2. **THE PRINCIPLES OF RADIOLOGICAL PROTECTION**

2.1 International Recommendations

17. Many controlled discharges of wastes with low levels of radioactivity are made routinely to the environment. These discharges come from a range of human activities including nuclear power facilities, hospitals and research laboratories, and industries that process materials that are incidentally radioactive by virtue of their content of natural radionuclides. These discharges are limited through application of internationally agreed radiological protection principles and criteria.

18. Ionising radiation can cause health effects. At the doses of interest in this report, induction of fatal cancer is the health effect of most concern. Recommendations for the protection of people from the harmful effects of ionising radiation are made by the Interational Commission on Radiological Protection (ICRP). This was established by the Second International Congress on Radiology in 1928, following emerging findings about the health effects of ionising radiation. Originally it had the name of the X-ray and Radium Protection Committee but in 1950 it was restructured and acquired its present name. The Commission is a non-governmental body of experts. ICRP's latest recommendations for a system of radiological protection were published as ICRP Publication 60 in 1991 (ICRP 1991).

19. The available evidence supports the assumption that there is no threshold of dose below which there is no probability of causing health effects. An assumption underlying the ICRP Recommendations is that for small increases in dose above the dose from natural radiation sources, the increment in risk is proportional to the increment in dose with no threshold. This is the so-called 'linear no-threshold' assumption. Thus, standards and recommendations are based on limiting by all reasonable means the risk of health effects but not of eliminating that risk entirely. The primary aim of radiological- protection, as stated by ICRP, is to provide an appropriate standard of protection for mankind without unduly limiting the beneficial practices giving rise to the radiation exposure.

20. The recommendations made by ICRP form a basis for the European Basic Safety Standards (EC, 1996), which are mandatory within the European Union, and for the International Basic Safety Standards which are issued under the auspices of a number of international agencies, primarily the Intemational Atomic Energy Agency (IAEA 1996).

21. There are two categories of radiation dose. The first category is the dose[2] to an individual. The unit of radiation dose is the sievert (Sv). This is a large unit and doses are usually reported in millisieverts (mSv), one thousandth of a sievert, or microsieverts (μSv), one millionth of a sievert. From the 'linear no threshold' assumption, the health risk to an individual from ionising radiation is directly proportional to the dose. The second category is the sum of the doses to all the individuals in an exposed population. This is called the collective dose; the unit of collective dose is the mansievert

2 In this report, the term 'dose' refers to effective dose as defined in ICRP Publication 60.

(manSv). It can be shown from the linear no-threshold assumption that the number of radiation-induced health effects (in this context, usually the number of fatal cancers) in an exposed population is in proportion to the collective dose. The proportionality factor between a dose of radiation and the corresponding risk to health is termed the risk factor. The value of the risk factor depends, amongst other things, upon the age of the person receiving the dose. ICRP recommends a risk factor of 0 05 per Sv for fatal cancer for general application in the radiological protection of the general public. It is an average value for a population of all ages. This risk factor means that the risk of death from cancer from a dose of 100 mSv (0.1 Sv) to an average individual would be 0.005 or 1 in 200. Similarly, the statistical number of fatal cancers predicted due to collective dose of 100 manSv would be around 5.

22. The system of radiological protection distinguishes two broad categories of situations: practices and interventions. Practices are human activities that add doses to those people already receiving. Industries discharging radionuclides to the environment could be practices as the discharges cause doses to some individuals over and above those that they would normally incur from natural radiation. A distinguishing feature of practices is that they are undertaken as a matter of choice for some beneficial reason. The benefit should be sufficient to offset not only the costs and other inconveniences caused by the operation of the practice, but also of the detriment from the attributable radiation exposure. Steps taken to control doses from practices are planned in advance and are applied to the source of the exposure. Interventions are human activities that reduce the doses that people are receiving, or are likely to receive, from existing situations, the presence of which is not a matter of choice. The actions taken to reduce doses normally have to be applied in the environment and can involve, for example, relocation of people or taking measures to prevent the consumption of particular foodstuffs. Intervention reduces doses from situations that are regarded as unsatisfactory from a radiological protection viewpoint. An example of intervention is the actions taken during an accidental release of radionuclides in order to reduce the doses to people from the accident. Another example is the remedial action taken in some homes to reduce doses from the naturally occurring gas radon. The generation of electricity using nuclear power is a practice and the system of protection for practices applies. Therefore, the remainder of this section focuses on this system.

23. ICRP defines practices as "those human activities that increase overall exposure to radiation [by] introducing whole new blocks of sources, pathways and individuals, or by modifying the network of pathways from existing sources to man and thus increasing the exposure of individuals or the number of individuals exposed (ICRP 1991, pare 106)". Emphasis is on the control of the source of exposure and this can generally be planned for before commencing the practice.

24: The system of radiological protection recommended by ICRP for proposed and continuing practices has the following principles:

(i) No practice involving exposures to radiation should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes. **(The justification of a practice.)**

(ii) In relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be received should all be kept as low as reasonably achievable, economic and social factors being taken into account. This procedure should be constrained by restrictions on the doses to individuals (dose constraints), or the risks to individuals in the case of potential exposures (risk constraints), so as to limit the inequity likely to result from the inherent economic and social judgements. **(The optimisation of protection.)**

(iii) The exposure of individuals resulting from the combination of all the relevant practices should be subject to dose limits, or to some control of risk in the case of potential exposures. These are aimed at ensuring that no individual is exposed to radiation risks that are judged to be unacceptable from these practices in any normal circumstances. Not all sources are susceptible to control by action at the source and it is necessary to specify the sources to be included as relevant before selecting a dose limit. **(Individual dose and risk limits.)**

25. In simpler terms, these principles may be phrased as follows: Radiation can cause harm and therefore any intended use should be worthwhile (Justification) and, this being the case, all reasonable steps should be taken to reduce exposures (Optimisation). Doses and risks from uses of radiation should be kept within pre-defined limits or constraints (dose and risk limitation) - obviously, this principle does not apply to sources which cannot be controlled. In applying this system, it is the additional dose over and above that incurred from the natural background radiation that is taken into account. The world-wide average annual individual dose from natural radiation is 2.4 mSv.

2.2 Application of System of Protection for Practices

26. ICRP has divided exposures into three categories: occupational, medical and public. There can be differences in the application of the system of protection to these different categories. Occupational exposures are those incurred at work as the result of situations that can reasonably be regarded as the responsibility of the operating management. Exposures to natural sources at work may also require consideration in some situations. Medical exposure is confined to exposures incurred by individuals as part of their diagnosis and treatment and to exposures other than occupational incurred knowingly and willingly by individuals helping in the comfort and support of patients undergoing diagnosis and treatment. Public exposure encompasses all exposures other than occupational and medical from sources under control. Occupational and public exposures are relevant to this report.

27. The justification of a practice such as nuclear power requires that there should be an overall positive net benefit. The doses and risks from the disposal of wastes will be some of the many factors that are taken into account in this decision. However, ICRP considers that the management and disposal of the radioactive wastes arising from a practice does not require justification in its own right (ICRP 1997). Furthermore, radiation detriment, which is reflected in the individual and collective doses, may be only a small part of the overall detriment from the introduction of a practice. Consequently, the decision regarding whether a practice should be considered justified is likely to invoke factors that go far beyond radiological protection.

28. The process of optimisation of protection is broadly intended to ensure that the resources expended in reducing radiation detriment, ie, in reducing individual and collective doses, are not disproportionate to the benefits gained. In optimising protection it is important that all relevant aspects of radiation detriment are considered. For example, one option for the management of liquid radioactive wastes might be treatment to extract some fraction of the radionuclide content prior to release to the environment. The extracted radionuclides will require storing and eventually, disposal; the doses to workers and members of the public from these operations will be factors in the optimisation decision. There are various procedures available for optimisation of protection. Many of these procedures involve comparing reductions in the numbers of health effects in the exposed population with the resources required in order to achieve that reduction. Radiological protection is optimised when the next step in reducing the health effects can only be achieved by a seriously disproportionate use of resources. The health impact is usually estimated from the collective dose.

29. Evaluating the collective dose to the workers is relatively straightforward. However, particular problems can arise concerning both the estimation of collective doses to members of the public and their meaning. One issue is that a collective dose to an exposed population of members of the public is often the result of the summation of very small individual doses to very large numbers of people. Thus, although the resultant collective dose may be numerically large, from the perspective of the individual, the risks from the exposure may be insignificant. Further issues arise because collective doses from releases of long-lived radionuclides to the environment can be delivered over very long time periods. Both the magnitude of the individual doses and the size of the exposed population become increasingly uncertain as the time increases. Another factor is that current judgements about the relationship between a radiation dose and the consequent health effects (see the first section) may not be valid for future generations. For these reasons, ICRP has recommended that, generally "forecasts of collective dose over periods longer than several thousands of years and forecasts of health detriment over periods longer than several hundred years should be examined critically" (ICRP 1997).

30. The process of optimisation is subject to constraints on the level of individual dose delivered by the source for which protection is being optimised. For example, an option for the management of radioactive waste that could result in a dose to a worker or a member of the public that is likely to exceed the appropriate value of the constraint should be rejected and alternatives investigated. The constraint helps to prevent individuals receiving inequitable levels of dose; its chosen value should take account of the levels of dose likely to be incurred in well-managed operations. Different dose constraints could be set for different practices, sources or operations. ICRP did not recommend any values for dose constraints in its 1990 recommendations but, subsequently, it has recommended an upper value for the dose constraint for members of the public of 0.3 mSv y-1 (ICRP 1997). Values for dose constraints for use in optimising situations involving occupational exposure have not, as yet, been recommended by ICRP.

31. The remaining principle is compliance with dose limits. There are different limits for members of the public and for workers. The principal dose limit for members of the public is 1 mSv in a year although higher doses may be allowed in some years, provided the five-year average does not exceed 1 mSv in a year. The limit applies to the total dose from all sources, subject to control through the system of protection for practices: medical exposures and exposures to natural radiation are excluded. For occupational exposure, ICRP recommends a dose limit of 20 mSv per year averaged over 5 years, with the further provision that the effective dose should-not exceed 50 mSv in any single year. These limits apply to the sum of the exposures incurred at work as a result of situations that can reasonably be regarded as the responsibility of the operating management. In the case of both public and occupational exposure, there are additional limits on doses to the lens of the eye and the skin and, in the case of occupational exposure only, on the doses to the hands and feet. The internationally recommended dose limits are given in Table 1.

Table 1: Recommended dose limits

	Dose limits	
Application	Occupational	Public
Effective dose	20 mSv per year, averaged over defined periods of 5 years	1 mSv in a year
Annual equivalent dose in the lens of the eye	150 mSv	15 mSv
the skin	500 mSv	50 mSv
the hands and feet	500 mSv	-

32. Dose limits should be distinguished from constraints. Dose constraints are source-related and are applied prospectively in order to establish whether a proposal involving radioactivity is broadly acceptable, whereas dose limits are applied retrospectively to verify that an appropriate level of protection for the public is being provided. For comparison with limits, doses are usually assessed, at least partly, on the basis of measurements of radionuclide concentrations or dose rates in the environment.

33. The international recommendations and standards place limits and constraints on doses to individuals; there are no corresponding criteria for collective doses. The main use of the quantity collective dose is in comparing the numbers of health effects from different sources of radioactivity, and for different radiation protection options, during the process of optimisation of radiological protection.

34. In applying limits and constraints, it is not practicable to assess doses to each individual member of the public. The critical group approach is used in order to arrive at an estimate of the likely dose to the most exposed individual. A critical group is a group of members of the public who, by virtue of location and habits, is expected to receive the highest doses from the source in question. The group is usually relatively small in size and usually comprises a few to a few tens of individuals; the average individual dose in the group is compared with the constraint or limit.

35. The system of protection for practices as described above requires amendment before it can be applied to the disposal of long-lived solid radioactive waste such as high level wastes from reprocessing and spent nuclear fuel. This is because releases of radionuclides into man's environment from such disposals may occur many thousands of years into the future. This introduces large uncertainties into estimates of critical group doses. These uncertainties arise, at least in part, from the fact that future events and processes can have a considerable influence on the magnitude of future doses. Nevertheless, an important principle in radioactive waste management is that future generations should be protected to the same extent as are present generations (IAEA 1995). This implies the use of radiological protection criteria based on present day experience but modified to take account of future uncertainties.

36. From our present day perspective, events and processes may have probabilities of occurrence associated with them ranging from the likely to the very unlikely. Future sequences of events having similar radiological consequences and other similar features are sometimes grouped together in a scenario. In the light of this, in 1986, ICRP issued recommendations for radiological protection criteria for the disposal of long-lived radioactive wastes. These criteria included a dose limit on the

annual dose from the most likely future scenario and a risk limit on less likely scenarios where risk is broadly defined as

The probability of receiving a dose x the probability that that dose will give rise to a health effect

37. These risks are summed to a critical group over scenarios, as appropriate. Recently, ICRP has clarified and expanded its recommendations for the disposal of long-lived radioactive waste (ICRP 77). ICRP emphasises that estimates of doses or risks to individuals and populations at times longer than several hundreds of years into the future should be regarded as indicators of safety rather than predictions of what the actual doses may be.

38. In comparing options for the management of radioactive wastes, it is important to recognise that it is the differences between the options that should form the basis for comparison. Although a quantitative comparison can still be difficult if there are temporal and spatial differences between the radiological impacts delivered by different options. However, when comparing options which deliver doses to future populations, the analysis can be truncated at the point where the uncertainties obscure differences between the options.

2.3 Regulatory Practice

39. Competent national regulatory authorities develop regulatory requirements, such as discharge limits, based on the ICRP recommendations.

40. In accordance with national regulation, operators will apply for construction permits and operating licenses with sufficiently detailed safety assessment reports. These reports usually contain detailed descriptions of site and plant characteristics, operating conditions, estimated radioactive release, estimated radiological impacts, models used to evaluate the impacts and measures to comply with the regulatory requirements.

41. The competent regulatory authorities review the operator's safety assessment report and issue permit or license. Whenever necessary, the authorities may attach specific conditions to the permit or license.

42. When the plant subsequently begins operation, the operator shall comply with regulatory requirements and implement its own monitoring programme to ensure that the plant is operated within the requirements. Local or national competent bodies also implement independent monitoring programme.

2.4 The Environment

43. The need to allow specifically for the potential impact of ionising radiations on the environment as a result of releases of radioactive wastes into it has, for a long time, been subsumed into statements made by the ICRP. In its Publication 26 (ICRP 1977) the Commission stated that:

> *"Although the principal objective of radiation protection is the achievement and maintenance of appropriately safe conditions for activities involving human exposure, the level of safety required for the protection of all human individuals is thought likely to*

be adequate to protect other species, although not necessarily individual members of those species. The Commission therefore believes that if man is adequately protected then other living things are also likely to be sufficiently protected. "

44. More recently (ICRP 1991) the Commission has stated that, although its environmental interests are solely concerned with the transfer of radionuclides through the environment, since this directly affects the radiological protection of man, nevertheless:

"The Commission believes that the standard of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk. Occasionally, individual members of non-human species might be harmed, but not to the extent of endangering whole species or creating imbalance between species "

45. Much of the current emphasis behind environmental protection in the case of <u>non-radioactive</u> pollutants is based on the premise that, in order to protect and sustain the human species, it is first necessary to protect the environment. It has been pointed out that this is the opposite of the framework used for radiological protection, and that there has never been an internationally agreed set of criteria for the protection of the natural environment from the effects of ionising radiations (Pentreath 1998). Some of the criteria that might be considered within an overall theoretical framework, what is still required to achieve them, and what the practical implications are from a regulatory perspective, have recently been explored (Pentreath 1998; Pentreath 1999; Woodhead 1998).

46. A review published by the IAEA (IAEA 1992) concluded that there was, at that stage, no convincing evidence from the scientific literature that chronic radiation dose rates below I milligray/day would harm animal or plant populations, and that it was highly probable that limitation of the exposure of the most exposed humans (the critical group) living on and receiving full sustenance from the local area, to 1 millisievert/year would lead to dose rates to plants and animals in the same area of less than 1 milligray/day. (In terms of units, one should note that it is generally not appropriate to use the Sievert for species other than humans, and that the Gray should be used).

47. More recently, from extensive reviews of the available data, it has been concluded (UNSCEAR 1996, Woodhead 1998) that under continuing lifetime irradiation there are unlikely to be any significant effects in wild populations of either terrestrial plants and aquatic organisms (freshwater, coastal marine and deep ocean) at absorbed dose rates less than 400 micrograylhour, or of terrestrial animals at absorbed dose rates less than 40 microgray/hour, from all sources. In each case, the limiting dose rates from the contamination relate to the most highly exposed individuals in the populations in the expectation that the mean dose rates across the populations would be lower in a majority of situations. There is also the qualification that the limiting dose rates relate to exposures from low LET radiation.

48. Further consideration is currently being given to this subject internationally, in particular through the activities of the ICRP and the IAEA. It must be recognised, however, that any framework and criteria specifically for the protection of the environment from ionising radiation are currently at the stage of development rather than implementation. In these circumstances, the basis of the present