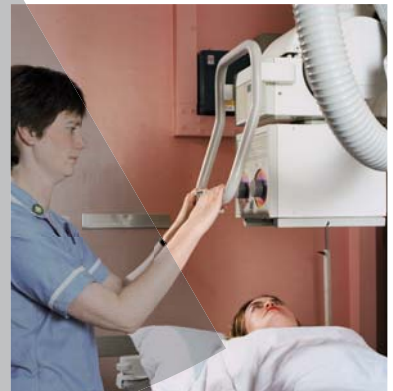
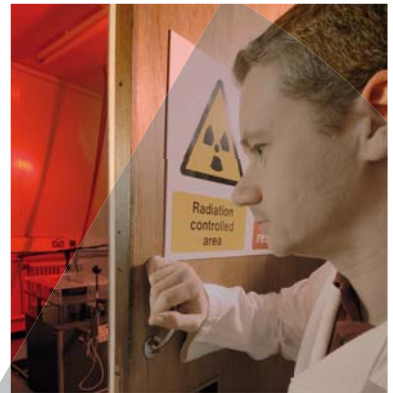


# Application of the 2007 Recommendations of the ICRP to the UK

Advice from the Health Protection Agency





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# Contents

<b>Application of the 2007 Recommendations of the ICRP to the UK</b>		
Advice from the Health Protection Agency		1
1	Introduction	3
2	Background	4
2.1	Summary of changes to the ICRP recommendations	4
3	Biological Basis for the 2007 Recommendations of the ICRP	7
3.1	Deterministic effects (tissue reactions)	7
3.2	Cancer	8
3.3	Heritable effects	9
3.4	Nominal risk coefficients	10
3.5	Genetic susceptibility	11
3.6	Non-cancer diseases	11
3.7	Effects in the embryo and fetus	12
3.8	Interaction between radiation and other agents	12
4	Dosimetry	13
4.1	Radiation weighting factors	14
4.2	Tissue weighting factors	16
4.3	Calculation of effective dose	17
4.4	Doses from external exposures	19
4.5	Doses from internal exposures	20
4.6	Collective dose	22
5	ICRP System of Protection	25
5.1	Categories of exposure	25
5.2	Types of exposure situation	26
5.3	Definition of a source	27
5.4	Principles of protection	28
5.5	Dose limits, constraints and reference levels	32
5.6	Medical exposure of patients, comforters and carers and volunteers in biomedical research	36
6	Application of the ICRP System of Protection	40
6.1	Planned exposure situations	40
6.2	Emergency exposure situations	46
6.3	Existing exposure situations	55
7	Conclusions	63
8	Acknowledgements	64
9	References	65



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## Advice from the Health Protection Agency

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### Abstract

The Health Protection Agency (HPA) advises UK bodies with responsibility for protection against radiation on the applicability to the UK of recommendations issued by the International Commission on Radiological Protection (ICRP). After a consultation process lasting several years, the ICRP issued new recommendations for a system of radiological protection in 2007. These recommendations replace the previous recommendations issued in 1991.

Following a period of public consultation, the HPA has developed this advice on the application of the new ICRP recommendations to the UK. The HPA welcomes the ICRP recommendations, which represent an update, consolidation and development on the previous recommendations. Overall, they do not imply any major changes to the system of protection applied in the UK.





# 1 Introduction

A function of the Health Protection Agency (HPA) is the provision of information and advice on radiological protection of the community (or any part of the community) from risks connected with radiation. This function is inherited from one of the predecessor organisations of the HPA – the National Radiological Protection Board (NRPB). The NRPB specifically advised UK bodies with responsibility for protection against radiation on the applicability to the UK of recommendations issued by the International Commission on Radiological Protection (ICRP). The HPA is continuing with this function and, following public consultation in 2008, has developed the following advice on the applicability to the UK of the 2007 recommendations of the ICRP (ICRP, 2007a). The HPA response to the comments received during the consultation is given elsewhere (Cooper et al, 2009).

This HPA response to the 2007 recommendations is structured as follows. Section 2 provides background on the ICRP recommendations, summarising the key differences between the new recommendations and the previous recommendations. Section 3 addresses the biological basis for the recommendations, Section 4 discusses dosimetric aspects and Section 5 addresses the system of protection. Issues related to implementation of the system are discussed in Section 6.

For the first time the ICRP has considered the protection of the environment explicitly in its recommendations. This is outside the remit of the HPA unless any issues related to protection of the environment also impact on public health.

## 2 Background

After a consultation process lasting several years, in 2007 the ICRP issued new recommendations for a system of radiological protection in Publication 103 (ICRP, 2007a). These recommendations replace the previous recommendations published in 1991 as the 1990 recommendations of the ICRP (ICRP, 1991a).

The aims stated by the ICRP in undertaking this revision were:

- a to take account of new biological and physical information and of trends in the setting of radiation safety standards,
- b to improve and streamline the presentation of the recommendations.

### 2.1 Summary of changes to the ICRP recommendations

In this section the main points of the 2007 recommendations are compared with those of the 1990 recommendations. Further details on these points are given in subsequent sections of this report.

#### 2.1.1 Biological effects

In both sets of recommendations, the ICRP recognises two categories of health effects from radiation\* exposure.

- a **Effects which have a threshold above which the severity of the effect is related to radiation dose** These effects are referred to as deterministic effects in the 1990 recommendations and either deterministic effects or harmful tissue reactions in the 2007 recommendations. The introduction of the term ‘tissue reaction’ does not mark any change in the understanding of such effects but rather is intended as a descriptive aid.
- b **Effects with no threshold for which the probability of occurrence, but not severity, is related to dose** These effects, which continue to be termed stochastic effects, are the induction of cancer and the induction of heritable effects.

The body of information on the health effects of radiation has expanded since 1990 but there are few significant changes to the qualitative understanding of such effects. It remains the case that deterministic effects are not expected to occur at absorbed doses less than about 100 mGy. The ICRP has acknowledged, however, that forthcoming data on radiosensitivity of the eye may indicate that its

\* The term ‘radiation’ in this document refers to ionising radiation.

currently quoted threshold value for cataract induction is too high. These data will be considered by the ICRP when available.

The ICRP continues to maintain that for radiological protection purposes a linear non-threshold dose–response model is appropriate for estimating stochastic effects at effective doses below 100 mSv. The risk factor (risk per unit dose) used for fatal and non-fatal cancer is substantially unchanged between the 1990 and 2007 recommendations. The risk of breast cancer is judged to be greater than previously estimated and the risk of heritable disease is judged to be lower than estimated before.

Since 1990, evidence has emerged for the induction of circulatory disorders by radiation at absorbed doses above 500 mGy. Currently there is no agreed scientific basis for extrapolation of such risks to lower doses. The ICRP does not, therefore, recommend the inclusion of these non-cancer diseases in the calculation of radiation detriment\*.

### 2.1.2 Dosimetry

The dosimetric system is essentially unchanged. There are, however, a few changes to some of the factors used in the calculation of the ICRP protection quantities, equivalent dose and effective dose. The radiation weighting factor for protons is decreased from 5 (in the 1990 recommendations) to 2 (in the 2007 recommendations) and is also applied to charged pions. The factor for neutrons is represented as a revised continuous function of neutron energy, replacing the previous continuous function and without an alternative step function since this has not been used in practice.

There have been a number of changes to values of tissue weighting factors used in the derivation of the quantity effective dose. The main changes are a reduction in the value for the gonads, reflecting current understanding of heritable risk, and an increase in the value for the breast, reflecting increased knowledge. There is also an improved procedure for dealing with remainder tissues. Other developments include the adoption of defined male and female phantoms for use in dose calculation, and the explicit averaging of equivalent doses to males and females in the calculation of effective dose.

### 2.1.3 System of protection

The fundamental principles of radiological protection – justification, optimisation and application of dose limits – remain the same and the dose limits are unchanged. The ICRP has, however, made some changes to the structure and terminology of the system of protection in order to improve clarity and utility.

The 1990 recommendations subdivided the system of protection into ‘practices’ and ‘interventions’. *Practices* are where radiation exposures and risks are being added to the prevailing levels, such as during the operation of nuclear power stations. *Interventions* are where radiation exposures and risks are being

\* Radiation detriment is a concept used to quantify the harmful effects of radiation exposure in different parts of the body. It is defined by the ICRP as a function of several factors, including incidence of radiation-induced cancer and heritable effects, lethality of these conditions, quality of life and years of life lost owing to these conditions.

reduced, such as during actions taken to reduce existing radon exposures. The system of protection is applied somewhat differently in the two cases.

The 2007 recommendations identify a core system of protection – justification and optimisation – which should be applied to any situation of radiation exposure. The ICRP has divided exposure situations into three types, namely: *planned exposure situations* which involve the deliberate, legitimate introduction and operation of sources; *existing exposure situations* which are situations where exposures already exist when a decision on protection has to be taken; and *emergency exposure situations* which require urgent action to avoid or reduce undesirable exposures. These three types of situation encompass the entire range of plausible exposure situations. The ICRP now emphasises that optimisation with restrictions should be universally applied prospectively in these situations, when a decision on radiological protection is being taken. These restrictions are termed constraints for planned exposure situations and reference levels for existing and emergency exposure situations. Constraints and reference levels are important as they mark a boundary between acceptable and unacceptable protective options. The value selected for the constraint or reference level will be dependent upon the characteristics of the exposure situation under consideration. Guidance is given by the ICRP on the selection of the value for a constraint or reference level in these three types of exposure situation. Dose limits continue to be applied to sources subject to regulatory control, which are a subset of planned exposure situations.

The main implications of this change from practices and interventions to the three types of exposure situations occur in the area of emergency exposure situations. In the 1990 recommendations these situations were regarded as interventions with optimisation considering mainly the magnitude of the reduction in projected doses. In the 2007 recommendations application of optimisation with reference levels places additional emphasis on the level of dose remaining after action has been taken; the intention of emergency planning should be to select protective options that will result in a residual dose below the value of the reference level.

Additionally, the ICRP has recognised the need for stability in international and national regulations and has maintained as much stability in the recommendations as is consistent with new scientific information and societal expectations.

# 3 Biological Basis for the 2007 Recommendations of the ICRP

The 2007 recommendations of the ICRP summarise the judgements and recommended policies on the biological effects of radiation exposure and the health risks associated with such exposures (ICRP, 2007a). The treatment of biological issues is structured around the major classes of recognised health effect of radiation – deterministic effects (harmful tissue reactions) and stochastic effects (cancer and heritable effects) with consideration being given to non-cancer diseases, the impact of genetic susceptibility and exposure *in utero*.

## 3.1 Deterministic effects (tissue reactions)

Having reviewed the available data, the ICRP recommends no changes in dose limits for specific tissues and it remains the case that at absorbed doses below 100 mGy of high or low LET radiation\*, no deterministic tissue injury is expected. The ICRP notes that new data on risks to the eye may become available and expects to provide further recommendations on protection of the eye in 2010.

The HPA agrees with the ICRP judgements on radiation-induced tissue injury. However, it is noted that data incompatible with the judgements on risk to the eye are now available from studies of Chernobyl clean-up workers (Worgul et al, 2007) and the Japanese atomic-bomb survivors (Neriishi et al, 2007), in addition to earlier analyses cited by the ICRP. The HPA has conducted a review of the effects of radiation on the eye, concluding that the lens of the eye is more sensitive than is assumed in the ICRP recommendations (Ainsbury et al, 2009).

The ICRP has undertaken to explore risk to the eye and the HPA is supportive of this initiative. Pending the outcome of the ICRP review of effects on the eye, the annual dose limits for the eye recommended by the ICRP for planned exposure situations appear to be satisfactory (15 mSv for members of the public and 150 mSv for workers). However, in considering other exposure situations, the HPA wishes to highlight the possibility that cataracts may develop at absorbed doses below the threshold of 1.5 Gy given by the ICRP. The HPA will comment on recommendations made by the ICRP on protection of the eye.

\* Linear energy transfer (LET): the average amount of energy lost per unit track length. Low LET is characteristic of electrons, X-rays and gamma rays; high LET is characteristic of alpha particles and neutrons.

## 3.2 Cancer

The ICRP maintains that for radiological protection purposes a 'linear non-threshold' (LNT) dose–response model is appropriate for the projection of risk at acute or annual doses below 100 mSv (effective dose\*).

The HPA agrees that the LNT model remains the best justified model for setting radiological protection standards and criteria and provides an approach that will continue to encourage justification and optimisation. Furthermore, the HPA suggests that above 100 mSv and up to 500 mSv, effective dose may be used for practical radiological protection purposes, although the results should be treated with some caution. Above 500 mSv deterministic effects may become more important for some tissues.

The ICRP notes that there remains some uncertainty on the processes that contribute to or modulate radiation tumorigenesis. Further, the ICRP notes that there has been and remains significant interest in the potential impact of phenomena such as genomic instability, bystander signalling and adaptive response.

The HPA agrees that knowledge and understanding of these and other processes is insufficiently developed to prompt any change in approach to cancer risk estimation. As noted by the ICRP, human epidemiological studies remain the primary source of quantitative risk data and all contributing processes should be accounted for adequately. However, some uncertainties remain on the mechanisms operating at low doses and the associated risks.

The ICRP estimates of cancer risks are based mainly on new data on cancer incidence from the Life Span Study (LSS) of Japanese atomic-bomb survivors (Preston et al, 2007). These incidence data, which were not available at the time of the 1990 recommendations, should provide more accurate information on cancer diagnoses when compared with mortality data. Whilst information is available from epidemiological studies of other radiation-exposed groups, the LSS is particularly valuable in estimating radiation risks, because of the very long follow-up, the large size of the cohort and the inclusion of people of all ages and both sexes who received a wide range of doses. The estimates of cancer incidence from this study are broadly compatible with those from studies of populations with medical and occupational radiation exposures.

The HPA agrees with the ICRP approach of relying primarily upon the atomic-bomb survivor LSS supplemented by other data for the calculation of cancer risk coefficients.

\* If unqualified, it should be assumed that in this report 'dose' refers to 'effective dose'.

It is argued by the ICRP that the Dose and Dose Rate Effectiveness Factor (DDREF), used in the calculation of risks at low or chronic exposures from high dose data, cannot be precisely calculated at present and that the recommended value of 2 is compatible with other recent estimates, notably the estimate of 1.5 presented by the BEIR VII Committee (2006).

The HPA agrees that a value of 2 remains a reasonable estimate of DDREF and that any more precise estimate would be incompatible with the generalised approach adopted by the ICRP for radiological protection purposes. The HPA notes that recent findings from the UK National Registry for Radiation Workers (Muirhead et al, 2009) provide more evidence in favour of a value of DDREF for all cancers other than leukaemia that is less than 2 rather than greater than 2, although the latter possibility cannot be ruled out; the corresponding data for leukaemia are in line with a value of DDREF of 2. The HPA also notes that a working party of the ICRP is currently reviewing information on DDREF and the HPA will continue to monitor developments.

### 3.3 Heritable effects

The ICRP notes that there remains no direct evidence from human epidemiological studies of heritable effects of radiation exposure and justifies the inclusion of a component of heritable risk in detriment estimates on the basis of the observed mutational effects in experimental animals. An explicit and scientifically justified approach to estimation of heritable risk is used by the ICRP. This change is welcomed by the HPA. The move to extend estimates of heritable risk over two generations rather than, as previously, to equilibrium in the population is justified by the ICRP on the basis that this is not expected to lead to a significant underestimation of heritable effects as calculations indicate that the risk projected over ten generations is not substantially different from that projected over two generations (see ICRP, 2007a: Annex A, and UNSCEAR, 2001). The overall impact of the new method of calculation is a reduction in the contribution of heritable effects to radiation detriment (see Table 3.1).

**TABLE 3.1 Detriment-adjusted nominal risk coefficients for stochastic effects after exposure to radiation at low doses or low dose rates ( $10^{-2} \text{ Sv}^{-1}$ ), based on an average across Asian and European-American populations (from ICRP, 1991a, 2007a)**

Exposed population	Cancer		Heritable effects		Total	
	ICRP 2007	ICRP 1990	ICRP 2007	ICRP 1990	ICRP 2007	ICRP 1990
Whole	5.5	6.0	0.2	1.3	5.7	7.3
Adult	4.1	4.8	0.1	0.8	4.2	5.6

The HPA agrees that it is still not possible to estimate risks of heritable disease from human epidemiological studies and endorses the new methods for estimating heritable disease risks. The HPA wishes to note that scientific expertise in the calculation of heritable risk is very scarce and the ICRP may encounter difficulties in revising estimates of heritable risk in the future. Mutation data from repeat sequences such as minisatellites now provide some direct evidence for human germline mutation by radiation. This evidence may increase in the future and could impact on estimation of heritable disease risk.

### 3.4 Nominal risk coefficients

The ICRP argues that its nominal risk coefficients should apply to whole populations and not to individuals. It is noted by the ICRP that differences exist in risks to males and females and that age-at-exposure can also have an impact on risk. While presenting risk data specific for females and males, sex- and age-averaged risk coefficients continue to be recommended. Discussion of ICRP judgements on the radiation weighting factors ( $w_R$ ) and tissue weighting factors ( $w_T$ ) used to calculate equivalent and effective dose can be found in Section 4. The recommended risk coefficient values are presented in Table 3.1 alongside the previously recommended values from the 1990 recommendations (ICRP, 1991a).

The HPA agrees that the approach adopted by the ICRP is appropriate within a system of radiological protection. However, it is clear that there is now a level of precision in risk estimates for certain population subgroups be they defined by sex, age or other factors and this is likely to increase. Therefore there will be situations where population subgroup risk coefficients will be more useful – for example, in estimating risk to individuals after specific known exposures. Nonetheless, the HPA agrees that a simple set of averaged risk coefficients is appropriate for regulatory purposes and general usage in radiological protection. For other purposes, such as calculating probability of causation for an individual or known population, the HPA agrees with the ICRP view that more specific data should be used. The independent Advisory Group on Ionising Radiation (AGIR) published estimates of leukaemia risk for a UK population in 2003 (AGIR, 2003). The AGIR is preparing a report on risk estimates for solid cancers in a UK population; see the HPA website ([www.hpa.org.uk](http://www.hpa.org.uk)).

Due largely to the change in method for the calculation of the risk of heritable effects, the detriment-adjusted nominal risk coefficients have reduced somewhat. The ICRP points out that this drop is not significant and should not justify any increase in exposure. This is particularly true in the case of the gonads; although hereditary risk estimates are smaller now, the HPA does not consider that this justifies any reduction in protection of these organs.

For the first time cancer incidence rather than mortality data are used in risk coefficient calculation. Given the uncertainties discussed in Annex A of the 2007 recommendations, the ICRP recommends that a value of 5% per Sv is used as the approximate overall fatal risk coefficient. This risk coefficient is wholly compatible with that presented by the ICRP in its 1990 recommendations.



The HPA agrees with the ICRP conclusion that the small difference in the estimate of nominal risk since 1990 is of no practical significance.

### 3.5 Genetic susceptibility

On the issue of whether genetic susceptibility might influence estimates of radiation risk, the ICRP argues that strongly acting genetic modifiers of cancer risk are too rare in the population to have a significant impact. Further, it is judged that the impact of weak genetic risk modifiers is too uncertain to be taken into account at present.

The HPA agrees with these population-based judgements and notes that the existing human genetic variation in disease risk should, to some extent, be accounted for in the range of risk coefficient values calculated from human epidemiological data. However, as noted in Publication 79 (ICRP, 1999), there are possible implications for radiation cancer risk in individual carriers of strongly acting genetic modifiers, particularly those receiving high dose medical exposures.

### 3.6 Non-cancer diseases

The ICRP notes that some studies, particularly the atomic-bomb survivor LSS (Preston et al, 2003), have identified an increased mortality and/or incidence for non-cancer diseases in irradiated populations. These are mainly circulatory, respiratory or digestive disease. The ICRP judges that, while evidence for increased mortality from these diseases is good at absorbed doses of several gray (Gy) or more, there are uncertainties in the shape of the dose–response at low doses and the LSS data are consistent both with there being no dose threshold for risks of disease mortality and with a threshold of around 0.5 Sv. On this basis the ICRP does not recommend the inclusion of non-cancer disease risk into calculations of nominal risk coefficients for stochastic effects.

The HPA agrees with this position in relation to radiological protection at normal levels of exposure. However, it is likely that further data will emerge, both epidemiological and mechanistic, that may impact upon these judgements – for example, from analyses of radiation workers in the UK (McGeoghegan et al, 2008; Muirhead et al, 2009) and at the Mayak nuclear plant in Russia (Azizova and Muirhead, 2009). The HPA will keep this situation under review.

### 3.7 Effects in the embryo and fetus

The 2007 recommendations note that the human embryo and fetus present a special case for protection. In the absorbed dose range below 100 mGy lethality and malformations are unlikely and the impact on IQ should be low. Given the limitations of the available data, no specific estimate was made of lifetime cancer risk following *in utero* exposure, but the conclusion was reached that the risk is no greater than that following exposure in early childhood, at most a few times greater than to the population as a whole. It was also concluded that the available data were insufficient to delineate cancer risks in different organs and tissues.

The HPA agrees with these points. In particular, it notes that new findings for the Japanese atomic-bomb survivors support the idea that the lifetime cancer risk following *in utero* exposure is no greater than that following exposure in early childhood (Preston et al, 2008). However, given the highly dynamic nature of development, *in utero* risk to specific tissues is highly unlikely to be uniform at all gestational ages. Risks of specific cancers can be expected to vary substantially during fetal development and similarity to risks following exposure in early childhood should be seen as an approximation relating to overall risk. Nonetheless the HPA endorses the approach that, in the absence of further evidence, for protection purposes the age- and sex-averaged tissue weighting factors used for postnatal exposures should be applied also to prenatal exposures.

### 3.8 Interaction between radiation and other agents

The ICRP states that there is insufficient evidence for interaction between radiation and other agents to justify modification of low dose risk estimates.

The HPA agrees that there is insufficient information available to justify modification of risk estimates due to interactions with other agents in general, although there is sound evidence for an interaction between tobacco smoke and radon exposure in the causation of lung cancer (eg Darby et al, 2005). However, there are few data from other epidemiological studies that can be used to distinguish radiation risk to smokers and non-smokers. Therefore the HPA agrees that it is currently inappropriate to develop radiation risk coefficients that apply specifically to smokers and non-smokers or that incorporate other modification factors to account for exposures to other agents.

## 4 Dosimetry

The principal quantities recommended by the ICRP for use in radiological protection continue to be:

- a the mean absorbed dose in an organ or tissue,  $D_T$ , given in terms of energy absorbed per unit mass (joules per kilogram,  $\text{J kg}^{-1}$ ), and units of gray (Gy),
- b the equivalent dose in an organ or tissue,  $H_T$ , obtained by weighting absorbed dose using defined radiation weighting factors,  $w_R$ , to take account of the relative effectiveness of different radiation types, per unit absorbed dose, in causing stochastic effects at low doses. The equivalent dose,  $H_T$ , in tissue or organ  $T$  is given by

$$H_T = \sum_R w_R D_{T,R}$$

where  $w_R$  is the radiation weighting factor for radiation  $R$ , and  $D_{T,R}$  is the mean absorbed dose in organ or tissue  $T$  from radiation  $R$ ,

- c the effective dose,  $E$ , obtained as the sum of equivalent doses to each organ or tissue, weighted using defined tissue weighting factors,  $w_T$ , to take account of the contribution of the individual organs and tissues to overall detriment from cancer and hereditary effects is given by

$$\begin{aligned} E &= \sum_T w_T H_T \\ &= \sum_T w_T \sum_R w_R D_{T,R} \end{aligned}$$

where  $H_T$  is the equivalent dose in tissue or organ,  $T$ ,  $w_T$  is the weighting factor for tissue  $T$  and  $\sum w_T = 1$ .

The use of effective dose allows the summation of doses from intakes of different radionuclides and from external sources and comparison with dose limits, constraints, etc, that relate to whole-body radiation exposure. Equivalent and effective doses from intakes of radionuclides are commonly integrated over a 50-year period for adults and to age 70 years for children and the resulting values are referred to as committed effective dose. While the units of equivalent and effective dose are  $\text{J kg}^{-1}$ , they are given the special name sievert (Sv) to distinguish these ICRP protection quantities from the scientifically defined quantity, absorbed dose (Gy).

The HPA continues to endorse the use of the ICRP protection quantities for radiological protection purposes. It is noted that they were devised to allow doses from different internal emitters and external radiation to be summed for comparison with limits, constraints and optimised levels that relate to whole-body exposure. Individuals may be exposed externally and internally to radiation of different qualities (eg photons, neutrons and alpha particles) and the spatial and temporal distributions of doses delivered from internal emitters may differ widely. The ICRP scheme provides a highly convenient method for the summation of all such doses for protection purposes, but it is important to recognise that simplifying assumptions are made in these calculations and the results can only be regarded as providing an approximate measure/indication of risks to individuals.

The ICRP has made some changes to values of radiation weighting factors and tissue weighting factors and the calculation of effective dose; these are referred to below (Sections 4.1 and 4.2). This is followed by further consideration of the use of effective dose (Section 4.3) and of dose assessments for external and internal exposures (Sections 4.4 and 4.5).

## 4.1 Radiation weighting factors

The radiation weighting factors now recommended by the ICRP are compared with those previously recommended in Table 4.1.

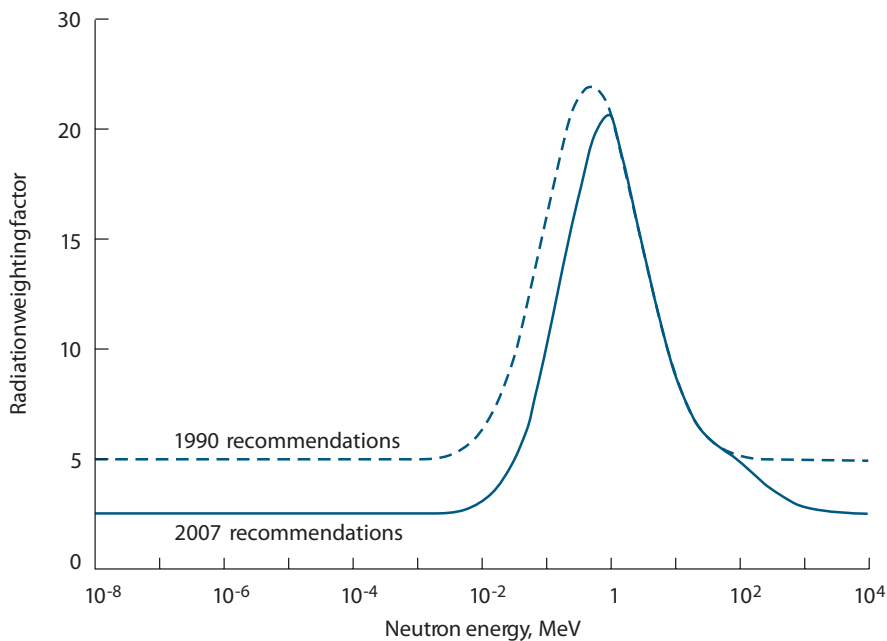
**TABLE 4.1 ICRP recommended radiation weighting factors (ICRP, 1991a, 2007a)**

Radiation type	Radiation weighting factor, $w_r$	
	ICRP 2007	ICRP 1990
Photons	1	1
Electrons and muons	1	1
Protons and charged pions	2	5*
Alpha particles, fission fragments and heavy ions	20	20
Neutrons	Revised continuous function of neutron energy	Step and continuous functions of neutron energy

\* Pions were not considered.

The changes in radiation weighting factors introduced for neutrons and protons do not reflect the availability of additional data but rather a reconsideration of appropriate treatment of radiation weighting for protection purposes. Protons are of principal concern as part of the radiation fields experienced by aircrew and astronauts. Since such exposures are largely to high energy protons (above 100 MeV) with low LET (linear energy transfer), it is considered reasonable to use a single  $w_R$  value of 2. The abandonment of a step function for neutron  $w_R$  as a function of energy is a reflection of the fact that in practice only a continuous function was used. The major change in the continuous function is a lower  $w_R$  value at low energies which more properly reflects the low LET contribution from secondary photons. In addition, there are good theoretical reasons for assuming that  $w_R$  values at high energies will converge with that for protons (see the figure). The introduction of a  $w_R$  for charged pions will have a small impact on effective dose in the space environment and also around high energy accelerators.

**FIGURE Comparison of the ICRP recommended continuous energy functions for the radiation weighting factor for neutrons (ICRP, 1991a, 2007a)**



It has been argued (eg Edwards, 2003) that the ICRP treatment of radiation weighting exhibits inconsistencies, is unnecessarily complex for protection purposes, and over-interprets the available biological data. Thus, the use of a single value of 1 for all low LET radiations appears inconsistent with the use of a complex energy function for neutron  $w_R$  which relies upon physical considerations as well as relative biological effectiveness (RBE) data. A simple and consistent scheme might apply a  $w_R$  of 10 to

the high LET component of neutron dose and to alpha particles and 1 to all other radiations. However, it is recognised that an important consideration in the case of neutron exposures is the relationship between effective dose and measurements made using operational quantities. As discussed below, this relationship is improved by the revised energy function for neutron  $w_R$  and, in particular, the operational quantity,  $H_p(10)$ , will not now underestimate effective dose across a range of neutron energies.

The HPA welcomes the detailed explanation provided by the ICRP on the background to the choice of  $w_R$  values, accepts the basis for the revised energy function for neutrons and the change to a value of 2 for protons, and endorses the continued use of values of 1 for low LET radiations and 20 for alpha particles.

The Advisory Group on Ionising Radiation (AGIR) has issued a report on doses and risks from intakes of tritium, as tritiated water or as organically-bound tritium (eg as may be present in food) (AGIR, 2007). The recommendation was made that an RBE value of 2 should be used for tritium in epidemiological studies and in individual retrospective risk assessments. The AGIR also suggested that consideration be given by the ICRP to the use of a radiation weighting factor of 2 for routine radiological protection. However, the AGIR also discussed differences in RBE between other low LET radiations, including the recognition of experimental evidence that soft X-rays (eg as used in mammography) have RBE values compared to cobalt-60 gamma rays that are similar to those for tritium beta particles. The ICRP position is that the complexity of considering such differences is not warranted for the purposes of the protection system.

The HPA considers that further increases in complexity in the calculation of equivalent and effective dose are undesirable and inconsistent with their intended use (see Section 4.3). Specifically, a  $w_R$  of 1 should continue to be applied for tritium.

## 4.2 Tissue weighting factors

The tissue weighting factors now recommended by the ICRP are listed in Table 4.2.

The values of some of the tissue weighting factors have been changed from those in the 1990 recommendations on the basis of better knowledge of the radiosensitivity of the tissues (see Section 2). The main changes are a reduction of the value of the tissue weighting factor for the gonads from 0.20 to 0.08, an increase from 0.05 to 0.12 for the breast, and the inclusion of more tissues in the remainder group. The basis for the changes in estimates of risks of heritable effects and breast cancer are discussed in Section 2. Tissue weighting factors continue to represent averages across the sexes and across all ages (see Section 4.3). The change in treatment of remainder tissues is discussed below (see Section 4.5).

The HPA considers that these tissue weighting factors are appropriate for radiological protection purposes, based on current estimates of stochastic risks.

**TABLE 4.2 ICRP recommended tissue weighting factors,  $w_T$  (ICRP, 2007a)**

Tissue	$w_T$	$\sum w_T$
Bone marrow, breast, colon, lung, stomach and remainder tissues (13*)	0.12	0.72
Gonads	0.08	0.08
Bladder, oesophagus, liver and thyroid	0.04	0.16
Bone surface, brain, salivary glands and skin	0.01	0.04

\* Remainder tissues: adrenals, extrathoracic (ET) region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (male), small intestine, spleen, thymus and uterus/cervix (female).

### 4.3 Calculation of effective dose

An important change introduced in the 2007 recommendations is that doses from external and internal sources will be calculated using reference computational phantoms of the human body based on medical tomographic images, replacing the use of simplified mathematical models. For adults, equivalent doses will be calculated by averaging of values obtained using male and female phantoms. Effective dose coefficients will then be calculated using age- and sex-averaged revised tissue weighting factors, based on updated risk data and intended to apply as rounded values to a population of both sexes and all ages.

Thus, equivalent doses to organs and tissues,  $H_T$ , will be calculated separately for males and females and then averaged in the calculation of effective dose,  $E$ :

$$E = \sum_T w_T \left( \frac{H_T^M + H_T^F}{2} \right)$$

where  $H_T^M = \sum_R w_R D_{T,R}$  (male) and  $H_T^F = \sum_R w_R D_{T,R}$  (female)

It is made clear by the ICRP that effective dose is intended for use as a protection quantity on the basis of reference values and relates to reference persons rather than specific individuals. Sex-averaging in the calculation of equivalent and effective doses, implicit in the use of hermaphrodite mathematical phantoms, will become explicit in the averaging of equivalent doses to adult male and female phantoms. Sex- and age-averaging in the derivation of tissue weighting factors can be seen, from the information provided by the ICRP, to conceal differences in estimates of absolute radiation detriment between men and women and between adults and children.

The HPA supports the ICRP approach and maintains the view that practical protection would not be improved by calculating effective dose separately for males and females and that to do so might give a misleading impression of the precision of these quantities. Similar considerations apply to the possibility of more complex treatments of radiation weighting or effective doses for different age groups. The main uses of effective dose are in prospective dose assessment for planning and optimisation in radiological protection, and retrospective demonstration of compliance for regulatory purposes.

For normal dose assessment purposes, therefore, the HPA recommends that the most appropriate approach is to use equivalent and effective dose as defined by the ICRP. However, for estimates of dose and risk to individuals – for example, for the purposes of calculating the probability of cancer causation, best scientific information would be used, including appropriate RBE values and risk factors specific to those individuals. These are applications for which the ICRP protection quantities were not intended and for which the simplifications inherent in the use of radiation and tissue weighting factors are inappropriate.

It is noted that, particularly for medical applications, there may be a need for calculations that have the convenience of the approaches adopted by the ICRP but avoid some of the simplifications. The HPA is aware that the ICRP intends to provide further advice on the applicability of effective dose in different circumstances and will consider alternatives. The HPA is considering the specific needs of assessments applied to medical procedures and will provide advice that is informed by international developments.

Because ICRP dose coefficients are calculated as reference values, applying to reference persons, they are not regarded as subject to uncertainty. Thus, in general, point estimates of effective dose are used with no consideration of uncertainties. An exception may be occupational exposures in which uncertainties are assessed for the exposure conditions. In such a case, a range on assessed intake would result in a range on effective dose, calculated using reference dose coefficients. Similarly, uncertainties in effective doses to members of the public might be related to a probability distribution on concentrations of a radionuclide in a foodstuff, for example.

It is recognised, however, that there are uncertainties associated with all aspects of the estimation of doses and risks at low doses. Uncertainties in biokinetic models and their parameter values depend on the availability of reliable data and often include the applicability of animal data to humans. Dosimetric uncertainties include the treatment of source and target distributions within tissues for radionuclides with short-range emissions. RBE values are often difficult to assess from available animal and human data and the applicability of *in vitro* endpoints to cancer in humans may be questionable. Uncertainties in estimates of cancer risks include assumptions regarding the transfer of risks across populations, the validity of different risk models, the use of a dose and dose rate effectiveness factor (DDREF) and the use of a linear dose–response relationship at low doses. However, while estimates can be made of uncertainties in tissue doses, RBE and risk estimates, these cannot be translated simply into uncertainties in effective dose.



The HPA position on this subject is that an increased understanding of the various contributions to uncertainty is an important goal and estimates of uncertainties may help to inform judgements on the control of exposures. Consideration of uncertainty in effective dose, together with uncertainties in values of parameters used to assess effective dose including exposure scenarios, may be useful in assessments of the adequacy of monitoring programmes. However, for general protection purposes, the HPA endorses the ICRP approach of the use of reference dose and conversion coefficients with no routine assessment of uncertainties.

## 4.4 Doses from external exposures

The introduction by the ICRP of reference computational phantoms will lead to greater standardisation of dose calculations. Following completion of adult male and female phantoms, the ICRP will also develop reference phantoms for children of defined ages and for the pregnant woman and fetus. In general, it is expected that the use of the new phantoms will result in only small changes in effective dose, although equivalent doses to some organs and tissues could change substantially in some cases, particularly for lower energy photons.

Annex B of the 2007 recommendations provides an explanation of the relationship between the protection quantities, equivalent and effective dose, and the operational quantities used in the measurement of external exposures. For the control of effective dose, the operational quantities are ambient dose equivalent,  $H^*(10)$ , for area monitoring and personal dose equivalent,  $H_p(10)$ , for individual monitoring. In general, the operational quantities provide a conservative measure of effective dose. This is likely to remain the case for photons, although it is noted that this conservatism may be reduced in some cases, including the important example of the relatively high doses received by interventional radiologists and cardiologists using X-ray imaging techniques. For neutrons, there are currently circumstances in which the operational quantities underestimate effective dose. Using the revised energy function for radiation weighting factor introduced in the 2007 recommendations, the operational quantities are more reliably conservative. However, it is noted that there may still be circumstances in which effective dose may be underestimated, including the use of a personal dosimeter on the front of the torso in measurements of neutron exposures that include a large posterior–anterior component.

The operational quantities, directional dose equivalent,  $H'(0.07, \Omega)$ , and personal dose equivalent,  $H_p(0.07)$ , are used for monitoring low penetrating radiations, eg beta particles, and for the control of doses to the skin and the hands and feet. The ICRP has previously recommended that the operational quantities  $H'(3, \Omega)$  and  $H_p(3)$  are appropriate for assessing the dose to the lens of the eye. There have always been practical difficulties with this approach (for example, the lack of an accepted phantom and suitable conversion coefficients). Instead, the quantity  $H_p(0.07)$  is often used as a conservative estimator of  $H_p(3)$ , although for the rare cases where the dose from beta radiations is important, the overestimation of dose is substantial. The ICRP now suggests that the use of  $H'(3, \Omega)$

and  $H_p(3)$  be discontinued. However, for several reasons the HPA considers that it is advisable that they are retained.

Firstly, the accurate assessment of dose to the lens of the eye will become more important if the risk of cataracts at lower doses is assessed to be greater than previously thought (see Section 3.1). Secondly, as applications of beta radiations develop, eg in medicine, they may become more important in eye dosimetry, and it would be wise to have a suitable dose quantity available. Finally, conversion coefficients for  $H_p(3)$  have recently been produced (Ferrari et al, 2007) and, if these are widely adopted, operational difficulties will be significantly reduced.

The ICRP is due to publish new conversion coefficients giving equivalent doses and effective dose for neutrons, photons and electrons and also for protons, pions, muons and heavy ions.

The HPA endorses the continued use of the operational quantities,  $H^*(10)$ ,  $H_p(10)$ ,  $H'(0.07, \Omega)$  and  $H_p(0.07)$ , but also considers that  $H'(3, \Omega)$  and  $H_p(3)$  should be retained. The HPA recognises the efforts made by the ICRP to standardise and improve the measurement and interpretation of external exposures, including the introduction of reference phantoms and the revision of the energy function for neutron  $w_R$ . When the new conversion coefficients are available, the HPA will give further consideration to the relationship between the protection and operational quantities.

## 4.5 Doses from internal exposures

Following publication of the 2007 recommendations, the ICRP will provide revised dose coefficients for the ingestion and inhalation of radionuclides, giving values of committed equivalent doses and committed effective dose per becquerel (Bq) intake. In addition to changes to radiation and tissue weighting factors and the use of new reference phantoms, changes are being made to dosimetric and biokinetic models. A new alimentary tract model, issued as Publication 100 (ICRP, 2006a), will be used, and some updating of the Publication 66 respiratory tract model (ICRP, 1994) is planned. Skeletal dosimetry will be improved to take account of the macro- and micro-structure of individual bones and changes are being made regarding the location and dimensions of target regions for the induction of bone cancer and leukaemia. Improved biokinetic models will be adopted for the tissue distribution and retention of a number of elements and their radioisotopes. Because of the uncertain effect of the combination of these changes, it is difficult to predict the effect on dose coefficients for individual radionuclides. In most cases, changes in effective dose can be expected to be small, while changes in some equivalent doses will be larger. It might be argued that, for routine protection purposes relating to low dose exposures, the extent of the effort involved in improving methodology for internal dosimetry is not justified. It is noted, however, that the same methodology is also used to assess doses in situations where it is important to provide best estimates of absorbed or equivalent doses to organs and tissues, preferably with assessment of uncertainties. Such applications include epidemiological studies and dose

reconstruction in the determination of probability of causation. It is also important that the methodology employed can pass the test of pertinent scientific scrutiny (eg CERRIE, 2004).

Following the explanation of the use of the protection quantities given in the 2007 recommendations (see above), the ICRP intends to provide further advice that should include the application of dose coefficients for the embryo and fetus and the breastfed infant following radionuclide intakes by the mother, referred to collectively as offspring doses. The NRPB has given advice on the implications of dose coefficients for the embryo and fetus in the context of protection from both occupational and environmental exposures (NRPB, 2005). In Publication 101 the ICRP considered the application of dose coefficients for all age groups, including offspring dose coefficients, in the assessment of doses to the 'representative person' (ICRP, 2006b; see Section 5.5.2).

The HPA has given detailed advice on the treatment of offspring doses in different situations of environmental exposures, including emergencies (HPA, 2008). As a general point, the HPA welcomes the increased initiatives being taken by the ICRP to provide explanation of the intended application of its dose coefficients.

A specific issue of data interpretation arises in the retrospective assessment of 'dose of record' for occupational intakes of radionuclides. The ICRP states that the dose coefficients used in such calculations should be as published by the ICRP with no departure in anatomical, physiological and biokinetic characteristics from those of the 'reference male' and 'reference female'. If sufficient information is available and assessed doses warrant a detailed assessment, changes can be made to the assumed particle size distribution of an inhaled material and its solubility and absorption characteristics in the respiratory and alimentary tracts. Since such changes relate to exposure conditions in the workplace, it is appropriate to apply them in the estimation of intake and the calculation of effective dose. Examples of the use of material-specific data in the calculation of doses from inhaled radionuclides have been given by the ICRP (2002). However, the ICRP now explicitly rules out changes in biokinetic assumptions that relate to individuals in the calculation of effective dose.

Following an incident in a workplace, comprehensive bioassay data (eg urinary excretion and organ retention) may occasionally be obtained which cannot be fitted satisfactorily using standard ICRP models, with changes relating only to material-specific parameters. For example, to provide a good fit to data for lung clearance it might be necessary to vary rates for particle clearance (individual-specific) as well as absorption to blood (material-specific). A series of measurements of whole-body or organ retention (eg of tritiated water or caesium-137) may require consideration of individual-specific retention, rather than standard model assumptions, to provide a best estimate of intake and dose. Otherwise, in such circumstances, a different estimate of intake and dose might be calculated from each measurement. Given the complexity of the relationship between different biokinetic parameters, a pragmatic approach may be to allow experienced dosimetrists some flexibility on this issue, but with a clear requirement to justify their approach to dose assessment to the regulatory authority, bearing in mind that individual-specific dose estimates may be either lower or higher than reference calculations.

The HPA endorses the overall approach taken by the ICRP to the calculation and recording of effective dose to workers exposed to external sources of radiation and intakes of radionuclides. Thus, the recorded dose is the value of effective dose that the 'reference person' would register under the conditions of external exposure and radionuclide intake measured for the worker. In the interpretation of bioassay data relating to radionuclide intake, in most cases only reference model parameter values and the dose coefficients published by the ICRP will be used. At higher doses and when sufficient data are available, changes may be made relating to the exposure conditions, specifically to material-specific biokinetic parameter values. While changes to individual-specific biokinetic parameter values are not formally allowed by the ICRP in the calculation of effective dose, the HPA recognises the complex judgements that may be required in the interpretation of bioassay data and considers that some circumstances may justify such changes. The HPA view is that in rare cases of dose assessments based on extensive data, where doses justify a detailed analysis, a UK approved dosimetry service may agree approaches with the regulatory authority and advisory bodies such as the HPA. It is noted that the ICRP may provide further advice on this subject. The HPA agrees with the ICRP that there should be no requirement to recalculate previously recorded doses using revised dose coefficients. Current dose coefficients are to be used until new values are available and receive legislative endorsement.

## 4.6 Collective dose

The quantity collective effective dose,  $S$ , is calculated as the sum of all individual effective doses in the exposed population over the time period or during the operation being considered. The special name used for the collective effective dose quantity is the 'man sievert'. This summation relies upon the linear non-threshold (LNT) assumption (see Section 3.2). The ICRP notes that collective effective dose is an instrument for optimisation, for comparing radiological technologies and protection procedures, particularly for occupational exposures. The ICRP adds that the quantity is not intended as a tool for epidemiological studies and it is inappropriate for use in risk projections, particularly when very small doses to large numbers of people are being summed. The underlying biological and statistical uncertainties are cited as the reason for this position. In the 1990 recommendations (ICRP, 1991a) both collective equivalent dose and collective effective dose were introduced. Since the intended purpose of the collective quantities is to serve as an instrument of optimisation of protection, only collective effective dose is retained in the 2007 recommendations.

The HPA recognises the concerns of the ICRP over the use of collective effective dose and agrees that it is misleading to estimate health effects by multiplying the full collective effective dose, integrated to long times and over large populations, by a risk factor. In addition to the inevitable uncertainty in such calculated values for collective doses, it is difficult to put those health risks into context or to make

meaningful comparisons. However, the HPA considers that there can be situations other than as part of optimisation procedures where the estimation of health effects from collective effective doses could be useful. For example, they could be used to indicate whether a particular situation warrants a detailed epidemiological study. However, care should be used in comparing collective effective doses and associated health effects in different populations.

There may also be specific situations where collective equivalent dose to an organ or tissue may be relevant to the optimisation process. For example, if considering the release of a mix of radionuclides to the environment including isotopes of elements such as iodine, which gives rise to doses mainly to one specific organ, it may be useful to estimate collective doses to the particular organ, in this case the thyroid.

The ICRP recommends that when exposures occur over large populations, areas and time periods with the range of individual doses spanning several orders of magnitude, the distribution should be characterised by division into ranges of individual dose, each covering no more than two or three orders of magnitude, with population size, mean individual dose and uncertainty being considered separately for each range. There are problems in implementing this recommendation in the context of public exposure. When assessing collective effective doses to members of the public from releases of radionuclides to the environment, the ingestion of contaminated food is often an important exposure pathway. As it is not possible to know exactly where everyone obtains their food, collective effective doses from the ingestion pathway are generally based on the production of food and the distribution of individual doses is not known. It is, therefore, not usually possible to carry out the disaggregation of collective effective dose by range of individual doses as recommended by the ICRP. A European Union study considered collective effective doses for routine discharges (Smith et al, 2006). This study found that collective effective doses can be determined for population groups for limited geographical areas over various time periods as proposed by the ICRP. However, consideration of individual dose distributions within each population group is not possible if ingestion of food is an important exposure pathway. The study proposed that *per-caput* doses can be estimated corresponding to different group doses and that these could form a useful input to optimisation and option comparisons for decision making.

The concept of collective effective dose remains a useful tool in relation to operational radiological protection. In particular, it has an important role in the planning of complex work involving multiple workers. The HPA agrees that unqualified use of the aggregated quantity collective effective dose should be avoided where possible. More relevant information for decision making can be obtained by breaking down the total collective effective dose by geographical region and population groups (eg UK, Europe and the world). For members of the public, where it is not normally possible to break down the collective effective dose into individual dose bands, the use of *per-caput* doses may also form a useful input. Furthermore, in comparing options for the purposes of optimisation of protection, it is the differences between the options that are important not the absolute values. The HPA also continues to endorse the views previously expressed by the NRPB that

comparisons of process/disposal options should be based on truncated collective effective doses and that a period of 500 years is appropriate for this truncation. It is also noted that assessments of collective effective dose in the far future are uncertain in view of the uncertainties in, for example, the biosphere, human behaviour and population size. As a result, long-term (ie thousands of years into the future) collective effective dose is not considered to be a useful discriminator for solid waste disposal. The use of collective effective dose is considered further in Sections 5.4.2 and 6.1.1 on the application of the ICRP system of protection.

## 5 ICRP System of Protection

The ICRP now clearly states that the system of radiological protection applies in principle to all sources of radiation regardless of size and origin. However, it is recognised that it is inappropriate to treat all sources and exposures in the same way and with the same level of resources. The ICRP has defined two concepts to delineate the extent of radiological protection control for regulatory purposes. The first is the exclusion of certain exposure situations from legislation because they cannot be controlled by any reasonable means (for example, potassium-40 in the body or exposure to cosmic radiation at sea level). The second is the exemption from some or all radiological protection legislation for situations where such controls are felt to be unwarranted (for example, very low levels of radioactivity in building materials).

The HPA welcomes the fact that the ICRP now clearly states that its system of protection applies to all sources of exposure. The HPA also notes that the concepts of exclusion and exemption are well established and endorses their continued use in the UK.

It is noted that the concept of clearance of material containing radioactivity from regulatory control is not explicitly included in the 2007 recommendations (ICRP, 2007a). Clearance is a concept introduced by the Euratom Basic Safety Standards (EC, 1996) that specifically addresses the unwarranted regulation of disposal (including recycling and reuse) of waste materials with very low levels of radioactivity from a regulated site. The ICRP gives further guidance on exclusion and exemption in Publication 104 (ICRP, 2007b).

### 5.1 Categories of exposure

The ICRP continues to consider three main categories of exposure: occupational, public and medical exposures. These categories are defined as follows.

**Occupational exposure** is defined by the ICRP as all radiation exposures of workers incurred as a result of their work arising from situations that can reasonably be regarded as being the responsibility of the operating management.

**Public exposure** encompasses all exposures of the public from a source other than occupational and medical exposures.

**Medical exposure** includes the following:

- a exposures of individuals for diagnostic, interventional, and therapeutic purposes, including exposure of the embryo/fetus or infant during medical exposure of patients who are pregnant or breastfeeding,
- b exposures (other than occupational) incurred knowingly and willingly by individuals such as family and close friends helping either in hospital or at home in the support and comfort of patients undergoing diagnosis or treatment,
- c exposures incurred by volunteers as part of a programme of biomedical research that provides no direct benefit to the volunteers.

The distinction between the three categories of exposure (occupational, public and medical exposures) has proved useful. An important ICRP recommendation is that ‘no attempt be made to add the exposures to the same individual from the different categories of exposure for regulatory purposes’ (ICRP, 2007a: paragraph 171).

The HPA continues to endorse the use of the three exposure categories (public, occupational and medical exposures). Currently no attempt is made to add exposures to the same individual from the different categories of exposure. Continuation of this approach is recommended.

## 5.2 Types of exposure situation

The ICRP has introduced three types of exposure situations: planned, emergency and existing exposure situations which address all conceivable circumstances of radiation exposure. These are defined by the ICRP as follows.

**Planned exposure situations** are situations involving the deliberate introduction and operation of sources. Planned exposure situations may give rise both to exposures that are anticipated to occur (normal exposures) and to exposures that are not anticipated to occur (potential exposures).

**Emergency exposure situations** are situations that may occur during the operation of a planned exposure situation, or from a malicious act, or from any other unexpected situation and require urgent action in order to avoid or reduce undesirable consequences.

**Existing exposure situations** are situations that already exist when a decision on control has to be taken, including prolonged exposure situations after emergencies.

These three situations largely replace the previous categorisation into **practices** and **interventions** adopted in the 1990 recommendations (ICRP, 1991a). The ICRP notes, however, that the terms ‘practice’ and ‘intervention’ have become widely used in radiological protection. It will continue to use the term



practice to denote an activity that causes an increase in exposure or risk of exposure to radiation and to use the term intervention to describe protective actions taken to reduce exposures. The ICRP has clarified its use of the term practices stating ‘practices can be activities such as a business, trade, industry or any other productive activity; it can also be a government undertaking, or a charity. It is implicit in the concept of a practice that the radiation sources that it introduces or maintains can be controlled directly by action on the source’ (ICRP, 2007a).

**The HPA considers that the categorisation into the three types of exposure situations assists in application of the system to all circumstances of radiation exposure and is therefore welcome.**

In Section 6 these exposure situations are discussed in more detail in relation to the three categories of exposure. However, it is important to recognise that in radiological protection there will sometimes be situations which do not fit neatly into one of these exposure types or where there is overlap. This need not be a problem as the 2007 recommendations use the same basic approach for all exposure situations. However, it is noted that further guidance may be required in the future in relation to specific legislation and this is discussed further in Section 6. The ICRP continues to make the distinction between source-related considerations and individual-related considerations and this approach is followed in this document.

### 5.3 Definition of a source

The ICRP defines the term source ‘to indicate any physical entity or procedure that results in a potentially quantifiable radiation dose to a person or group of persons’ (ICRP, 2007a: paragraph 174). Defining a source is difficult and much depends on the context of the use of the term. As noted by the ICRP, it is important that the radiological protection policy is not distorted by either splitting up sources to avoid action or combining them to exaggerate the need for action. The ICRP advocates agreement on the definition of a source between regulatory authorities and users and notes that generally ‘the definition of a source will be linked to the selection of the relevant protection strategy’ (ICRP, 2007a: paragraph 175). This is consistent with the UK definition of a single new source, defined as ‘a facility or group of facilities, which can be optimised as an integral whole in terms of radioactive waste disposals’ (GB Parliament, 1995).

**The HPA considers that the current situation in the UK regarding defining sources is adequate and there is no need for change in this area.**

## 5.4 Principles of protection

The basic principles of radiological protection remain as follows, using the definitions in the 2007 recommendations.

**Justification** – ‘any decision that alters the radiation exposure situation should do more good than harm’. This principle applies to all exposure situations.

**Optimisation of protection** – ‘the likelihood of incurring exposures, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors’. This principle applies to all exposure situations.

**Dose limitation** – ‘the total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits recommended by the Commission’. This principle is individual related and applies in planned exposure situations only.

The HPA considers that these three basic principles of radiological protection have stood the test of time and should remain the basis for all international advice and UK legislation.

### 5.4.1 Justification

The justification principle applies to decisions altering the radiation exposure situation, either an increase or a decrease in exposure. Decisions leading to an increase in exposure generally concern planned exposure situations, specifically practices. The HPA considers that in this context, the principle of justification should generally be applied in a high-level decision on whether to adopt a new practice, eg a new use for radiation/radioactivity or a new process that generates radiation/radioactivity. The increase in radiation detriment should be explicitly considered in the decision-making process. Overall, there should be sufficient individual or societal benefit to compensate for the detriment from the exposure and the other consequences of the practice. Sometimes, as noted by the ICRP, the radiation detriment will be a small part of the total. The HPA cautions against applying the justification principle to individual components of a practice in isolation. In this context the HPA notes that the ICRP has stated that ‘Waste management and disposal operations are an integral part of the practice generating the waste. It is wrong to regard them as a free standing practice that needs its own justification. The waste management and disposal operations should therefore be included in the assessment of the justification of the practice generating the waste’ (ICRP, 1997a). The justification of practices is addressed in UK legislation (GB Parliament, 2004). Similarly, when introducing a protective strategy for reducing exposures that would otherwise be received in existing and emergency exposure situations, the anticipated benefits achieved by the strategy should be expected to outweigh the detriment from the averted radiation exposure and the individual and societal harms inevitably associated with the strategy itself.

The ICRP considers that certain exposures should be deemed to be unjustified without further analysis, unless there are exceptional circumstances. These include the following groups of exposures (ICRP, 2007a: paragraph 210):

- a increasing, by deliberate addition of radioactive substances or by activation, the activity of products such as food, beverages, cosmetics, toys, and personal jewellery or adornments,
- b radiological examination for occupational, health insurance, or legal purposes undertaken without reference to clinical indications, unless the examination is expected to provide useful information on the health of the individual examined or in support of important criminal investigations. This almost always means that a clinical evaluation of the image acquired must be carried out, otherwise the exposure is not justified,
- c medical screening of asymptomatic population groups involving radiation exposure, unless the expected advantages for the individuals examined or for the population as a whole are sufficient to compensate for the economic and societal costs, including the radiation detriment. Account should be taken of the potential of the screening procedure for detecting disease, the likelihood of effective treatment of cases detected, and, for certain diseases, the advantages to the community of control of the disease.

The HPA continues to endorse the important principle of justification; this is essentially a matter for the UK Government and the 2007 recommendations should not require any changes to legislation. The HPA notes that the ICRP goes further in providing practical examples to illustrate unjustified exposures than it did in the 1990 recommendations. While this approach is welcomed, the examples given require clarification in the UK context. Some new or existing activities that appear to be in categories (b) and (c) could be considered to be already justified or would be candidates for further analysis to establish whether they could be justified. One example is the current development of low dose X-ray techniques for the screening of air passengers for concealed weapons, drugs, etc. This development is prompted by raised security concerns. A second example is targeted health screening programmes, eg breast mammography. Nevertheless, in many cases screening of asymptomatic individuals following self-referral (or, more correctly, self-presentation) is likely to be unjustified in the context of radiological protection.

### 5.4.2 Optimisation

The principle of optimisation of protection is the cornerstone of the system of protection. It means that there should be a balance between the levels of radiation exposure and the implications, both financial and societal, of their reduction. The ICRP has introduced dose and risk constraints/reference levels as restrictions on the optimisation procedure to ensure that the optimisation procedure does not lead to

‘severely inequitable outcomes’. The 2007 recommendations emphasise the importance of constrained optimisation for all exposure situations (planned, existing and emergency).

The 2007 recommendations elaborate on previous ICRP advice on the application of optimisation, noting the range of different tools and processes that have been used in the application of optimisation, and recognising that the choice of approach needs to be tailored to the needs of the protection issue under consideration. It is important that the resources expended during optimisation are consistent with the potential health consequences and that the process adopted is accessible to all those affected by the outcome. The ICRP clearly states that ‘optimisation of protection is not minimisation of dose’.

The HPA broadly agrees with the advice on optimisation provided in the 2007 recommendations. The HPA feels that a simple cost–benefit analysis exercise, where the costs of introducing a measure to reduce exposure are balanced against the nominal cost of the saving in exposure, is not generally helpful. However, the ICRP advises that a ‘cost for unit collective dose’ can be useful in some applications of optimisation. Previously, the NRPB published reference values for this cost for workers, members of the public and those undergoing medical diagnosis and treatment (NRPB, 1993b). These values are now some 15 years out of date. The HPA notes that in many protection decisions taken in the UK, the process of optimisation does not explicitly take account of a cost for unit collective dose. However, the HPA recognises that there appears to be support in the UK for the use of a monetary value for unit collective dose. Therefore the HPA will consider initiating a programme of work on this topic.

One confusion that can arise with regard to assigning monetary value to collective dose or health outcomes, is that standard economic methods apply discounting to monetary costs that occur in the future. The HPA recognises that economic discounting is an appropriate approach for outcomes that will require the expenditure of money in the future (and therefore investment of a smaller sum ‘now’). However, it is important to distinguish this (valid) practice from the discounting of future doses or health outcomes which would imply that health outcomes in the future are of less concern. The HPA considers that future generations should be afforded the same level of protection as the current generation, so discounting of doses and health outcomes may not be acceptable.

### 5.4.3 Dose limitation

For planned exposure situations only, excluding medical exposures of patients, dose limits also apply. These are restrictions on the sums of the occupational or public doses from all regulated sources. An individual-related dose assessment is carried out for comparison with the dose limit. The ICRP recommended dose limits have not changed in the 2007 recommendations and are given in Table 5.1.

**TABLE 5.1 ICRP recommended dose limits in planned exposure situations (ICRP, 2007a)**

Type of limit	Occupational	Public
Effective dose	20 mSv per year, averaged over defined periods of 5 years	1 mSv in a year
Annual equivalent dose in:		
Lens of the eye	150 mSv	15 mSv
Skin	500 mSv	50 mSv
Hands and feet	500 mSv	–

The limits on effective dose are for the sum of the effective doses from external exposure in the specified period (eg 1 year) and the committed effective dose from intakes of radionuclides in the same period. For adults the committed effective dose is for a 50-year period after intake, while for children it is calculated for the period up to age 70 years. For occupational exposure there is a further provision in the recommendations that the effective dose should not exceed 50 mSv in any single year and additional restrictions apply to the occupational exposure of pregnant women. The ICRP also states that for public exposures in special circumstances a higher value of effective dose could be allowed in a single year, provided that the average over 5 years does not exceed 1 mSv per year.

The flexibility on the occupational dose limit is included in UK legislation, although there are very few individuals who have received effective doses greater than 20 mSv in a year. In the NRPB response to the 1990 recommendations of the ICRP (NRPB, 1993a) it was stated that ‘there appears to be no practical need for the 5-year averaging’ and only the 20 mSv effective dose limit was recommended for occupational exposures.

The HPA continues to recommend the use of an occupational dose limit of 20 mSv in a single year with no allowance for higher annual doses based on averaging over several years. Furthermore, the HPA supports the ICRP policy that the methods of protection at work for women who are pregnant should provide a level of protection for the embryo/fetus broadly similar to that provided for members of the public and specifically that after declaration of pregnancy the dose to the fetus should not exceed about 1 mSv. However, the HPA supports the ICRP view that for the purposes of controlling occupational exposure there is no other reason to distinguish between the sexes.

For public exposures the HPA continues to recommend the dose limit of 1 mSv in a year, with no averaging of exposures between years. The only circumstance where the additional flexibility of averaging between years may be justified is that of the exposure of certain persons, other than comforters and carers (who are covered by the HPA advice on medical exposures), arising from the medical exposure of another

person. These potentially exposed persons are those, probably close family members of the individual medically exposed, who are judged to gain a net benefit from close contact with the individual causing their exposure, eg young children of a medically exposed parent who cannot knowingly and willingly agree to the exposure. The HPA advises that such persons, provided an explicit consideration of the net benefit to the individual receiving the additional exposure is undertaken, may be allowed to receive an exposure in excess of 1 mSv in a year. In such circumstances, the HPA advises that sufficient flexibility is provided by the ICRP recommended averaging of the dose limit for members of the public over a 5-year period. Therefore the HPA advises that the current approach specified in the Ionising Radiations Regulations 1999 (GB Parliament, 1999) of placing a limit of 5 mSv effective dose over a 5-year period continues to be appropriate for this specific circumstance.

Dose limits for members of the public are applicable to planned exposures from all sources, excluding medical exposures of patients. They are not applicable to natural background radiation exposures and other existing exposure situations, or to emergency exposure situations. However, it is not clear from the 2007 recommendations what the situation is regarding past planned exposures. This is important as many controlled releases of radioactivity to the environment contain long-lived radionuclides which can accumulate in the environment and continue to give exposures. In its response to the 1990 recommendations, the NRPB recommended that exposures from past controlled releases should be included in any comparison with the dose limit (NRPB, 1993b). This is particularly important given the practical issues regarding the interpretation of measurements of radionuclides in the environment which are due to past and present planned exposures.

The HPA continues to recommend that exposures from past controlled releases should be included in any comparison with dose limits.

The application of these principles to the different types and categories of exposure is discussed in Section 6 of this document.

## 5.5 Dose limits, constraints and reference levels

The 1990 recommendations of the ICRP introduced the concept of dose constraint within the process of optimisation for practices. A dose constraint is a restriction on the dose to an individual from the planned operation of the source being optimised. The 2007 recommendations extend this approach to all exposure situations. The restrictions are termed dose constraints in planned exposure situations, primarily in this context practices, and reference levels in emergency and existing exposure situations. Options resulting in doses greater in magnitude than such restrictions should be rejected at the planning

stage. Diagnostic reference levels provide a similar function to constraints during the process of medical imaging.

**The HPA welcomes the use of constraints and reference levels as restrictions in the optimisation of protection as this will aid in the transparency of radiological protection decisions and should enhance protection.**

The dose and risk constraints and the reference levels are all intended to be applied to a single source prospectively. They are intended to aid planning and optimisation and are not intended to be the same as regulatory limits. The ICRP has stated that 'if following the implementation of an optimised protection strategy, it is subsequently shown that the value of the constraint or reference level is exceeded, the reasons should be investigated but this fact alone should not necessarily prompt regulatory action.' (ICRP, 2007a: Executive Summary, paragraph p).

**The HPA endorses the ICRP view that if it is subsequently shown that the value of a constraint or reference level is exceeded following the implementation of an optimised protection strategy, this fact alone should not necessarily lead to regulatory action.**

### 5.5.1 Numerical values for dose constraints and reference levels

The appropriate upper bound for optimising protection with regard to a particular activity or plan will vary according to a number of factors, including the overall benefit to society conferred by that activity, the cost and practicability of protection options, and the benefit received by those incurring the exposure. The ICRP therefore recommends that national authorities should set appropriate reference levels for specific activities. To provide guidance to national authorities, the ICRP has published ranges of dose levels to indicate where national constraints or reference levels of dose are most likely to lie in different situations. This guidance is summarised in Table 5.2 below.

**The HPA broadly welcomes this guidance.**

The application of this guidance in the UK is discussed in Section 6.

**TABLE 5.2 ICRP framework for source-related dose constraints and reference levels (ICRP, 2007a)**

<b>Range for upper bound on optimisation (constraint or reference level) (mSv effective dose)</b>	<b>Characteristics of the exposure situation</b>	<b>Examples</b>
>20–100 Higher reference levels may exceptionally be set for trained and informed emergency workers	Extreme exposure situations that normally require protective actions to be applied to exposure pathways, since source either impracticable to control or uncontrolled	Emergency exposure situations
>1–20	Individuals will usually receive benefit from accepting the exposure situation Protection may be applied to exposure pathways or to source	Occupational exposure in planned situations, and during remedial actions taken after an emergency Comforters and carers of patients treated with radiopharmaceuticals Existing exposure situations
1 or less	Benefit to society rather than to individual Protection usually applied to source	Public exposure in planned situations

### 5.5.2 Representative person

In Publication 101, the ICRP introduced the term ‘representative person’ for assessing doses to members of the public (but not for medical exposures) (ICRP, 2006b). This term is also used in the 2007 recommendations and is defined as ‘An individual receiving a dose that is representative of the more highly exposed individuals in the population. This term is the equivalent of and replaces “average member of the critical group” described in previous ICRP recommendations’. It should not be confused with the term ‘reference person’, which is a standardised computational model used in the calculation of equivalent and effective dose as discussed in Sections 3 and 4.

As noted by the ICRP this is a change in terminology rather than a significant change in how doses are calculated for comparison with criteria. In UK legislation and guidance the term ‘critical group’ has been used for some time and there is a widespread understanding of its use. Also the Euratom Basic Safety Standards refer to the ‘reference group’ as being representative of those individuals in the population who receive the highest doses (EC, 1996).

The HPA considers that the terms ‘representative person’, ‘critical group’ and ‘reference group’ are all equivalent and refer to those individuals in the population of interest who receive or are expected to receive the highest doses. Therefore, there is no immediate need to change the terminology in current UK legislation, guidance



and publications. However, gradually the term representative person should be adopted to ensure consistency with ICRP advice and terminology likely to be used elsewhere. The guidance given in Publication 101 (ICRP, 2006b) on assessing doses to the representative person for the purpose of radiological protection of the public is broadly compatible with current UK practice and the previous HPA (NRPB) advice.

The assessment of doses to the representative person for protection of the public can involve consideration of a number of different age groups. The ICRP has published dose coefficients for the ingestion and inhalation of a large number of radionuclides by 1, 5, 10 and 15 year old children and adult members of the public (ICRP, 1996a,b). In Publication 101, the ICRP provided guidance on the need to assess doses to all age groups for which dose coefficients have been published. It was concluded that in most cases it is sufficient to consider doses to the three age groups, 1 and 10 year old children and adults. This is consistent with current UK practice (eg EA et al, 2002) and European Commission (EC) guidance (EC, 2002). The ICRP has also given dose coefficients that consider *in utero* exposure of the embryo and fetus and transfer of radionuclides in breast milk to the newborn infant, following ingestion or inhalation of radionuclides by the mother. In the 2007 recommendations, the ICRP notes (paragraph 188) that in most cases the dose to the embryo/fetus and breastfed infant will be small compared to doses received by the adult. However, this is not always the case and recently the HPA has issued guidance on the application of these dose coefficients in dose assessments for members of the public (HPA, 2008). It was found that for four radionuclides, phosphorus-32 and -33, calcium-45 and strontium-89, the embryo/fetus and breastfed infant may receive significantly higher doses than other age groups in some exposure situations.

The HPA agrees that in most situations when assessing radiation doses to representative persons for protection of the public it is sufficient to consider exposure of 1 and 10 year old children and adults. However, for phosphorus-32 and -33, calcium-45 and strontium-89, doses to the embryo/fetus and breastfed infant should be considered in all assessments where these radionuclides form a significant part of any release of radioactivity to the environment. Specific advice regarding the age groups to consider for different exposure situations is given in Section 6.

The concept of the critical group/representative person is particularly important for planned releases of radionuclides to the environment. Here the dose or risk to the average member of the critical group (now the representative person) is compared to the annual dose limit or the appropriate dose/risk constraint for members of the public. The 2007 recommendations also envisage the concept of the representative person being applied to emergency and existing exposure situations. Section 6 considers the application of the representative person to planned, emergency and existing exposure situations.

## 5.6 Medical exposure of patients, comforters and carers and volunteers in biomedical research

Within the 2007 recommendations, the ICRP has designated medical exposures as belonging to planned exposure situations. The ICRP dose limits for planned situations do not, however, apply to medical exposures.

### 5.6.1 Scope of medical exposure

The ICRP considers the medical exposure of patients, the exposure of those acting as comforters and carers (other than as part of their occupation) and those undergoing exposures as volunteers in biomedical research as being medical exposures.

With regard to patients, the ICRP includes those exposed for diagnostic, interventional and therapeutic purposes and includes doses to the embryo/fetus or breastfed infant of a medically exposed female. It is not clear whether the ICRP advice is intended to apply to other patients who undergo planned exposures to radiation for other reasons such as radiotherapy planning. These exposures do not use the radiation itself for diagnosis or treatment. Similar arguments might be proposed regarding manipulations under fluoroscopic control, which would not usually be classified as interventional.

The HPA believes it is clearer and more inclusive to retain the more precise phraseology in UK regulations defining patients as ‘those who undergo exposure as part of their own diagnosis or treatment’.

The HPA also advises that medical exposure of the unborn child should be considered when justifying and optimising the exposure of the mother. Any exposure of an infant as a consequence of breastfeeding should be considered when justifying and optimising an exposure of the female, but treated as an exposure of a member of the public.

National legislation and international standards and directives have previously taken a far wider view than that now held by the ICRP of the range of exposures that might be considered as medical exposures.

In particular, the ICRP does not appear to include, within Chapter 7 of the recommendations covering medical exposures, exposures of asymptomatic individuals for their individual health assessment, exposures of those included within population health screening programmes, or exposures for occupational health surveillance or for medico-legal purposes (including those as part of criminal investigations or health insurance purposes). The ICRP has suggested within its recommendations that such exposures may be deemed to be unjustified unless there are exceptional circumstances.

It is important that exposures of these types, where justified, are conducted under the same principles as other medical exposures.

The HPA considers that current UK regulations are clear on the scope and application of medical exposures [the Ionising Radiation (Medical Exposure) Regulations, 2000 (GB Parliament (2000))] and advises that these regulations do not require change in this respect, thus ensuring that individual health assessment, population screening, occupational health surveillance and medico-legal exposures are subject to requirements for justification and optimisation.

### 5.6.2 Principles of protection in medical exposure

The ICRP recognises the fundamental differences between medical exposures and exposures in other planned situations. This is most marked in the adoption of justification and optimisation, while recognising that the principle of dose limitation cannot be applied as it may do more harm than good.

For justification, three levels are proposed by the ICRP.

- a At the first level, the use of radiation in medicine is accepted as doing more good than harm to the patient. This level of justification can now be taken for granted and is not discussed further by the ICRP.
- b At the second level, a specified procedure with a specified objective is defined and justified (eg chest radiographs for patients showing relevant symptoms, or a group of individuals at risk to a condition that can be detected and treated). The aim of the second level of justification is to judge whether the radiological procedure will usually improve the diagnosis or treatment or will provide necessary information about the exposed individuals.
- c At the third level, the application of the procedure to an individual patient should be justified (ie the particular application should be judged to do more good than harm to the individual patient).

The HPA endorses the ICRP application of the principle of justification in medical exposures, emphasising the importance of the third level of justification which should take account of the specific objectives of the exposure and the characteristics of the patient involved.

The ICRP recommends the same conceptual approach to optimisation of medical exposures as applied to the other categories of exposure (see Section 5.4.2). In the case of medical exposures, however, optimisation is not restricted by constraints or reference levels (see Section 5.5). Instead diagnostic reference levels are applied in the optimisation of exposures from medical imaging procedures.

The values for diagnostic reference levels are specific to particular procedures. They are used in medical imaging to indicate whether in routine conditions, the levels of patient dose from, or administered activity (amount of radioactive material) for, a specified imaging procedure are unusually high or low for

that procedure. If so, a local review should be initiated to determine whether protection has been adequately optimised or whether corrective action is required.

The use of diagnostic reference levels has long been promoted by the HPA (NRPB, 1990a). The ICRP provides useful clarification that these levels only apply to diagnostic exposures while giving helpful pointers to optimisation approaches in interventional procedures. Diagnostic reference levels do not, strictly, apply to interventional or planning procedures but they do provide useful concepts and practical approaches that can be carried over to interventional techniques.

**The HPA emphasises the importance of the principle of optimisation in medical exposures, noting that the current approach in UK regulation attaches a corresponding level of importance to this principle. The HPA continues to endorse the use of diagnostic reference levels in medical imaging procedures.**

The ICRP addresses the specific problem of medical exposure of those who may be pregnant and, while accepting the potential harm to the embryo/fetus, balances this against the possible risk to the patient of not submitting to the procedure. In most diagnostic procedures, the overall risk to the patient of not undertaking the exposure will be much greater. Many interventional and radiotherapy procedures remote from the pelvis can proceed if properly planned without significant harm to the embryo/fetus. Further, the ICRP provides positive advice regarding termination of pregnancy on the basis of radiation dose to the embryo/fetus, noting that absorbed doses below 100 mGy to the embryo/fetus should not be considered a reason for terminating a pregnancy.

**The HPA endorses the 2007 recommendations on the protection of the embryo/fetus during medical exposure.**

Comforters and carers are exposed as a consequence of medical exposures. The ICRP recommends the use of constraints rather than dose limits for this group of people. The ICRP suggests that a dose constraint of 5 mSv per episode (ie for the duration of a given release after therapy) is reasonable but that it needs to be used flexibly. For example, higher doses may well be appropriate for parents of very sick children. The ICRP has also usefully clarified that young children and infants, as well as visitors not engaged in direct care or comforting, should not be classed as comforters and carers but rather as members of the public for radiological protection purposes.

**The HPA endorses the ICRP recommendations for comforters and carers, specifically noting that children and infants should not be classified as comforters and carers.**

Volunteers in biomedical research are the final group considered by the ICRP within the context of medical exposures and the ICRP treats this type of exposure as if it were medical exposure. Volunteers may be healthy and therefore will receive no direct benefit from the exposure. Others may benefit if they

suffer from a condition under consideration within the research study. The use of dose constraints in such research is identified and further guidance on the values for the constraints is provided. These values depend upon the perceived benefit to society from the research and are taken from a previous ICRP publication (ICRP, 1991b).

The HPA notes that the concept of constraints can only apply to a single source and therefore within research it is assumed constraints can only apply to a single research study. Further discussion and advice are required regarding an annual restriction, which is neither a constraint nor a limit, on the dose received by normal healthy volunteers from a range of separate research studies in which they may participate.

# 6 Application of the ICRP System of Protection

In the previous section, the ICRP system of protection was described and advice given on its general applicability to the UK. Here, aspects of implementing the ICRP system in the UK are discussed in more detail, with advice on their implementation. Each of the three ICRP exposure situations, planned, emergency and existing, is covered in turn. The HPA wishes to emphasise, however, that the same basic approach is applied in all three situations.

## 6.1 Planned exposure situations

The ICRP states that 'Planned exposure situations are situations involving the deliberate introduction and operation of sources' (ICRP, 2007a). These are situations where radiological protection can be planned in advance so do not include, for example, the malevolent use of radioactive material. Planned exposure situations may give rise both to exposures that are anticipated to occur (normal exposures) and to exposures that are not anticipated to occur (potential exposures). Planned exposures may relate to both occupational and public exposure; medical exposures of patients are also planned but are considered separately both by the ICRP and in this HPA response (see Section 5.6).

Planned exposures include the use of radioactive materials in the workplace and public exposures resulting from planned releases of radioactivity to the environment, including from authorised liquid or atmospheric discharges, or disposal of solid wastes. Doses from direct external exposure from normal planned operations are also included. There can be situations when an emergency or existing exposure situation becomes a planned exposure situation. The radiological implications of land contaminated with radioactive material will normally be treated as an existing exposure situation. However, the redevelopment of such land should be treated as a planned exposure situation as the redevelopment could lead to new exposures to the contamination, which can be controlled. It should also be noted that land contaminated with radioactive material on a nuclear licensed site or other site where access by members of the public is already controlled, is also treated as a planned exposure situation. Similarly, when dealing with the aftermath of an emergency situation, workers involved in recovery operations will be treated in a similar manner to those exposed in planned exposure situations. Naturally occurring sources of radiation will often be considered as existing exposures. However, where practices (eg processing ores) lead to enhanced levels of naturally occurring radiation the resulting occupational and public exposures should be treated as planned exposures.

In planned exposure situations there is a level of exposure to workers or the public which is expected and can be estimated. However, there may be deviations from planned procedures including accidents,

leading to higher exposures. The situation might be planned but these higher exposures are not. Such exposures are referred to by the ICRP as potential exposures.

In the following sections, the application of the 2007 recommendations to planned exposures is considered in the context of public, occupational and potential exposures; as noted earlier, medical exposures are considered in Section 5.6.

The HPA considers that a planned exposure situation is one in which it is possible to plan radiological protection in advance. For example, as well as routine discharges from nuclear installations, a mine being opened leading to exposure to radon gas underground and discharges from the oil and gas industry are both examples of planned exposure situations. The HPA, therefore, also considers that the redevelopment of a radioactively contaminated site is a planned exposure situation. However, planned exposures in an emergency situation are an exception in that the dose limits and constraints may not apply.

### 6.1.1 Public exposure

Public exposure covers all exposures of the public except for occupational exposures and medical exposures of patients. As such it includes exposures from natural sources of radiation as well as from human activities. In the context of planned exposures the areas of interest are public exposures due to planned releases of radioactivity to the environment from liquid and atmospheric discharges, as well as solid waste disposal. Human activities may lead to sources of enhanced levels of naturally occurring radiation and the public exposure due to these sources should be considered in the same way as for man-made radiation sources.

The HPA considers that the 2007 recommendations of the ICRP do not introduce any changes that require amendments to UK legislation or practice relating to the authorisation of atmospheric or liquid discharges. As discussed in Section 5, the basic ICRP principles are retained and the dose limit for members of the public remains as 1 mSv per year. As previously, the HPA recommends that exposures resulting from past planned releases should be included in any comparison with the dose limit. Previously, the NRPB recommended a maximum dose constraint for proposed controlled sources of 0.3 mSv per year, noting that dose constraints lower than this could be set where such doses are readily achievable (NRPB, 1993b). The HPA continues to recommend this approach but re-emphasises that the 0.3 mSv per year value is a maximum and that regulators should set lower, more challenging dose constraints where appropriate. At the design stage of new plant it is more straightforward to take measures to reduce exposures of the public than it is when measures have to be introduced to existing plant. Therefore, it is recommended that

for new nuclear power stations and new facilities for the disposal of radioactive waste, regulators consider applying a more challenging dose constraint, taking into account the levels of protection that can be achieved internationally. The HPA specifically advises the UK Government to select a value for the constraint for members of the public for new nuclear power stations and waste disposal facilities that is less than 0.15 mSv per year (see also HPA, 2009a). Such a constraint would apply only to new plant as a design criterion and would not apply to existing facilities which should operate within current arrangements. This advice takes into account uncertainties in the understanding of some health effects with the possibility that judgements on risks from radiation might change on the timescale of the planning and construction of such plants when, for example, further data are available on risks of non-cancer health effects.

For both the effective dose limit and dose constraint the relevant exposure is the annual effective dose to the representative person summed over all relevant exposure pathways. As noted in Section 5.5.2, the representative person is equivalent to the critical group and so advice and practice relating to assessing critical group doses also applies to assessing doses to the representative person. The existing HPA generalised derived limits and generalised derived constraints are based on the 1 mSv per year dose limit and the 0.3 mSv per year dose constraint and as such are still valid for current facilities. Eventually they will be revised to take account of changes in dose coefficients for ingestion and inhalation due to revisions to the tissue weighting factors (see Section 4.2) and changes to biokinetic and dosimetric models being introduced by the ICRP.

In the UK the Environment Agencies, Food Standard Agency and the HPA (as NRPB) developed a set of principles for the assessment of public doses relating to the authorisation of discharges of radioactive wastes to the environment (EA et al, 2002). The HPA is also a member of the National Dose Assessment Working Group which provides guidance and information relating to the assessment of radiation exposures from such discharges. NDAWG has also published guidance related to the retrospective assessment of planned releases of radioactivity to the environment (NDAWG, 2005). The 2007 recommendations are consistent with this guidance and advice except for the change in terminology from critical group to representative person.

In assessing exposures from planned releases of radioactivity to the environment it is generally sufficient to consider three age groups (1 and 10 year old children and adults) for the representative person. However, in some limited cases it might also be necessary to consider the embryo/fetus and breastfed infant, notably when the release contains isotopes of phosphorus, calcium or strontium. The HPA has published guidance on when the embryo/fetus and breastfed infant need to be considered in assessing radiation doses to members of the public (HPA, 2008) (see Section 5.5.2).



The ICRP has retained the concept of collective dose for members of the public, although as discussed in Section 4.6 it has recommended more restrictions on its use.

The HPA continues to recommend that for discharge authorisation purposes collective doses truncated at 500 years should be estimated for the populations of the UK, Europe and the world. This is sufficient for comparisons of process/disposal options. The average annual individual dose in a population (called the *per-caput* dose) can also be estimated from the collective dose (see Smith et al, 2006). Together with the estimated doses to the representative person, the *per-caput* dose can be taken as an indication of possible health risks to the exposed population and also gives an indication of the radiological implications of the build-up of radionuclides in the environment. Calculated average annual individual doses for a population group in the nanosievert (nSv per year) range or below could be ignored in the decision-making process as the contribution to an individual's total dose will be insignificant. Higher annual doses do require consideration in this context.

As noted earlier, the HPA considers that the redevelopment of a radioactively contaminated site is a planned exposure situation. The NRPB provided advice on radiological protection objectives for such situations (NRPB, 1998). Although there are clearly differences in terminology, the HPA considers that this advice remains generally valid and is consistent with the 2007 recommendations. The advice gives guidance on appropriate maximum levels of constraints for these situations; these were originally couched in terms of risk. The HPA is taking this opportunity to clarify that the recommended maximum dose constraint for site redevelopment is 0.3 mSv per year in circumstances where the exposure is reasonably likely to occur.

The 2007 recommendations briefly mention how disposal of solid radioactive waste fits into the new system of protection and refer to existing advice issued by the ICRP in Publication 81 (ICRP, 1998). The HPA considers that there are some areas where the advice in Publication 81 is not entirely consistent with the 2007 recommendations and therefore these sections should be viewed as being superseded by the 2007 recommendations. The main example is the criterion used to evaluate human intrusion. Disposal of radioactive waste is a planned situation and hence dose constraints and risk constraints apply. However, since the radiological impact will not be received for many years, the application of the new ICRP system is not straightforward. The HPA has developed specific advice on radiological protection criteria for solid waste disposal (HPA, 2009a).

### 6.1.2 Occupational exposure

The ICRP defines occupational exposure 'as all radiation exposure of workers incurred as a result of their work' (ICRP, 2007a). Owing to the presence of radiation everywhere, the ICRP limits the use of occupational exposure to 'radiation exposures incurred at work as a result of situations that can

reasonably be regarded as being the responsibility of the operating management'. The worker and employer should have 'recognised rights and duties in relation to occupational radiological protection'. The ICRP continues to recommend the classification of areas of work rather than of the workers themselves and to distinguish between 'controlled areas' and 'supervised areas'.

The HPA welcomes the retention of the concept of classification of areas and notes that this and other ICRP recommendations on occupational exposure are consistent with the current UK approach and legislation. HPA experience is that the requirement to designate areas as controlled or supervised based on the level of hazard presented and the degree to which special procedures are required in order to minimise exposure/potential for exposure is an effective control measure. It is noted that in practice in the UK it is not often the case that a controlled area is within a supervised area as stated by the ICRP.

The 2007 recommendations also cover the protection of female workers including those who are (or may be) pregnant and those who are breastfeeding. The ICRP has provided dose coefficients for effective dose to the embryo/fetus consequent on maternal intakes during pregnancy together with information regarding doses to offspring following intakes of radionuclides by breastfeeding mothers (ICRP, 2001, 2004).

The HPA supports the recommendations made and, in particular, the continuation of the recommendation that after declaration of pregnancy working conditions should be controlled so as to seek to ensure that the effective dose to the embryo/fetus for the remainder of the pregnancy is kept below 1 mSv. Advice on the implications of the ICRP dose coefficients for the embryo/fetus has already been given by the HPA (NRPB, 2005a) and remains valid. A key conclusion is that there are a small number of radionuclides (notably isotopes of phosphorus, calcium and strontium) where the ratios of the fetal to adult effective doses per unit intake are relatively high, particularly for the ingestion pathway. For these radionuclides greater care is required in the control of worker risks than might have been envisaged prior to the provision of radionuclide dose coefficients for *in utero* exposure. As stressed by the ICRP, this does not mean that cessation of all work with radioisotopes will be necessary during pregnancy. The HPA considers, as previously advised (NRPB, 2005a), that women of reproductive capacity who might work with the identified radionuclides should be provided with appropriate information and encouraged to declare pregnancy early. The consideration of additional precautions for certain radionuclides should be extended to women who have returned to work following pregnancy but who are still breastfeeding their child.

One particular occupational exposure situation considered by the ICRP is the control of exposures in aviation. The ICRP has retained the recommendation that it is only aircrew that should be considered as being occupationally exposed and not frequent-flyer passengers. There appears to be an inconsistency in approach here in that if an individual is a frequent flyer (and at risk of exposure) due to the nature/requirements of their work, it is difficult to see why this is not treated as occupational exposure. However, because there are great practical difficulties in frequent flyers being treated as occupationally exposed, the HPA supports the ICRP recommendation.

The HPA does not recommend any specific dose constraints for occupational exposure as these rely upon judgements of what is achievable in particular situations. As discussed above for public exposure, it is more straightforward to take measures to reduce exposures at the design stages of new plant than for existing plant. To take account of the relatively low level of occupational exposures achievable in new nuclear plant, together with uncertainties in the understanding of some health effects, the HPA recommends that the UK Government should consider setting dose constraints for occupational exposure at new nuclear plants on a similar basis to those discussed above for public exposure.

### 6.1.3 Potential exposure

The ICRP defines potential exposure situations as those that occur as a result of deviations from planned operating procedures or where exposure situations can be foreseen as possible, but not certain to occur, such as exposures in the future from disposals of radioactive wastes, accidents or malevolent incidents. A further example of potential exposure is heterogeneous contamination (eg particles) where there is a probability associated with exposure. ICRP advice on potential exposures has been given in a number of earlier publications. Advice on situations where the potential exposures would primarily affect small numbers of individuals who are also subject to planned exposures is set out in Publication 76 (ICRP, 1997b). This advice continues to represent the ICRP view for these situations. For potential exposure situations which could result in both a large number of people exposed to health risks and also other harmful consequences, such as contaminated land and food restrictions, ICRP advice is set out in Publication 64 (ICRP, 1993a), and extended to malicious incidents in Publication 96 (ICRP, 2005). Finally, for potential exposures in the far future, eg from disposal of solid radioactive wastes, ICRP advice is presented in Publication 81 (ICRP, 1998).

In summary, the ICRP advises that it is important to consider the possibility of potential exposures both in the regulation of planned exposures (including medical) and when evaluating risks from exposures to 'existing situations' or situations of malicious origin. Wherever possible, the factors that might give rise to these exposures should be identified and the probability of occurrence of different levels of exposure evaluated. All reasonable steps should be taken to prevent the occurrence of potential exposures and to reduce the probability of occurrence of those that cannot reasonably be prevented. The ICRP recommends the use of risk criteria to act as constraints on the optimisation of potential exposures.

The HPA agrees with the general approach of the ICRP to potential exposure situations.

The HPA notes that the concept of a 'risk constraint' for potential exposures of workers could pose particular problems for 'small users' of radioactivity (eg universities or hospitals); for many routine applications outside the nuclear industry there are no practical data on the probability of occurrence of potential (typically very localised) incidents that could result in exposure. The HPA is of the view that existing requirements for prior risk assessments, which require users to consider inherent risks of exposure both during normal routine situations and in potential accident situations and to mitigate or address as appropriate, already strike the right balance. Further elaboration of the existing system would result in little added value.

## 6.2 Emergency exposure situations

The 2007 recommendations of the ICRP reflect a refocusing of the underlying philosophy of radiological protection regarding emergencies. Formerly, the ICRP recommended the consideration and optimisation of different protective actions separately. In its new advice, the ICRP also advocates optimisation of the overall response strategy. Furthermore, it recommends that this optimisation of the overall strategy be carried out in the context of optimisation below a reference level of dose. The ICRP has also highlighted the importance of planning for changes in the emergency situation, as the characteristics of the situation evolve.

The HPA judges that the practical implementation of the ICRP extensions to its previous advice does not require substantial or immediate revision of the UK emergency preparedness arrangements. Rather, it considers that the publication of the 2007 recommendations provides an opportunity for considered re-appraisal of the UK arrangements.

In the following sections, the key elements of the 2007 recommendations, as applied to emergency exposure situations, are summarised and developed for application in the UK.

### 6.2.1 Principles for emergency preparedness and response

The ICRP has retained its principles of justification and optimisation as applicable to both emergency exposure and existing exposure situations. Whereas in the 1990 recommendations (ICRP, 1991a) and Publication 63 (ICRP, 1992) the application of these principles was discussed in relation to the justification and optimisation of individual protective actions, the 2007 recommendations emphasise the importance of ensuring that the overall response is also justified and optimised. This is an important additional focus for emergency response planning.

On the basis of its experience in emergency exercises, the HPA is not aware of significant improvements that could be made to UK arrangements with regard to optimisation of the overall response. However, the HPA suggests that publication of the recommendations presents an opportunity for a review of UK arrangements from the perspective of the justification and optimisation of overall protection from all exposure pathways (eg considering food pathways together with those included in site emergency plans). The HPA therefore invites the responsible UK authorities to consider undertaking such a review.

In its 1990 recommendations the ICRP also advised that ‘... at some level of dose, approaching that which would cause serious deterministic effects, some kind of intervention would become almost mandatory’. This concept was elaborated in Publication 63 (ICRP, 1992): ‘The first concern in the event of a radiological emergency is to keep the exposure to individuals from all pathways below the thresholds for serious deterministic health effects ... . In fact, when deciding on the implementation of protective actions, the decision maker should first determine whether the protective action is justified from the point of view of those individuals who are most at risk’. Unfortunately, because this requirement to focus first on those individuals at risk of suffering severe deterministic injury\* was not presented as a ‘principle’ for intervention, this requirement was not encapsulated in the Euratom Basic Safety Standards (EC, 1996). Although NRPB advice expressed this as an explicit third principle: ‘Serious deterministic health effects should be avoided by introducing countermeasures to keep doses to individuals to levels below the thresholds for these effects’ (NRPB, 1990b), the UK Radiation (Emergency Preparedness and Public Information) Regulations (GB Parliament, 2001), based on the Euratom Basic Safety Standards, make explicit reference only to the principles of justification and optimisation. The 2007 recommendations continue this separation of basic principles from the advice with regard to severe deterministic injury. Paragraph 35 states that ‘Situations in which the dose thresholds for deterministic effects in relevant organs could be exceeded should be subjected to protective actions under almost any circumstances ...’ and paragraph 241 repeats this advice more strongly: ‘Situations in which the dose threshold for deterministic effects in relevant organs or tissues could be exceeded should always require action’ (ICRP, 2007a). Whilst the ICRP clearly intends that its advice will ensure protection against serious deterministic injury, the evidence of legislation following the 1990 recommendations demonstrates that if this purpose is not enshrined as a principle, it may not receive sufficient explicit attention in the emergency planning process. In particular, the emphasis on optimisation of protection over groups of people may overlook the importance, in planning, of addressing separately the specific protection needs of those at risk of severe deterministic injury in the event of an accident.

\* By ‘severe deterministic injury’ to an individual the HPA means injuries that are directly attributable to the radiation exposure, that are irreversible in nature and that severely impair the health and/or quality of life of that individual, eg lung morbidity and early death.

The HPA recommends that, if relevant UK regulation is revised in the future, it should include a third principle of explicitly planning to avoid severe deterministic injury in the event of a radiological emergency. In making this recommendation, the HPA recognises that severe deterministic injuries, if they occur at all, are most likely to occur to those close to the initiating event or source of release.

## 6.2.2 Management of emergency exposure situations

Within the framework described in the 2007 recommendations, emergency response and its aftermath will involve evolution through two types of exposure situations: emergency exposure situations and existing exposure situations. The ICRP uses the categorisation of exposure situations to highlight differences in the way these situations are managed; there may not be clear cut boundaries between the physical attributes of the exposures themselves. The management of emergency exposure situations is characterised by a recognition that the situation is ‘abnormal’ and that actions are required both to protect people and to help restore the situation to ‘normal’. Emergency response management is therefore concerned with initiating and managing change on a short timescale. Existing exposure situations resulting from emergencies, however, are situations in which the ongoing radiation risks are tolerable, even with only limited, or no, further protective actions, although the environmental contamination and potential exposures are recognised as being higher than would be accepted for planned situations. In short, it is recognised that the impact of significant further environmental remediation on those affected, and on society more generally, would outweigh any expected benefits. Thus a new ‘normality’ can be established and require sustaining. The management of existing exposure situations is therefore characterised by an enabling and promotion of ‘normal living’ in an area recognised as having higher potential exposures than other areas. This may involve continuing, less disruptive, protective actions – such as health checks and regular environmental monitoring – but the focus of management is on the *maintenance* of normal living, not on *change* towards normal living.

Physically, emergency exposure situations are likely to be characterised by one or more of the following: significant uncertainty concerning current and future exposures, rapidly changing rates of potential exposure, potentially very high exposures (ie those with the potential to cause severe deterministic injury), and loss of control of the source of the exposure or release. Any or all of these features may continue to dominate how the response is managed for an extended period of time (ie months or even years), although, for small accidents, the emergency exposure situation may be very short (days or even hours). In the subsequent existing exposure situations, there is less uncertainty with regard to current and future potential exposures, rates of exposure are not changing rapidly with time, exposures are well below the thresholds for deterministic health effects, and the initiating source of exposure or release is under control (ie there is no further risk of an additional contribution to the levels of exposure). The physical transition between these situations is unlikely to be sharply delineated. It is possible (for large events, likely) that the appropriate response phase will vary between locations, eg that the response in one area may be emergency response, whilst in another, it may be existing exposure response. It is therefore a management decision that determines when the transition from one type of response to the

other should take place. This decision will be based on a range of factors, including physical, social, economic and practical ones.

The HPA considers that the ICRP approach to the planning for and management of the response to radiation emergencies is helpful, and invites appropriate bodies in the UK to consider whether it would be useful to review the current UK arrangements [eg as set out by the Nuclear Emergency Planning Liaison Group (NEPLG, 2009) and by the Cabinet Office in its UK resilience guidance (Cabinet Office, 2009)] in the context of clarifying management transitions (eg from an emergency to an existing exposure management regime). The HPA suggests that one factor relevant to the move from managing the situation as an emergency exposure to an existing exposure is when the Ionising Radiation Regulations (GB Parliament, 1999) are fully re-applied.

### 6.2.3 Emergency phases

The ICRP identifies several phases for emergency exposure situations: *early* (which may be further subdivided into *pre-release* and *post-release*), *intermediate* and *late*. In the UK the early phase is frequently termed the emergency phase, and the intermediate and late phases are usually termed the recovery or remediation phases. The ICRP terms the phase of emergency response which occurs after a management decision is taken to move to an existing exposure situation, the *rehabilitation* phase. The HPA suggests that clarity would be preserved if the UK retains its use of the terms emergency phase and recovery phase for emergency exposure situations, and introduces the term rehabilitation phase to denote the phase of emergency response which occurs after a management decision is taken to move to an existing exposure situation.

The HPA recognises that there is scope for confusion regarding the terms ‘remediation’ and ‘rehabilitation’, since some remediation may be carried out during the rehabilitation phase. It should be noted, however, that it would be expected that most remediation would be carried out during the recovery phase. From this perspective, the HPA suggests that it would assist in avoiding confusion if the term ‘recovery’ is used to describe the phase of emergency response during which decontamination and other longer-term protective measures are carried out, and the term ‘remediation’ is reserved for describing the protective actions themselves (which may be carried out in either the recovery or the rehabilitation phase).

### 6.2.4 Reference levels

The ICRP recommends the application of reference levels of dose as a restriction on the optimisation of protection strategies for emergency response planning. The ICRP distinguishes the role of the reference level during planning from that during the response to an actual emergency. During the response to an

actual emergency, the reference level should be treated as a benchmark, ie one of the factors against which the success of the response strategy should be judged, and not as an overriding constraint determining success or failure of the response. The ICRP recommends separate bands of reference levels that are applicable to emergency exposure situations and to existing exposure situations. The ICRP intends that national authorities will set reference levels appropriate to particular planning situations, for application in their own country.

The HPA supports the intent of the ICRP that optimised emergency plans should not result in some population groups receiving unreasonably high exposures as a result of an accident or incident. The approach of optimising the planned response such that doses received are below an appropriate reference level of dose is one way of achieving this. The HPA therefore invites relevant authorities to consider whether explicit adoption of this approach in the UK would provide an overall net benefit to the planning arrangements in the UK, and, if so, to specify appropriate reference levels for application in different circumstances.

The reference levels are expressed as effective dose attributable to all exposures due to the incident integrated over a period of one year (or less if the total exposure is received over a shorter time). In this context the effective dose is defined as the sum of the external whole-body dose received during the period and the committed effective dose from radionuclide intakes occurring during that period.

The HPA advises that the use of a reference level expressed in terms of effective dose is appropriate for application to the overall emergency response in situations where there is no potential for individuals to be at risk of severe deterministic injury, and where absorbed doses in organs and other tissues are below the relevant thresholds for tissue reactions (ie where the exposure does not primarily irradiate one part of the body). In emergency exposure situations where individuals are at risk of severe deterministic injury, the HPA advises that planning for the protection of these individuals must take priority over optimisation of the overall response, as described in its advice on the protection of those on-site at the time of an accident (NRPB, 2005b). Where the possibility of severe deterministic injury is not expected, the HPA advises that the use of effective dose in setting a reference level requires the assumption of linear response that underpins the concept of effective dose to be valid. This will vary with the type of radiation and form of exposure. For example, for external gamma exposures that are essentially uniform across the body, it would be appropriate to adopt reference levels up to around 1 Sv effective dose (see, for example, NRPB, 2005b). Where external exposure is likely to expose one part of the body preferentially (eg beta contamination on skin), or where internal exposures may occur, it would be necessary to restrict reference levels expressed as effective dose to



values rather lower than 1 Sv. The HPA further advises that, in situations where specific organs are likely to receive most of the exposure (eg releases to atmosphere of radioiodine), consideration should be given to the specification of supplementary reference levels for the relevant organ dose.

The maximum reference level recommended by the ICRP for application to emergency exposure situations is 100 mSv effective dose (see Table 5.2, page 34).

The HPA recognises that planning to reduce doses below (or well below) 100 mSv in a year is an appropriate aspiration for many postulated emergency situations and the protection of potentially exposed population groups. This reference level (100 mSv) would only apply in circumstances where plans could reasonably be in place to protect people to below this level. Notably, there are some types of emergency, particularly very large accidents and malicious attacks, where it is impractical to plan to control exposures immediately following the initiating event (eg because the exposures occur too rapidly and without warning, or because the exposures are not initially known to be occurring). For such events, the emphasis should be on reducing their likelihood to a very low level, whether by additional prior protection measures to reduce the likelihood of accidents, or by appropriate intelligence and policing in the case of malicious attacks. However, it is still important that emergency response plans are developed for these potential exposure situations. Where it is impractical to plan to reduce doses initially received or committed below a specified reference level, the HPA suggests that the ICRP recommendations concerning the application of reference levels should be applied to doses that the response can reasonably be expected to influence, ie a test of practical controllability through protective actions should be applied.

Depending on the situation being planned for, the HPA suggests it may be appropriate to plan to avoid higher exposures for most population groups, but not all, or it may be appropriate to plan to reduce doses received or committed after a specified time to levels below the reference level. For those groups for whom it is not feasible to plan to keep doses below the ICRP maximum reference level, the greatest consideration should be given to practicable protective measures that could prevent exposures causing serious deterministic injury.

The HPA recommends that specific guidance should be prepared on how the principles of radiological protection (as discussed in Section 5.4) and the ICRP recommended upper reference level should be applied for extreme exposure situations.

## 6.2.5 Protection of those involved in implementing protective actions

The ICRP intends its upper reference level to apply to all exposures received during an emergency, including those received by emergency workers. However, it notes that 'in exceptional situations, informed volunteer workers may receive doses above this band to save lives, prevent severe radiation-induced health effects, or prevent the development of catastrophic conditions' (ICRP, 2007a: footnote to Table 5). It further notes that occupational exposures resulting from 'long-term recovery operations should be treated as part of planned occupational exposure' (ICRP, 2007a: footnote to Table 4).

The HPA considers that this advice is entirely consistent with its existing advice for the protection of emergency workers (NRPB, 1990c) and with current UK practice. The HPA therefore advises that the 2007 recommendations do not require any change in the UK management framework for protecting workers involved in implementing protective actions in an emergency situation.

As indicated above, if the scale of the emergency requires a rehabilitation phase, then the ICRP (and the HPA) recommends that this should be managed as an existing exposure situation. The range advised by the ICRP for selection of reference levels for existing exposure situations is 1–20 mSv effective dose (see Table 5.2).

## 6.2.6 Detailed and outline emergency response planning

The 2007 recommendations could give the impression that detailed response planning is advised for all postulated emergency situations, regardless of the likelihood of occurrence of these situations. The HPA does not consider this to be the intent of the ICRP.

The HPA advises that the UK approach of developing detailed plans for reasonably foreseeable emergency situations and outline plans for less likely scenarios continues to provide an appropriate balance between the provision of protection and the use of finite resources.

## 6.2.7 Application of the concept of representative person to emergency planning

In the event of an emergency exposure situation involving more than a few individuals, it is likely that those exposed will receive a distribution of doses, depending on their individual characteristics, their locations and their behaviours during the course of the event. In order to develop a response plan that both specifically caters for the needs of those potentially at risk of severe deterministic injury, and appropriately optimises protection for all others potentially exposed, it is necessary to identify a set of representative persons, each for a particular subgroup of the population. Population subgroups may be

formed according to a number of factors – in particular, location, specific protection needs and societal priorities. The number of subgroups identified will represent a compromise between the need to develop a practicable plan and the need to be able to provide appropriate protection to all groups, taking into account the large uncertainties associated with estimating doses received during emergencies. Generally, where people in a range of age groups are present in a location, it will be sufficient to define a single representative person for the most vulnerable age group, particularly for the planning of protective actions during the emergency phase. For most exposures, it will not be necessary to prepare plans specifically for women who may be pregnant or breastfeeding.

Considering the risks of stochastic effects from exposures *in utero* and during breastfeeding, a recent study by the HPA has shown that, for all but a few ‘unusual’ radionuclides, emergency plans that protect young children will also provide appropriate protection for the unborn child or breastfeeding infant (HPA, 2008). For protection against *in utero* exposure causing mental retardation, the ICRP considers (ICRP, 2007a: Section A.3.2) that absorbed doses below 300 mGy to the embryo/fetus will not cause severe mental retardation. The ICRP further advises that the data for IQ losses are unclear, but that ‘any effects on IQ following *in utero* doses of a few tens of milligray would be of no practical significance for the vast majority of individuals’.

The HPA continues to advise that, for the protection of the general public, emergency response plans should be optimised with respect to the likely exposure of children. For situations where the exposed population group does not include children (eg industrial estates), it may be appropriate to optimise plans based on the most vulnerable age group present.

The HPA recognises that the potential health risk to individuals exposed during an emergency exposure situation may be dominated by factors other than age, particular for those present ‘on-site’ at the time of an accident. The HPA has published advice on planning the protection of these individuals (NRPB, 2005b). This advice continues to be relevant.

### 6.2.8 Dose terminology for emergency response planning

The ICRP defines three types of dose: *residual dose*, *projected dose* and *averted dose*. Residual doses are those expected to be received, taking account of any protective actions (planned and/or implemented). The total residual dose is the sum of exposures over all exposure pathways. Projected doses are those expected to be received in the absence of protective actions. These are used to scope the probable impact of the event, and hence the scale of response that is likely to be required. Averted doses are the contributions to the projected dose that are expected to be averted by planned or implemented protective measures. Averted dose is the appropriate quantity for specifying intervention levels for individual protective actions.

Where exposures would be expected to continue over a year or more, the quantity to be compared with the ICRP reference level is the 'one year' total residual dose, ie the sum of committed effective dose for intakes over one year and external whole-body exposures received over one year, as a result of the emergency. Where exposures are likely to be received over a relatively short period of time, then it is the total residual dose that should be compared with the reference level.

Whether or not the UK adopts the full recommendations of the ICRP regarding the application of reference levels to the optimisation of the overall response to emergencies, the HPA recommends that the UK adopts the ICRP definitions for residual, projected and averted dose, to avoid potential misunderstandings.

### 6.2.9 Application of emergency reference levels (ERLs) of dose

The role of intervention levels within emergency planning has not changed with the introduction of the latest advice from the ICRP. However, the need for planners to consider the optimisation of the plan over all response phases serves to highlight the role of intervention levels as useful inputs as opposed to absolute criteria for developing the plan. In particular, in circumstances for which it appears that no single protective measure on its own is sufficient to reduce residual doses to below the reference level, it may be necessary to combine several protective measures, one or more of which would appear unjustified by simple comparison with its intervention level, to achieve this outcome. In this case, the intervention level would act as a prompt to consider the introduction of that measure more carefully, to determine whether or not an alternative measure or manner of introduction might increase the expected benefits or decrease the expected harms. The ICRP therefore continues to recommend use of intervention levels in planning, provided they are applied flexibly, as an aid to developing an optimised overall protection strategy.

The UK emergency reference levels (ERLs) of dose (NRPB, 1990b, 1997a) and other dose criteria, eg the recommended framework for developing recovery strategies (NRPB, 1997b), were explicitly developed for flexible application. The HPA advises that the ERLs and associated guidance on emergency response planning continue to be appropriate for use in the UK. The HPA notes that the current EU directives (EC, 1987, 1989, 1990) relating to radioactive contamination in foodstuffs were developed taking into account a wide range of factors including public health, the need to maintain the food supply and the practicalities of regulating trade in potentially contaminated foodstuffs. The HPA has provided advice on the application of these directives in the UK (NRPB, 1994). The HPA advises that these directives continue to represent both regulatory requirements and sound application of radiological protection principles.

Optimisation of the overall response strategy requires planning for the withdrawal of protective actions as well as their initiation. The HPA will develop further guidance on the withdrawal of protective actions.

## 6.3 Existing exposure situations

### 6.3.1 General

Existing exposure situations are those that are already in existence when a decision on control has to be taken. They include situations involving exposures from naturally occurring radionuclides, such as radon in dwellings or the workplace, and from man-made radionuclides, such as land contaminated by previous nuclear site operations.

Many existing exposure situations involve naturally occurring radionuclides. Some of these, such as exposure to potassium-40 incorporated into the human body and exposure to cosmic rays at ground level, are excluded from regulatory control as they cannot be controlled by any reasonable means. Others, for which regulatory control is, or may be, required, include radon in dwellings and land contaminated with materials containing high levels of naturally occurring radionuclides. Such contamination may, for example, result from radium luminising activities carried out on the site or from the use of industrial byproducts with enhanced concentrations of naturally occurring radionuclides (for example, metal production slags used as aggregates on some construction sites).

The ICRP states that existing exposure situations that may cause exposures high enough to warrant radiological protective actions, or at least their consideration, include 'radon in dwellings or the workplace, and naturally occurring radioactive material (NORM)' (ICRP, 2007a). It is important to recognise that not all exposures to NORM can be classed as existing exposure situations. As indicated in Section 6.1, industrial installations and processes that either use materials with enhanced levels of naturally occurring radionuclides or produce materials and waste streams with enhanced levels of naturally occurring radionuclides should be considered as planned exposure situations.

The ICRP indicates that existing exposure situations involving man-made radionuclides include land contaminated as a result of previous activities on the site or by residues of radioactive discharges, where such activities and discharges were not conducted within the ICRP framework or equivalent (ICRP, 2007a).

The HPA endorses the ICRP position that land contaminated as a result of activities on a site or by residues of radioactive discharges, where such activities and discharges were not conducted within the ICRP framework or equivalent, should be considered as existing exposure situations. The HPA considers that this applies whether the radionuclides involved are man-made or naturally occurring. The HPA further notes that residues from discharges authorised by the appropriate UK regulatory bodies should be considered as part of the overall system for planned exposure situations, rather than as existing exposure situations, except in exceptional circumstances.

The ICRP also recommends that 'the management of long-term contamination resulting from an emergency situation should be treated as an existing exposure situation'.

The HPA endorses the ICRP position that the management of long-term contamination resulting from an emergency situation should be treated as an existing exposure situation, as this allows for consistent treatment of all related long-term exposure situations, but notes the need for consistent approaches and strategies at all stages following an emergency situation (ie seamless transition). Further guidance is given in Section 6.2.

The ICRP recommends that reference levels, set in terms of individual dose, should be used in conjunction with the implementation of the optimisation process for exposures in existing exposure situations. As indicated earlier, the HPA welcomes the use of reference levels as restrictions in the optimisation of protection.

The 2007 recommendations state that the objective for existing exposure situations is to implement ‘optimised protection strategies, or a progressive range of such strategies, which will reduce individual doses below the reference level. However, exposures below the reference level should not be ignored; these exposure circumstances should also be assessed to ascertain whether protection is optimised, or whether further protective measures are required’. This statement makes clear that reference levels should not be treated as targets or limits but as constraints on optimisation, and this is in agreement with the HPA understanding of the concept. The often iterative nature of the optimisation process is also reflected in the description of the process. This arises primarily because the effectiveness of some strategies cannot be predicted in full beforehand. It is important, however, that the advice not be interpreted as ‘the further below the reference level the better’.

The ICRP indicates that reference levels for existing exposure situations should be set typically within the 1 mSv to 20 mSv band of projected dose (see Table 5.2). The HPA agrees with this approach and advises that current UK regulations and advice for such situations are generally consistent with this objective.

Factors to be considered in setting reference levels for existing exposure situations include the feasibility of controlling the situation and past experience of the management of similar situations.

It is important to note that existing exposure situations can be very complex, involving several exposure pathways and potentially giving rise to wide distributions of annual individual doses (eg following nuclear accidents). Any optimisation process must consider the full range of doses. However, the reference level will generally be defined in relation to those most exposed, ie the representative person.

The ICRP states that individuals should receive general information on the existing exposure situation and the means of reducing their dose. It is further noted that in situations where individual lifestyles are key drivers of the exposures (eg if living on contaminated land following a nuclear accident), individual monitoring or assessment may be important requirements. The HPA agrees that this will generally be

appropriate but also notes the potential need for the involvement of affected individuals and communities in developing appropriate optimised strategies.

The ICRP notes that in most existing exposure situations, especially those involving exposures resulting from human actions (eg long-term contamination from accidents), there is a desire from the exposed population to ‘reduce exposures to levels that are close to or similar to situations considered as “normal”’.

The HPA recognises that the desire of the exposed population in existing exposure situations to reduce exposures to levels that are close to or similar to those in situations considered as ‘normal’ is an important input to decisions on optimisation strategies, whilst noting that, in this context, it considers that the concepts of ‘normal’ and ‘normality’ do not refer to conditions as they were before the exposure situation arose but to a new status quo acceptable to all stakeholders involved.

### 6.3.2 Radon

At the time of writing, the HPA was consulting publicly on the limitation of human exposure to radon-222 and its radioactive decay products within the UK (HPA, 2009b). Some aspects of protection referred to here are subject to the outcomes of that consultation. Where appropriate, the extant position in the UK is used as a basis for the advice given here, together with reference to the HPA consultation on radon, but without pre-judging the outcome of that work.

The ICRP recommendations on protection against radon exposure in dwellings and workplaces are given in Publication 65 (ICRP, 1993b). Current UK policy and practice are largely consistent with that advice. The 2007 recommendations are broadly consistent with Publication 65, but less prescriptive, leaving more of the implementation to national authorities.

The ICRP now recommends that the estimation of risk from domestic radon exposure should include the results of pooled residential case-control studies. It notes that the epidemiological studies on miners are still of great value for investigating dose-response relationships and confounding effects of smoking and exposure to other agents. It also notes that the currently available epidemiological evidence indicates that risks other than of lung cancer from exposure to radon (and its decay products) are likely to be small.

The HPA agrees that the estimation of risk from domestic radon exposure should include the results of pooled residential case-control studies, but notes that the ICRP does not provide:

- a any estimates of risk from radon exposure based on those studies,
- b any indication of whether estimates of risk are likely to be different from those based on epidemiological studies on miners,

- c a revised dose conversion convention [mSv per unit exposure (time-integrated air concentration)],
- d guidance on how to apply the results of the pooled residential studies to a specific population.

The ICRP recommends applying the source-related principles of radiological protection for controlling radon exposure, meaning that national authorities need to set national reference levels for workplaces and homes to aid the optimisation of protection. It reaffirms that radon exposure at work at levels above the appropriate national reference level should be considered part of occupational exposure, whereas exposure at levels below should not. Nevertheless, optimisation is a requirement below the national reference level. For the sake of continuity and practicability, the ICRP retains the upper value of 10 mSv for the annual dose reference level given in Publication 65, and upper values for the reference level expressed in activity concentrations of 1500 Bq m<sup>-3</sup> for workplaces and 600 Bq m<sup>-3</sup> for homes. (The difference is mainly due to the shorter time spent at work than at home over a year.) The ICRP adds that in the interest of international harmonisation of occupational safety standards, the single action level value of 1000 Bq m<sup>-3</sup> established in the International Basic Safety Standards (IAEA et al, 1996) might be used globally to define the entry point for occupational protection requirements for radon exposure situations. The ICRP also recommends that national authorities should periodically review the values of the national reference levels for radon exposure to ensure that they remain appropriate.

**The HPA endorses the overall approach of the ICRP to the control of radon exposures in the home and workplace.**

The HPA notes that the setting of national reference levels, and considering radon exposure at work at levels above (but not below) the national reference level as part of occupational exposure, is consistent with existing UK policies. The UK already has reference levels for radon: the action levels which, at the time of writing, are 400 Bq m<sup>-3</sup> for workplaces [set in the Ionising Radiation Regulations, 1999 (GB Parliament (1999))] and 200 Bq m<sup>-3</sup> for homes [advised by the HPA (NRPB, 1990d)], are well below the ICRP upper values. The HPA considers, however, that the concentrations recommended by the ICRP as upper values are high by modern standards and has some concern that they might lead to suggestions that reference levels in the UK, and most if not all other countries, are unduly restrictive. The HPA considers that the action level of 1000 Bq m<sup>-3</sup> in the International Basic Safety Standards (IAEA et al, 1996) is inappropriate for the UK. The UK has a mature programme for occupational protection against radon, and the current level of 400 Bq m<sup>-3</sup> in the UK is manageable.

The ICRP recommends that all reasonable efforts should be made to reduce radon exposures in homes and workplaces to below the reference levels that are set at the national level and to a level where protection can be considered optimised. The actions taken should be intended to produce substantial reductions in radon exposures. It is insufficient to adopt marginal improvements aimed only at reducing the radon concentrations to a value just below the national reference level. Responsibility for taking



action against radon in homes and other premises will often fall on the individual owners, who cannot be expected to carry out a detailed optimisation exercise for each property. Therefore, in addition to reference levels, regulatory authorities may also wish to specify levels at which protection against radon can be considered optimised, ie where no further action is needed. For the UK, the HPA has advised that all new buildings should include simple measures to reduce indoor radon concentrations (HPA, 2009b). This reflects the lower cost of implementing such measures at the design and building stages compared with those of later testing and remediation.

**The HPA agrees with the ICRP recommendations for applying the principle of optimisation of protection to reduction of radon levels, noting that existing UK policy is consistent with the recommendations.**

The HPA already advises that reasonable measures should be taken that are likely to produce as large a reduction in radon concentrations as possible, not just to get below the action level, because there is relatively little difference in cost between remedial measures that vary greatly in effectiveness. In the UK, it is considered that for most workplaces if the concentration is below  $400 \text{ Bq m}^{-3}$ , protection can be considered to be optimised, and no further action is needed. Thus  $400 \text{ Bq m}^{-3}$  is both the reference level and the optimisation level. In some workplaces where the equilibrium factor between radon and its decay products is very different from normal (eg certain mines) the optimisation level may be lower.

The ICRP states that there is merit in defining radon-prone areas in which the concentration of radon in buildings is likely to be higher than is typical of the country as a whole. This allows attention to be focused on radon where it is most exigent and action to be concentrated where it is most likely to be effective.

**The HPA defines radon-prone areas for the UK, currently referred to as radon Affected Areas, to achieve the objectives set out by the ICRP. The HPA consultation on radon intervention proposes options for how this might be applied in future.**

The ICRP recognises explicitly that for many individuals radon is an important source of exposure which, in principle, can be controlled.

The HPA considers that the ICRP should place greater emphasis on exposure to radon. For most of the world's population, radon is the largest single source of exposure to radiation, accounting for about half the total exposure (UNSCEAR, 2000). Radon concentrations are very variable and the HPA estimates that about 250,000 people in the UK live in homes with concentrations above its action level, and as a result receive doses at least ten times higher than the average. Radon concentrations are easy to measure and straightforward to reduce. There is therefore great potential for reducing exposure. However, HPA experience suggests that there are challenges in persuading householders and others to obtain measurements and take remedial action. The HPA has developed expertise in designing appropriate surveys and follow-up activities that seek to maximise these aspects of radon control.

The HPA welcomes application of the 'source-related' principle to control radon exposure, and thereby make it explicitly consistent with protection against other sources. However, the HPA is disappointed that the ICRP did not take the opportunity to give a greater emphasis to protection against radon exposure in its new recommendations. The HPA is currently preparing revised advice on protection against radon in the UK.

### 6.3.3 Radioactively contaminated land

The NRPB provided advice in 1998 on radiological protection objectives for land contaminated with radionuclides (NRPB, 1998). This was developed from the 1990 recommendations of the ICRP and was intended to be consistent with them. The scope of the guidance covers the majority of situations where land may be contaminated, except areas contaminated as a result of accidental releases that are beyond site premises.

The advice identifies two general categories of exposure situation: first, those where a change of use is proposed that will result in exposures (eg site redevelopment) and, second, those where contamination is discovered on land to which the public already has access (ie land already developed for industrial, housing, leisure use, etc). The advice notes that the ICRP classification of exposure situations at that time into practices and interventions was not always helpful in relation to contaminated land, but broadly applied the 1990 principles for practices to the first type of situation and the principles for intervention to the second. As discussed in Section 6.1, the HPA considers that, in general, the redevelopment of a radioactively contaminated site is a planned exposure situation. Where members of the public are already exposed to contaminated land, the HPA considers that this is an existing exposure situation.

The 1998 NRPB advice gave guidance on the application of the principles of justification and optimisation for both types of exposure situation that is consistent with the 2007 recommendations of the ICRP. Appropriate dose constraints for planned exposures are discussed (see Section 6.1). For existing exposure situations no detailed guidance on reference levels is given; however, it is noted that if the projected lifetime effective dose is expected to exceed 1 Sv then implementation of measures to reduce this dose will almost certainly be justified.

More recently, the HPA has provided guidance on dose criteria for the designation of radioactively contaminated land (HPA, 2006). This related specifically to the development of regulations on the identification and remediation of radioactively contaminated land in, to use the terminology introduced in the 2007 recommendations, existing exposure situations.

On the basis of a review of existing advice, including that from the ICRP, and consideration of relevant national circumstances, the HPA concluded that intervention actions would normally be justified if people were receiving an effective dose of around 10 mSv per year from the contamination, where such a dose continues at a reasonably constant rate for a significant proportion of an individual's lifetime. The HPA further argued that the designation of land as radioactively contaminated should be based on a level of exposure at which it is appropriate that the site is investigated and remedial options are considered, but

that intervention actions need not necessarily be undertaken as they may not be justified, and that this level of exposure is clearly below 10 mSv per year. A recommended value of 3 mSv per year from the contamination was selected for this purpose. This value has been incorporated into UK regulatory guidance (Defra, 2006).

The HPA considers that the characteristics of such existing exposure situations are such that, under the 2007 recommendations, reference levels in the 1 mSv to 20 mSv band of projected dose would be deemed appropriate. The HPA therefore considers that its guidance on dose criteria for the designation of contaminated land is consistent with the 2007 recommendations. The HPA notes that the level of 3 mSv per year should not be interpreted as a reference level, as it is not an upper level for optimisation. It is a practical criterion specific to the particular regulatory context derived from consideration of a number of factors, including a consideration of appropriate reference levels. In general it is noted that although reference levels are useful radiological protection concepts, it may sometimes be necessary, for regulatory purposes, not to use them directly but to use them as inputs to the derivation of appropriate dose levels for more practical application.

It is important to note that the advice on criteria for the designation of contaminated land (HPA, 2006) also applies in the longer term to contamination resulting from emergency situations. The approach in the two areas is therefore consistent.

The HPA considers that its advice on radioactively contaminated land (NRPB, 1998; HPA, 2006) remains valid and is consistent with the 2007 recommendations, whilst noting that there are clearly some minor differences in terminology.

### Potential exposures

HPA advice on dose criteria for land designation also addresses situations where there is a possibility of occurrence of exposures but the probability is low. Examples include land contaminated with a small number of radioactive ‘hot’ particles. There is very little ICRP guidance on the treatment of potential exposures under these circumstances. HPA guidance on the designation of land as contaminated under these circumstances was developed on the basis of the level of risk implied by a 3 mSv per year level, the need to consider the possibility of deterministic effects and the possible non-linearity of the dose–response curve at effective doses above 100 mSv, but it is recognised that in the majority of these cases decisions on designation would need to be undertaken on a case-by-case basis. The HPA guidance has been directly incorporated into regulatory guidance for England and Wales (Defra, 2006).

Current international and national advice, including that from the ICRP, on existing exposure situations where the probability of exposure is significantly less than unity (eg land contaminated with radioactive ‘hot’ particles), is very limited. Such situations are not specifically addressed in the new ICRP recommendations. In the UK there are a number of sites where contamination of this type is a significant radiological protection issue. This is clearly an area in which further guidance is required. The HPA

considers it important to note in this context that, in its view, the ICRP recommended bands of reference levels (Table 5.2) strictly apply only in cases where doses are reasonably certain to occur and are thus not strictly applicable to situations of heterogeneous contamination. The HPA will issue further guidance on the radiological implications of heterogeneous contamination.

#### 6.3.4 Long-term contamination following emergency situations

The 2007 recommendations of the ICRP have introduced a number of changes to the overall framework for radiological protection following accidents and incidents. These include the recommendation that the management of long-term contamination resulting from an emergency situation be treated as an existing exposure situation, with reference levels to be set typically in the 1 mSv to 20 mSv band of projected dose (see Table 5.2).

The current advice from the HPA is based on a division of the response to an emergency into two stages: emergency and recovery (NRPB, 1990b, 1997b). The recovery phase addresses the issue of long-term contamination. Guidance has been given on the application of the principles of justification and optimisation of intervention strategies in the recovery phase as has some advice on appropriate dose criteria (NRPB, 1997b).

The HPA considers that, aside from differences in terminology, its current radiological protection advice on the recovery phase (NRPB, 1997b) is broadly consistent with the 2007 recommendations of the ICRP in relation to the treatment of long-term post-emergency contamination.

As discussed in Section 6.3.3, the HPA guidance on criteria for the designation of radioactively contaminated land also applies to long-term post-accident contamination (HPA, 2006), and this is considered consistent with the new ICRP recommendations.

It is anticipated that, in response to the ICRP recommended changes to the overall framework for accidents and incidents, additional guidance in this area will be issued at some later stage by the HPA.

## 7 Conclusions

The HPA welcomes the 2007 recommendations of the ICRP, which represent an update, consolidation and development on the previous recommendations and publications (ICRP, 2007a). A linear non-threshold model is still considered appropriate for estimating stochastic risks for radiological protection purposes at doses below 100 mSv. Furthermore, the risk factor for fatal and non-fatal cancer is substantially unchanged between the 1990 and 2007 recommendations (ICRP, 1991a, 2007a). Tissue and radiation weighting factors are updated. The change from ‘practices and ‘interventions’ to the three types of exposure situations (planned, emergency and existing) is welcomed as it facilitates application of the system to all circumstances of radiation exposure. Overall, however, the 2007 recommendations do not imply any major changes to the system of protection applied in the UK.

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