4 - DOSE LIMITS AND RISK

THE ICRP

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 organizations 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 reorganized in 1950. The name was changed to the **International Commission on Radiological Protection** — universally abbreviated to the ICRP. The Commission is composed of a chairman and not more than 12 members chosen on the basis of their recognized expertise in radiation protection and related fields, without regard to nationality. The ICRP is widely recognized today as the chief authority in protection from the harmful effects of ionizing radiation and has responsibility for presenting recommendations on all aspects of this subject. These recommendations usually are adopted without significant change by most countries and are incorporated into their laws.

In Canada, the **Atomic Energy Control Board (AECB)** is the Federal Regulatory Agency. The AECB bases its regulations on the recommendations made by the ICRP.

ICRP 26 and ICRP 60

The ICRP published an important document in 1977. It is ICRP Publication 26, known as ICRP 26, and it describes the ICRP system of dose limitation. A revision of ICRP 26 was published in 1991. This is called ICRP 60. Our Radiation Protection Program is based on the principles outlined in both of these reports. Throughout this book, the revised values of ICRP 60 are used. Those of you who have read a previous version of this book will notice some big changes in this chapter.

Before we get to the dose limits, it's worthwhile to introduce some of the concepts that are described in detail in ICRP 26.

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.

Chapter 3 dealt with the biological effects of radiation; they are classified as somatic and hereditary. The ICRP divides the somatic effects into **stochastic** or **non-stochastic** effects. Stochastic means "arising from chance; involving probability". It is worth quoting from ICRP 26:

> **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.**
>
> **NON-STOCHASTIC effects are those for which the severity of the effect varies with the dose, and for which a threshold may therefore occur.**

For example, 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 Fig. 3.8, page 119). 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 non-stochastic effect with a threshold value of around 8 Gy for chronic exposures (pages 131-132). ICRP 60 uses the term "deterministic" to replace "non-stochastic". We'll stick with what we're used to from ICRP 26.

Let's digress for a moment to give you a couple of everyday examples of non-stochastic 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. Compare this with winning a million bucks in a lottery; this is pure chance - the probability 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 pretty remote because I never buy any tickets.

To return to ICRP 26 again:

The aim of radiation protection should be to prevent detrimental non-stochastic effects and to limit the probability of stochastic effects to levels believed to be acceptable.

This is a most important objective. The non-stochastic effects can be prevented by setting annual dose limits low enough so that no threshold dose would ever be reached during a person's lifetime. The stochastic effects are limited by applying annual dose limits which, in ICRP 60 words, define the boundary line between unacceptable and tolerable, i.e., just tolerable. This is quite a big change from ICRP 26, which considered doses just below the limit to represent a level of risk that was no greater than the risks of other occupations with high standards of safety. By the end of this chapter, you'll be able to judge for yourself exactly what this means.

The main features of the ICRP recommendations are the following:

(a) No practice shall be adopted unless its introduction produces a positive net 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 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. On the other hand, the tiny levels of radiation in smoke detectors 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 in Chapter 7.

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

The AECB usually adopts the recommendations of the ICRP, and in 1984 they issued for public comment the first of several draft regulations based on ICRP 26. Comments were many and varied: the final version of the revised regulations never made it out of Ottawa before the AECB was behind the eight ball again with ICRP 60.

In NB Power, we've used the ICRP 26 approach right from the start, and we have now adopted the changes of ICRP 60 as well. Once the AECB eventually does its thing, the rest of the country will be following in our footsteps.

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. To keep it simple, from now on we'll use "dose" to mean equivalent dose (mSv), not absorbed dose (mGy), unless clearly stated otherwise.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 Atomic Radiation Workers (ARWs).

ATOMIC RADIATION WORKERS are people who may be routinely exposed to ionizing radiation as a result of their occupation.

As mentioned before, the dose limits are intended to prevent non-stochastic 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 non-stochastic effects. Indeed, there are.

LIMITS FOR STOCHASTIC EFFECTS

The whole-body dose limit given in ICRP 26 was 50 mSv a year. This limit has been reduced in ICRP 60, which reads as follows:

> *"...results indicate that a regular annual dose of 50 mSv, corresponding to a lifetime dose of 2.4 Sv, is probably too high, and would be regarded by many as clearly so."*

and

> *"...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 shall describe them one at a time.

External whole-body doses (from neutron or gamma radiation) are assessed by determining the dose in tissue at a depth of 1 cm. We call this **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. This will be very different from H_D for exposures to external beta radiation, which exposes the skin but not the deeper tissues. If you have received only gamma or neutron radiation, H_D and H_S should be the same.

O.K. That takes care of whole-body 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 an ARW who has received a whole-body dose, H_D, of 10 mSv from external gamma radiation and, in addition, a tissue dose, 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, w_T**, by which doses to tissue must be multiplied to arrive at a whole-body dose with a risk comparable to the tissue dose.

In our example, Joe ARW 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 50x0.05=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 $\mathbf{H_W}$).

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

where H_W = weighted dose.
w_T = tissue weighting factor
H_T = tissue dose

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 $\mathbf{H_{WB}}$.

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,

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

<u>It is this value of H_{WB} to which the dose limit of 20 mSv applies.</u>

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 hereditary effects. The weighting factors are listed below. We don't expect you to remember them, but we do expect you to understand how they are used. Some of you will notice that more tissues are listed now than before, and that most of the weighting factors have changed a bit.

TABLE 4.1. 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

These weighting factors apply to both sexes and all ages. The sum of the weighting factors = 1.0. This has to 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 $H_T = 1$, the sum of the w_T must also be 1.

The high value of 0.20 for the gonads allows for the fact that the hereditary risk is about 20% of the total risk. The Remainder includes nine other organs not listed above. If you are craving to know which they are and how you deal with them, read ICRP 60 or ask someone from Health Physics.

The remainder doesn't include the extremities (hands, forearms, feet, ankles), the lens of the eye, and the skin. No stochastic effects are found for the extremities and the eye lens, and their limits are set by the threshold values for non-stochastic effects. The same applies for the skin, for which stochastic effects are very unlikely as indicated by the very small weighting factor of 0.01.

Skin doses that are more than a couple of percent above whole-body doses are very rare at Point Lepreau. We have decided not to multiply the excess skin dose by 0.01 to add it to your effective whole-body dose, because normally we'd be looking at additions of a few µSv to annual whole-body doses of several mSv. It just isn't worth the effort, especially when you consider that we can't measure the doses received by your TLD badge to better than ± 10%. In special cases of skin dose much greater than the deep dose, we'd include the $H_T w_T$ for the skin in the effective whole-body dose, H_{WB}.

In practice, almost all exposure to radiation at a nuclear plant is wholebody exposure from gamma and neutron radiation and tritium. Since we started up in 1983, we've found doses to individual tissues (lung and stomach) on about half a dozen occasions — and they were very small doses. We expect a few people to get extremity exposures, 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 number-crunching is all done by the lads in the Health Physics Department, and entered into your dose records.

LIMITS FOR NON-STOCHASTIC EFFECTS

Non-stochastic effects should be prevented. ICRP believes that they will be prevented if we adhere to the H_{WB} limit described above. There are only three exceptions, i.e., three non-stochastic limits not covered by this scheme:

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_T = 100 mSv over 5 years (i.e., an average of 20 mSv/y) is the stochastic limit for the whole body,

and H_T = the non-stochastic limit: 500 mSv/y for skin and extremities, and 150 mSv/y for the lens of the eye.

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

Example 1

Jim has received the following doses in one year:

H_D (external, whole body) = 8 mSv
H_S (external, skin) = 20 mSv
H_T (internal, lung) = 10 mSv
H_T (internal, thyroid) = 30 mSv

Jim'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.

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

Remember, we don't include the skin's weighted dose for the reasons given on page 4-6 ($H_T w_T$ is only 0.2mSv). The skin dose of 20 mSv is subject only to the 500 mSv/year limit for non-stochastic 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?

$$
\begin{aligned}
H_{WB} &= H_D + \text{sum of all } H_T w_T \\
&= H_D + H_T w_T\ (\text{tritium}) + H_T w_T\ (\text{thyroid}) \\
&= 4.6 + (8.7 \times 1^*) + (30 \times 0.05)\ \text{mSv} \\
&= 4.6 + 8.7 + 1.5\ \text{mSv} \\
&= \underline{14.8\ \text{mSv}}
\end{aligned}
$$

* w_T for tritium is 1.0 because all tissues are exposed, i.e., the sum of all the $H_T w_T$ in Table 4.1 is just H_T. Therefore, any tritium exposure is merely an H_D exposure. H_X is ignored, because there are no stochastic effects for extremity exposures.

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. Add to this the extremity dose H_X = 12.2 mSv to get 25.5 mSv. Since the limit is 500 mSv for the extremities, that leaves 474.5 mSv to go.

In practice, gamma and tritium exposures should always cause the H_{WB} limit to be approached before any non-stochastic 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 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. For all nuclear stations, the AECB has approved the following interpretation:

The H_{WB} limit applies to an EQUIVALENT CALENDAR YEAR (ECY), which is a period of time equal to a calendar year starting on a specific date.

We use four ECY start dates: January 1, April 1, July 1, and October 1. Each one of these is allocated to roughly one quarter of the people in each work group that does radiation work. For example, if your ECY starts on July 1, you are normally permitted to accumulate a maximum whole-body dose of 20 mSv from July 1 until the next June 30. The same thing applies for the non-stochastic limits of 500 mSv a year. Note that the ECY start dates are only approximate; the actual start date is the beginning of the nearest two-week monitoring period.

The advantage of the ECY approach is that it will ensure that some members of any one work group will not have accumulated much dose at the time it may be needed for unplanned maintenance work in high radiation fields.

ICRP 60 "... 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 a single year."

I imagine that the AECB will support this recommendation, and not hold us to 20 mSv in every year. The complete set of limits is given below. These limits will become part of Canadian Law, once the AECB overcomes the legal red tape to make it happen. This could take a while.

TABLE 4.2. DOSE LIMITS

	ARWs	Non-ARWs
Stochastic Limits (Effective Whole-Body Dose)	20 mSv per year, averaged over a period of 5 years, with no more than 50 mSv in any one year.	1 mSv per year
Non-Stochastic Limits		
the lens of the eye	150 mSv	15 mSv
the skin	500 mSv	50 mSv
extremities	500 mSv	-

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 20 mSv an administrative limit for each ECY — to exceed it, you'll need approval from the Station Health Physicist himself.

3. Female workers who are known to be pregnant are limited to 2 mSv of whole-body dose for the remainder of the pregnancy, because the foetus is very sensitive to radiation. We don't allow any radiation work for pregnant women: if you are one, tell your supervisor, so that you can be reassigned to another job, if necessary.

4. Those of you who've been around for earlier rounds of this course may wonder what happened to the quarterly limits. They're history. So are the old 500 mSv individual tissue limits. With the new limits, ICRP sees no need for them.

Finally, some comments on dose limits for people who are not ARWs. 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.

Operating data from our first eight years at Point Lepreau show that the maximum dose to the local people is about 1 μSv/y. This is 0.1% of the limit; trivial compared with the background radiation dose (see p. 3-12).

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 frightening*, 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. (* 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.)

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.

Atomic Radiation 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 if they are spending most of their time on New Brunswick's roads, you can count on a fair amount of stress as well.

ACUTE RADIATION RISK

The acute radiation risk in the nuclear power industry is virtually zero. Although 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, there have been no deaths yet due to radiation in approximately 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. Most of our emphasis can therefore be 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 Atomic Radiation 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 ARWs 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. At the time of writing (Feb '91), we've been operating Point Lepreau for about eight years. 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 lost life expectancy. Bear with me, and you'll get the drift.

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 a hundred, or one chance in 12,500. If we write the risk as a fraction, it is an annual risk of 1/12,500. 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. Well, is that safe or isn't it?

Let's take another well-known risk statistic and put it into the same format so that we can compare it. For example, in New Brunswick the risk of dying in a traffic accident is 4E-8 for every mile you drive (1983 data). 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 1.6/0.04 or 40 times greater than the hourly radiation risk at work.

Instead, if we want to 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 shift at Point Lepreau. The fatal traffic accident risk connected with this is twice 1.6E-6, or 3.2E-6 for driving there and back.

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.

LOST LIFE EXPECTANCY

Lost Life Expectancy (LLE) is another popular way of expressing risk. Let's assume that you work 45 years (20 to 65) as an ARW 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 are one of the unlucky 0.36 percenters, 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 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 realize that the 20 days is an average to represent the LLE of all the ARWs 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., like a lottery.

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 calculate the LLE from driving to work every day:

We've already worked out the daily risk from driving there 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 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.

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.

I think the idea of LLEs 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.

A CATALOGUE OF RISKS

Bob Wilson, once known as the Director of Health and Safety at Ontario Hydro (or as the Oatmeal Savage to the guys who worked for him), looked at accident data in Canadian industry (1967 - 1976). His results are shown in Table 4.3. Mining, forestry and fishing are dangerous jobs. Even within any one particular industry, there are large variations in the occupational risks for the different jobs. For example, look at the Ontario Hydro risk data, for the same 10 year period, shown in Table 4.4 for the more hazardous jobs.

TABLE 4.3. RISKS OF CANADIAN INDUSTRIES (1967 - 1976)

Industry	Hours of Work for 1 in a Million Risk	LLE (days)
Average all	14.0	70
Mining	1.5	660
Forestry	1.7	580
Fishing	2.3	430
Construction	4.9	200
Transport	6.6	150
Public admin.	16.0	62
Manufacturing	17.0	58
Agriculture	37.0	27
Trade	37.0	27
Service	53.0	19
Finance	125.0	8

You might think that if you had a very safe job (can you name some?) you'd avoid most of the risk in life. Unfortunately, this isn't true. Everything you do has some risk attached to it. For instance, there are dangers in all types of travel, but there are dangers in staying at home — 40% of all fatal accidents occur there.

TABLE 4.4. ONTARIO HYDRO RISKS (1967 - 1976)

Occupation	Hours of Work for 1 in a Million Risk	LLE (days)
Utility average	10.0	100
Linemen	1.1	900
Handymen	3.6	270
Electricians	10.0	100
Riggers	10.0	100
Foresters	10.0	100
Mechanics, Fitters	17.0	60

Professor Bernard L. Cohen of the University of Pittsburgh has analyzed U.S. risk data for all kinds of activities. Most of the information in Table 4.5 is taken from his superb book, "The Nuclear Energy Option — An Alternative for the 90s", Plenum Press, 1990.

This is fascinating reading. If the anti-nukes are getting to you, this book is the ammunition you need. Why not get your local library to invest in a few copies and perhaps some of his ideas will spread. Let's hope so.

TABLE 4.5. LLEs IN THE U.S. DUE TO VARIOUS RISKS

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

* Asterisks indicate averages over the whole U.S. population; others refer only to those exposed.

Table 4.5 shows that the risks associated with radiation are not proportional to the amount of screaming and yelling 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 an ARW 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 again.

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 4.5, you can see that in most cases this isn't happening. And that doesn't make sense.

Risks arise on all sorts of occasions, as is shown by this reprint from Yachting Monthly of an incident that actually happened. The ship's captain said that he was anxious for the owners to receive his report before the press got to hear of it, because he was sure that they would "overdramatise the affair".

It was dark when the ship reached the river entrance and picked up her pilot. An apprentice was sent to take the 'G' flag down. It was his first trip and he was not very bright and he couldn't roll up the flag properly. The Captain on the bridge saw the mess he was making and walked over to show him how. He first folded the flag in half, then bid the lad hold the two corners while he proceeded to roll. 'Let go', he said to the lad when the roll was complete. But the lad held on. The Captain lost his patience. 'Let go!' he shouted, and that's when the trouble began.

The First Mate, inside the Chartroom, unaware of what was happening outside, heard the Captain's cry, left his chart, picked up the megaphone and ran outside. 'Let go!' he shouted to the Third Mate with the anchor party forward. The ship was travelling at harbour full speed at the time, the anchor had not yet been 'walked out'. It was uncommon to let go an anchor in such circumstances ...unless it was an emergency. The Third Mate did as he was bid.

The noise of the screeching chain deafened the countermands, sparks and dust filled the air. Neither the windlass brake nor ultimately the bitter end fitting could check the cable. Soon the entire run, plus fitting, was over the side.

At the side of the river was a tributary spanned by a swinging bridge. The sheering action of the anchor caused the ship to career madly towards this. With great presence of mind, the bridge operator swung open his bridge just in time to let the ship through. He did not, unfortunately, have time to halt the oncoming traffic, and as the ship shot into the narrow canal, a farm lorry, a car and two cyclists dropped on to the deck. The farm lorry was full of pigs.

In an effort to arrest the ship's progress, the Third Mate, on his own initiative, decided to drop the starboard anchor... belatedly on the bridge operator's cabin.

Another attempt to bring the ship to a halt, this time by her Captain, had even worse results. He rang 'emergency full astern' just as a tug was racing up behind to take the vessel's towing spring. The ship stopped, the tug didn't. She was mortally holed by the ship's churning propellers. Then, just as the tug's crew were being rescued, as the bridge operator was being brought stunned from his cabin, and as the pigs began foraging on the foredeck, the entire location was plunged into sudden darkness. The dragging anchor had severed the cable which carried the town's electricity supply.

SUMMARY

The ICRP is a renowned international organization which publishes recommendations on radiation protection. In Canada, the Atomic Energy Control Board is the Federal Regulatory Agency. Its regulations very closely follow the recommendations of the ICRP.

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

Stochastic effects are those arising from chance: the greater the dose, the more likely the effect. Non-stochastic 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 4.1. You needn't memorize them, but you should understand their purpose.

The limit for non-stochastic effects for the skin and the extremities is 500 mSv/year; for the eye lens it is 150 mSv/year.

The ECY is a period of 52 consecutive weeks starting on or near January 1, April 1, July 1 or October 1.

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

PROBLEMS

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

2. Separate annual dose limits are set for stochastic and non-stochastic 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 ARWs working at Point Lepreau?

3. Are the following effects stochastic or non-stochastic? In each case the effect is followed by the exposure that could cause it.
   (a) Erythema; exposure to the sun.
   (b) Fatal lung cancer; smoking.
   (c) Serious hereditary ill-health in your future children; radiation exposure.
   (d) Killed in a car accident; miles driven.
   (e) Killed in a fall; parachuting.
   (f) Severity of injury; height of fall.
   (g) Degree of intoxication; volume of booze drunk
   (h) Electrical burns; electric current.
   (i) Full house in poker; number of deals.
   (j) Obesity; food.
   (k) Hearing impairment; listening to rock groups.
   (l) Death; Russian roulette.
   (m) Pregnancy; sex.

4. Jadwani Jones has an ECY starting on July 1. Today is June 18 (I know it isn't, but I'm making up the question, not you). JJ's total dose received so far in his ECY is as follows:

   $$H_D = 8 \text{ mSv}, \; H_S = 12 \text{ mSv}$$

   He has now been scheduled for some work that is expected to give him a daily gamma dose of 1 mSv, starting today. What is the last day he can work without exceeding any dose limits. (For this and any other problems, the dose limits to be used are those listed in Table 4.2.)

5. So far in his current ECY, 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 ECY limit? Would the answer be the same for a woman? What if she is pregnant?

6. So far in this ECY you have received a total whole-body dose of 8.6 mSv. You are now going to receive the following exposures:

beta	4 mSv
gamma	3 mSv
neutrons	1 mSv

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

7. 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 for that year?

8. 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.

Your ECY date is October 1. Today is October 22. Your dose since October 1 is: $H_D = 6.0$ mSv, $H_S = 9.0$ mSv.

(a) How much whole-body and shallow 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 (December 31)?

(c) And how much more for the rest of the ECY?

9. A check valve in a purification system causes a gamma radiation field of 0.2 mGy/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 minimizing dose? Why or why not?

10. 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 me, and John Paciga will give you $10.

11. Risk can be defined as the probability of an event occurring times its severity if it does occur. Use this idea 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.