European Commission

Radiation protection 129

Guidance on the realistic assessment of radiation doses to members of the public due to the operation of nuclear installations under normal conditions.

A great deal of additional information on the European Union is available on the Internet.
It can be accessed through the Europa server (http://europa.eu.int).

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Guidance on the realistic assessment of radiation doses to members of the public due to the operation of nuclear installations under normal conditions

Recommendations of the group of experts set up under
the terms of Article 31 of the Euratom Treaty

Directorate-General Environment
Directorate C – Health and environment
Unit C. 4 - Radiation protection

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This report can be found at:

http://europa.eu.int/comm/environment/radprot/index.htm#studies

Foreword

The assessment of radiation doses to individuals in the population is an important part of the system of radiation protection. A significant concept for calculating such doses is that of reference groups in the population. Reference groups correspond to critical groups as defined by the International Commission on Radiological Protection (ICRP) and are intended to be representative of those people in the population who receive the highest doses. The ICRP has recommended that the mean dose to the critical group should be compared with the dose limit and dose constraint for members of the public.

Article 45 of the European Union's Basic Safety Standards Directive (Council Directive 96/29/Euratom) explicitly requires that Member States' competent authorities shall ensure that estimates of doses from practices subject to prior authorisation shall be made as realistic as possible for the population as a whole and for reference groups.

EU Member States currently use different approaches both to identify reference groups and to calculate the corresponding doses. This guide should help to avoid misunderstandings between Member States, resulting from differences in the assessment of the impact of nuclear installations. It should also allow the Commission to carry out comparisons between the levels of exposure of the public for different plants, the estimates being made on a comparable basis.

The present document offers a common methodology in view of the harmonisation of approaches for calculating doses to members of the public throughout the EU.

The effort put into achieving a high degree of realism must be commensurate with the radiological significance, hence some simplification can be pursued. This document also provides guidance as to how a fair balance between realism and simplicity can be achieved.

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1. INTRODUCTION

The aim of a realistic assessment is to estimate doses as closely as possible to those that would actually be received by members of the public. This is not straightforward and requires judgement but the aim is to avoid significant over- or underestimation.

The primary application of this guidance is for *retrospective assessments* due to the discharge of radioactive effluents from nuclear installations during normal operations. Retrospective assessments consider doses that are currently being received or that were received in the past. It is likely that information will be available on the location and behaviour of reference groups and measurements of radionuclides in the environment may also be available.

Although the emphasis is put on retrospective assessment much of the guidance in this report is also relevant to *prospective assessment*. Prospective assessments consider doses that may be received in the future, e.g., from planned discharges. In this case judgement is needed on what may happen in the future, e.g., regarding changes in land use, and normally such assessments include an element of caution in the assumptions adopted.

It should be noted that the guidance is also relevant to non-nuclear industries, such as hospitals or pharmaceutical facilities.

This report considers all stages in the assessment of doses to reference groups, in particular: the specification of the source term, including the likely discharges from different types of nuclear installations; the exposure pathways that should be considered and their relative importance; methods for assessing doses for the important exposure pathways; issues to be considered in identifying reference groups; other factors involved in dose assessments, such as realism of the assessment, variability and uncertainty and the use of measurement data.

Finally, it should be noted that this report is based on a study by NRPB and GRS commissioned and funded by the Directorate-General Environment of the European Commission. The study, entitled "Guidance on the assessment of radiation doses to members of the public due to the operation of nuclear installations under normal conditions." can be found on the European Commission Radiation Protection Unit web site:

http://europa.eu.int/comm/environment/radprot/index.htm#studies.

2. SOURCE TERMS

To do a realistic dose assessment it is essential to obtain as much information as possible relating to the radionuclides discharged. Data will need to include:

- Type and amount of radionuclides being discharged;
- Chemical and physical form of release;
- Location and condition of release.

Assessments of doses can only be carried out on a radionuclide-specific basis. Where groups of radionuclides have been reported it is necessary to either split the discharge for the groups of nuclides between the radionuclides known to have been discharged, or to use a "representative" radionuclide. Thus, it might be cautiously assumed that ^{239}Pu is representative of total alpha activity and ^{137}Cs is representative of total beta activity. To help in splitting the discharge between specific radionuclides, the likely discharge rates from typical nuclear installations and the likely breakdown of any aggregated discharges can be used.

Where the chemical form is likely to be important in a dose assessment, the operator should provide the relevant information. This also applies to the physical form, for example, for particulate releases to atmosphere, where the size of the particles can affect the subsequent doses from the discharges.

The assessment will need to take account the location of release (e.g., atmospheric release from a stack of a height of 80 m or vent from a building, river or coastal area to which liquid effluents are being discharged).

Exposures are typically assessed on the assumption of annual discharges. This assumes that the activity is discharged continuously and uniformly throughout the year. In practice, discharges will never be uniformly continuous. Given the other uncertainties in the assessment process, the results based on continuous release remain valid for normal operational daily variations in discharges. However, if a significant proportion of the annual discharge was released in a short time period, this could lead to higher annual reference group doses than those assessed for a uniform release rate over the year, depending on the conditions at the time of release. It should be noted that, conversely, high activity short term releases could occur at times which would lead to lower doses (e.g., during winter, when few crops are harvested).

3. EXPOSURE PATHWAYS

When radionuclides are released into the environment there are a number of different ways in which they can lead to radiation doses to individuals. The different ways are referred to as exposure pathways and radiation doses need to be assessed for each important exposure pathway. There are many different possible exposure pathways and it is not necessary to consider every possibility in a realistic assessment of doses. This section discusses the importance of different pathways and makes recommendations on which pathways should almost always be considered in an assessment, those which may need to be considered and those which rarely need to be considered.

Moreover, in the case of aquatic discharges, the local-specific pathways should be split into those that will give rise to relatively important doses and those that could give rise to lower doses. The relatively important pathways are those which lead to doses that exceed or are comparable to the dose from the most dominant ‘conventional’ pathway. Less important pathways are those giving rise to doses around one order of magnitude less than the most dominant "conventional" pathway. A "conventional" pathway is one which is typically found at the majority of sites, e.g., for maritime sites: consumption of fish, time spent on intertidal areas. Unconventional pathways are those that may occur around a few sites, e.g., consumption of cow’s milk from animals grazing on salt marshes, but are not characteristic of most sites.

3.1. Atmospheric discharges

Pathways that should always be considered

In general terms these pathways are:

- Ingestion of radionuclides in terrestrial food (e.g., milk, meat, vegetables and fruit);

- Inhalation of radionuclides in the atmosphere;
- External irradiation from radionuclides in the atmosphere and deposited on the ground.

For any assessment it is important to consider the agricultural practice around the nuclear installation. The foodstuffs considered are general groups, for example, green vegetables includes all types of leafy and leguminous vegetables. The calculations of doses from meat and milk are generally based on cows. However, if local information indicates that there are no cows in the vicinity of the site but that sheep or goats are present, then such pathways should be considered. Local conditions may also affect which foodstuffs should be considered and the relative importance of these, but in general it is important to consider the ingestion of terrestrial foods when assessing radiation doses from releases into the atmosphere.

Pathways depending on local conditions

The ingestion of radionuclides in "free foods" is an example of a potential exposure pathway, which should be only considered when local habit data suggest this may be of relevance. Free foods include berries, mushrooms, crab apples, rabbits, pheasants, venison, etc. When considering the ingestion of free foods, it is essential to have information on local habit data. Regional or national habit data cannot take account of the free foods available in an area and large variability is observed between regions. In addition, soil- to-plant transfer factors for many wild plants, e.g., lichen, are difficult to obtain and can vary widely. For example, many different species of mushroom grow in different areas, and since radionuclide uptake is species-specific it would be very difficult to assess accurately doses due to ingestion of wild mushrooms in a general way. Consequently, it is not possible to give generic guidance on how to calculate realistic radiation doses from this pathway, due to the site-specific nature of the assessment.

It is not normally necessary to consider food products from pigs and poultry that are housed inside and fed from a number of sources, most of which will be some distance from the site of interest. However, they may be important in specific locations if other foods are not grown close to the location of interest.

Pathways not normally considered

Doses from drinking water and consumption of fish, where the discharges into the atmosphere, with subsequent deposition onto land and water surfaces, are generally negligible.

The deliberate ingestion of soil by children or adults does not need to be considered in assessments because this pathway is a recognised medical condition, known as *pica*, which tends to last for a relatively short time. Inadvertent ingestion of soil and dust does not normally need to be considered.

3.2. Aquatic discharges: marine, estuarine, riverine*

Discharges to the aquatic environment can result in markedly different doses for the same release rates depending on the receiving water body. For example, the doses received from

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[1*] For discharges to lakes the situation will be similar to that for discharges to rivers. The same exposure pathways should be considered with local factors taken into account. Limited calculations for discharges to a lake in the UK indicate that doses are likely to be higher for discharges to a lake than for discharges to a river because of the limited movement of water out of the lake.

discharges to a river would be dependent on the volumetric flow of the river. Similarly, doses from discharges to the marine environment are affected by the currents in the area. Additionally, radionuclides exhibit different sediment partitioning and biota uptake in marine and freshwater environments. In general, assessments of doses from aquatic discharges must include an element of site-specificity in the modelling of their impact.

Pathways that should always be considered

These pathways are most likely to be present at all locations and can be considered "conventional" pathways. In general terms, these pathways are:

- Ingestion of radionuclides in the main aquatic foods (e.g. fish, crustaceans, and molluscs);
- External irradiation from gamma-emitting radionuclides on beaches or sediments.

Pathways depending on local conditions

- Important pathways to consider if local conditions indicate that this is appropriate:

These pathways give rise to relatively important doses for the majority of sites, irrespective of the local dispersion conditions in the locality of the site. The pathways also represent those likely to give doses of the order of the most dominant “conventional” pathway.

For instance, in the case of marine discharges, if there are indications that local people consume marine plants then the doses received from this pathway can form a significant proportion of the total dose received by an individual. Habit surveys should be used, where possible, to identify whether individuals ingest marine plants in the locality of a site. Other pathways which can result in relatively important doses if local conditions suggest they occur are the consumption of marine biota other than plants, e.g., aphrodite aculeate (sea mice) and the ingestion of animal products produced from animals grazing on salt marshes. However, as the process of uptake of radionuclides into such biota is not fully understood and the accumulation of radionuclides into salt marshes cannot be easily modelled, then dose estimates should be based on environmental measurement data.

In the case of riverine discharges external exposure on houseboats can be a relatively important pathway due to the amount of time spent on the water with relatively little shielding. Data on occupancy times should be taken from habit surveys, if available. The pathway, if present, is likely to give doses of the order of the most dominant "conventional" pathway.

- Pathways that could be considered if local conditions indicate that this is appropriate:

In the case of marine discharges, the ingestion of crops grown on soil conditioned using seaweed (e.g., grain, root vegetables) could be relevant if it occurs in the locality of the site. Seaweed can be used as a conditioner to improve soil fertility. This allows radionuclides incorporated in the seaweed to be available for uptake by crops grown on such soil. Exposure while swimming could be relevant if there are individuals who spend long periods of time swimming, e.g., an hour a day. An additional pathway for consideration is desalinated water used for drinking water. The importance of this pathway will be very much dependent on the location of the abstraction of the seawater compared to the discharge point and whether the desalinated water is used for drinking water.

In the case of estuarine discharges, it is important to consider the ingestion of aquatic plants taken from an estuary as a pathway. The doses received from this pathway can form a significant proportion of the total dose received by an individual. Habit surveys should be used, where possible, to identify whether individuals ingest aquatic plants in the locality of a site.

In the case of riverine discharges, it can be important to consider the ingestion of freshwater molluscs and crustaceans. Ingestion of animal meat or milk from animals drinking river water should be considered as a pathway if it is likely to occur. These pathways give rise to relatively important doses for some sites, depending on the local dispersion conditions in the locality of the site. The ingestion of crops grown on previously flooded land can form a significant proportion of the total dose, especially to infants. The inadvertent ingestion of river-bank sediment becomes important for younger age groups, depending on the mix of radionuclides released to the river. External exposure during swimming or while using boats for recreational purposes can be important, depending on the occupancy and radionuclides released. Skin doses from fishing gear should be considered if identified. Although the ingestion of treated drinking water gives relatively small doses, the ingestion of untreated drinking water can occur and in some local circumstances may give rise to relatively important doses.

Pathways not normally considered

- Marine discharges

Inhalation of seaspray and inadvertent ingestion of seawater while swimming are generally unimportant pathways. Doses from crops or animals farmed on land exposed to seaspray or reclaimed from the sea are often negligible. This is also the case of inadvertent ingestion of beach sediment. Although the doses from this pathway are insignificant (i.e., of the order of a few $\mu Sv.y^{-1}$), the relative contribution from this pathway is higher for infants, as they receive less exposure from conventional pathways (e.g., consumption of seafood, exposure from sediments).

Negligible doses are found to be received from beta-emitters in beach sediment and the inadvertent ingestion of seawater. The doses from beta-emitters entrained in fishing gear give extremely small doses. The exposure of individuals who spend time on boats does not lead to significant doses. The inhalation of resuspended sediments or conditioned soil are both generally insignificant contributors to dose.

- Estuarine discharges

The following pathways generally give rise to insignificant doses: inhalation of seaspray and inadvertent ingestion of seawater and estuarine sediment; ingestion of crops or animals farmed on land exposed to seaspray and crops grown on soil conditioned with seaweed; exposure to beta-emitters in estuarine sediment and from beta and gamma-emitters entrained in fishing gear; the skin dose received while bait-digging; the inhalation of resuspended sediments or conditioned soil; the exposure of individuals who spend time on boats.

- Riverine discharges

The following pathways are generally insignificant contributors to the doses: the ingestion of treated drinking water taken from the river into which a site discharged; consumption of freshwater plant and waterfowl; the ingestion of crops irrigated using river water or crops grown on soil conditioned using river plant; inadvertent ingestion of river water while swimming; the external exposure of individuals on previously flooded land and the exposure from beta-emitters on river-bank sediment; the inhalation of resuspended river-bank sediments.

4. METHODOLOGY FOR THE CALCULATION OF DOSES

Doses are calculated taking into account the activity concentrations in the environment: air, soil, food, etc., the habits of local people, e.g., the amount of locally grown food eaten, amount of time spent on beaches and the dose coefficients (Sv/Bq) specific for the different radionuclides.

The most realistic method for assessing doses to members of the public is by extensively monitoring the exposure pathways and conducting surveys of the habits of local people. However, this approach is costly, both in monetary terms and in time. Typically, an assessment would use a combination of measurement and modelled data with either the modelled data providing information where the measured data is at the limit of analytical detection, or the measurement data being used to verify the modelled data.

A number of models are available and although no specific recommendations are made (IAEA, 2001) and (Simmonds et al., 1995) are useful references. However, it must be noted that the model given (IAEA, 2001) is intended for screening purposes and uses conservative generic values. If a realistic assessment is intended these values would need to be replaced by more realistic and preferably site-specific values. It is necessary that any models used are robust and fit for the purpose. Measures should have been taken to ensure that the models are valid. This means that the models should have been tested to ensure that they are behaving as intended and, where possible, should be compared with measurement data to ensure that they are an adequate representation of reality. For example, an IAEA programme called VAMP, Validation of Environmental Model Predictions, (Koehler et al., 1991) tested the predictions of the mathematical models against results of measurements made after the Chernobyl accident.

4.1. Atmospheric discharges

If models are used to predict activity concentrations in the air and on the ground account should be taken of the range of meteorological conditions that occur in the course of a year. Besides radioactive decay, the effects of wet and dry deposition should be considered. The meteorological conditions should be appropriate for the site in question and should preferably be averaged from several years of data. Such data may be available for the site itself or from nearby meteorological stations. The atmospheric dispersion model also needs to take into account the height of the release, taking into account the effects of nearby buildings and any plume rise due to the thermal buoyancy and/or momentum of the released material. Gaussian plume dispersion, based on the use of stability category meteorological data (Pasquill, F.A., 1976) can be used. A new generation of models has been developed, e.g. ADMS (Carruthers et al., 1994) and AERMOD (Cimorelli et al., 1998). However, when considering continuous releases there is little difference between the new models and the Gaussian plume model, e.g., as implemented in PC-Cream (Mayall et al., 1997).

It is common practice to use a generic model for the transfer of radionuclides through terrestrial foodchains. In such models similar foods are grouped together for modelling purposes, for example green vegetables and root vegetables are considered rather than specific crops, such as cabbage or carrots. In most cases it will be acceptable to use generic parameter values for the foodchain model. However, if extensive measurements have been made close to the site then it may be appropriate to use site-specific values for particular parameter values.

For modelling the resuspension of radionuclides deposited on the ground two approaches are possible. The first uses a resuspension factor to relate the ground deposition to the activity concentration in air, while the second uses a dust loading approach (Simmonds et al., 1995).

A model may also be required to calculate external radiation exposure from deposited material. This should allow for the downward migration of radionuclides in the soil, as well as the build-up of activity due to continuous deposition.

4.2. Aquatic discharges

Radionuclides discharged to water bodies are dispersed due to general water movements and sedimentation processes. Liquid radioactive wastes may be discharged to freshwater, marine or estuarine environments. Much depends on the local characteristics of the receiving environment and it is not possible to have a totally generic model for liquid releases. Discussion on the various models available for simulating transfer in the aquatic environment has taken place in a European Commission Concerted Action (Simmonds et al., 2000). Models available vary in purpose and complexity and should be selected appropriately. Examples of compartmental models available for marine discharges are PC CREAM (Mayall et al., 1997) and Poseidon (Lepicard et al., 1998). Both of these models represent the European marine waters as a series of inter-linked water and sediment compartments. Another approach is that used for CSERAM (Aldridge J.N., 1998). This is a more complex model used for a specific region of the marine environment, i.e. the Irish Sea. All of these models are likely to give similar results for continuous routine releases.

If water is discharged into a river, the influential parameters are the discharge rate and the river flow rate, the river size, the sedimentation rate and the nature of the sediment. Generally speaking, the maximum concentration within the water body is near the discharge point. At a distance of some 10 km downstream, the radionuclide concentrations in the water body are homogeneous (SSK, 1992). However, additional dispersion occurs due to sedimentation and the presence of tributary waters leading to a reduction in radionuclide concentration.

The amount of dispersion may be different for the different pathways, for example, water for irrigation purposes is abstracted solely during summer dry periods. The amount of dispersion for this pathway should therefore to be based on the summertime flow rate (SSK, 1992). The fish habitat may comprise of tributaries of small rivers and streams both up- and downstream of the discharge point. The amount of dispersion will be an average weighted over the different compartments of the river that are used to calculate the radionuclide concentration in the fish.

If a lake is the receiving medium, then the maximum dispersion depends on the flow rate of the water passing through the lake. In countries with seasonal drought the concentration of radionuclides in the lake may vary throughout the year, especially if the draining from the lake ceases completely for a period of time.

In assessing doses to the reference group, the highest activity concentrations - and hence doses - will generally arise close to the discharge point. However, there is a possibility of exposures arising from further afield, for example where drinking water is abstracted or where there is a major fishery. Freshwater may be used for irrigation of agricultural land and then the transfer of radionuclides to the terrestrial foodchains needs to be considered. The models discussed above for releases to the atmosphere can be used also where the source of radionuclides is via irrigation water.

4.3. Accumulation of radionuclides in the environment

When radionuclides are continuously discharged they accumulate in the environment up to the point where equilibrium conditions are reached. Equilibrium conditions mean that the rate of discharge of a radionuclide equals the rate of transfer out of the environment being considered. The point at which equilibrium conditions are reached is dependent on the behaviour, chemical form and radioactive half-life of the nuclide. For example, ^{131}I reaches equilibrium very quickly, as it has a radioactive half-life of 8 days. ^{99}Tc also achieves equilibrium conditions relatively quickly in the marine environment, despite having a half-life of 212860 years. This is due to the fact that it disperses rapidly in the marine environment. For radionuclides such as ^{239}Pu which have long half-lives and are not chemically mobile it can take many decades before equilibrium is reached. For assessments which are based on past discharges any models used need to take account of this build-up in the environment.

The length of time needed to account for build-up will depend on the likely lifetime of the plant and whether a similar plant could be built at the same locations. Plant lifetimes are likely to be in the range of 30 to 100 years. (Simmonds et al., 1995) assume continuous discharges for 50 years to represent the estimated lifetime of nuclear installations.

4.4. Progeny ingrowth

A radionuclide may decay into a progeny which is also radioactive and this may need to be taken into account in realistic dose assessments. In some cases, the decay products may be more radiologically harmful than the parent and so it is important to consider the ingrowth. An example of this is ^{241}Pu (beta emitter) which decays into ^{241}Am (an alpha emitter). Although the maximum possible activity concentration of ingrown ^{241}Am is 30 times lower than that of the parent ^{241}Pu, the ingestion and inhalation dose coefficients for ^{241}Am are a factor of 50 and 70 times higher, respectively, than those of ^{241}Pu. The peak of ^{241}Am activity will occur about 75 years after the discharge of ^{241}Pu. Therefore when assessing doses from a site which discharges ^{241}Pu, the doses from ^{241}Am must also be considered.

In other cases the situation is more simple in that the progeny has a short radioactive half-life and can be considered to be in equilibrium with the parent. In this case the two radionuclides are simply considered together. For example, this is the case for ^{137}Cs and its progeny ^{137m}Ba, which are always considered together. In some cases for very long lived radionuclides the ingrowth of any progeny takes place on such a long timescale that it is not necessary to include this in assessments of routine discharges.

4.5. Discharges to sewage works

It is intended that this guidance should also be relevant to non-nuclear sites, such as hospitals and research facilities. Although nuclear power production sites do not discharge directly to sewage works there are cases of hospitals and research facilities which do. Work by (Titley et al. 2000) has indicated that if radioactive waste from a non-nuclear site is discharged directly to a sewage works there is the potential for sewage workers to receive significant doses. Therefore, when assessing doses from a site which directly discharges to a sewage plant, it is important that the doses to sewage workers are assessed. Account also has to be taken of the radiation doses that could arise from the disposal of the sewage sludge. Possibilities include incineration of the sludge or using the sludge as land treatment [see (Titley et al. 2000), (NRPB, 1998) and (NRPB, 2000)].

5. REFERENCE GROUPS

A significant concept for calculating doses to the public is that of reference groups in the population. Reference groups correspond to critical groups as defined by the International Commission on Radiological Protection (ICRP) [(ICRP, 1977) (ICRP, 1991)] and are intended to be representative of those people in the population who receive the highest doses. The ICRP (ICRP, 1991) has recommended that the mean dose to the critical group should be compared with the dose limit and dose constraint for members of the public.

In specifying reference groups two broad approaches are possible. The first involves carrying out surveys of the local population to determine their habits, where they live, etc. From these surveys the people who are receiving or who received the highest doses can be identified. The second approach involves using more generalised data to establish generic groups of people who are likely to receive the highest doses.

Reference groups can be identified for retrospective dose assessment through local knowledge and site-specific habit surveys supplemented as necessary by the use of generic studies of habits. Reference groups for prospective assessment can be identified in the same way but consideration must be given as to whether the selected habits are likely to be sustained or new habits occur during the time period of interest.

Information in a generalised form can be used where limited or no local information is available, or to establish generic reference groups. In general, it is better to use local or regional data for the purpose of defining reference groups. However, generalised data could be used where doses are considered low, for example in relation to limits or constraints, and where regional variations are likely to be small. Generalised data may also be used when assessments extend over long time periods and relate to future rather than past exposures. It is important that any data used for reference groups are applicable over the time period being considered. It is also useful to compare the generalised data with the local habit data to enable the local data to be put into context.

Reference groups are intended to be representative of individuals likely to receive the highest doses. As indicated in section 3, there are many different possible exposure pathways but they vary markedly in importance. It is therefore neither necessary nor helpful to look at every possibility in order to make a realistic estimate of dose, as long as the important pathways have been considered. For example, the marine pathways that should always be considered are consumption of fish, crustaceans and molluscs and exposure to contaminated beach sediments. Assessment of dose from these four pathways will typically ensure that the reference group dose is adequately estimated. For example, some individuals in the reference group may swim frequently but the dose from this pathway is negligible compared to the doses arising from consumption of seafood. However if a local survey indicates that no fish are caught locally then closer attention may have to be paid to the less important pathways, e.g., handling of fishing gear, to ensure that the reference group dose is fully represented.

Given that the definition of a reference group requires that the habits of the group are reasonably uniform, the group will usually comprise up to a few tens of persons. It is not appropriate to use extreme habits for the reference group. However, where *the normal behaviour* of only one or two individuals results in them being significantly more highly exposed than any other individuals, then the reference group should be deemed to comprise only those one or two individuals. "Normal behaviour" is taken to mean behaviour which is likely to occur on a continuing basis, e.g. exposure arising as a result of the location of a house or a form of employment, and is not dependent on the presence of a particular individual. It is important that when occupancy or dietary habits are used they are appropriate for the entire year, e.g. if the dietary survey is done in the summer account must be taken of the fact that diets are likely to be different in the winter.

The following sections discuss factors relevant to the identification of reference groups for the key routes of exposure. The people who are the most exposed will depend on the radionuclides discharged and the particular environment. It may be necessary to consider more than one group of people to determine which is most exposed. For a few installations direct external irradiation from the site itself is the dominant exposure pathway (Robinson et al., 1994). In this case the reference group is identified by measurements made around the site combined with knowledge as to the location and occupancy of nearby dwellings.

5.1. Atmospheric discharges

The radiation exposures will depend on the concentrations of radionuclides in air and on the ground around the site resulting from the discharges. This depends in turn on the location of the discharge points, the height of the release and the atmospheric conditions.

- Inhalation:

For inhalation of radionuclides in the plume, individuals working or living at locations with the highest air concentration will generally receive the highest doses from this pathway. Account has to be taken of occupancies as well as the activity concentrations in air in determining the location with the highest doses from inhalation. Inhalation rates for various age groups from the ICRP Task Group report on the model of the respiratory tract (ICRP, 1994) are to be considered.

- External irradiation:

A distinction should be made between the exposure resulting from material deposited on the ground or the exposure in the atmosphere. For external irradiation from deposited material, groups located where there is the highest ground deposition are likely to receive the highest exposures. However, the area of highest ground deposition is not necessarily the area with the highest activity concentration in air. Therefore individuals who receive the highest exposure due to irradiation from deposited material may not coincide with the individuals with the highest doses due to irradiation from the atmosphere.

For time spent indoors account should be taken both of the degree of shielding offered by the building to reduce external irradiation exposure and of the occupancy of the building.

- Consumption of terrestrial foods:

Atmospheric discharges lead to a transfer of radionuclides to terrestrial foods. People who subsequently ingest these foods must be considered. It is necessary to identify the areas of land used for agricultural production where the deposition from atmosphere is highest. It is possible that people grow vegetables in their gardens and this should be considered if appropriate. Local factors should be taken into account in determining the foods to consider, e.g., reindeer grazing on lichen may be an important pathway for certain regions.

Agricultural production occurs over large areas and so it is unrealistic to assume that all food consumed could be produced close to the source of the discharge. It might be cautiously assumed that a few foods could be produced over an area which has a centre at a distance of few hundred metres from a discharge site's boundary. However, where it assumed that a number of different types of foods (e.g., milk, meat and vegetables) are produced close to the source of discharge, then it is more realistic to take account of the need for larger grazing areas, movement of livestock around a farm and rotation of crops. Thus, a distance of 500 m from the site fence would be a more realistic minimum distance for the production of food.

Intake rates of different terrestrial foods are required to estimate doses. Information is available for the EU of the amount of food consumed for the population as a whole. For estimating doses to reference groups higher intakes are used for the key foods (milk, root vegetables, fruit and green vegetables) as the aim is to calculate doses to the group that is most exposed. Ideally, survey information would be available, showing the distributions in intakes for different foods and for combinations of foods. There is evidence from UK national and regional habit surveys that people rarely consume more than two foods at high rates (Ministry of Agriculture, Fisheries and Food, 1996). The amount of food derived from local sources will also need to be determined, as local agricultural practices and lifestyles will vary according to the site considered. The most cautious assumption will be to assume that all the terrestrial foods are locally produced. However, this would probably be unrealistic and lead to an overestimation in doses.

5.2. Aquatic discharges

For discharges to the marine environment, the most exposed groups are likely to include those persons who consume higher than average amounts of locally caught seafood (fish, crustaceans and molluscs) and those people who spend a relatively large amount of time on areas of sediment or sand and so are exposed to external irradiation (this could also include handling sediment or sand). It should be noted that the reference group for marine discharges does not necessarily live close to the source of the discharge. The activity concentration of seafood is very dependent on the site that the fish, crustaceans, etc., inhabit. Therefore it is important to obtain local information on the activity concentrations in seafood likely to be significant contributors to dose, i.e., for those foods which are consumed in large amounts or those which may particularly concentrate the radionuclides.

For discharges to freshwater the exposure pathways of concern may include consumption of freshwater fish and exposure to due irradiation whilst on river banks.

5.3. Combinations of habits

Reference groups will need to have combinations of habits, both high and average, based on local knowledge and plausible assumptions. These combinations of habits will need to be realistic and not lead to implausible situations, for example someone having an excessive intake of calories. Again a full range of exposure pathways should be considered for each of the potential reference groups. However, in most cases it is not realistic to assume that the same people are most exposed from all pathways and so a simple addition of doses attributed to different pathways is not necessarily appropriate. Instead, a combination of habits typical of average and most exposed people may be assumed, i.e., both average habit data and higher than average habit data are required to assess doses. For example, members of the reference group who eat locally produced terrestrial foods at higher than average rates could be assumed to eat a proportion of locally produced aquatic foods at average rates.

5.4. Age of groups

The (CEC, 1996) gives dose coefficients for the ingestion and inhalation of radionuclides for six age groups.

It should be stressed that the groups who receive the highest doses are 1-year olds, 10-year olds or adults. Therefore the limiting dose will be adequately represented by assessing doses to three age groups without considering the other age groups.

There will always be concern for the protection of unborn and newborn children. Consideration has been given to:

- Breast-fed infants:

It appears that the 1-year old infant consuming cow's milk receives a higher estimated dose than the breast-fed infant. Consequently, it is unnecessary to estimate doses for breast-fed infants.

- Foetus:

Foetal doses are not normally included in assessments of radiation doses for members of the public exposed due to routine discharges from nuclear installations. A recent publication of the ICRP (ICRP, 2001) permits the assessment of foetal doses. It appears that in general the foetus is not the most exposed group. However, recent work published indicates that radioisotopes of the elements required by the foetus for skeletal growth, such as those of calcium (ICRP, 2001) and phosphorous (Phipps et al., 2001), which are also important in the growth of mineral bone, may result in the foetus being the most restrictive group. Foetal doses should be considered if making an assessment where there are significant discharges of radioactive isotopes of these elements.

5.5. Dose coefficients

For dose assessments the dose coefficients published in the EURATOM Directive should be used. Where data are provided for more than one chemical form of an element and the actual chemical form is not known, the defaults should be taken from (ICRP, 1996). If required, dose coefficients for tritium and ^{14}C in a vapour state should be taken from a Communication regarding the EURATOM directive (CEC, 1998). Expert judgement should be used to determine the most appropriate chemical form for use in the assessment, rather than assuming the chemical form that leads to the highest dose coefficient.

6. ISSUES IN ACHIEVING REALISTIC ASSESSMENTS

6.1. Realism of assessment

The assessment must reflect the transfer of the radionuclides through the environment to man. This is not an easy task. Discrepancies can occur at many stages, for example:

- If modelling radionuclides in the environment is not a true representation, e.g., if the model predicts activity concentrations of ^{129}I in milk significantly greater than those measured.
- When measurement data are not an accurate reflection of the real environment, e.g., a few measurements of the concentrations of ^{239}Pu in offal are taken as representative of the local

area, but if more measurements were made the average concentration could be significantly higher or lower.

- If significant exposure pathways are omitted, e.g., consumption of reindeer meat (from reindeer that have been eating lichen with high uptakes of caesium) has not been included.
- If assumptions relating to the habit data for the reference group are not representative, e.g., it is assumed that all fish consumed is locally caught, whereas in reality only 10% is local.

These points emphasise the importance of having a good understanding of local conditions around the installation being assessed. When deciding whether to investigate further any discrepancies it is advisable to consider the extent of the discrepancy, as obtaining site-specific data can be time-consuming and costly. For example, if the dose estimated for the reference group is 200 $\mu Sv.y^{-1}$, which is mainly due to the consumption of molluscs based on assumed consumption rates, then it would useful to determine the local consumption rates. However, if the dose is of the order of a few $\mu Sv.y^{-1}$ then a detailed survey of local consumption rates may not be justified.

6.2. Variability and uncertainty

Assessments of doses necessarily entail a series of assumptions about the behaviour of the reference group and about the transfer of radionuclides in the environment. The estimated mean dose to the reference group is therefore within a distribution of possible doses. There are two aspects to this distribution referred to as the uncertainty and the variability. The uncertainty reflects the amount of knowledge about the system being investigated and relates to how accurately the dose can be estimated: for example, how well are all of the parameter values in the calculation of doses known? The variability refers to the actual differences that occur both in transfer in different environments and between individuals within a group; for example, differences in how much of a particular food is eaten or in where individuals spend their time. This topic is discussed in more detail in (IAEA, 1989) and a number of studies have been carried out to investigate uncertainty and variability [e.g. (Smith et al., 1998), (Jones et al., 2000)]. In addition this subject has been examined in France by the Nord-Cotentin Radioecology Group (GRNC, 2002).

When carrying out an uncertainty/variability analysis one of the important first steps is to estimate the dose using "best estimates" of the parameter values. This will indicate whether it is worthwhile proceeding with the work, e.g., if doses are of order of 10 $\mu Sv.y^{-1}$ then it may not be effective continuing with the work. The "best estimate" dose is also a useful benchmark against which to compare any results from the uncertainty/variability analysis. For example, if "best estimate" dose is 200 $\mu Sv.y^{-1}$ but the uncertainty/variability analysis indicates a distribution of doses from 200 $\mu Sv.y^{-1}$ to 600 $\mu Sv.y^{-1}$, with the mean being 400 $\mu Sv.y^{-1}$, then it would advisable to re-examine the distribution associated with the input parameters.

Another useful exercise is to identify the input parameters which have the greatest influence on the doses. This is done by performing a sensitivity analysis. For this various parameters and asumptions are made and the effects of these changes on the estimated doses are studied.

A workshop (Walsh et al., 2000) was held in the UK to consider the implications of distributions in critical group doses for the system of radiological protection. Participants included representatives from regulators and operators of nuclear establishments, the European Commission (DG Environment) and ICRP. It was concluded from the workshop that variability studies are useful when examining the composition of reference groups, to ensure that it is not composed solely of individuals with extremes of behaviour, and that it adheres to the ICRP homogeneity criteria (ICRP, 1985). It was concluded that an uncertainty/variability study need not be carried out for every assessment, but could be valuable to improve understanding of reference group dose assessments.

6.3. Use of measurement data

By using measurements that have been made around a nuclear installation a more realistic estimate of doses can be obtained than by using modelled results alone. For retrospective assessments the most realistic assessment of doses is obtained by using measured activity concentrations in environmental media. This is not always possible, as full measurement data may not be available or measurements are below limits of detection, and modelling is then required. An assessment in which the limit of detection is assumed to be the actual activity concentration will not give a realistic assessment of doses. Preferably, the assessment should be based on modelling with the model results being checked to ensure that they are less than the detection limits. Similarly, where most activity concentrations are below limits of detection except for one or two actual measurements, it is worth comparing the results with model predictions to check their validity. Modelling is also required for prospective assessments. However, measurement data are still valuable to determine the accuracy of the models for the local conditions. It must be remembered that measurement data could include contributions from sources other than that of the site being considered, e.g., natural radionuclides, fallout from atmospheric weapons testing, and the Chernobyl accident and other sites discharging radionuclides into the environment.

In order to get an understanding of the extent of the difference between using measurements and modelled results, the following calculations were done using an earlier study, in which measured activity concentrations had been used to estimate doses. Reference group doses around a number of nuclear sites in England and Wales were estimated in (Robinson et al., 1994). The doses estimated for Sellafield for 1991 were used for the purposes of comparison as a lot of measured data was available. For the aquatic pathways, i.e., consumption of aquatic foods and external irradiation, the doses had been calculated entirely on the basis of environmental measurements. However, for releases to atmosphere where site-specific monitoring data were not always available, were incomplete or were lower than the detection limits, the results of predictive environmental models had been used to supplement the measurement data. In order to see the effect of using model results rather than measurements doses were re-calculated for Sellafield. The ratios obtained are doses calculated due to a combination of measurements and modelled results used in the original study compared to modelled results alone. The ratio of 0.7 for aquatic foods is mainly due to the model predicting higher activity concentrations of ^{106}Ru and ^{239}Pu than were measured. However, for the consumption of terrestrial food and inhalation pathways the measurements are higher than the modelled predictions. This is due to the measurements including the build-up of ^{90}Sr, ^{137}Cs and ^{239}Pu from previous discharges from Sellafield, whereas the modelled results were based on a single year's discharge.

Measurement data are valuable for validating models being used for an assessment. If the data indicate that the modelled results are deviating significantly from the measurements there are two approaches that can be taken. Firstly, it may be necessary to revise the model. Secondly, if it is judged that in general the model works well but there are peculiarities specific to the site of interest then the measurement data can be used to correct the modelled results. Obviously, for retrospective assessments, it is more realistic to use the measurement data themselves. For prospective assessments, however, this will not be possible. Therefore, the model can be run on the basis of past discharges and the results compared to the measurement data. It is important that the build-up of radionuclides in the environment is modelled, as the measurement data will inherently include contributions from past discharges. The ratio of the predicted to observed data can then be applied to modelled results required for prospective assessments.

7. CONCLUSIONS AND RECOMMENDATIONS

The primary application of this guidance is for realistic assessments of doses to members of the public from nuclear installations during normal operation. The emphasis is on retrospective assessments, although many of the ideas are also applicable to prospective assessments.

The NRPB and GRS report "Guidance on the assessment of radiation doses to members of the public due to the operation of nuclear installations under normal conditions" covers all stages of an assessment of doses to members of the public. The five stages are, in sequence: identification and quantification of sources, modelling the transfer into the environment and gathering of measurement data, determination of exposure pathways, identification of reference groups, estimation of doses for the reference groups.

In order to perform a realistic assessment the most important recommendation in this report is:

- It is important to obtain as much site-specific information as possible.

The following recommendations are a summary of points made in the NRPB and GRS report:

Specification of source term

The type and amount of radionuclides being discharged, and the type and location of release must be determined. Unless a significant proportion of the annual discharge is released within a short period, it can be assumed that the discharges are continuous, given the other uncertainties in the assessment process.

Determination of exposure pathways

The report separates the exposure pathways into three types:

- those that should almost always be considered, e.g., consumption of food;
- those that should be examined depending on local conditions, e.g., consumption of milk from animal grazing on salt marshes;
- those that normally should not be considered, e.g., inhalation of seaspray.

The main focus of the assessment should be on the pathways contributing the highest doses to the reference group.

Methods for assessing doses

The most realistic method of dose assessment is by the extensive monitoring of the main exposure pathways. However this is time-consuming, costly and levels in the environment may be below the analytical limits of detection. Typically, an assessment will involve a combination of measurement and modelled data. Any models used should be robust, fit for purpose and have been validated against measurement data. Models need to take account of both accumulation in the environment (e.g. ^{239}Pu has a long half-life and can build up in the local environment) and progeny ingrowth (e.g., ^{241}Pu decays into ^{241}Am, which is more radiologically harmful). A realistic assessment relies on the parameter values in the model and the habit data used being a realistic representation of the situation around the site.

Identification of reference groups

Reference groups are intended to be representative of individuals likely to receive the highest doses. Given that the definition of a reference group requires that the habits of the group are reasonably uniform, the group will normally comprise up to a few tens of individuals. It is not appropriate to use extreme habits for the reference group. However, where the normal behaviour of only one or two individuals results in them being significantly more highly exposed than any other individuals, then the reference group should be deemed to comprise of only those one or two individuals.

Generalised habit data can be used where site-specific information is not available. There is a paucity of published data concerning the consumption and occupancy rates for EU countries. More information for the different age groups is needed on:

- Indoor/outdoor occupancies;
- Occupancies over intertidal areas and riverbanks;
- Consumption of terrestrial and aquatic foods for both average and high rate consumers for different age groups.

Reference groups will need to have combinations of habits, both high and average, based on local knowledge and plausible assumptions. These combinations of habits will need to be realistic and not lead to implausible situations, for example someone having an excessive intake of calories.

For dose assessments the dose coefficients published in the EURATOM Directive should be used. Where data are provided for more than one chemical form of an element and the actual chemical form is not known, the defaults should be taken from (ICRP, 1996). If required, dose coefficients for tritium and ^{14}C in a vapour state should be taken from a Communication regarding the EURATOM Directive (CEC, 1998). Expert judgement should be used to determine the most appropriate chemical form for use in the assessment, rather than assuming the chemical form that leads to the highest dose coefficient.

The report recommends that it is sufficient to consider three age groups; 1-year olds, 10-year olds and adults. Foetal doses should be borne in mind if significant amounts of radioactive isotopes of calcium and phosphorus, which are used by the foetus for skeletal growth, are discharged.

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