CHAPTER 5

DOSE LIMITS AND RISK

INTRODUCTION

Now that you are a big name in the biological effects of ionising radiation, you are ready to understand the principles that are used to set dose limits. This chapter talks about those principles, gives the dose limits for occupational exposure and for the general public, and compares the risks of working with radiation with some other common risks.

THE ICRP AND THE CNSC

Even before the 1920's it became well known that the radiation dose received by an individual had to be limited to prevent injury. Various organisations began to study the problem and issue recommendations for the control of radiation exposure. In 1928, an international commission (then called the International X-Ray and Radium Protection Committee) was formed to make recommendations with regard to radiation protection.

This Committee was reorganised in 1950. The name was changed to the **International Commission on Radiological Protection** — universally abbreviated to the **ICRP**. The Commission is a non-government international scientific organisation. It has a chairman and not more than 12 members chosen on the basis of their recognised expertise in radiation protection and related fields, without regard to nationality. The ICRP is widely recognised today as the chief authority in the protection from the harmful effects of ionising radiation. It has the responsibility for presenting recommendations on all aspects of this subject. These recommendations usually are adopted without major changes by most countries and are incorporated into their laws. This makes the radiation protection approaches remarkably consistent throughout the world (unlike most other things).

In Canada, the **Canadian Nuclear Safety Commission (CNSC)** is the Federal Agency responsible for regulating radiation protection. It bases its regulations on the recommendations made by the ICRP. The CNSC used to call itself the *Atomic Energy Control Board (AECB)* — the name has changed, but the players haven't.

THE OBJECTIVES OF RADIATION PROTECTION

The main objective of radiation protection is to protect individuals, their offspring and mankind as a whole, while still allowing necessary and beneficial activities involving radiation exposure.

The biological effects of radiation are classified as somatic and hereditary. The ICRP divides the somatic effects into **stochastic** and **deterministic** effects. Stochastic means "arising from chance; involving probability". It is worth quoting from the ICRP:

STOCHASTIC effects are those for which the probability of an effect occurring, rather than its severity, is regarded as a function of dose, without threshold.

DETERMINISTIC effects are those for which the severity of the effect varies with the dose, and for which a threshold may therefore occur.

My dictionary says that stochastic means “governed by the laws of chance”. It doesn’t offer an opinion on deterministic, but “based on natural laws” is close. You’ll appreciate that reading ICRP documents can often make your head hurt: I’ve tried to distil their thoughts into English that we can understand.

Anyway, cancer is a somatic effect that is stochastic. In other words, the probability of contracting cancer increases with the dose, but once you get it, the severity of the disease is the same no matter how big the dose was that caused it. We assume that the relationship is linear for the range of doses we're concerned with (shown in the Region of Interest of Fig. 4.3, page 93). That is, twice the dose means twice the chance of getting cancer. Hereditary effects are also stochastic effects. No threshold is assumed for either.

In contrast to this, cataract of the eye lens is a deterministic effect with a threshold value of around 8 Gy for chronic exposures (page 101).

Let's digress for a moment to give you a couple of everyday examples of deterministic and stochastic effects. Sunburn has a threshold; above this threshold exposure, the degree of sunburn becomes more and more severe with increasing exposure to the sun, and below the threshold no harm is done. So sunburn from exposure to the sun is a deterministic effect.

Compare this with winning a million bucks in a lottery; this is pure chance and therefore stochastic. The probability of winning depends on the exposure (the number of tickets you buy), but the magnitude of the effect doesn't change. You either win a megabuck or you don't. (If you're like me, the chances are even smaller, because I never buy any tickets.)

In 1977, the ICRP defined the two major aims of radiation protection. The first is to prevent any early effects from high radiation dose. The second is to limit the probability of radiation-induced cancers and serious genetic disorders to levels deemed to be acceptable by society. Or in their words:

The aim of radiation protection should be to prevent harmful deterministic effects, and to limit the probability of stochastic effects to levels believed to be acceptable.

This is a most important objective. We can prevent the deterministic effects by setting annual dose limits low enough so that no threshold dose would ever be reached during a person's life-time. We can limit the stochastic effects by applying annual dose limits that, in ICRP's words, define the boundary line between unacceptable and tolerable, i.e., just tolerable. By the end of this chapter, you'll be able to judge for yourself exactly what this means.

The present system of radiation protection is based on three important principles spelled out by the ICRP:

(a) No practice shall be adopted unless its introduction introduces a net positive benefit.

This eliminates the "frivolous" use of radiation. For example, in the 1950's many shoe stores would X-ray feet to see whether the new shoes would fit. This is no longer permitted, because even a moron can figure it out by trying them on, provided that he gets them on the right feet and not back to front. Yet smoke detectors don't fall into this category: the tiny levels of radiation emitted by them are more than offset by the very real benefits they offer.

(b) All exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account.

This statement is known as the **ALARA** principle. ALARA stands for **A**s **L**ow **A**s **R**easonably **A**chievable. The ALARA principle means that we should make all reasonable efforts to keep our radiation doses as low as we can, while at the same time not wasting zillions of dollars to do so. ALARA calls for judgement and common sense. We'll have more on this elsewhere.

(c) The dose to individuals shall not exceed the limits recommended for appropriate circumstances by the Commission.

This means that nobody should be exposed to an unacceptable degree of risk from activities involving radiation exposure.

THE DOSE LIMITS

In any organ or tissue, the total dose due to occupational exposure consists of the dose contributed by external sources (i.e., those outside the body) during working hours plus the dose contributed by internal sources taken into the body during working hours. The limits apply to this total dose received on the job. They do not apply to medical exposure or exposure to background radiation. The limits presented here apply to **Nuclear Energy Workers (NEW)**. We've already met these characters on page 81.

Nuclear Energy Workers are people who may be routinely exposed to ionising radiation as a result of their occupation.

As mentioned before, the dose limits are intended to prevent deterministic effects, and to limit the occurrence of stochastic effects to a tolerable level. This means that there should be two sets of limits, one for stochastic effects, and one for deterministic effects. Indeed, there are.

LIMITS FOR STOCHASTIC EFFECTS

It is worth quoting the ICRP:

> *"...the ICRP has reached the judgement that its dose limit should be set in such a way that the total dose received in a working life would be prevented from exceeding about 1 Sv received moderately uniformly year by year...and that this figure would only rarely be approached."*

and

> *"...The ICRP recommends a limit on whole-body dose of 20 mSv per year, averaged over 5 years (i.e., 100 mSv in 5 years) with the further provision that the dose should not exceed 50 mSv in any single year."*

External and internal whole-body doses must be added; the total dose must not exceed the limits given above.

The external and internal doses are assessed in what appears to be a complicated manner, although it is fairly straightforward once you get familiar with it. We'll describe them one at a time.

External radiation dose (from neutron, gamma, and beta) is measured on the basis of whether it delivers dose to the whole body or to the skin. The dose in tissue at a depth of 1 cm is called **deep dose** (symbol $\mathbf{H_D}$), because it is received deep in the body. **Shallow dose** (symbol $\mathbf{H_S}$) is the dose received by live skin tissue. Neutron and gamma radiations contribute to both deep and shallow dose, but beta radiation

H_S	H_D
γ	γ
n	n
β	no β

OK. That takes care of dose received from external radiation. What about internal dose? This can be received by the whole body (for example, if a radionuclide is uniformly distributed throughout the body, as would be the case for tritium), or it can be received by particular tissues only. How can this be? Most radioactive materials taken into the body tend to accumulate in certain organs or tissues, rather than spreading throughout the body. We'll have more to say about this in Chapter 8. For the time being, it is enough to know that radioactive iodine, for example, will collect in the thyroid gland and then mainly irradiate this organ without giving comparable doses to the rest of the body.

How are we going to handle local exposures like this as distinct from whole-body exposure? This is best illustrated with an example. Take the case of a NEW who has received a whole-body dose, H_D, of 10 mSv from external gamma radiation and, in addition, a **tissue dose**, $\mathbf{H_T}$, of 50 mSv to the thyroid gland. How do we compare the relative biological importance of these two doses, one to the whole body and the other to only one organ?

ICRP believes that the dose limits for stochastic effects should be based on the idea that the relative risks should be equal, regardless of whether the dose applies to the whole body (H_D) or whether only some tissues (H_T) are irradiated. In order to make these risks equal, the ICRP has determined

weighting factors, $\mathbf{w_T}$, by which doses to tissue must be multiplied to arrive at a whole-body dose that would have the same risk of fatal cancer as the tissue dose.

In our example, Joe NEW had 10 mSv of gamma dose (H_D,) and 50 mSv of tissue dose (H_T) to the thyroid. If the thyroid tissue dose is multiplied by its weighting factor of 0.05, we get 50 x 0.05 = 2.5 mSv. What it means is this: a dose of 2.5 mSv to the whole body presents the same risk of causing a stochastic effect (i.e., fatal cancer) as a dose of 50 mSv to the thyroid alone. We call this product of the tissue dose and its weighting factor the **weighted dose** (symbol $\mathbf{H_W}$).

$$\mathbf{H_W = H_T\, w_T}$$

In this definition, H_W = weighted dose, H_T = tissue dose and w_T = tissue weighting factor.

In our example, a 10 mSv gamma dose to the whole body and a 50 mSv dose to the thyroid is the same, in terms of risk, as a whole-body dose of 10 + 2.5 = 12.5 mSv. We call this the **effective whole-body dose**, written as $\mathbf{H_{WB}}$. (I told you we had a lot of names for dose; we haven't finished yet.)

If more than one tissue is exposed, the various values of $H_T w_T$ are added to the deep dose H_D to form the effective whole-body dose, H_{WB}. In other words,

$$\mathbf{H_{WB} = H_D + \text{the sum of all } H_T w_T}$$

It is this value of $\mathbf{H_{WB}}$ to which the dose limit of 20 mSv a year applies.

The values of w_T aren't all the same. You wouldn't expect equal doses to many different organs to produce the same potential degree of harm. For example, a dose to the lung could lead to lung cancer, which is usually fatal — yet the same dose to the skin is much less likely to cause a fatal skin cancer. In setting the weighting factors, the ICRP also took into account the latent period of the cancers, because a shorter latent period implies a longer period of time for which you will no longer be around. In addition, they made allowance for non-fatal cancers and hereditary effects. The weighting factors are listed in Table 5.1. You don't have to remember them, but you should understand how they are used.

These weighting factors apply to both sexes and all ages. The sum of the weighting factors = 1.0. This has be so, because when the whole body is exposed to a gamma dose of 1 mSv, for example, we could work out the effective whole-body dose by adding up all the $H_T w_T$ values. Since H_T = 1 mSv and H_{WB} = 1 mSv, the sum of all the weighting factors w_T must also be 1.

The high value of 0.20 for the gonads reflects the fact that the hereditary risk is about 20% of the total risk. The *Remainder* in Table 5.1 includes nine other organs not listed above. If you are craving to know what they are and how you deal with them, ask someone from Health Physics.

The remainder doesn't include the extremities (hands, forearms, feet

TABLE 5.1. TISSUE WEIGHTING FACTORS

Tissue or Organ	*Weighting Factor w_T*
Gonads	0.20
Red Bone Marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus (canal from mouth to stomach)	0.05
Thyroid	0.05
Skin	0.01
Bone Surface	0.01
Remainder	0.05

received by your TLD badge to better than ± 10%. Only for special cases of skin dose much greater than the deep dose would we include the $H_T w_T$ for the skin in the effective whole-body dose, H_{WB}.

In practice, almost all doses at a CANDU plant are whole-body dose from gamma and tritium with very little neutron radiation. Since we started up in 1983, we've found very small doses to individual tissues (lung and stomach) on only about half a dozen occasions. We expect a few people to get extremity doses, but they will be the exception rather than the rule. In any case, you'll never have to do anything with the H_T or the w_T values. If you ever do receive tissue dose, the lads in the Health Physics Department do all the number crunching, and they enter the results into your dose records.

LIMITS FOR DETERMINISTIC EFFECTS

Deterministic effects should be prevented. ICRP believes that they will be prevented if we adhere to the H_{WB} limit of 20 mSv/y described above. There are only three exceptions for which the deterministic limits are higher than the stochastic limits. They are shown below.

TABLE 5.2. DETERMINISTIC LIMITS

The lens of the eye is limited to	**150 mSv/year.**
The skin is limited to	**500 mSv/year.**
The extremities are limited to	**500 mSv/year.**

THE SYSTEM OF DOSE LIMITATION

We now have two sets of limits:

H_{WB} = an average of 20 mSv/year with not more than 50 mSv in any one year, the stochastic limit for the whole body, and

H_T = the deterministic limits: 500 mSv/y for skin and extremities, 150 mSv/y for the eye lens.

Neither limit may be exceeded. Let's look at a couple of examples to see how the system works.

Example 1

Bernie has received the following doses in one year:

H_D (external, whole body) = 8 mSv
H_S (external, skin) = 12 mSv
H_T (internal, lung) = 10 mSv
H_T (internal, thyroid) = 30 mSv

Bernie's a pretty sloppy worker since he has received thyroid and lung dose from the inhalation of radioiodine and particulate material. Both are easily prevented, but for the sake of the example let's see what his H_{WB} turns out to be.

$$\begin{aligned} H_{WB} &= H_D + \text{sum of all } H_T w_T \\ &= H_D + H_T w_T \text{ (lung)} + H_T w_T \text{ (thyroid)} \\ &= 8 + (10 \times 0.12) + (30 \times 0.05) \text{ mSv} \\ &= 8 + 1.2 + 1.5 \text{ mSv} \\ &= \underline{10.7 \text{ mSv}} \end{aligned}$$

Remember, we don't include the skin's weighted dose for the reasons given on page 114. The shallow dose of 12 mSv is subject only to the 500 mSv/year limit for deterministic effects, because the probability of stochastic effects is negligible.

Example 2

Ten Speed has received the following doses so far this year:

H_D (external, whole body) = 4.6 mSv
H_X (extremities) = 12.2 mSv
H_T (tritium, whole body) = 8.7 mSv
H_T (thyroid) = 30.0 mSv

How much more whole-body dose can he receive in the rest of the year without exceeding the dose limits?

$$\begin{aligned} H_{WB} &= H_D + \text{sum of all } H_T w_T \\ &= H_D + H_T w_T \text{ (tritium)} + H_T w_T \text{ (thyroid)} \end{aligned}$$

**) w_T for tritium is 1.0, because all tissues are exposed, i.e. the sum of all $H_T w_T$ in Table 5.1 is just H_T. Therefore, you can treat any tritium dose as an H_D dose. H_X is ignored, because there are no stochastic effects for extremity dose.*

= 4.6 + (8.7 x 1*) + (30 x 0.05) mSv

= 4.6 + 8.7 + 1.5 mSv

= 14.8 mSv

Therefore he would be allowed to receive a whole-body dose of 5.2 mSv in the rest of the year, before reaching the 20 mSv limit.

How much extremity dose is he allowed to get in the rest of the year? 474.5 mSv. Why? His extremities have already received a dose of 4.6 + 8.7 = 13.3 mSv from external and tritium exposures. (The thyroid dose adds nothing.) To this we need to add the measured extremity dose (12.2 mSv) to get 25.5 mSv. Since the limit is 500 mSv for the extremities, that leaves 474.5 mSv for the remainder of the year.

In practice, gamma and tritium exposures should always cause the H_{WB} limit to be approached long before any deterministic skin, extremity or eye lens limit. I doubt whether we'll ever see it the other way around.

DISCUSSION OF ANNUAL DOSE LIMITS

If you routinely pick up a dose to the whole body of 0.4 mSv per week, and if you work 50 weeks a year (some of us only take two weeks of vacation), then by the end of the year you will have reached the H_{WB} limit. However, during certain times, such as the annual shutdown, you might be required to work on or near very radioactive equipment for short periods of time. If you were to receive 0.4 mSv routinely every week, then such times of higher exposure would obviously cause you to exceed the dose limits by the end of the year. Therefore, on the average, normal operating doses must be quite substantially less than 0.4 mSv per week. This is of course supported even more so by the ALARA principle.

Canadian law states that an average of 20 mSv of effective whole-body dose shall not be exceeded in a year, without specifying whether the year is a calendar year or any other period of 52 consecutive weeks. At Point Lepreau, we now use a calendar year, although we didn't in the past (see the box on the next page).

The H_{WB} dose limit applies to a calendar year, i.e., Jan 1 to Dec 31.

Table 5.3 summarises the dose limits for Nuclear Energy Workers and for the general public.

TABLE 5.3. DOSE LIMITS

	NEWs	*Non-NEWs*
Stochastic Limits (Effective whole-body dose)	20 mSv/year, averaged over a period of five years, with no more than 50 mSv in any one year.	1 mSv/year
Deterministic Limits		
Lens of the eye	150 mSv/year	15 mSv/year
Skin	500 mSv/year	50 mSv/year
Extremities	500 mSv/year	

Some comments:

1. The limits do not apply to doses received from background radiation, from medical treatment, and from emergency actions carried out to save human life.

2. The effective whole-body dose limit of 20 mSv is an average value over five years. The real limit is 100 mSv in 5 years, with not more than 50 mSv in any one year. At NB Power, we've decided to make our limit 20 mSv for each year — to exceed it, you'll need approval from the Senior Health Physicist.

3. Female workers who are known to be pregnant are limited to 4 mSv of whole-body dose for the remainder of the pregnancy, because the foetus is very sensitive to radiation. If you are pregnant, you are required to the Senior Health Physicist. If you don't want to be exposed to radiation at work we'll make every effort to find you a non-radiation job for the remainder of your pregnancy.

Until 1999, we had what we called an *Equivalent Calendar Years (ECY)* starting at the beginning of January, April, July and October. These start dates were spread more or less equally among all the members of a work group. For example, my start date was April. That meant, for me the dose limit of 20 mSv applied to the year from April 1 to the end of March 30 in the following year.

The idea behind this was to ensure that we would always have some people available for shutdown work or unplanned maintenance who hadn't yet received much radiation dose, and so wouldn't be close to their dose limit.

I think this was a prudent approach at the time we started up and really didn't know what dose was needed to maintain and operate the station. Since then it has become clear that the doses are low enough for us not to need this extra complication. In October 1999, everyone's ECY start date became January 1, and the ECY concept was history.

Finally, some comments on dose limits for people who are not NEWs. The lower limits are based largely on the reasonable view that members of the general public derive less benefit from the radiation dose than we do (jobs), so they should be limited to lower doses and hence lower risks. The average population exposure from any nuclear activity is actually a lot less than the limit would indicate, because the limit applies to those members of the general public most at risk.

For nuclear power stations, these would be the local inhabitants who live 24 hours a day at the exclusion zone boundary and drink the water and breathe the air that may contain trace amounts of radioactive materials. The average dose to the general public (in our case the inhabitants of the Province) would be a lot less than the dose to the people living near Point Lepreau G.S.

The thinkers amongst you will have realised that reducing the stochastic limits for non-NEWs makes sense, but reducing the deterministic limits for non-NEWs dose not. If 150 mSv/y to the eye can't hurt you, why drop the limit to 15 mSv/year? You can write to the CNSC and ask them, if you have nothing better to do with your time.

Operating data from all the years since we started up Point Lepreau show that the maximum dose to the local people is about 1 μSv a year. This is 0.1% of the limit; trivial compared with the background radiation dose (see page 82).

RISK

Exposure to radiation involves some risk. How much? If you believe the majority of the media reports, you'd expect it to be right up there with juggling chainsaws, stomping rattlesnakes, flying hot-air balloons over transmission lines, or eating PCB sandwiches*). The truth is rather less scary, and in the rest of this chapter we'll compare the risks of injury from radiation exposure with some of the more common risks of everyday life. Some of the information might surprise you.

CATEGORIES OF RISK

There are two types of risk to which we are all exposed, namely **acute** risk and **chronic** risk. Acute risks are those where the harmful effects are felt immediately, and chronic risks are those where the harmful effects don't show up until much later.

Nuclear Energy Workers are not normally at acute risk from radiation (i.e., death following exposure to large overdoses of radiation, such as 5000 mGy or more in a short time), but they are exposed to a chronic risk of somatic (cancer) or hereditary damage.

The concept of acute and chronic risks applies to other professions as well. For example, miners face an acute risk of being buried in collapsing tunnels and a chronic risk of contracting respiratory diseases.

Another example? Long-distance truck drivers are exposed to an acute risk of highway accidents and a chronic risk of ill-health from long hours of sitting in a fixed position combined with high noise levels and the breathing of exhaust fumes from their own and other vehicles. And when they drive in our winters, you can count on a fair amount of stress as well.

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*) If you have to pick one, go for the sandwiches. The toxicity of PCBs is at about the same level of harm as aspirin tablets. I kid you not.

ACUTE RADIATION RISK

The acute radiation risk in the nuclear power industry is virtually zero. What about Chernobyl? It is true that the 31 fatalities at Chernobyl are a tragic example of a worst case disaster resulting from a poor nuclear reactor design and a badly managed operation. Yet there have been no deaths yet due to radiation in well over a billion man-hours of work by the operating staff in the civilian nuclear power program in the western world.

Compare this record with the fatality rate from industrial accidents in Canada, i.e., 7 per 100 million man-hours worked. The past excellent safety record for acute radiation risk means that we obviously know how to prevent fatal radiation exposures in the nuclear power business. Most of our emphasis is therefore put on the reduction of chronic risks, i.e., reducing the levels of routine everyday radiation exposures.

CHRONIC RADIATION RISK

The accepted value of the radiation risk for Nuclear Energy Workers is 4% per sievert, i.e., if you receive a radiation dose of one sievert, you will have an extra 4% chance of contracting a fatal cancer at some time in the future. I say "extra", because about one in every four people dies of cancer anyway. The figure of 4% per sievert applies to both sexes. Added to the cancer risk is the hereditary risk of 0.6% per sievert for NEWs who plan on having children after the exposure.

OCCUPATIONAL RADIATION RISK

What is the radiation risk of working at Point Lepreau? It depends on the dose; we need to know what average dose we can expect. Based on our dose records, the average annual dose to our staff at Point Lepreau has been about 2 mSv. At 4%/Sv, this represents a risk of 0.008% for each year you work.

There are two ways of expressing such a risk to make it easier to compare with other risks arising in industry. One is the hourly risk, and the other is the loss of life expectancy. Bear with me, and you'll get the drift.

HOURLY RISK

Let's look at an example of expressing risk as **hourly risk**. If you work at Point Lepreau, you have a radiation risk of 0.008% for each year of work. This is 0.008 in 100, or one chance in 12,500. If we write the risk as a fraction, it is a risk of 1/12,500 each year. If you work 2000 hours a year, the hourly risk is 1/(12,500 x 2000) = 0.04E-6. (Let's leave the complication of overtime aside, OK?) In other words, your hourly radiation risk is 0.04 of one chance in a million. Alternatively, every 25 hours of work gives you a one in a million risk of contracting a fatal cancer.

We could also look at the daily risks. We just multiply the hourly radiation risk by 8, the number of hours worked. We get 8 x 0.04E-6 = 0.32E-6 for working an eight hour day at Point Lepreau. Well, is that safe or isn't it? It is certainly safer than getting there!

The fatal traffic accident risk connected with driving 40 miles to work and 40 miles back home is 3.2E-6. *This means that travelling to and from work each day is ten times as risky as the radiation hazards you are likely to face once you get there*.

Let's take another well-known risk statistic and put it in the hourly format so that we can compare it. For example, in New Brunswick the risk of dying in traffic accidents is 4E-8 for every mile you drive. If it takes you an hour to drive 40 miles to work, the hourly risk will be 40 x 4E-8 = 1.6E-6, i.e., 1.6 chances in a million. This is 40 times greater than the hourly radiation risk at work.

LOST LIFE EXPECTANCY

Lost Life Expectancy (LLE) is another popular way of expressing risk. Assume that you work 45 years (20 to 65) as a NEW and get 2 mSv a year. Your total dose will be 90 mSv, giving you a total risk of 4% x 0.09 = 0.36% of getting a fatal cancer. If you're unlucky (about 1 chance in 300), you will die of a radiation-induced cancer. You will therefore not live as long as you would have otherwise.

How many years did you miss out on? Let's assume that the cancer was caused by an exposure at age 40 (in the middle of your working life), and that the latent period before the cancer did its thing was 15 years. So your life expectancy has been reduced to 55 years from the normal 70. Tough luck.

Your LLE = 0.36% x 15 years
= 0.0036 x 15 years
= 0.054 years = 20 days

Now, you must realise that the 20 days is an average to represent the LLE of all the NEWs who get 2 mSv each year —
— a person will either lose no days at all or some number of years related to when the cancer was induced. Remember, it is a stochastic effect, i.e., pure chance.

ICRP has gone to the trouble of calculating the average lost life expectancy (for all the different fatal cancers) for workers exposed to a constant annual radiation dose for every year from age 18 to age 65, and they came up with a figure of 13 years. So we'll use 13 years instead of 15 years in our example. This gives us an LLE of 17 days instead of 20.

We can also work out the LLE from driving to work every day. The answer comes to 372 days.

This is an interesting number. The risk of dying in a traffic accident on the way to or from work was ten times greater than the risk of dying of cancer, but the LLE from the traffic accident is 372/17 or 22 times bigger.

This just reflects the fact that the cancer causes you to lose less of your remaining life than the traffic accident. In these examples, I used the average Lepreau dose of 2 mSv. If you're in a high dose work group, you'll also be smart enough to figure out how your own risk comparison will change.

We've already worked out the daily risk from driving to work and back is 3.2E-6. Do this 235 times a year, and you have an annual risk of 235 x 3.2E-6 = 7.5E-4. Then work for 45 years, and your total risk is 45 x 7.5E-4 = 0.034. We'll assume that the accident would happen in the middle of your working life at age 40, and since you would be killed immediately, you'd lose 30 years of life.

Your LLE = 0.034 x 30 years
= 1.02 years
= 372 days.

I think the LLE idea s is a very useful way of comparing risks. For example, even if the risks of the traffic accident or the radiation-induced cancer were equal, the smart money would go with a cancer death perhaps 15 to 20 years from now rather than getting splattered in a traffic accident today. This idea of expressing the risk from an occupation (or any leisure activity) in terms of expected loss of life is being used more and more.

Table 5.4 gives the risks of fatal accidents at work in Canadian industries. ('Government' includes police and fire-fighters.) The table is based on data from the Occupational Safety and Health Branch of Labour Canada.

I added the LLE figures. They are based on 30 years of lost life for each accident, except for the radiation risk, where I used 13 years.

Even within any one particular industry, there are large variations in the risks for the different jobs. In our industry, line workers have a far greater risk than anyone else.

TABLE 5.4. RISKS OF ACCIDENTAL DEATH IN CANADIAN INDUSTRY

Industry	*Hours of work for 1 in a million risk*	*LLE (days)*
Finance	120	8
Service	80	12
Trade	40	25
2 mSv radiation /year	25	17
Government	22	45
Manufacturing	22	45
Transportation	8	125
Construction	6	165
20 mSv radiation/year	2.5	170
Mining	2.2	450
Forestry	1.9	550
Fishing and Hunting	1.0	990

Professor Bernard L. Cohen of the University of Pittsburgh has analysed U.S. risk data for all kinds of activities. Most of the information in Table 5.5 is taken from his superb book, "*The Nuclear Energy Option — An Alternative for the 90s*", Plenum Press, 1990. This is fascinating reading.

Table 5.5 on the next page shows that the risks associated with radiation are not proportional to the number of words devoted to them by the newspaper scribes and the talking heads on TV. In fact, you could argue that the radiation risks of having a job as a NEW at Point Lepreau (LLE = 17 days for 2 mSv/year) means that you will avoid the risks of being poor (LLE = 3500 days). And if you smoke, you'd better look at the table carefully.

TABLE 5.5. LLEs IN THE USA DUE TO VARIOUS RISKS

Activity or Risk	*LLE (d)*	*Activity or Risk*	*LLE (d)*
Living in poverty	3500	*Average job: occupational accidents*	74
Being male rather than female	2800	*AIDS*	70
Cigarettes (male smokers)	2300	*Small car versus standard size*	50
**Heart disease*	2100	*Drowning*	40
Being single (much worse for men)	2000	*Falls*	39
Working as a coal miner	1100	*Radon in homes*	35
Cancer	980	*Fire: burns*	27
Stroke	520	*Poison*	24
All accidents	435	NEW dose (2 mSv/y)	17
Vietnam army service	400	*Air pollution from coal-fired generation*	12
Alcohol	230	*Bicycle accidents*	5
Motor vehicle accidents	180	Snowmobiling	2
Pneumonia and influenza	130	*Airline crashes*	1
Drug abuse	100	*Hurricanes and tornadoes*	1
Accidents at home	95	*Being struck by lightning*	20 h
Suicide	95	Living next to PLGS (about 1 μSv/y)	20 min
Homicide	90	Dose from Three Mile Island accident	6 min

* The activities in *italics* give the LLE averaged over the whole U.S. population; the others refer only to those exposed. (Obviously, if you never travel in a plane, the LLE of 1 day doesn't apply to you: the risk of a plane falling out of the sky and flattening you is ignored.)

Prof. Cohen has taken this approach to its logical conclusion: he argues that those activities with a high LLE obviously should have proportionately more resources devoted towards making them safer than those with a low LLE. If you look at Table 5.5, you can see that in most cases this isn't happening. And that doesn't make sense.

SUMMARY

The ICRP is a renowned international organisation that publishes recommendations on radiation protection. In Canada, the Canadian Nuclear Safety Commission (ex-AECB) is the Federal Regulatory Agency. Its regulations very closely follow the recommendations of the ICRP.

Limits on radiation dose are set by the CNSC. The limits are intended to limit stochastic effects to an acceptable level, and to prevent deterministic effects completely.

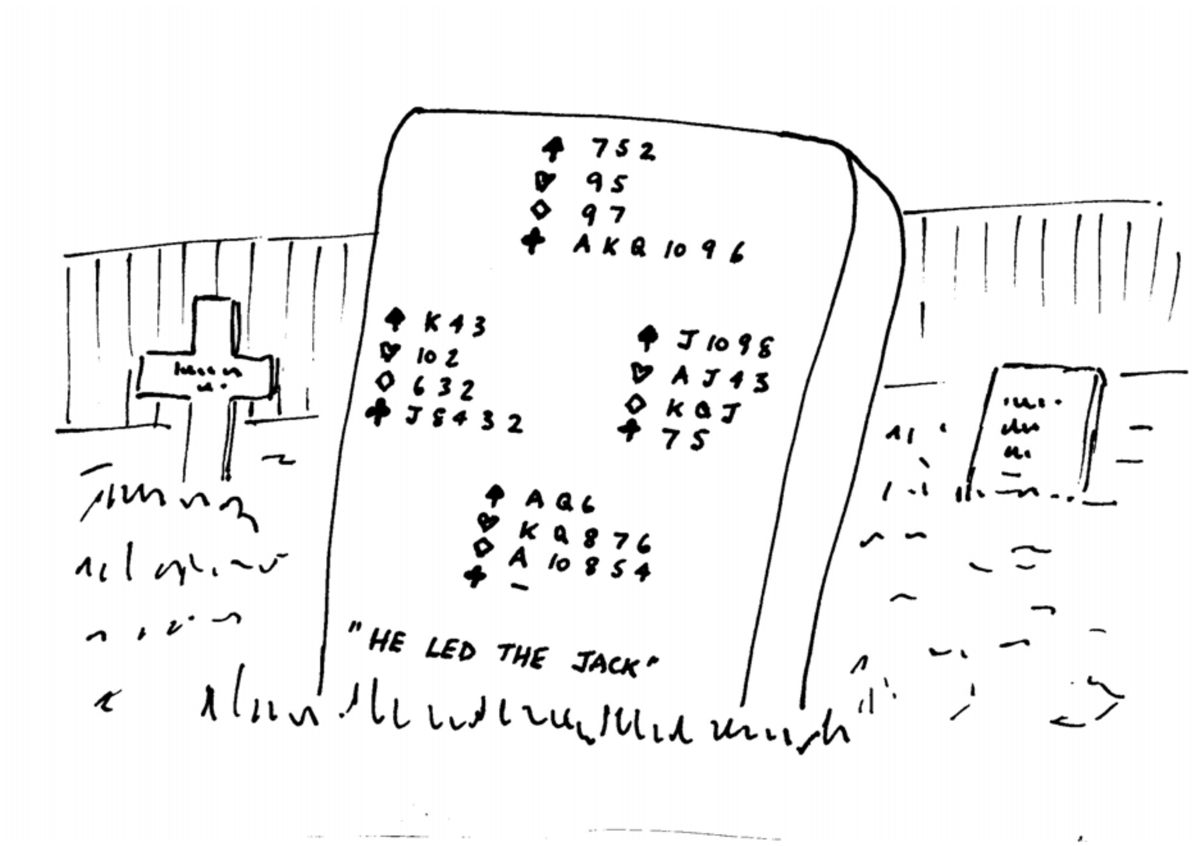
Stochastic effects are those arising from chance: the greater the dose, the more likely the effect. Deterministic effects are those which normally have a threshold: above this, the severity of the effect increases with the dose.

The whole-body limit for stochastic effects is 20 mSv/year, averaged over five years. This limit includes the weighted contributions from any individual tissues. The weighting factors are given in Table 5.1. You needn't memorise them, but you should understand their purpose.

The limit for deterministic effects for individual tissues is 500 mSv/year, except for the lens of the eye: its limit is 150 mSv/year.

The dose limits described in this chapter apply to routine operations. They do not apply to an emergency situation when human life is endangered.

Radiation risks are acute and chronic. The acute risk is negligible at PLGS. The chronic risk from a dose of 2 mSv/year over a working lifetime can be expressed as a Lost Life Expectancy of about 17 days.


♠ 7 5 2
♥ 9 5
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♣ A K Q 10 9 6
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♥ 10 2
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♣ J 5 4 3 2
♠ J 10 9 8
♥ A J 4 3
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♥ K Q 8 7 6
♦ A 10 8 5 4
♣ –
"HE LED THE JACK"

PROBLEMS

1. What is the main reason for avoiding unnecessary radiation exposure, even if your accumulated dose is well below the dose limits?

2. Good station design is obviously one of the features that enable us to keep doses ALARA. What are some of the others?

3. Separate annual dose limits are set for stochastic and deterministic effects.
   (a) What is the underlying philosophy the ICRP used in setting limits for the two types of effect?
   (b) What are the annual limits for NEWs working at Point Lepreau for
      1) stochastic effects,
      2) deterministic effects.

4. Indicate whether the following effects are stochastic (S) or deterministic (D)

Effect	*Exposure Causing the Effect*	*S or D*
Fatal car accident	Miles driven	
Heat stroke	Hours worked in hot environment	
Lung cancer	Number of cigarettes smoked	
Erythema (reddening of skin)	Exposure to the sun	
Killed in a fall	Parachuting	
Severity of injury in a fall	Height of fall	
Degree of intoxication	Volume of booze drunk	
Fatal aviation accident	Number of times flown	
Obesity	Food	
Hearing impairment	Listening to rock groups	
Pregnancy	Sex	
Death	Russian roulette	
Electrical burns	Electric current	
Full house in poker	Number of deals	
Hitting “a hole in 1”	Number of times you play golf	
Hereditary ill-health in your future children	Radiation exposure	

5. So far this year, Harvey Wallbanger has received whole-body doses of 2 mSv from natural background radiation, 30 mSv from medical tests and 15 mSv at work. What remaining dose is he allowed without exceeding his annual limit? Would the answer be the same for a woman? What if she is pregnant?

6. Explain in your own words what the symbols H_D, H_S, H_T, H_X, w_T, and H_{WB} stand for.

7. You must work in the following conditions for 1 hour

general gamma	150 μSv/h,
general beta	400 μSv/h,
general neutron	100 μSv/h,
tritium	40 μSv/h.

   (a) Which of the following whole body doses will you receive?
   250 μSv, 290 μSv, 400 μSv, 690 μSv.

   (b) Which of the following shallow doses will you receive?
   250 μSv, 290 μSv, 400 μSv, 690 μSv.

8. (a) This year Jadwani Jones has received deep dose of 8 mSv and shallow dose of 12 mSv. He has now been scheduled for some work which is expected to give him a daily gamma dose of 1 mSv, starting today. Today is Dec10 (I know it isn't, but I'm making up the question, not you). What is the last day he can work without exceeding any dose limits?

   (b) What if today were December 20?

9. So far this year you have received a total whole-body dose of 8.6 mSv. You are now going to receive the following doses:

beta	4 mSv,
gamma	3 mSv,
neutrons	1 mSv.

   After this, how much more H_{WB} will you be allowed to receive this year without exceeding any limits?

10. Geordie Hinney received the following doses last year:

H_D (gamma)	12 mSv,
H_X (beta, gamma)	31 mSv,
H_T (thyroid)	10 mSv,
H_S (beta, gamma)	25 mSv.

   What was his whole-body dose last year?

11. You are needed for a high radiation job. Based on a reliable radiation survey, it is estimated that you will receive the following doses:

beta	50.0 mSv
gamma	5.4 mSv
neutrons	1.4 mSv
tritium	3.6 mSv.

   Today is December 22. Your dose this year is: H_D = 6.0 mSv, H_S = 9.0 mSv.

   (a) How much whole-body and tissue dose will you receive from this job?
   (b) How much more H_{WB} and H_S will you be allowed to receive by the remainder of the calendar year?

12. A check valve in a purification system causes a gamma radiation field of 0.2 mSv/h at a nearby control panel. Each week, an Operator spends about half an hour at this control panel.
    (a) What annual dose could be saved by shielding the check valve?
    (b) It was decided to have the check valve completely shielded. Two Service Maintainers installed the lead shielding and the doses they picked up from this job were:

        Larry: H_D = 1.5 mSv, H_X = 16 mSv

        Vince: H_D = 2.2 mSv, H_X = 28 mSv.

        Was this an effective approach to minimising dose? Why or why not?

13. The terms "voluntary" and "involuntary" are often used to describe risk. Name two risks that could be considered as voluntary. How about two involuntary risks? Can you think of any activity at all that has zero risk? If you can, prove it to Laurie Comeau, and he will give you $20.

14. Risk can be defined as the probability of an event occurring times its severity or consequence if it does occur. Give an example of each of the following risks:
    (a) High probability and high consequence,
    (b) High probability and low consequence,
    (c) Low probability and high consequence,
    (d) Low probability and low consequence.
    (e) Use the idea of risk = probability x consequence to explain why major earthquakes and explosions have a very small effect on lost life expectancy compared with such things as drowning, suicide, or car accidents.