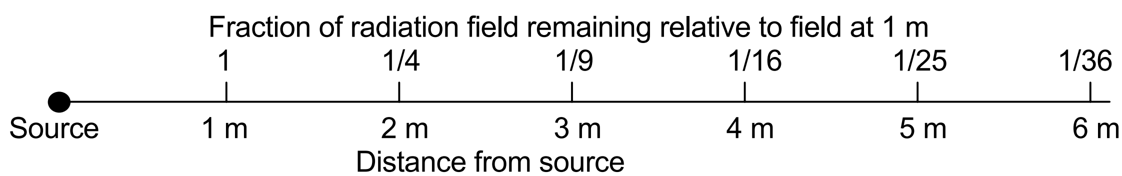


*Fig. 7.4. Fraction of Radiation Field Remaining at Various Distances from a Point Gamma Source*

***Examples*:**

(a) If the gamma radiation field at 1 metre from a source is 320 μSv/h, what is it at 4 metres?

Figure 7.4 shows that the field at 4 metres has been reduced to 1/16 of its level at 1 m. Therefore it will be (1/16) x 320 μSv/h = 20 μSv/h at 4 m.

(b) If the gamma radiation field at 6 m from a source is measured to be 20 μSv/h, what radiation field would you expect at 4 m from the source?

Figure 7.4 tells us that the field at 1 m would be 36 times greater than at 6 m, and that the field at 4 m would be 1/16 of that at 1 m. Hence the field at 4 m = (36/16) x 20 μSv/h = 45 μSv/h.

The second example leads us into an easy method to use, if you want to calculate gamma radiation fields at various distances from the source.

It is based on common sense applied to a **distance factor**. Divide the larger distance by the smaller distance and square the result; this is your distance factor. Now multiply or divide the known dose rate by this distance factor. Multiply if the dose rate should increase and divide if it should decrease.

Look again at example (b). The larger distance is 6 m and the smaller distance is 4 m. The distance factor is $(6/4)^2 = 1.5^2 = 2.25$. Since we are moving towards the source, the radiation field will increase. Therefore, we multiply the dose rate of 20 μSv/h by 2.25 to get 45 μSv/h for the dose rate at 4 m.

***Examples using the Distance Factor:***

If the gamma radiation field is 500 μSv/h at 3 metres from a source, what will it be at 1 metre and at 10 metres?

(a) Radiation field at 1 m:
The field will be greater because we are going closer. The distance factor is $(3/1)^2 = 9$.
Therefore, the field is 500 x 9 = 4500 μSv/h = 4.5 mSv/h.

(b) Radiation field at 10 m:
The distance factor is $(10/3)^2 = 3.33^2 = 11.1$. The field will be smaller, so we divide the dose rate by 11.1: that is, 500/11.1 = 45 μSv/h.

The above example illustrates that if you move from 1 metre to 10 metres away from a source (i.e., by a factor of 10), the radiation level drops by a factor of 100. Just as startling an increase will occur if you move closer to a source. Calculations of this kind illustrate the fact that increasing your distance from a point source can make a tremendous difference in the dose that you receive.

For example, imagine that a point source (such as a small chunk of broken spent fuel) is emitting gamma radiation with a dose rate of 10 Sv/h at 0.5 m. A person who is positioned 0.5 m away from the source for a one hour would receive a dose of 10 Sv. This is certainly enough to kill him. If he is 2.5 m away, the dose rate would only be 1/25 of that or 0.4 Sv/h = 400 μSv/h. There would be no significant effects if he stood there for one hour. In this (rather extreme) example, a couple of metres makes the difference between death and no real effect (other than exceeding the dose limit).

The Inverse Square Law will show that if a person is very near a small gamma source, some parts of his body may receive a much higher exposure than other parts.

Consider your friendly Maintenance Supervisor shown in Fig. 7.5. If the gamma field at his waist level is 5 mSv/h at 90 cm from the source, and if his head is 30 cm from the source, the dose rate to the head would be much greater than to the waist.

You should be able to work out that the dose rate at his head is 45 mSv/h, and if he were to move his head closer to the pipe it would be higher still.

Fig. 7.5. Maintenance Supervisor

If you pick up sources, the distance to the sensitive part of your skin becomes *negligible*, and will result in enormous dose rates compared to those at a few cm. The moral is pretty obvious: **don't pick up sources with your hands.**

**What can you do to increase the distance from the source?**

- Use remote handling tools or remote controls. Tongs or long-handled tools are a good way of increasing your distance from a source. This is very important for beta sources: as you get close to them the dose rate goes up much faster than it would for gamma sources. In contact with your hands, beta doses can be enormous. Always use tongs when handling small sources.

- Use remote observations if you can. Video cameras and even binoculars are useful for observing equipment operation, instrumentation, displays or whatever you need to see in a high radiation field.

- Can you move to another work location? If a pump or valve in a high radiation field needs to be rebuilt, often it can be removed from the system so that you can work on it in a low dose-rate area.

- Identify low dose-rate “waiting areas” and make sure people wait there when they aren’t actively working in the radiation fields.

- When you are doing gamma surveys, keep the gamma meter at arm’s length from you when approaching gamma sources. The dose rate to your body will be a lot less than that indicated by the meter.

**Limitations of the Inverse Square Law**

1. The law is valid only for gamma rays because you can neglect any shielding by the air. This is not true for alpha or beta radiation. Alpha particles have only a small range in air (less than 10 cm for the highest energy alpha particles). Once the distance from the source becomes greater than this, no alpha particles are detected. The range of beta particles is usually much greater, but the same reasoning applies. Furthermore, beta particles all have different ranges, even if they all come from the same source. Because of scattering, they won't travel in straight lines anyway.

2. In theory, the Inverse Square Law holds true only for "point" gamma sources. In practice, a source may be quite large and the detector will only "see" it as a point source when the detector is sufficiently far away from it. We assume that the Inverse Square Law won't hold until the detector is about five source diameters from the source.

3. When shielding is placed between the source and the detector, the inverse square law can only be applied if due allowance is made for the gamma photons absorbed by the shielding.

4. If the gamma radiation is in the form of a beam, the inverse square law won't apply either, because there is no spreading out.

When Point Lepreau was first taken to high power levels, radiation beams were found coming from the horizontal flux detector housings located in the north reactor wall (just inside the Equipment Airlock). These beams were less than 10 cm in diameter, which made them hard to find.

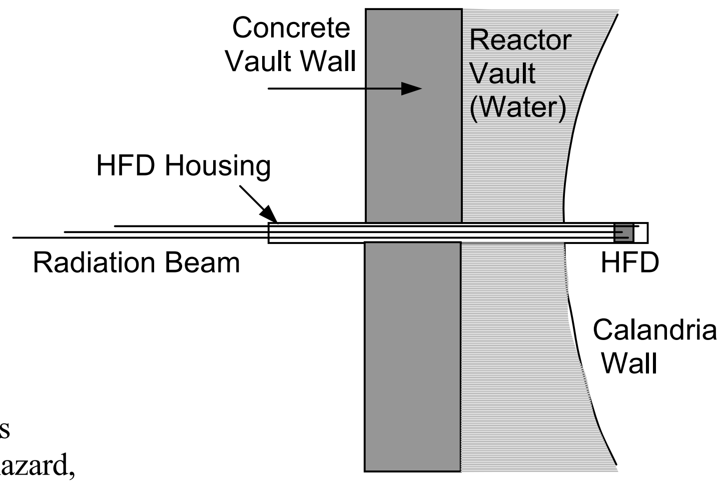


*Fig. 7.6. Radiation Beams from the HFDs*

At 10% of full reactor power, the beam intensities were about 3 mSv/h gamma and 1 mSv/h neutron. Lead blankets were strategically placed to minimise this hazard, and were later replaced by permanent shielding.

The story doesn't end there. In the 1995 outage, the shielding was removed to support some in-core measurements. Unfortunately, it wasn't replaced before start-up. (This isn't as amazing as it sounds, because the housings look pretty well the same with and without the shielding.) It wasn't until May of the next year that this was realised.

Frank Whitenect, who was a Radiation Control Tech at the time, noticed that his PAD beeped outside the Equipment Airlock. Instead of assuming that his instrument was faulty (an all too common reaction for some people), he carefully surveyed the area and found narrow beams coming from two flux detector housings. At contact with the housings, the beams were about 5 cm in diameter with 60 mSv/h gamma and 15 mSv/h neutrons. Outside the Airlock in the Service Building, the gamma beam was still 100 µSv/h and about twice the diameter.

Other radiation beams are found at the flexible ventilation ducts around the PHT main circulating pumps. These ducts (four for each pump) exhaust air from the pump bowl cavity through a one-metre thick concrete platform to the Boiler Room. At 100% power, these beams amount to about 5 mGy/h gamma and 1 mSv/h neutron. Because they shine directly upwards, they are not normally a problem.

**Line Sources and Plane Sources**

We have pointed out that the Inverse Square Law applies only to point sources. For a line source, e.g., a pipe carrying radioactive fluid, the gamma field does not drop as rapidly as you move further away from it as it would for a point source.

If you look at Fig. 7.7, I think you will understand why this is so. The photons from a point source spread out in two dimensions, but those from a line source spread out in only one dimension. B is twice as far away, and has only twice the area. So doubling the distance from a line source decreases the field by a factor of 2, not 4 as it would with a point source. Going ten times as far away, will drop the field from a line source by a factor of 10, and not by the factor of 100 that would apply to a point source.

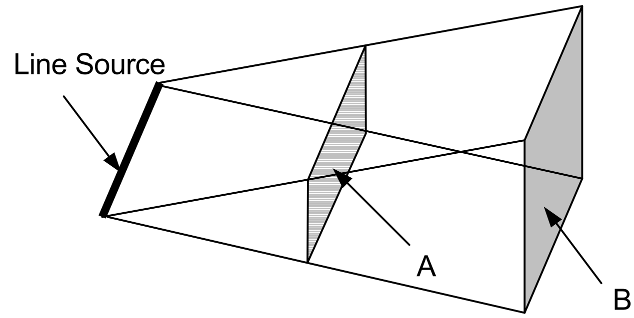


*Fig. 7.7. The Spread of Gamma Radiation From a Line Source*

For a large plane (or area) source, there will be only very little reduction in the gamma fields as you move away from it. This is shown in Fig. 7.8, which shows the Reactor Face in the Fuelling Machine Vaults at Point Lepreau (the photo was taken during commissioning).

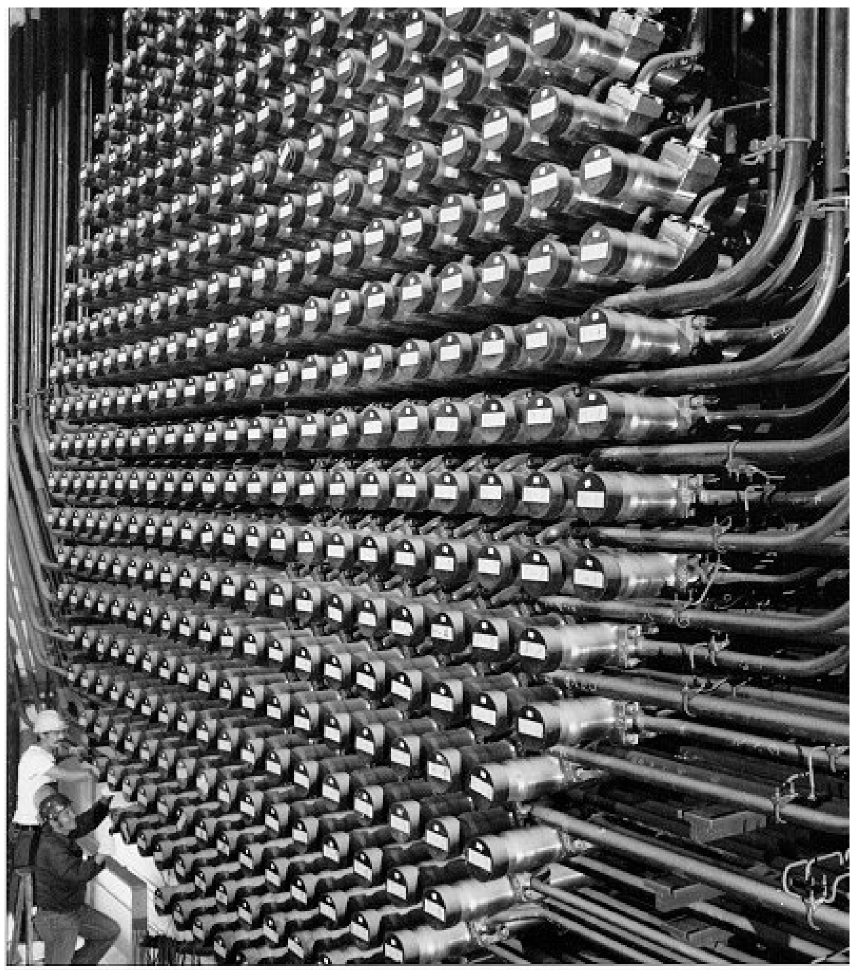

*Fig. 7.8. The Reactor Face at Point Lepreau (a Plane Source)*

For example, the gamma dose rates at 2 m away from the reactor end face or at 4 m away shouldn't change much. You would not be able to measure a significant drop in gamma radiation intensity until you moved far enough away from the plane source for the spreading out of the gamma photons to become significant.

Now see if you can think of some examples of line sources and plane sources that you might encounter in your work at the station.

**Beta Emitters as External Sources**

Most sources at Point Lepreau contain a mixture of beta and gamma emitters. Beta radiation from a source that is enclosed in a pipe or other container will be effectively absorbed and you need worry only about the gamma emitters.

Exposed (unshielded) beta emitters can cause some surprising external radiation fields. Why? Because of the limited range of beta particles, we would expect beta radiation to drop off much more quickly with distance than gamma radiation — if you turn this argument around, it is obvious that beta radiation will increase much more rapidly than gamma radiation as you approach the source.

**Decreasing your distance from a beta source will sharply increase the radiation level.**

Usually beta-gamma sources have enough shielding to absorb all the beta radiation. But if they do not, beware! A 10 MBq beta source delivers a dose rate of 200 mSv/h at 2 cm. At the point of contact, the dose rate would be greater than 1000 Sv/h. This is not a misprint.

**Always use tongs when you handle small beta sources.**

Never use tongues.

## 4. Shielding

We have discussed Time, Decay and Distance as ways of keeping radiation doses low. In some cases the only practical way of reducing radiation exposures to an acceptable level is to install shielding between the source and you. Radiation shielding is a very complex subject (i.e., I don't understand it very well), and therefore we'll discuss only some basic ideas.

**Alpha Shielding**

You may recall from page 28 (Fig. 2.12) that alpha particles have a very small penetrating ability — even in air the most energetic alpha particles cannot travel more than 10 cm. The dead layer of your skin will stop them completely. Because of this, alpha sources outside the body do not present an external hazard and so **shielding against alpha particles is quite unnecessary**. However, alpha particles with their Quality Factor of 20 are a very serious internal hazard; we have to be very careful to ensure that alpha sources are kept out of the body.

**Beta Shielding**

At Point Lepreau radioactive materials are normally contained in systems which completely shield people from beta particles. You may remember from page 30 (Fig. 2.15) that not very much shielding is needed for this.

However, when radioactive materials are released into the plant (like Ar-41), or when systems are opened for maintenance (e.g., removal and maintenance of pumps and valves), the shielding surrounding the beta source is removed. Then an external hazard can exist, because beta particles have a considerable range in air depending on their energies (up to several metres, see page 29).

The tissues exposed to external beta radiation are the skin (dose limit = 500 mSv/year) and the lens of the eye (150 mSv per year). Routine wearing of safety glasses will further reduce the hazard to the eye lens, which is already shielded by the cornea. However, this applies only to beta radiation, and not to gamma radiation. Why?

Since beta particles are so easily absorbed, nobody should receive an appreciable external dose from beta radiation if proper techniques are used.

We made some measurements with TLDs to find out to what extent beta radiation is absorbed by the protective clothing that we use. We used two different pure beta sources, strontium-90 and thallium-204. The maximum beta energies are 2.2 MeV (from the yttrium-90 daughter) and 0.763 MeV respectively. The results are shown opposite.

TABLE 7.3. ABSORPTION OF BETA RADIATION

| *Type of Material* | *Percent Absorption* | |
|---|---|---|
| | *Sr-90* | *Tl-204* |
| Safety Glasses (Lens) | 95 | 100 |
| Full-Face Respirator (Lens) | 80 | 100 |
| Plastic Suit | 10 | 60 |
| Rubber Gloves | 10 | 60 |
| Cotton Gloves (new) | 0 | 80 |
| Disposable Hood (for suit) | 0 | 25 |
| Brown Coveralls (new) | 0 | 15 |

**Gamma Shielding**

We already know that gamma rays will penetrate to great depths in materials and that no amount of shielding will stop all of the radiation. The effectiveness of gamma ray shielding is often described in terms of the half-value layer (HVL), which is the thickness of absorber required to reduce the gamma radiation to half its former intensity. You've already been introduced to this on page 30.

The first HVL reduces the radiation field by one-half. The second HVL reduces the radiation by one-half again, i.e., to one quarter of the original level. The radiation levels after successive HVLs are:

Radiation after 1 HVL $= (1/2)^1 = 1/2$ of the original
Radiation after 2 HVLs $= (1/2)^2 = 1/4$ of the original
Radiation after 3 HVLs $= (1/2)^3 = 1/8$ of the original
Radiation after 4 HVLs $= (1/2)^4 = 1/16$ of the original
Radiation after 5 HVLs $= (1/2)^5 = 1/32$ of the original

After n HVLs, a gamma radiation field will be reduced to $(1/2)^n$. This leads to the following useful guides:

**7 HVLs reduce the gamma field to 1%, and 10 HVLs reduce it to 0.1%.**

Gamma photons interact with electrons. Therefore those materials which have a large number of electrons per atom and a large number of atoms per unit volume will be the most effective gamma shields. Heavy metals like uranium, tungsten, gold and lead are good examples of such materials, although gold isn't used much.

Concrete is a good structural material, but lead is not because large lead shields require some sort of supporting frame. On the other hand, lead shields will be thinner than shields made of less dense materials, so for semi-permanent shielding we often use lead blocks, lead blankets or bags of lead shot. With these, the shield can be built up to fit the requirements. Lead blankets are useful for wrapping around pipes and hot valves, but you must make sure that the design will take the extra weight.

When you remove shielding to support maintenance activities, the radiation fields can increase drastically. Make sure that you warn people of this with signs. When the shielding is replaced, make sure that the radiation field returns to normal by surveying the area thoroughly. The HFD story on page 186 shows you how important this is.

Water may be used where it is necessary to see the source of radiation or to work on the source with remote tools. Spent fuel is usually stored in deep bays filled with water. This water also absorbs the heat being generated by the fuel elements, and the water is easily cooled and purified. We have some moulded plastic tanks (about 6 ft by 4 ft by 8") that we can fill with water and use as portable shielding. We fitted them with wheels and a drain valve (a design oversight!) to make life easier.

Figure 7.9 shows the HVLs of various materials for a range of gamma energies.

The HVLs are not constant for a given material, because the relative probabilities of the three gamma absorption processes (photoelectric effect, Compton effect, pair production) vary with gamma energy. In the range of energies that interest us, the HVL usually will increase with energy. For higher energy gamma photons you will need more shielding than for lower energy photons.

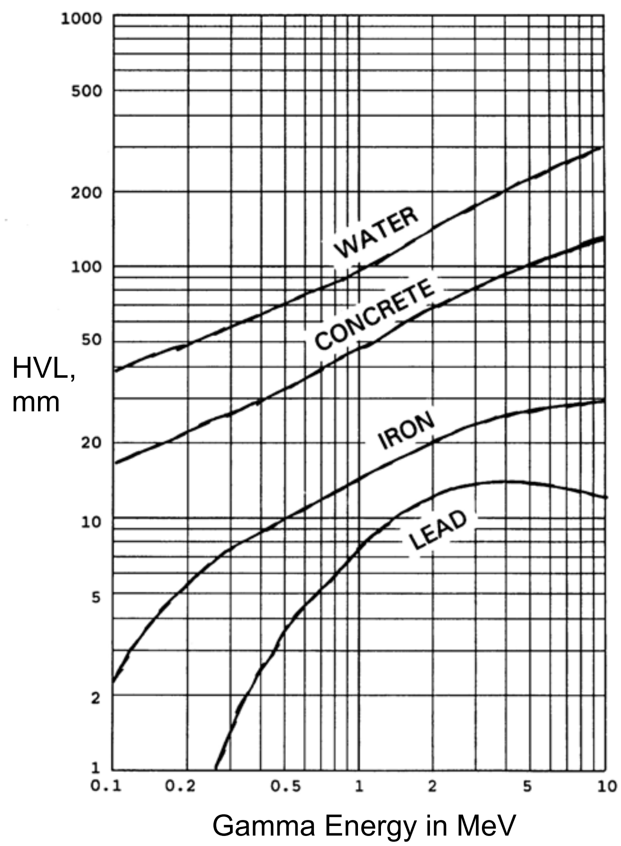


*Fig. 7.9. HVLs of Various Materials*

For gamma radiation with energies in the range where Compton scattering is the main absorption process, the weight of material required for a shield is generally about the same, regardless of the material used. For instance, the HVL of iron for 1 MeV gamma radiation is about 15 mm as compared with 47 mm for concrete. Since iron is about three times as dense as concrete, the total mass required for a shield will be roughly the same for both materials.

***Shielding Example:***

A beam of gamma radiation is found to be coming up through a small hole in the floor. A gamma survey meter shows a reading of 20 mSv/h at the hole. The gamma energy is assumed to be around 1 MeV. The radiation field has to be reduced to less than 10 μSv/h. We have some lead blocks 50 mm thick. How many would you need to block the beam?

The radiation field has to be reduced from 20 mGy/h (= 20,000 μSv/h) to 10 μSv/h, which corresponds to a factor of 20,000/10 = 2000. We know that 1 HVL will reduce the field by a factor of 2, and another 10 HVLs will reduce that by a factor of 1000, so we'll need 11 HVLs. Figure 7.9 tells us that the HVL for 1 MeV gamma radiation is 8 mm of lead. Therefore we'll need 11 x 8 mm, or 88 mm. It seems that two 50-mm lead blocks should do it.

What you'd do is get three lead blocks from Stores, shove them over the hole, and then measure the field again to make sure that they had taken care of the problem. You could rework this problem for steel sheet (use the HVL for iron) in case Stores are fresh out of lead blocks. A few copies of this book would do the job as well. See, it is useful.

It is very important that you appreciate that although these arithmetic exercises may be quite interesting, they are only meant to give you a clue as to how effective shielding can be. In practical work situations, you should **never** base your radiation protection plans on shielding calculations alone, but you should **always** measure the radiation field after the shielding has been put in position.

Some jobs require the use of temporary shielding while work is being done. You must ask yourself whether the extra dose you will absorb while you grunt the shield into position and then remove it again is going to be off-set by the reduced dose with the shielding. For a long job, temporary shielding will be worthwhile, but for a short job it may not be.

**GAMMA BUILD-UP**

The HVL values given so far apply only to narrow beams as shown in Figure 7.10, where the number of HVLs is not too large. In practice, we are more likely to come across gamma radiation that is not in the form of a beam, but that is spreading out in all directions as shown in Fig. 7.11.

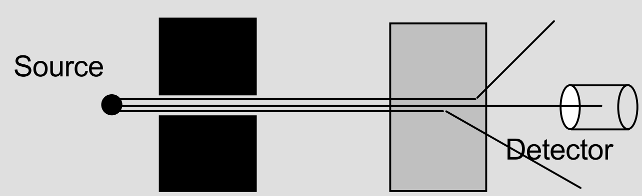

*Fig. 7.10. Narrow Beam Absorption*

In this case 3 HVLs would not reduce the field by a factor of 8, but rather less. The reason is that some photons, which would have missed the detector if there had been no shielding, are now scattered inside the shield (Compton effect) to interact with the detector.

In other words, the gamma field will be greater than you would expect. The thicker the shield, the greater will be the chance of these scattering effects. It is possible to work out what the extra field will be —
— such calculations are normally done by people who have nothing better to do. In practice, you would just keep on adding to the shielding until your instrument measured a radiation field that you considered to be OK.

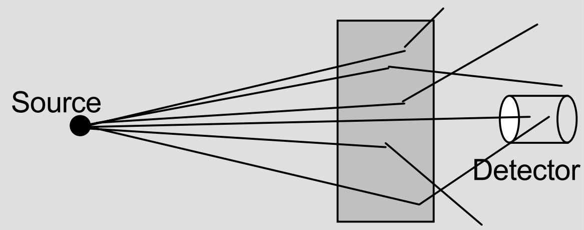


*Fig. 7.11. Broad Beam Absorption*

**Neutron Shielding**

Neutron shielding is a very complicated subject. We won't say very much about it, since I don't know much about it myself.

Fast neutrons must be slowed down before they are readily captured. Fast neutrons may be slowed down by two kinds of interactions:

1) Inelastic scattering of neutrons with heavy elements (especially iron). This interaction predominates for neutron energies greater than 1 MeV.
2) Elastic scattering with light nuclei such as hydrogen.

The resulting slower neutrons are captured by nuclei in the shielding material via an $(n,\gamma)$ reaction. Therefore gamma radiation will be produced as a result of the capture process and additional shielding must be added to absorb the gamma rays produced.

Water, paraffin, masonite, and polyethylene contain a high proportion of hydrogen and are therefore effective in slowing down neutrons. A thickness of 250 mm of water or paraffin will reduce the fast neutron dose rate by a factor of greater than 10. Concrete retains some water permanently, and is therefore very useful as a neutron absorber.

Practical neutron shields usually consist of light materials to slow the neutrons down, followed by heavy materials to absorb the slow neutrons and the capture gammas. Such shields can be arranged in the form of a thick sandwich of alternating layers of steel and masonite.

**Permanent Shielding**

So far, we have discussed how temporary shielding (lead bricks and lead blankets) can be used to reduce the radiation field, but we haven't said anything about permanently installed shielding. During the design of a nuclear generating station, it becomes clear which equipment will produce high radiation fields once the station operates. The designers attempt to calculate the radiation fields, both at power and during shutdown, so that appropriate shielding can be designed and installed during construction of the station. For PLGS, they did a good job.

**Reactor Shielding**

First of all, let us pay a tribute to the early workers in radiation, because if they hadn't discovered the harmful effects of radiation before we knew how to build reactors, a lot of us would no longer be around.

An operating reactor at power emits so much neutron and gamma radiation, that you would receive a lethal dose in less than one second if you stood beside it! A thick shield is required to absorb this tremendous amount of radiation, and to reduce it to levels we can live with. This shield is called the **Biological Shield.**

Historically, (NPD, Douglas Point, Pickering A) such shields have been made of heavy concrete with a thickness of just over 2 m. The concrete would be exposed to huge heat stresses: the effect of thermal radiation from the reactor and the effect of absorbing neutron and gamma radiation. To avoid these heat stresses, which would dry out and crack the concrete, **Thermal Shields** were required. These were designed to absorb the thermal radiation and most of the gamma radiation. (Remember: 5 HVLs will absorb 97% of the gamma energy and hence 97% of all the heat produced by it.) Cooling pipes embedded in the concrete took care of the rest. The problem with this was that when the cooling pipes corroded, it became a hell of a job to fix them. The approach taken at Bruce G.S. and at Point Lepreau was to combine the thermal shielding with the biological shielding.

The result is a water-filled, steel-lined concrete vault (Fig. 7.12). The water provides the shielding, and is circulated through heat exchangers to keep it cool. Ordinary concrete with no embedded cooling pipes is then adequate for the Calandria vault walls.

Shielding is often classified as **operational or shutdown shielding.** An operational shield provides adequate shielding at all power levels, whereas a shutdown shield is adequate only during shutdown.

The Reactivity Mechanism Deck on top of the reactor needs to be accessible at all times. Its shielding is an **operational shield**: it was designed to reduce the gamma field to about 40 μSv/h on the RM Deck at full power. What we get is 20 - 50 μSv/h gamma and around 100 μSv/h neutrons. This is quite a good agreement, because it is very difficult to predict the fields accurately, even with detailed and complex shielding calculations.

On the other hand, the shielding in the ends of the Calandria is **shutdown shielding** only. At full power, fields in the Fuelling Machine Vaults are around 150 mSv/h gamma and 200 mSv/h neutrons. One day after the shutdown, the fields have dropped to about 1 mSv/h (gamma only) at one metre from the reactor face. The shielding consists of 10-mm diameter carbon steel balls in the end shield. The end shield cooling system that cools the water in the vault tank also cools these steel balls. A shield plug at the ends of each channel shields the fuel channels themselves. If a shield plug is removed (for fuel channel maintenance), an intense beam of up to 500 mSv/h will shine out of the fuel channel.

**Other Permanent Shielding**

There lots of places in the Reactor and Service Buildings that are permanently shielded. Some examples are the Boilers, the Spent Fuel Bays, Spent Resin Storage Tanks, and Filters and Ion Exchange Columns of various purification systems. The water in the Spent Fuel Discharge, Reception and Storage Bays is considered to be permanent shielding. For this reason, steps are taken in design and operation to make sure that these bays cannot be emptied. If you want to have a bad nightmare, dream about putting the plug back in when the bay water drains out!

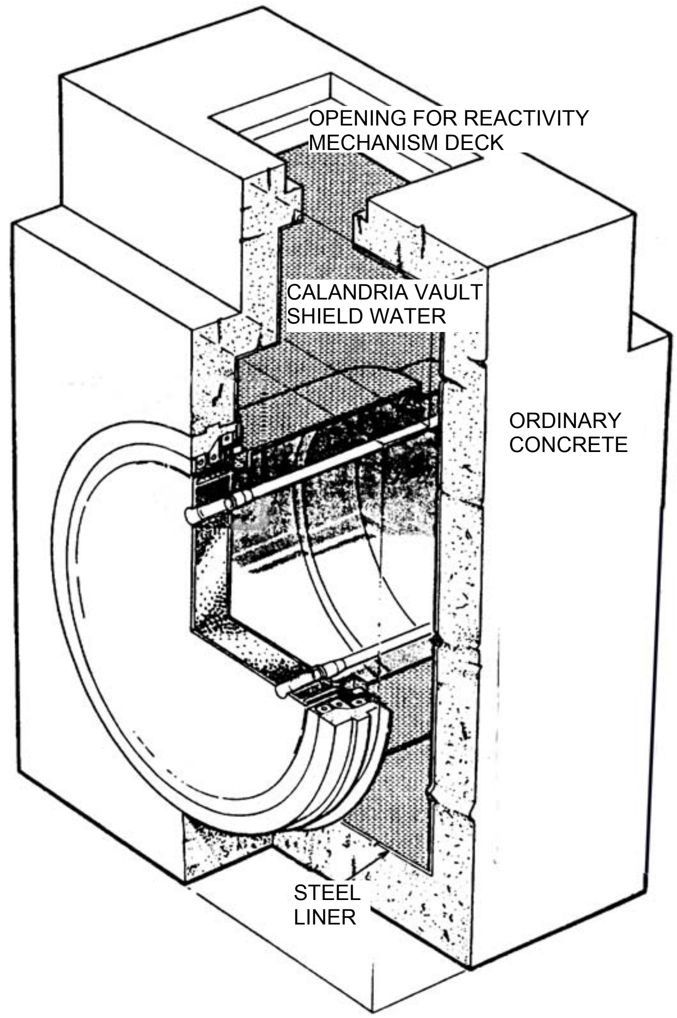


*Fig. 7.12. Reactor Vault Shielding*

**Shielding Penetrations**

Pipes to and from equipment located behind shield walls must pass through the shield at some point or other. The opening through the shield provides a path for the radiation. Such ducts should have one or more bends in them to eliminate the straight-through path. Then radiation will be scattered several times before it can leave the duct. So you'll appreciate that provision of these bends reduces the emerging radiation field significantly. This situation is much better than a straight-line path through which radiation can stream in a concentrated beam. Radioactive equipment which must be accessible can be shielded by an "access labyrinth", which is a sort of concrete maze.

## INSTALL PHYSICAL BARRIERS (ACCESS CONTROL)

After eliminating or minimising the hazards, this is the next most effective way to protect ourselves.

Access to the station is restricted to qualified personnel (training) and people escorted by them (supervision). Areas in the station are either **accessible at all times** or **access controlled**. Those that are accessible at all times have residual radiation hazards that are so low that they pose no problem. Access Controlled Areas often have high residual hazards, require Shift Supervisor approval before you can enter them (procedures), and are equipped with locks and interlocks (physical barriers) and alarming gamma monitoring systems (warning devices).

## Access Control System

The Access Control System controls entry to Access Controlled Areas with physical barriers, warning devices and procedures. We'll first describe the physical barriers. After that we'll introduce you to the warning devices and how they are tied into the physical barriers, and in the Applications Course you will be taught the procedures that you have to follow.

The Access Control System consists of three subsystems defined as:

Subsystem A (conditioned by reactor power level)
Subsystem B (conditioned by Fuelling Machine status)
Subsystem C (not conditioned).

Doors to **A** and **B** areas can only be opened with a special key of a weird shape. All **A** and **B** keys are locked in Panel 15 in the Main Control Room, and cannot be removed until special conditions have been met.

### Subsystem A

Access to **A** areas is conditioned by reactor power. If reactor power is greater than 2% of full power, the keys are locked in Panel 15 in the Main Control Room. An **A** key can be removed at less than 2% power, but an interlock with the Reactor Regulating System then inhibits power increases beyond 2%. The interlock remains in effect until the key is reinserted in Panel 15. There are only two **A** areas at Point Lepreau: the East and West Fuelling Machine Vaults.

### Subsystem B

Access to **B** areas is determined by the status of the Fuelling Machines (FM). Areas are the Spent Fuel Discharge Room, the FM Maintenance Locks and both FM Vaults.

For the S/F Discharge Room, the only condition that has to be met before its key can be removed from Panel 15 is that the ball valves (through which spent fuel passes into the room) must be closed.

Access to the FM Maintenance Locks requires the shielding doors separating them from the FM Vaults to be closed, and the door seals to be inflated. This will reduce the field to acceptable levels, even at full power.

Finally, access to both FM Vaults is **B** conditioned, because again the shielding doors and seals must be inflated. This guarantees that the fuelling machines will not be in the FM Vaults. Note that the FM Vaults are conditioned by **A** and **B**, whereas the other B areas are conditioned by **B** alone.

**Subsystem C**

**C** Areas are of lower hazards. The keys are under the control of the Shift Supervisor. We have only two **C** Areas; all of the Boiler Room is one, and the Moderator Enclosure is the other.

Note that the only way to get to the Moderator Enclosure is through the FM Vault access points, so it (the Moderator Enclosure) really has **A + B + C** control on it. The **C** access was added in 1984 as an extra measure of control.

**NOTES ON ACCESS CONTROL**

Entry to a locked **A** or **B** area under access hazard conditions requires that the door be left open and guarded to prevent unauthorised entry.

Entry to a locked **C** area does not require a Work Permit (unless the Shift Supervisor thinks otherwise). The access door can be left unguarded while work is in progress, but it must be locked on completion.

An override key that allows any key to be removed under any condition is under the control of the Shift Supervisor. It is used very rarely, maybe three or four times a year, to enter Access Controlled Areas for a few minutes to make a quick fix to some failed gizmo.

Removal of a **B** key requires consultation with the Fuel Handling Group (e.g., there may be spent fuel in the machines).

When access control is to be restored, the person locking the door must check thoroughly that nobody remains inside, and that the area is clean and tidy. This is particularly important in the FM Vaults and Maintenance Locks. (You can open the lock without a key from inside the areas.)

Exit is possible from inside even when the door is locked. The only exception is the Spent Fuel Discharge Room — here the large heavy shielding door at the entrance must be padlocked open and tagged to ensure that nobody closes it by mistake.

In the Main Control Room, audible and visual alarms come in whenever an **A** or **B** key is removed from Panel 15, and whenever an **A** or **B** door is opened.

## INSTALL WARNING DEVICES

At Point Lepreau, we have a permanently installed **Alarming Area Gamma Monitoring system**, known as (surprise) the **AAGM** system. It provides continuous monitoring of gamma radiation fields in various areas of the station, and it brings in audible and visual alarms if pre-set dose rates are exceeded. The function of the system is to alert you to unexpected radiation fields, so that you can get out of there.

The AAGM system has 35 different channels monitoring different areas of the Reactor and Service Buildings, where sudden increases in the ambient gamma fields are possible.

These radiation monitors of the AAGM system do not replace gamma survey meters and PADs. They will only indicate the gamma dose rate at the detector and will alarm if that dose rate exceeds the alarm set-point. Furthermore, if you are not working near the detector, it may not be able to sense an increased field at your work location. Instead, you must check your gamma survey meter and PAD regularly.

**Description of the AAGM System**

This system (see Fig. 7.13 on the next page) has the following components:

Detectors, Remote Annunciators, Remote Indicators, Control Units, and interfacing to the station control computers.

a) Detectors and Remote Annunciators are mounted on the wall in those areas where high radiation fields may occur. The Main Control Room also has an AAGM system for emergency conditions.

b) Each Remote Annunciator has visual and audible alarms which indicate gamma radiation exceeding a pre-set level (red strobe and siren) or equipment failure (amber strobe and bell).

c) A Remote Indicator is situated at an entrance to each monitored area and displays the detected gamma dose rate. A red light and an audible "sonalert" indicate that the alarm set-point has been exceeded and a green light indicates that the equipment is operating correctly. The normal alarm set point is indicated by a red mark on the Indicator scale.

d) There is a Control Unit for each monitor in the Control Equipment Room (behind the Main Control Room). This unit displays the measured dose rate, indicates exceeded set-points (red light), and tells us that it is operating normally (green light on). Alarm set-point adjustments and system checks can be made using the Control Units.

e) The AAGM system is connected to the station control computer. Alarm messages are displayed on the computer terminal in the event of High Radiation or Equipment Failure alarms. Each AAGM loop has its own computer alarm for high radiation, but there is only one common alarm to warn of equipment failure in nay loop.

f) The AAGM system is interlocked with the Access Control System described earlier. The alarms are normally set at 0.5 mGy/h, except for the FM Vaults and the Moderator Enclosure which are set at 1 mGy/h. This is much too low for some access controlled areas, because at full reactor power the alarms would be flashing and wailing continuously. For this reason, the High Radiation alarms, but not the Equipment Failure alarms, are disabled in areas for which the access control key is locked in Panel 15 in the Main Control Room. (This means that those areas are unoccupied, and the access doors are locked.) As soon as the key is removed, the alarms will be enabled.

g) If you have to enter an Access Controlled area and the alarm is on, the Control Room Operator would have to get the alarm set-point raised until the alarm clears. Otherwise, you would have no warning of an increase in fields above the present level. Once you leave the area and restore the key to Panel 15, the Operator must return the alarm set-point to its original level.

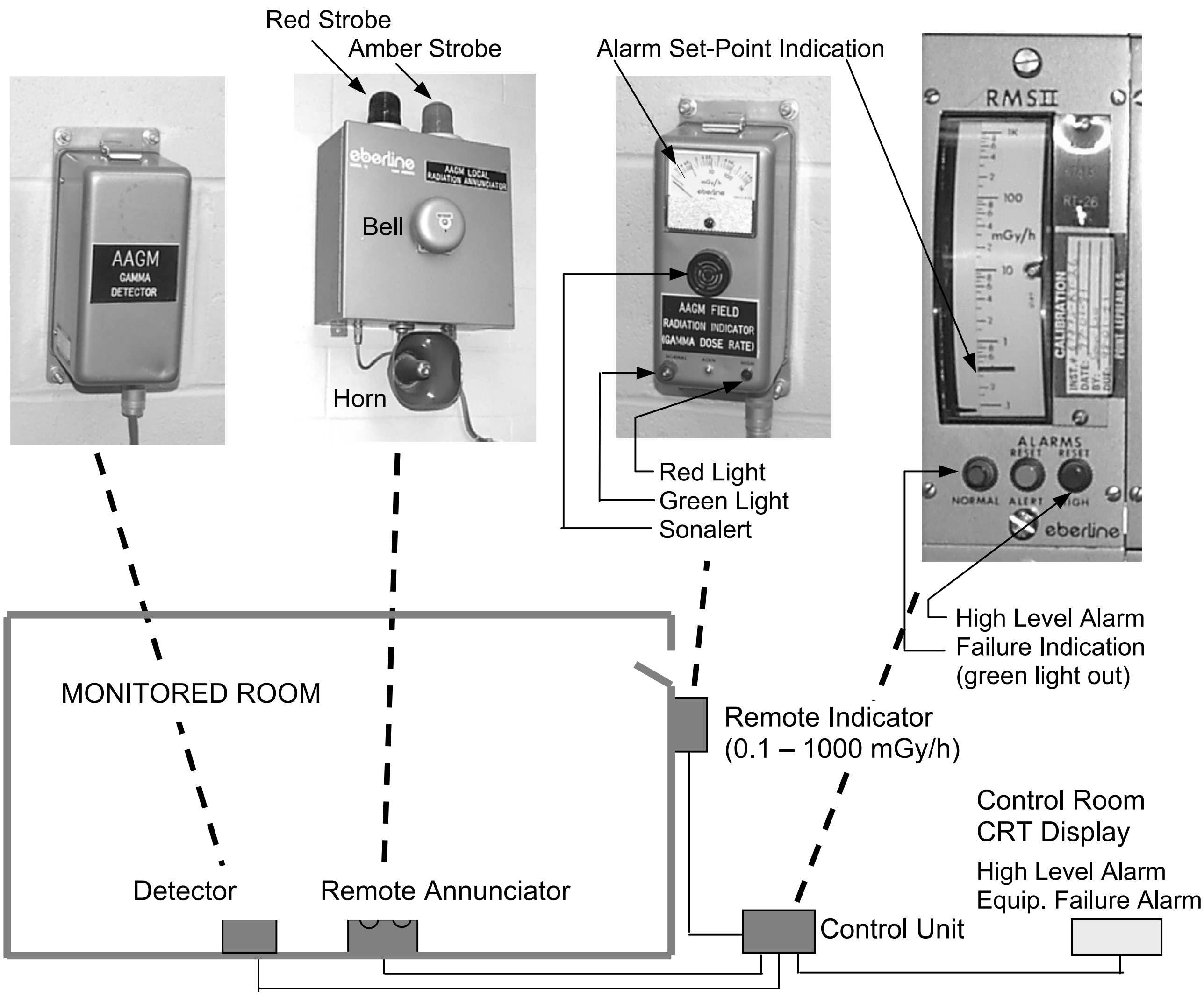


*Fig. 7.13. AAGM System*

**Action You Take If An AAGM Alarms**

What you do if an AAGM alarms is spelled out in Radiation Protection Procedure FM-1, part of which is reproduced on the next page. It is very important that you understand and do what is expected of you

**Portable Alarming Gamma Monitor**

You would use one of these instruments if the AAGM system were not available. For example, it may have failed in the area you where want to work, or you want to have this protection available to you in an area not served by the AAGM system.

The Eberline Control Unit has both “alert” and “High” alarms. When we installed the system, we decided to adjust the “Alert” and “High” alarm set-points to the same level, and we wired the alarm contacts for both in parallel. This may improve reliability, by providing redundant alarm logic, i.e., if a component fails in one path, we still get an alarm via the other path. If there is a “High” alarm, both the amber and red lamps will be on.

| | NERGIE NB POWER<br>Point Lepreau<br>Generating Station | **RADIATION PROTECTION PROCEDURES** | OM-03400<br>SV-1 |
|---|---|---|---|

Action You Take if an Alarming Area Gamma Monitor (AAGM) Alarms

**High Radiation Alarm**

| STEP | OPERATION |
|---|---|
| 1 | If a High Radiation alarm is annunciated (Red Strobe and/or Siren), leave the area immediately. Do this in a manner that does not jeopardize the safety of yourself or others. |
| 2 | Ensure that everyone has left the area. Check your PAD. |
| 3 | Inform the Control Room Operator of the situation as soon as possible. |
| 4 | Do not re-enter the room until the radiation conditions have been assessed. |
| 5 | Press the ACKNowledge button on the Radiation Indicator to silence the siren. The red strobe will continue to flash until the gamma dose rate falls below the alarm setpoint. Signpost the area to notify others of the conditions within the room. |
| 6 | The Shift Supervisor or his delegate shall record the details of the incident in the Station Log. If conditions are still abnormal at the end of the shift, update the Temporary File of the Hazard Information program. |

**Equipment Failure Alarm**

| STEP | OPERATION |
|---|---|
| 1 | If an Equipment Failure alarm is annunciated (Amber Strobe and/or Bell), check the gamma dose rate using your gamma survey meter. Leave the area immediately. |
| 2 | Inform the Control Room Operator of the situation as soon as possible. |
| 3 | Press the ACKNowledge button on the Radiation Indicator to silence the bell. The amber strobe will continue to flash until the equipment failure is corrected. |
| 4 | If you must return to this area to continue your work, have Radiation Control program your PAD to alarm at a dose and dose-rate level applicable to the situation if necessary. |
| 5 | The Shift Supervisor or his delegate shall record the details of the incident in the Station Log. If conditions are still abnormal at the end of the shift, update the Temporary File of the Hazard Information Program. |

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|---|---|---|---|---|
| P.S. Wilson | L.J.P. Comeau | April 1997 | 6 | 3 of 3 |

*Fig.7.14. Actions You Take if an AAGM Alarms (from Rad. Prot. Procedure FM-1)*

Fig. 7.15 shows one of these gizmos. It has a range from 10 μSv/h to 100 mSv/h with an analog scale. It responds to gamma radiation only. You just plug it into 110 V and it starts to work.

This instrument has an internal radiation source that causes it to read about 20 to 30 μSv/h in low background areas, so that you'll know it's working OK.

The horn is OK, but we didn't like the small red light that came with it (shown on top of the instrument case), so Henry Stuart added the big red beacon-on-a-stick. You set the alarm set-point yourself, and you'll learn how to do this in the Applications Course.

We use this instrument whenever radiography work is done in the station.

*Fig. 7.15. Portable Alarming Gamma Monitor*

### MINIMISE HUMAN ERROR POTENTIAL

This is the next most effective way of reducing our radiation exposure. I can't think of any brilliant examples right now, other than that I'm writing this at 2 a.m., and that certainly isn't what I should be doing to avoid making mistakes.

If you write Procedures, Work Plans, Operating Manuals, or whatever, please bear this in mind. Do it when you are alert. Make them easy to do right and easy to understand. Use short sentences and simple words that everyone can understand. If you are familiar with sesquipedalian words, keep them to yourself.

Design your plans and procedures so that it is difficult to go wrong. We both know that people will always find the easy way to do things — you have to make sure that the right way is the easy way. Don't set up things so that they are not the way people are used to using them. For example, light switch up means ON, turning taps anticlockwise means increasing the temperature, red lamps mean danger and green lamps mean things are normal.

### ESTABLISH PROCEDURES

Procedures are written step-by-step instructions that describe the correct and approved method of doing a job. Fig. 7.14 is an example. The last time I counted, we had over 160 different procedures in Radiation Protection and Industrial Safety. Since 1982, we've had four complete revisions of the procedures, plus about 30 minor revisions. Does that mean the original set were bad? Not really. They were revised because:

- we changed the way we did things to make life easier,
- we changed procedures to reflect increasing hazards,
- we incorporated operating experience from our and other nuclear plants,
- we added procedures to describe activities we hadn't anticipated,
- we added some new instrumentation and retired the old stuff,
- we changed procedures to reflect new dose limits and different regulations.

The procedures we have now are pretty good, and they reflect at least fifty years of operating experience in the nuclear business. So if you follow the procedures, you won't get into trouble. You may find that you are doing work for which no procedures exist, or that special circumstances make it impractical to follow the procedures. Well, we have ways of dealing with that too, and they'll be described in the chapter on Work Planning.

During the Applications Course you will study the Radiation Protection Procedures in detail and have an opportunity to apply them in various field exercises. At this point we will take a look at some of the procedures concerning radiation surveys and signposting.

**Radiation Surveys**

A survey is a measurement of radiation conditions. There are two reasons for doing surveys:

a) Changes in radiation levels may indicate changes in plant systems. For example in June, 1984, abnormal beta/gamma radiation fields in the Reactor Building indicated a release of fission product noble gases. This led to the discovery of a previously unknown PHT leak in the gas chromatography system.

b) Changes in radiation levels may indicate that changes in a work procedure are required. For example, it is usually faster to work on equipment in the field; but if the dose rates have increased significantly, it may be worth removing the equipment to an area with a lower dose rate and doing the work there.

There are both routine and job radiation surveys. A **routine survey** is an assessment of general radiation fields in an area and is normally done on a regular basis. A survey sheet is normally completed (e.g., see Figs. 7.24 and 7.25) and filed at Radiation Control.

A **job survey** is an assessment of radiation fields in a specific location. The person doing this type of survey will normally be working at the surveyed location.

**Doing a Radiation Survey**

The two factors governing your choice of survey instruments are the types of radiation and the range of dose rates expected.

As a general rule, an instrument should not be used in fields that cause it to indicate at the scale extremes. Use an instrument having a more suitable range. Table 7.4 below lists the ranges of some of the instruments used at Point Lepreau for surveys of external radiation ($\gamma$, $\beta$, n).

TABLE 7.4. SURVEY INSTRUMENTS

| *Instrument* | *Useful Range* |
|---|---|
| Low Range Gamma Survey Meter (5016) | 10 μSv/h – 100 mSv/h |
| Low Range Gamma Survey Meter (FAG) | 3 μSv/h – 1000 mSv/h |
| Emergency Gamma Survey Meter | 1 mGy/min – 2 Gy/min |
| Low Range Beta Survey Meter | 20 μSv/h – 500 mSv/h |
| Neutron Meter/Integrator | 10 μSv/h – 1000 mSv/h |

After selecting the appropriate survey meter, do the pre-operational checks:

1. Check for a valid calibration sticker.
2. Check the instrument battery condition.
3. For beta and gamma meters, check that the meter responds correctly to an Instrument Check Source. (You don't need to do this for the Emergency Gamma Meter, because it is checked every week.)

If the instrument fails any of these checks it is considered defective and should not be used. Take it to the Defective Instrument Shelf outside the Stores Issue Counter. Attach a completed Defective Instrument Tag to it. The tags are stored at the same place.

Precautions to keep in mind are:

- Avoid any unnecessary radiation exposure.
- If your instrument goes off-scale, believe it and retreat.
- For surveys in Zone 3 you need to wear a PAD.

**Gamma Surveys**

Fig. 7.16 shows you the steps of the Gamma Survey Procedure, SV-1.

You'll see that steps 1 and 12 mention a "Hazard Information Program". This is a computer database of hazards called HAZARD INFO. You learn how to use it in the Applications Course. HAZARD INFO is accessible to you 24 hours a day via the intranet. It is maintained by Radiation Control, who routinely check all new entries and delete any as needed (e.g., duplicate entries).

Note also the words on Hot Spot Stickers in Step 11. These are bright-yellow adhesive labels that you just slap on the equipment that's giving off high dose rates at contact.

Gamma surveys are probably the most frequent radiation surveys that you will make, partly because gamma radiation fields are common, and partly because you will also do gamma surveys while surveying for beta or neutron radiation.

| | NERGIE NB POWER<br>Point Lepreau<br>Generating Station | **RADIATION PROTECTION PROCEDURES** | OM-03400<br>SV-1 |
|---|---|---|---|

How to Perform Gamma Surveys

| STEP | OPERATION |
|---|---|
| 1 | Survey Sheets are available in the Radiation Control Office/ WCA to simplify the recording of survey data. Consult the Hazard Information Program for existing survey data. |
| 2 | Choose an appropriate gamma survey meter for the job.<br>Normally this would be:<br>R-Metrics (RD5016) - 10 uGy/h to 100 mGy/h<br>FAG (FH 401) - 3 uSv/h to 999 mSv/h |
| 3 | Perform the pre-operational checks for the instrument selected. |
| 4 | Switch the instrument on **before** entering any suspected or known radiation areas and take heed of any information displayed on warning signs. Note AAGM remote indicator reading if the area is under AAGM protection. |
| 5 | Choose an appropriate meter range before entering the area. If you are entering an area with unknown gamma fields select high range. The FAG is autoranging. |
| 6 | Watch the meter indication as you approach the area to be surveyed and if necessary, change ranges to give an on scale reading. |
| 7 | Move the instrument slowly in a large arc as you enter the area. The maximum readings obtained will indicate the general direction of the radiation sources in the area. |
| 8 | Establish the general fields by taking readings at waist height and at 1 metre from the sources. |
| 9 | If work is to be done, survey the work location and the access route. |
| 10 | If contact readings are needed to properly identify the radiation sources, they should be taken at 1 cm. |
| 11 | If localized sources with contact radiation fields of greater than 100 times the general area fields are found, they should be identified with "HOT SPOT" stickers. These stickers are available at smear counting stations. |
| 12 | When the survey is finished, warning signs should be placed to properly identify the hazards. Place completed survey forms in the Health Physics Out Basket located at the Work Control Area. If you think that the information from your survey will be of general interest, make an entry in the Temporary File of the Hazard Info Program. |

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| E.W. Turnbull | P.S. Wilson<br>L.J.P. Comeau | April 1997 | 6 | 2 of 2 |

*Fig. 7.16. How to Perform Gamma Surveys (from Rad. Prot. Procedures, SV-1)*

**Beta Surveys**

High levels of contamination mean beta radiation, either airborne (usually radioactive noble gases and their daughters) or from unshielded radioactive material. You will recall that almost all activation and fission products are beta-gamma emitters and that beta radiation cannot penetrate steel pipes, but can penetrate a metre or more of air. Therefore, opening a radioactive system greatly increases the beta fields immediately around it. Here are some examples of beta hazards found in a maintenance outage. Note that gamma fields are always found with high beta fields.

1. Entry into Boiler #4.

   The general gamma fields inside the boiler were 10 mSv/h and the contact readings were 15 to 20 mSv/h gamma and about 10 mSv/h beta. They were reduced to 5 mSv/h gamma, 2 - 3 mSv/h beta by laying lead blankets on the lower internal boiler surface.

2. Removal of Degasser Heater #7.

   The fields on the heater were 50 μSv/h gamma, 150 μSv/h beta.

Unshielded, contact beta-to-gamma ratios are often in the order of 2 or 3 to 1, but remember that the beta field falls far more quickly than gamma when the detector is moved away from a beta/gamma source. Beta radiation can be greatly reduced by using plywood, neoprene or similar materials for shielding. If you don't remember how to use the beta survey meter, check out page 144.

**Neutron Surveys**

The Neutron Meter (page 139) is a heavy instrument and not as simple to use as most of our other survey instruments. We don't expect you to drag this instrument around with you all the time. Simply put it down close to your work location in areas with a neutron field. In those cases where it may be impractical or hazardous to carry the meter, consult Health Physics before the work is done. They may approve alternative measurements, but these **must** be approved before the job starts.

The neutron dose that you receive on a job **must** be reported to Health Physics by completing a *Dosimetry Information Form*. We'll deal with that in Chapter 10, OK?

Most of the neutron radiation is emitted from the reactor core (fission neutrons and photoneutrons). A small fraction comes from the PHT and moderator pipework (photoneutrons). No matter where they come from, you should always assume them to be associated with significant gamma fields. Fig. 7.25 shows you where we have neutrons at power. During an outage, there are no neutron fields worth worrying about.

**Signposting**

We use temporary warning signs to alert people to hazardous conditions. You could argue that this section should belong in the "Install Warning Signs" of the Safety Precedence Sequence, but what I had in mind for that were permanently installed warning systems. The use of temporary warning signs really belongs in "Establish Procedures", so that's why we deal with them here.

An Area with external dose rates of more than 10 µSv/h is called a **RADIATION AREA**, and must be signposted. An area with internal committed dose rates greater than 10 µSv/h is called an **AIRBORNE AREA**, and must also be signposted.

The signs we have are chalkboards of about 60 cm by 60 cm. They have space for you to describe the hazard and to enter the date, time, and your name.

Two pairs of Velcro tabs are available:

a) a flash reading CAUTION, DANGER, or NOTICE can be placed at the top of the sign, and

b) a flash with the specific hazard is then put below it as shown here in Fig. 7.17 (Very neat, Frosty!). The specific hazard flashes we have are

| | |
|---|---|
| AIRBORNE AREA | AIRBORNE HAZARD |
| ELECTRICAL HAZARD | HOT ENVIRONMENT |
| MEN WORKING ABOVE | OPENING IN FLOOR |
| RADIATION AREA | RUBBER AREA |
| RUBBER CHANGE AREA | SLIPPERY FLOOR |
| TRIPPING HAZARD | STEAM LEAK |
| RADIATION/AIRBORNE AREA | |
| RESTRICTED RADIATION AREA | |

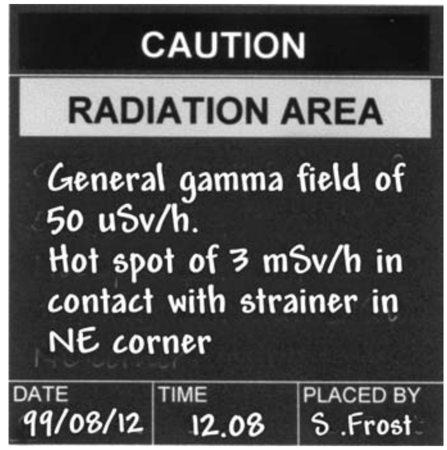


*Fig. 7.17. Layout of Warning Sign*

A word of explanation on the last two signs:

RADIATION/AIRBORNE AREA is used for external and internal hazards that add up to more than 10 µSv/h.

RESTRICTED RADIATION AREA is used when either the external, or the internal, or the total dose rate exceeds 5 mSv/h. You need Shift Supervisor approval to enter these areas.

The picture at the right shows a CAUTION sign in the field. CAUTION signs are used to post:

- Hazardous conditions that are not life-threatening,
- Rubber Areas and Rubber Change Areas (i.e., loose contamination),
- Radiation Areas (> 10µSv/h of external dose rate),
- Airborne Areas (>10 µSv/h of committed dose rate),
- Radiation/Airborne areas where the total dose-rate exceeds 10 µSv/h.


*Fig. 7.18. A Typical CAUTION Sign*

DANGER signs are used to post:

- Hazardous conditions that are life-threatening (e.g., high voltage, IDLH* Confined spaces),
- Restricted Radiation Areas (> 5 mSv/h),
- Restricted Radiation Areas where the total dose rate exceeds 10 μSv/h.

NOTICE signs are used for information only, e.g., “Airlock out of Service”.

The signs and the pre-printed flashes are kept at the **Protective Equipment Storage Locations**, called “**PESL**” (pronounced “pessel”). If you find signs with information that is no longer current, correct the sign or, if it is no longer needed, return it to the nearest PESL.

## TRAIN, MOTIVATE, AND SUPERVISE PERSONNEL

This category is pretty far down on the Safety Precedence Sequence, but it still important. Without the right training you will not be able to:

- recognise the hazards,
- assess the magnitude of each hazard,
- anticipate hazard changes.

### Recognising Radiation Hazards

You know from Chapter 2 that your body's senses cannot detect radiation. However, you can recognise the radiation warning symbol, you know that all radioactive systems are found in Zone 3 and you know how radiation fields are affected by time, distance and shielding. The next step is to learn something about the larger radioactive systems, i.e., their functions and their hazards.

**Primary Heat Transport (PHT) System**

The main purpose of the PHT system is to transport heat from the fuel bundles to the steam generators. The reactor contains 380 pressure tubes, with each one holding 12 fuel bundles. The heavy water, pressurised to about 10 MPa (almost 100 atmospheres) is circulated over the fuel bundles to remove the heat. The flow through a pressure tube is always in the opposite direction to the flow in the adjacent tube. Each end of a pressure tube expands into an end fitting connected to a carbon steel feeder tube. The feeder tubes at the downstream end rise above the reactor face to one of four outlet headers. Two discharge lines from each outlet header transport the water to a steam generator, or boiler. The physical layout is shown in Fig. 7.19.

The boilers are huge; about 18.5 m high and a few metres in diameter. The hot heavy water enters the primary side, where it is split among 3500 finger-sized boiler tubes, The tubes rise into the secondary side, and then return back down into the primary side to form a large U shape (upside-down U actually). Light water on the secondary side removes the heat from the heavy water by light water turning into high-pressure steam and that drives the turbine.

*IDLH means “Immediately Dangerous to Life and Health”. Serious stuff!

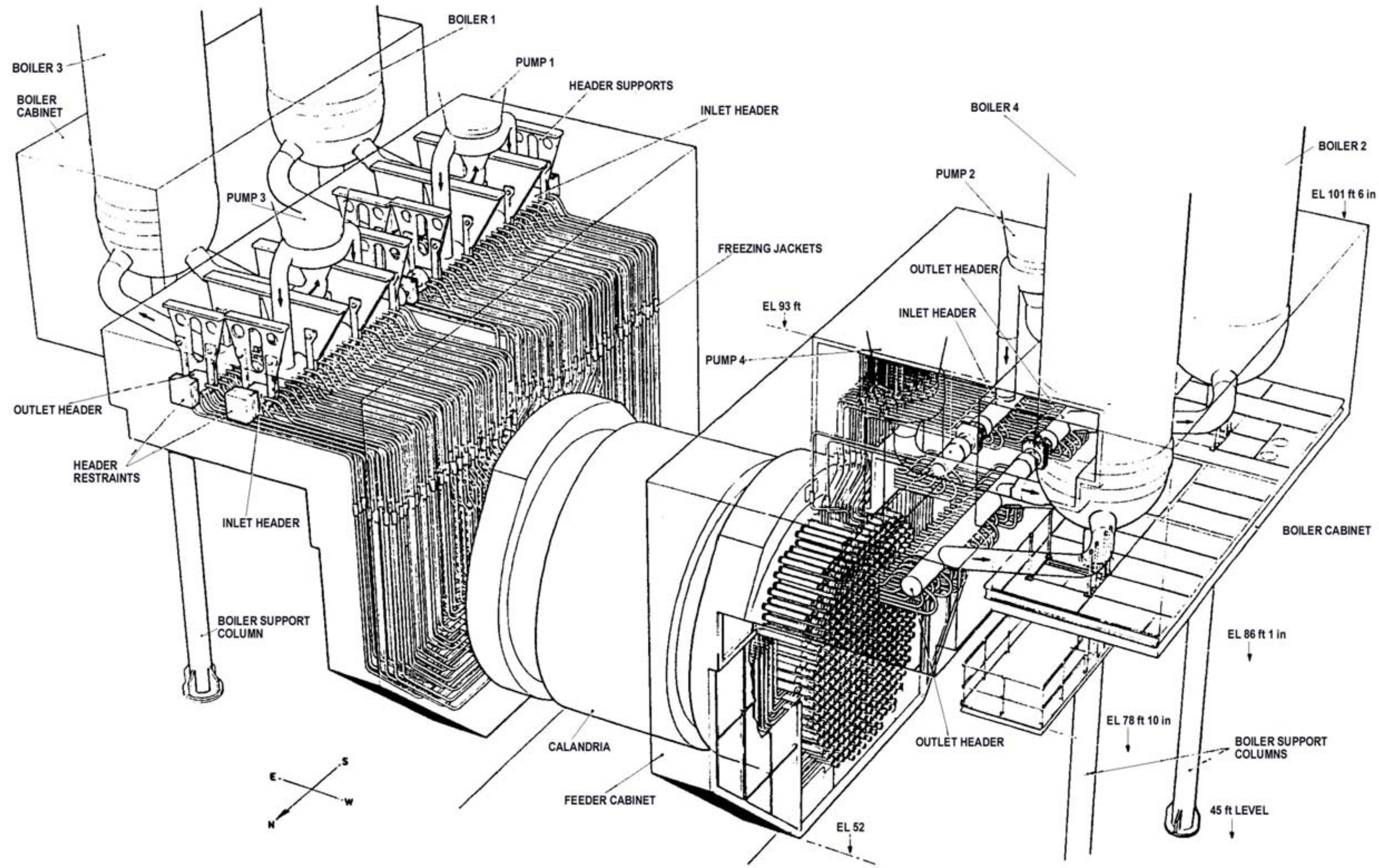


*Fig. 7.19. PHT Boilers and Feeders*

From the boiler, the now cooler heavy water continues on to a Heat Transport Pump, where it is discharged through two pipes to the reactor inlet header (there are four). Feeder tubes connect the header to the inlet end of a pressure tube.

The PHT system is divided into two separate figure-of-eight loops. If the unthinkable should happen, and a break occurs in the pipework, only one loop will be affected, and the amount of make-up water required to maintain cooling will not be as great. Each loop contains two pumps, two boilers, two inlet headers, and two outlet headers. The layout is shown in Fig. 7.20.

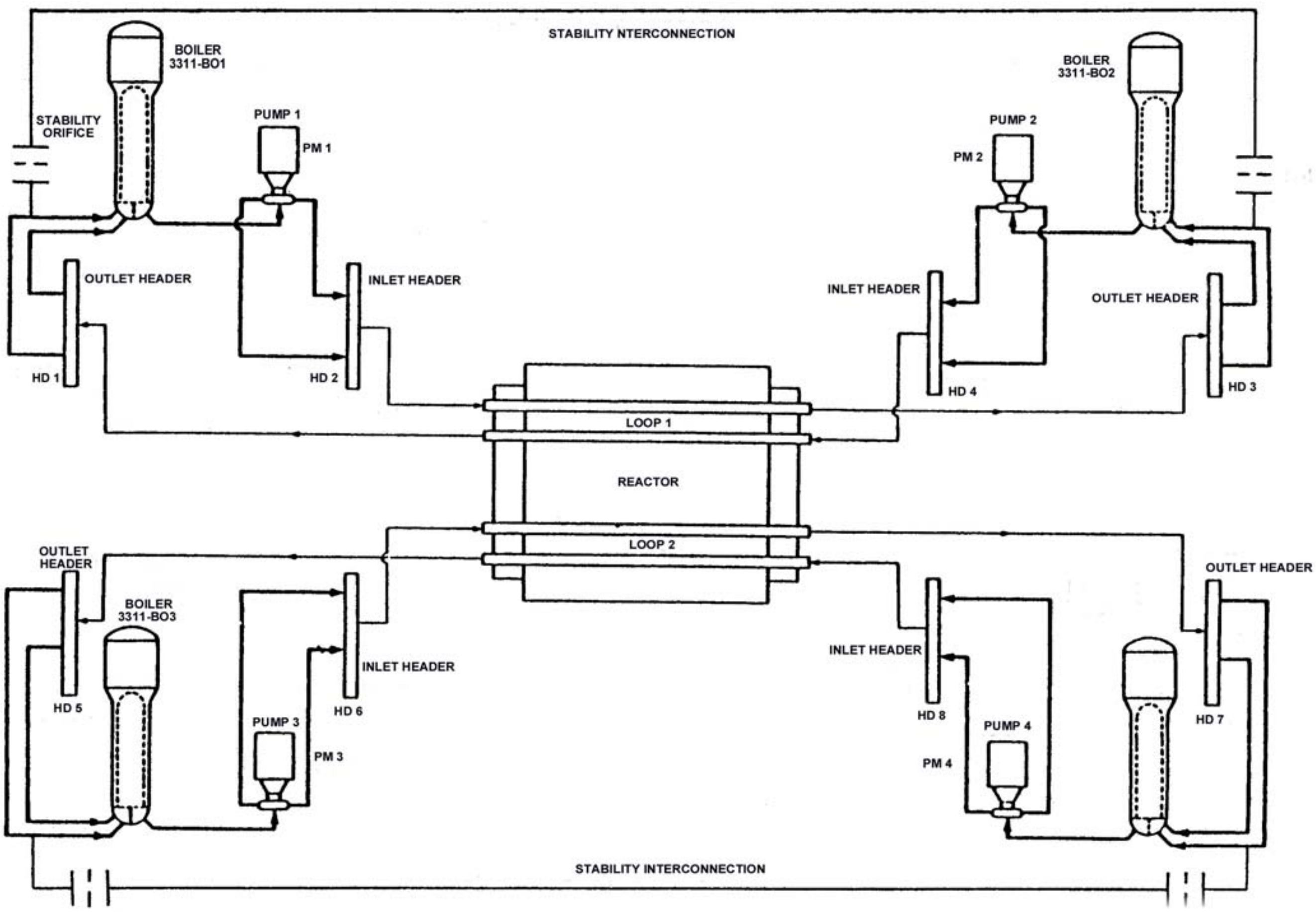


*Fig. 7.20. Heat Transport System Schematic*

The greatest concentration of neutrons is in the centre of the reactor. This means that the most heat will be generated there, and more coolant flow will be needed. For this reason, the feeder tubes for the central pressure tubes are larger in diameter than those for the outer portion. For you numbers people, the flow rate through the highest power channel is 24 kg/s, and the flow through each loop is 1.9 Mg/s. PHT water enters the reactor at 266ºC and exits at 310ºC.

## Radiation Hazards from the PHT System

Now that you're a big name in how the plumbing is hooked up, let's look at the hazards from it.

### *Tritium*

This is formed by activation of deuterium in the heavy water and is covered in detail in the next chapter.

### *Activation Products*

These are formed whenever materials are in the high neutron flux in an operating reactor. Whenever irradiated debris from corrosion or damage is transported through the reactor, it will be activated. It may plate out on the inside of pipes, pumps, etc., or come to rest at some obstruction in the system. Most activation products are beta/gamma emitters; examples are iron-59, zirconium-95 and Co-60. When they remain enclosed by pipework, only the gamma emissions are a hazard, but when the PHT system is opened there are usually beta fields as well. The oxygen in heavy water will be activated to oxygen-19 or nitrogen-16. Both nuclides emit high-energy gamma photons.

### *Fission Products*

These are formed whenever uranium or plutonium atoms undergo fission. Fission products are highly radioactive, but are contained within the fuel bundles. Should the sheathing around the fuel develop a leak (this is known as a fuel defect), some fission products will escape into the PHT system. The fission products that normally escape are gases (e.g., krypton and xenon), vapours (e.g., iodine), and those that are soluble in water (e.g., cesium).

Krypton and xenon can escape from the PHT system through leaks, during fuelling, or whenever the system is degassed. They are classed as external hazards because even if inhaled, they don't remain in your body. They rapidly decay to form short-lived airborne particulates, emitting beta and gamma radiation. A rising beta/gamma field with no apparent "source" signals their presence. Radioiodine vapours can also escape from the PHT system and are covered in the next chapter. Water-soluble fission products are released in PHT spills and will become contamination.

### *Gamma and Neutron Radiation*

While the reactor is critical, very high gamma fields will be emitted from PHT pipework, mostly from oxygen-19 and nitrogen-16. The gamma photons from N-16 can generate photoneutrons to cause neutron fields from PHT pipework, although most of the neutron fields found in the Reactor Building are caused by fission neutrons escaping from the core.

## MODERATOR SYSTEM

You already know that the main purpose of the moderator is to slow down the fission neutrons to thermal energies so that the chain reaction can be maintained. In addition to this, the moderator system cools and purifies the moderator water, and permits coarse reactor control by the addition and removal of neutron-absorbing chemicals.

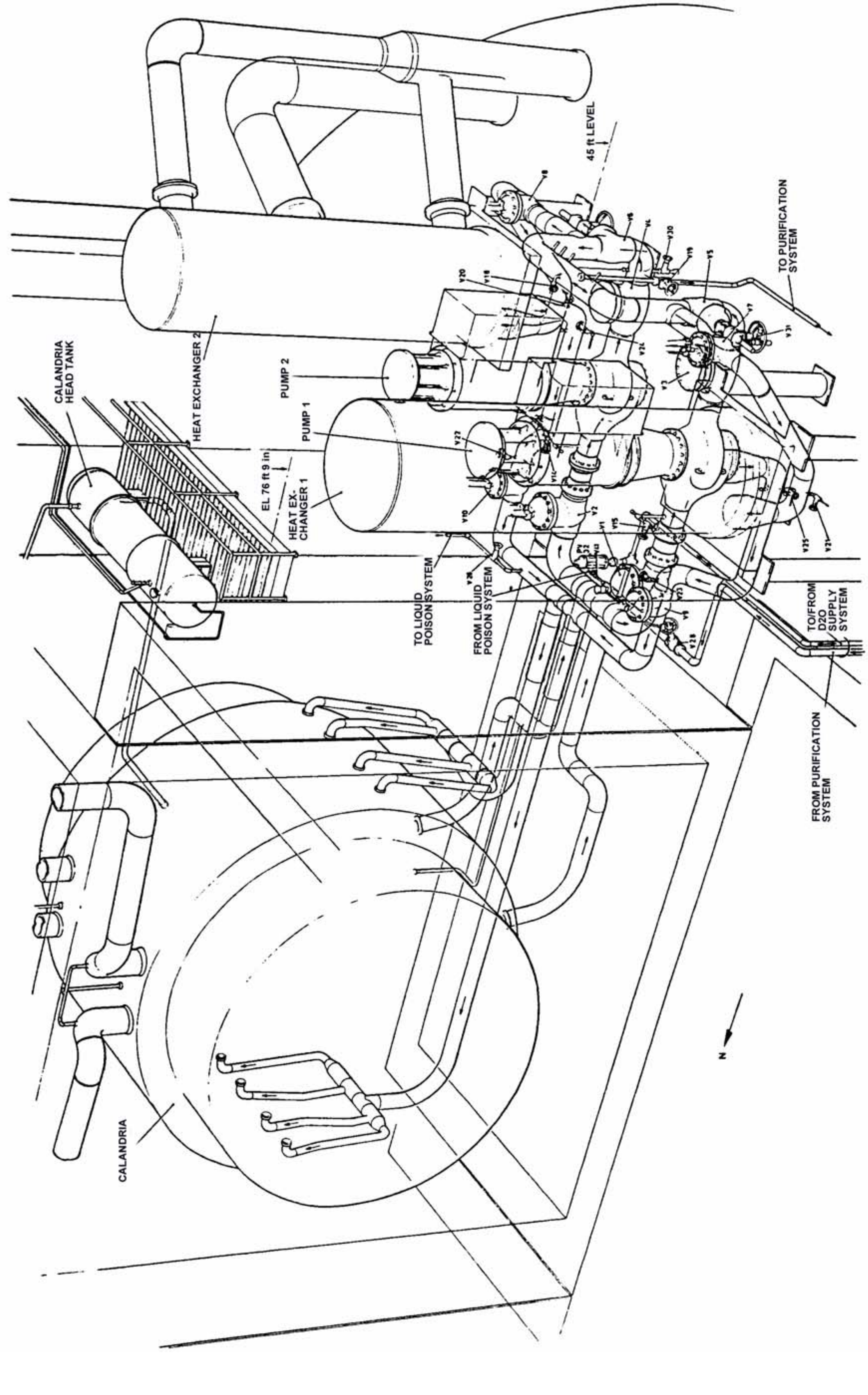


*Fig. 7.21. Main Moderator System*

Moderator water is pumped into the calandria through four inlets on each side. It leaves through two outlets at the bottom, then passes through heat exchangers before returning to the calandria (see Fig. 7.21). The temperature of the moderator water is kept at about 70ºC. In the unlikely event that we have serious damage to a pressure tube, the moderator system will act as a heat sink.

### Radiation Hazards from the Moderator System

#### *Tritium*

Moderator water spends far more time inside the reactor than does PHT water, so the tritium concentration is a lot higher, typically by a factor of 30. More in Chapter 8.

#### *Gamma and Neutron Radiation*

These are similar to those found in the PHT system, but with one important difference. The moderator system plumbing contains a lot more cobalt that the PHT system, so Co-60 activation tends to be more serious. High concentrations of activated gadolinium may be present in moderator water after Shutdown System 2 (SDS-2) has been fired. The most serious activation products are N-16 and O-19; both are short-lived, high-energy gamma emitters.

#### *Gamma and Neutron Radiation*

Gamma fields from activation products in the moderator system are generally higher than from the PHT system, because moderator water sees higher neutron concentrations. Gamma dose rates approaching a Sv/h can be found in the Moderator Enclosure at full power – mainly from N-16 and O-19, because the water has come directly from the core with hardly any time for decay. There are no fission products (why?), and photoneutron fields are negligible compared to gamma fields.

## LIQUID ZONE CONTROL SYSTEM

Fine reactor control is done by the LZC system, which is run by the Reactor Regulating System. There are six tubes running vertically through the core, three on each side. The two nearer the centre of the core have three compartments in them, while the others have two compartments each, for a total of 14 compartments. They contain light water, which, as I hope you'll remember, is quite good at absorbing neutrons. Reactor power can be controlled by varying the level of the water in the zone compartments.

### Radiation Hazards from the LZC System

The LZC water is circulated for cooling — this creates a radiation hazard from N-16 and O-19. The hazard is reduced by retaining the water in a shielded delay tank for a while to allow the field to decay a bit. There are no tritium hazards, and there are no photoneutrons either (why?).

**FUEL HANDLING SYSTEM**

CANDU reactors can fuel on-line, meaning we don't have to shut down to fuel. Apart from the obvious economic benefits, this means we can remove defect bundles before they crap up the PHT system (and eventually any areas that have PHT leaks).

New fuel is stored on pallets in the locked New Fuel Room. The International Atomic Energy Authority (IAEA) demands strict control of all fuel, so the movement of every bundle is tracked by its serial number. When we're operating, about 16 channels are fuelled each week, with eight of the twelve bundles in a channel being replaced.

We have two identical, remotely operated Fuelling Machines (FM). The FMs are normally stored in the two FM Maintenance Locks and are suspended from tracks. Each set of tracks connects with a bridge at each face of the reactor. Power-operated shielding doors separate the Maintenance Locks from the reactor. When closed, they allow access to the FMs when the reactor is at power. Heavy water, electric power, oil hydraulic connections, and control signals are fed to the FM via a flexible catenary that connects the mobile FM to the stationary auxiliary systems. Fig. 7.22 gives you the general idea.

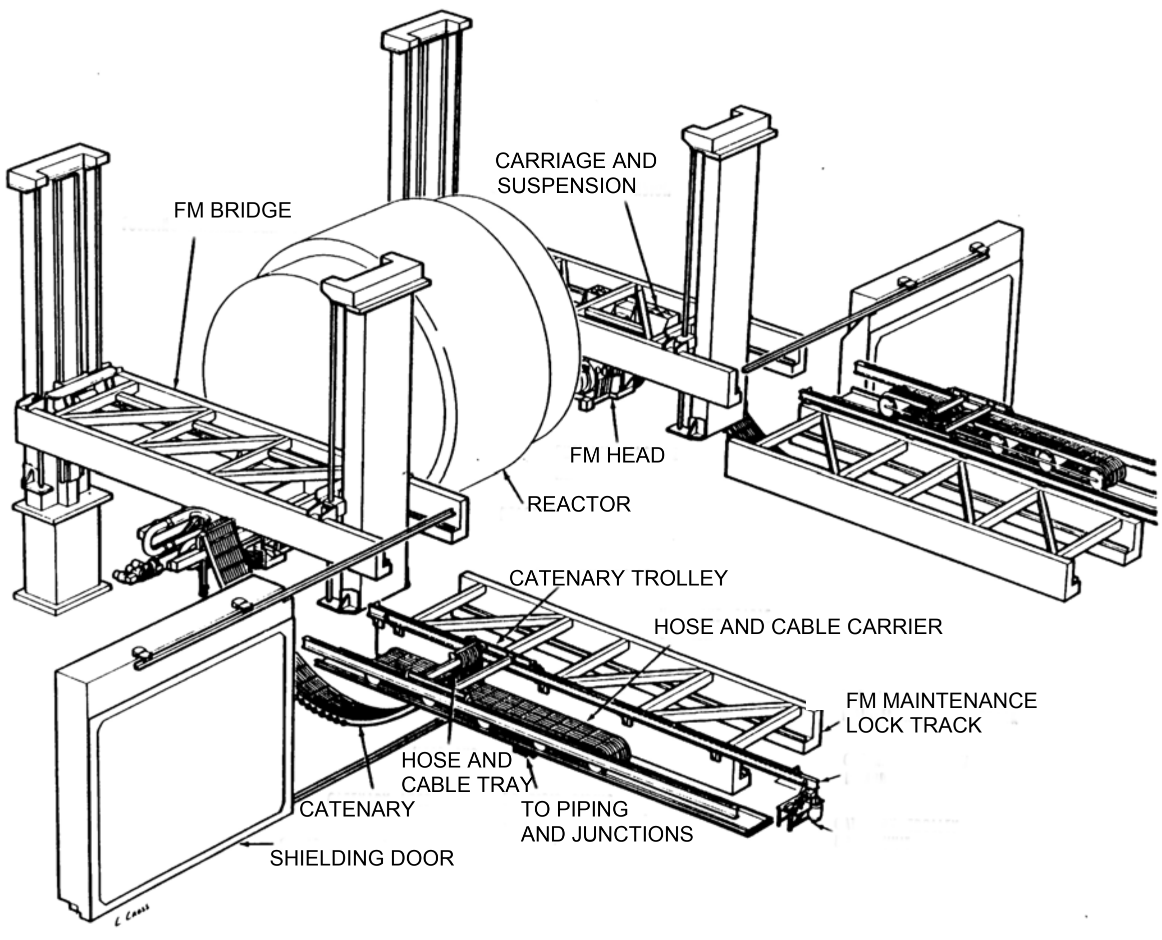


*Fig. 7.22. FM Catenary System*

In the Maintenance Locks, the FMs can lock on to the New Fuel Port to accept new fuel, or to the Spent Fuel Port to discharge spent fuel. Operations on the reactor are done by remote control. One of the FMs locks on to the New Fuel Port and accepts up to eight new fuel bundles. The shielding doors are opened, and the two FMs travel along the tracks on to the FM Bridges at each face of the reactor. The bridges are then raised and the FMs are positioned on the bridge so that they are located at each end of the selected fuel channel.

Both FMs move forward to home and lock on to the fuel channel end fitting to form a secure and leak-tight joint with the channel. The plugs from the snouts of the FMs are removed, and each FM is pressurised to PHT system pressure. The FMs remove the fuel channel closure plugs and store them in their magazines. The upstream FM removes the shield plug and inserts new fuel from the magazine into the channel. At the same time, the downstream FM removes the shield plug on its side and receives the spent fuel, which is stored in its magazine. Fuelling is in the direction of flow in the channel.

When the required number of fuel bundles have been inserted, the shield plugs and closure plugs are replaced and checked for leaks. The FMs then replace their own plugs in the snouts, retract from the end fittings and return to the FM Maintenance Locks. The FM containing the spent fuel

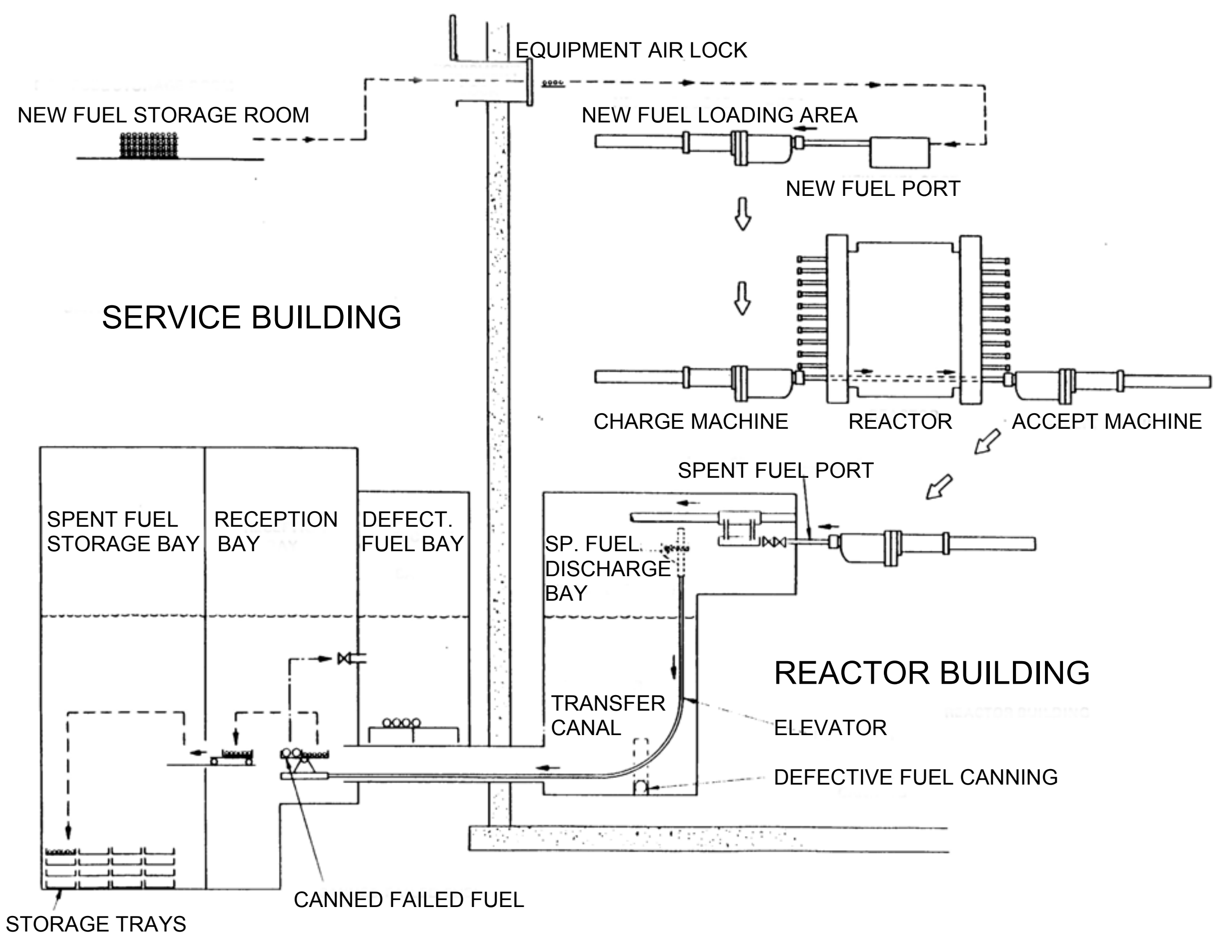


*Fig. 7.23. Fuel Handling Sequence*

discharges it through the Spent Fuel Port. Pairs of bundles are pushed through the port on to a ladle, which lowers them into a rack in the Spent Fuel Discharge Bay (SFDB). For a few seconds during this operation, the bundles are exposed to air; this is the only time they are not cooled and shielded. Defect bundles are canned in the SFDB and then stored there. Other bundles are moved to a rack in the Reception Bay, and later to the adjacent SF Storage Bay. After about seven years, the fission product activity has dropped enough that the bundles no longer need to be cooled. They are then sent to the Dry Fuel Canister Site.

### Radiation Hazards from the Fuel Handling System

The main hazard is the spent fuel with its colossal radiation fields. We described these in Fig. 2.39 on page 59. The activity is so high that if the fuel weren't cooled, it would melt.

#### *Tritium*

FM maintenance may result in exposure to tritium if the system is not completely drained.

#### *Fission Products*

Each spent fuel bundle contains a huge amount of fission products. If a spent fuel bundle is badly damaged the potential exists for extremely high beta and gamma fields around a Fuelling Machine and a large release of radioiodine vapours.

#### *Gamma Radiation*

Spent fuel bundles can have gamma fields that could give you a lethal dose in seconds, but are normally inside the reactor core or stored below several metres of water.

### OTHER SYSTEMS

The Zone 3 areas contain other radioactive systems as well as various radioactive subsystems of the four major systems mentioned above. You will learn more about plant systems and their hazards in the Systems Modules Training Program.

Always discuss potential hazards with your supervisor or with one of the lads in Radiation Control before performing unfamiliar work in Zone 3.

## Assessing the Magnitude of Radiation Hazards

You know from Chapter 6 which types of instruments we use to measure radiation, and their advantages and disadvantages. During the RPT Applications Course you will have some hands-on training with these instruments. Although instruments are essential to detect and measure radiation fields, you can get a feel for the hazard in advance by considering the following factors:

a) Reactor power level — the dose rate in many rooms in the Reactor Building increases in proportion to the reactor power level.

b) Time since first reactor start-up — the reactor first reached criticality on July 25, 1982 and first power was produced a month later. Since then the levels of long-lived activation products have been increasing.

c) Time since the reactor was last brought up to power (following a shutdown). After start-up there is a build-up of short-lived nuclides until they reach equilibrium levels, i.e., their rate of decay equals their rate of production.

d) If the reactor is shut down, the time since shutdown affects radiation fields, because short-lived nuclides decay away quickly causing radiation fields to fall.

e) Removal of shielding to allow maintenance — this will increase radiation fields.

f) Contaminated surfaces, liquids or air will increase the radiation fields.

g) Operating conditions may change the radiation fields if systems are isolated or opened. For example, gamma fields in the Moderator Purification Room will change in proportion to moderator water flow through the Moderator Purification System.

h) The presence of a defective fuel bundle in the reactor will cause an increase in radiation fields from activation and fission products in the PHT and FM systems. Fields will decrease when the defective fuel is removed.

Considering these factors before you start work will help you assess the potential hazards you're getting into.

**Typical Gamma Fields**

Gamma radiation fields in the normally accessible Zone 3 areas outside the Reactor Building are generally less than 10 μSv/h. (Notable exceptions are in the vicinity of the Moderator Purification and Spent Fuel Bay Purification Systems.)

Inside the Reactor Building is a different story. Normally accessible areas can have gamma dose rates ranging from below 10 μSv/h up to 50 mSv/h on localised equipment (hot spots). The access-controlled areas may have dose rates of over 100 mSv/h. That's why they're access-controlled.

TABLE 7.5. FIELDS 24 H AFTER SHUTDOWN

| *Location* | *Gamma Fields* |
|---|---|
| FM Vaults below Calandria Face | 1 – 2 mSv/h |
| FM Vaults – General Area | 100 – 300 μSv/h |
| Moderator Enclosure | 100 – 500 μSv/h |
| Boiler Room | 10 μSv/h |

You can examine survey results from other areas in the station by using the HAZARD INFO computer program. Some gamma fields 24 hours after shutdown are shown in Table 7.5. These fields were measured after six years of operation, and they haven't changed much since.

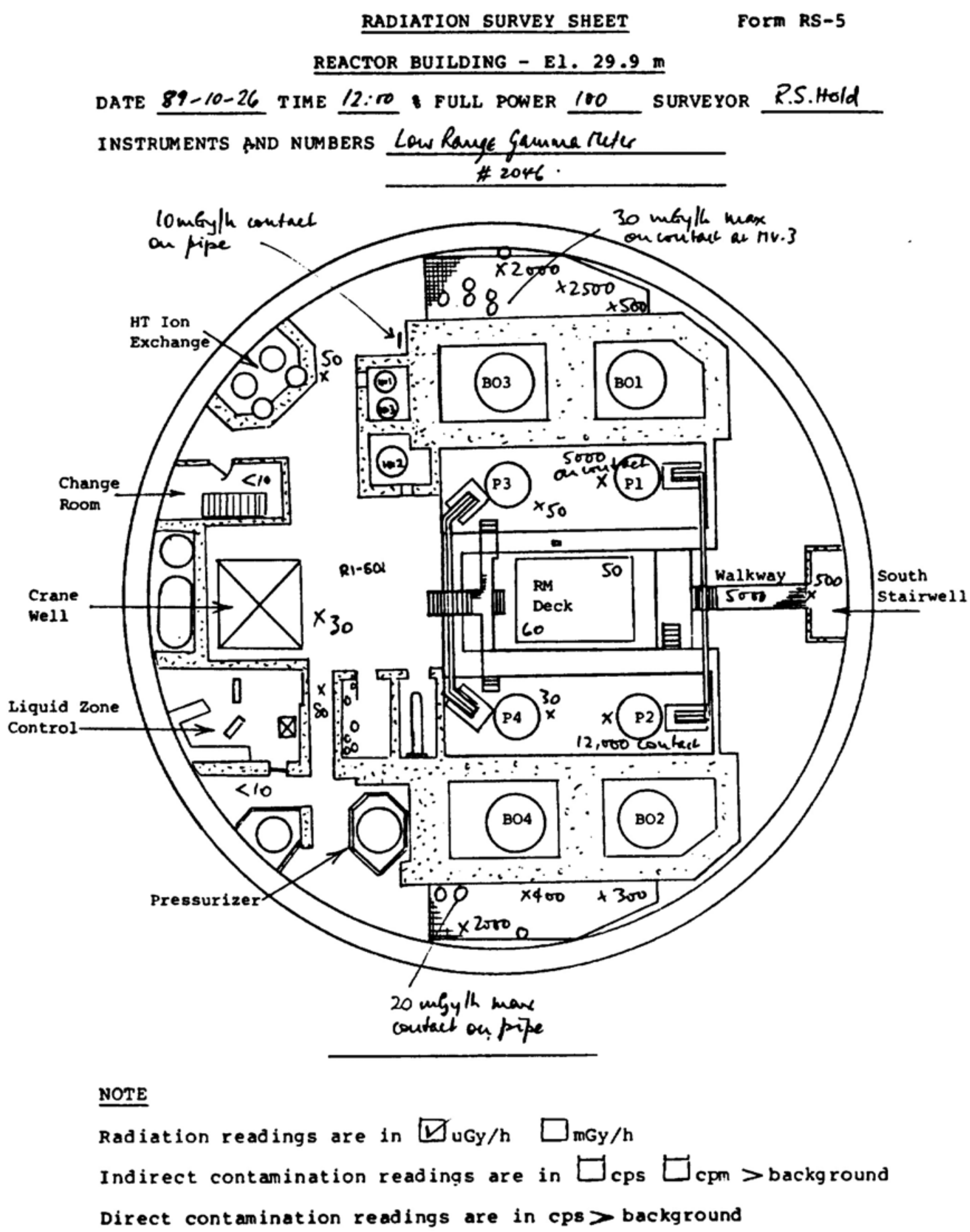


*Fig. 7.24. Typical Gamma Fields in the Boiler Room; 100 % Full Power, Six Years of Operation*

You should have a feel for the normal routine radiation conditions in the various accessible areas of the station. Fig. 7.24 shows typical gamma fields in the Boiler Room at 100% reactor power after about six years of full power operation. Notice how the fields vary from a few μSv/h to several Sv/h.

**Typical Neutron Fields**

Few neutron fields are found outside the Reactor Building. Exceptions are those locations where penetrations through the Reactor Building wall allow some gamma and neutron radiation to escape. For example, the $D_2O$ Vapour Recovery Room (S1-146) has some locations with fields of around 250 μSv/h gamma and 90 μSv/h neutron at 100% reactor power.

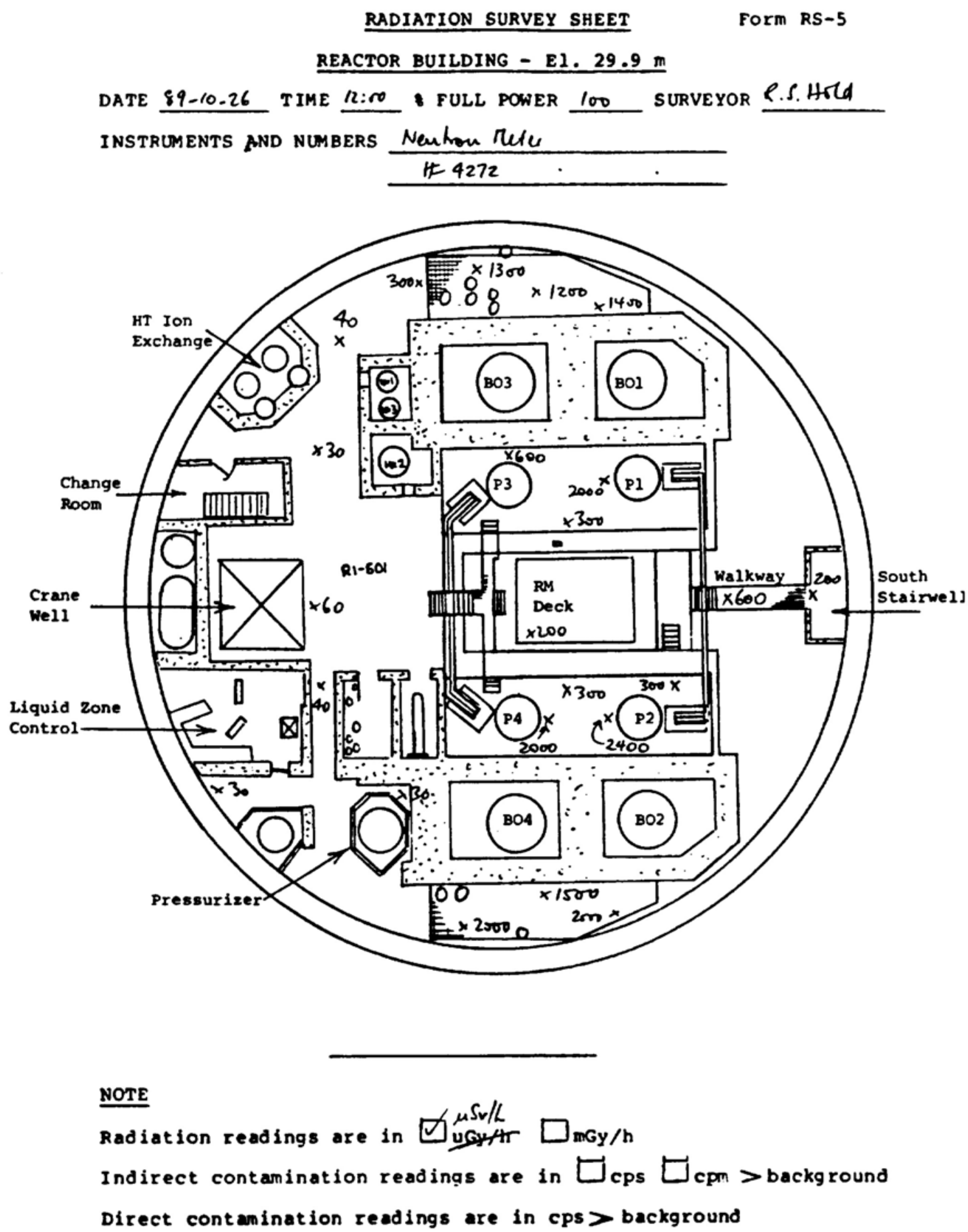


*Fig. 7.25. Typical Neutron Fields in the Boiler Room; 100 % Full Power, Six Years of Operation*

There are only a few areas that are normally accessible inside the Reactor Building that have neutron dose rates of greater than 10 μSv/h.

Figure 7.25 shows typical neutron fields in the Boiler Room at 100% reactor power. These fields should remain the same, regardless of the number of years of operation. Why? Notice how the fields vary with location. Note the neutron dose rate behind the boilers at the top and bottom of Fig. 7.25.

## Anticipating Hazard Changes

The factors discussed in the last section are important because they are variables; as they change, the hazard changes. Sometimes the change is predictable, and at other times it comes as a surprise. Let's look at some examples.

a) The most serious caper was when we cut out the R-16 pressure tube in 1998. An internal tube cutter shoved down the empty pressure tube was supposed to cut it into four sections (two end fittings with a length of attached pressure tube and the two remaining pressure tube lengths). The plan was

   - pull the end fitting piece into a special end-fitting flask at both sides of the reactor,
   - remove the end-fitting flasks and replace them with a pressure-tube flask on the west end,
   - then push the remaining two pieces of pressure tube from east to west into the pressure-tube flask.

   On the work platform the end-fitting flask was positioned very close to the reactor face. The Protection Assistant for the job, Andy Dykeman, was watching the fields at the gap between the flask and the reactor face with an extension FAG meter (Fig. 6.23, page 148). He was expecting a very short-lived increase to very high fields (~ 130 mSv/h) while the pressure tube slid into the flask. The field did not drop, and Andy at once raised the alarm and made sure everybody got out of there immediately. It turned out that the cut was not completed, and the pressure tube outside the flask remained exposed. This is a good example of how immediate action kept dose to negligible levels. Good job, Andy!

b) The filters on the fuelling machine PHT supply are changed when the flow becomes restricted. The filters rest inside a steel casing. Before a filter change, the gamma dose rate on the casing was about 5 mSv/h. Knowing the casing to be about 10 mm of steel, we expected 10 mSv/h on the filter, but actually measured about 30 mSv/h when the filter was removed. (Perhaps the initial survey was made when the filter was still full of heavy water.)

c) Helium is used as the moderator cover gas, because it does not absorb neutrons and cannot become activated. The Helium Storage Tank therefore should have no radiation hazard. A worker at Pickering G.S. noticed his gamma meter was indicating high radiation levels near this tank. A quick survey showed that gamma fields at the tank were around 5 Gy/h. It turned out that air cylinders were accidentally used to replace empty helium cylinders on the system. Air contains about 1% argon, and when it is exposed to neutrons it produces argon-41, a beta-gamma emitter.

d) An Active Workshop at another nuclear plant was highly contaminated and had general gamma dose rates of around 200 μSv/h. Two maintainers vacuum-cleaned the area for two hours. After they had finished, their TLDs showed doses of 6 mSv and 8 mSv. See if you can figure out why before you look at the answer on the next page.

As you can see, hazards don't always stay the same. After working in Zone 3 for a time you will probably have some of your own tales of sudden changes in radiation fields. You can keep yourself alert in these areas by asking yourself "What happens if ...?". Remain aware of the possibility of changing conditions.

## ACCEPT THE RESIDUAL HAZARDS

Once you considered all the things described above, you may decide to accept the hazard that remains. This is reasonable, because it is impossible to make everything absolutely safe. Also, to make something safe for one person may make it more risky for others. For example, is it reasonable to ask three people to spend an hour at a height to build a work platform for a half-hour job for one guy?


*An example of Chinese signposting sent to me by my old buddy Omar A. The picture shows the two-unit Qinshan CANDU station that Canada is building in China.*

*) 1.2 Sv/h was later measured on the vacuum cleaner from the crap it had picked up.

## SUMMARY

*The Safety Precedence Sequence indicates, in order of decreasing effectiveness, what you can do to minimise hazards:*

1. *Eliminate the hazard*
2. *Minimise the hazard*
3. *Install physical barriers*
4. *Install warning devices*
5. *Minimise human error potential*
6. *Establish procedures*
7. *Train, motivate and supervise personnel*
8. *Accept the hazard as it exists*

*The four methods of minimising the hazards of external sources are:*

1. *Minimise the source by decontamination and/or decay.*
   *Radiation fields from a source will be reduced to less than 1% for every seven half-lives the source is allowed to decay.*
2. *Reduce the time spent exposed to the source.*
   *Dose = dose-rate/time.*
3. *Increase your distance from the source.*
   *For "point" gamma sources, the field drops in proportion to the square of the distance from the source. For "line" gamma sources, the field drops in proportion to the distance from the source, and for large plane gamma sources it doesn't change much at all as you move away.*
4. *Use shielding.*
   *No shielding is needed for alpha radiation.*
   *Beta sources are usually completely shielded by the systems containing them, and a beta hazard will exist only when these systems are opened. Personal or protective clothing provides little beta shielding.*
   *Gamma shielding is best with high density, high Z materials.*
   *Effective neutron shields have a high hydrogen content (to slow the neutrons down) and incorporate gamma shields as well (to absorb the neutrons and the resulting capture gammas).*
   *Never rely on shielding calculations alone — always make radiation measurements after temporary shielding is installed.*

*The Access Control System consists of physical barriers, warning devices and procedural controls, and is designed to prevent entry to areas with high external radiation hazards. Reactor power (subsystem A) and/or fuelling machine status (subsystem B) condition the system. Subsystem C areas are controlled by the Shift Supervisor.*

*The Alarming Area Gamma Monitors provide audible and visual alarms when the detected dose rate exceeds a pre-set alarm. You can use a Portable Alarming Gamma Monitor in areas where you want local protection.*

*Take general radiation readings at waist height. Minimise the radiation dose that you receive when doing surveys. Signpost the area. A Radiation Area or Airborne Area has general radiation fields of more than 10 μSv/h. A Restricted Radiation Area has general radiation fields of above 5 mSv/h. Shift Supervisor approval is required before entry.*

*You must learn the hazards associated with each system. You must be able to anticipate changes in radiation fields when planning or doing work.*

*Most radiation hazards originate in the reactor core. Beta radiation is associated with high levels of surface or airborne contamination. Neutron radiation is mostly found in the Reactor Building when the reactor is at power.*

## PROBLEMS

1. What is the difference between internal and external radiation?

2. Describe four ways in which external radiation exposure can be decreased.

3. You are going to work in a gamma field of 1 mSv/h for 45 minutes. There are also neutrons of 0.6 mSv/h. What deep dose will you get? If you are only allowed 1 mSv for the job, how long could you work?

4. You are going to work for 20 minutes in an area where the gamma radiation field is decaying with a half-life of 3 hours. If it is 300 mSv/h now, how long will you have to wait to reduce your dose to just less than 1 mSv?

5. The radiation field coming from a small purification strainer was measured to be 3 mSv/h/h at 1 metre below the strainer. You have to work for an hour on a catwalk 3 m above the strainer. What will the field be there — assuming that it is all due to the strainer?

6. Suppose a piece of broken fuel was accidentally lifted out of the water in the Spent Fuel Receiving Bay and Joe Cretin was exposed to the piece of fuel for 5 minutes, facing it and 0.5 m from it, before he realised the danger. A quick gamma survey about half an hour later measured the gamma field at 2 m to be 4.0 Sv/h. Joe's TLD was read out shortly after, and indicated 4780 mSv deep dose, 9420 mSv shallow dose.

   (a) Is the deep dose result consistent with the facts given? Why?

   (b) How do you explain the shallow dose?

   (c) Assuming that the TLD deep dose estimate is the best we have, what are Joe's chances of survival? Hint: by estimating the dose to his back, try to get an average whole-body dose assessment.

   (d) What are the short-term and long-term consequences of this exposure?

7. The dose rate in air at 2 m from a spent fuel bundle removed from the reactor 4 hours ago is 120 Sv/h. If you are standing 5 m from the bundle (assume the inverse square law applies), how long would it take until you received the $LD_{50}$ dose (lethal to half the exposed) that is quoted in this course for the case of no medical intervention?

8. The gamma field coming from a spent fuel bundle was measured under water at 1 m from the end and at 1 m from the side of the bundle. Which measurement should give the greater reading?
   (a) the end,
   (b) the side,
   (c) both the same,
   (d) you can't tell.

9. You are going to work for one hour in an area where the gamma radiation field is decaying with a half-life of about 8 hours. The field now is about 15 mSv/h. You persuade your boss that it is smarter to do the job at this time tomorrow. The radiation dose you have saved yourself is about:

   a) 14 mSv,
   b) 13 mSv,
   c) 11 mSv,
   d) 7 mSv.

10. T F Exit is possible from an accessed controlled area even when the access door is locked.

    T F Audible and visual alarms high radiation alarms of the AAGM system in an access controlled area are disabled whenever the access key to that area is in Panel 15 in the Main Control Room.

    T F There is an override key whose use allows any A or B access control key to be removed under any operating condition.

    T F Access to locked A or B areas requires a Work Permit.

    T F The Fuelling Machine Vaults are under the control of both A and B subsystems of the access control system.

11. Before you enter this room, there are three indications available to you from the Remote Indicator outside the door. Match these to the conditions below by putting a 1, 2, 3, or 4 in the table under the appropriate indication:

    (a) green light on — (1) system failure
    (b) green light out — (2) system working OK
    (c) red light on — (3) high radiation level
    (d) red light out — (4) normal radiation level
    (e) dose rate reading below red line on the display
    (f) dose rate reading above red line on the display
    (g) What action could you take to protect yourself equally well, if it was necessary to work there during a system failure condition?

| | |
|---|---|
| a | |
| b | |
| c | |
| d | |
| e | |
| f | |

12. Room S1-005 (Moderator Purification) is protected by the AAGM system. The alarm set-point for this room is normally set at:

    (a) 0.5 mGy/h,
    (b) 1.0 mGy/h,
    (c) 50 μGy,
    (d) 2.0 mGy/h,
    (e) none of the above.

13. If an AAGM alarms on high radiation level in the area where you are working, you should do all of the following. List the first three actions you should take by indicating them with 1, 2, or 3. You need the right order.
    (a) Leave the area.
    (b) Read your PAD.
    (c) Signpost the area.
    (d) Call the Control Room Operator.
    (e) Check that everyone else has left.
    (f) Acknowledge the alarm.

14. A small beta source used in our lab for calibrating beta survey meters produces a measured dose rate of 90 mSv/h at 50 cm. Using this information, we calculate an approximate dose of 2.25 Sv/h at 10 cm. Is this calculated dose rate accurate, too high or too low? Explain.

15. (a) A long 1 inch diameter pipe carrying water from the liquid zone control system indicates a high gamma field at full power. This field is due to which two activation products?
    (b) Dwight measures this field and gets a reading of 1 mSv/h at 4 metres away from the pipe, i.e., sideways on. What field should he expect at 1 metre from the pipe?
        (1) 2 mSv/h,
        (2) 3 mSv/h,
        (3) 4 mSv/h,
        (4) 8 mSv/h,
        (5) 9 mSv/h,
        (6) 16 mSv/h,
        (7) none of the above.

16. You enter an area in the Reactor Building. You notice that the beta and gamma fields are pretty uniform, no matter where you measure them. The readings you get are:

    beta meter, shield closed:2 mGy/h
    beta meter, shield open: 6 mGy/h
    gamma meter: 1.8 mGy/h

    (a) Explain what could be causing these fields.
    (b) What is the beta field?
    (c) You spend half an hour in this area. What will your PAD indicate?
    (d) What deep dose and shallow dose should your TLD register from these exposures?
    (e) On leaving the Reactor Building, you set off the alarms on the Hand and Shoe Monitor at the Equipment Airlock. Why?

17. You are asked to survey an area that is expected to have a general gamma field of 2 mSv/h.
    (a) Which instrument would you select?
    (b) What checks do you make before using it?
    (c) What do you do if the instrument fails any one of these checks?
    (d) Give two reasons for doing surveys.
    (e) At what height from the floor are survey measurements normally taken?
    (f) What should you do after you have completed the survey?
    (g) What is a "hot spot sticker" and when would you use it?

(h) How is a Radiation Area defined?
(i) How is a Restricted Radiation Area defined?
(j) Whose approval is required to enter (h)?
(k) Whose approval is required to enter (i)?

18. Suppose an operator moved a drum of contaminated heavy water to an accessible area of the Reactor Building. After moving the drum, he measured the gamma radiation field and posted a sign at the drum stating as follows:
8 mGy/h on contact with drum
3 mGy/h 1 metre from drum.

Later the Radiation Control Supervisor recognised the inadequacy of the sign.
(a) In what way(s) was the posting of the radiation hazard inadequate?
(b) Give the shortcomings of the operator's handling of the whole situation.
(c) Whom does the Radiation Control Supervisor contact to have the radiation hazard properly posted?
(d) Who on shift is responsible for ensuring that everybody follows the radiation protection procedures?

19. For signposting, the following three Velcro stickers are available

NOTICE, CAUTION, DANGER

By writing N, C, or D against the following, indicate which would be the correct choice:

____ Equipment Airlock out of service
____ Radiation Area
____ Restricted Airborne Area
____ Rubber Area
____ Tripping Hazard
____ Steam Leak

20. At full power, the radiation fields in the FM Vaults near the reactor face are 150 mSv/h gamma and 200 mSv/h neutrons. At 1% of full power, the neutron fields there are 2 mSv/h. The gamma field at 1% of full power at the same location will be

(a) 1.5 mSv/h,
(b) less than 1.5 mSv/h,
(c) more than 1.5 mSv/h,
(d) you can't tell.