# 4. METHODOLOGY FOR DOSE ASSESSMENT

## 4.1 Introduction

127. This report considers the radiological impact on workers and members of the public arising from the various stages of the two fuel cycles described in Chapter 1. Other factors such as economic and political considerations are outside the scope. Where possible the report draws upon other studies and upon information published by national and international authorities. However, two new studies of doses to members of the public from discharges from nuclear fuel cycle facilities were undertaken to provide information for this study. In calculating doses to members of the public, assumptions have to be made about the habits of the individuals and about the characteristics of the environment in which they live. These assumptions can have a considerable influence on the magnitude of the calculated doses. For example, foodstuffs following discharges to the marine environment, some radionuclides may transfer to marine life and the magnitude of the resulting dose to an individual will clearly depend upon the amount of the marine foodstuff that he or she consumes. Consumption rates such as these can vary geographically and may also vary with time at the same location. Similarly, the collective dose from, say, discharges to atmosphere will, depending upon the particular radionuclides, be proportional to the population density around the discharging site and also to the agricultural productivity of the surrounding area. This introduces difficulties in making a general comparison of the radiological impact of components of the fuel cycle because the impact of a nuclear fuel cycle facility will depend to some extent on where it is located. Therefore, this study -a generic study- applied a set of standard assumptions in order to compare all stages of the two fuel cycles on a common basis.

128. This chapter describes: the radiological indicators considered; the reference fuel cycle facilities that were chosen together with their discharges; the methodology used to estimate doses to members of the public; and the methodology used to obtain doses to workers.

## 4.2 Radiological Indicators.

129. The principles of radiological protection have been described in Chapter 2. The main indicators of the radiological impact are the highest doses to individuals, the critical group doses, and the doses to all the individuals in an exposed population, the collective doses. The former can be compared with dose limits and constraints whereas the latter may provide an indication of overall health impact. Long-lived radionuclides, which are released to the environment at some stages in the fuel cycles, may remain in the environment for long time periods causing low level exposures of members of the public. Following the reasoning presented in Chapter 2, radiological impacts up to around 500 years into the future from releases of long-lived radionuclides are taken into account. Radiological impacts following the disposals of solid wastes from the final stages of the fuel cycles and from decommissioning of fuel cycle facilities are not considered; these materials are, or will be, handled in

a controlled manner within the system of radiological protection and, in many cases, materials with similar radiological impacts are likely to arise from both fuel cycles.

130. In order to assist in the comparison of the two fuel cycles, the collective doses to workers and to members of the public are normalised to electricity production in Gwa. This is not done for the doses to individuals as their magnitude depends upon the particular operating characteristics of the site involved. For example, if a particular amount of spent fuel is reprocessed in one year, the corresponding critical group doses (calculated as dose in a year, see Chapter 2) could be up to ten times higher than if the same quantity of spent fuel was reprocessed over a ten year period.

131. The term 'dose' in this report refers to effective dose and is the sum of the annual external effective dose and the committed effective dose from intakes over one year integrated to 50 years for adults and to 70 years for infants. Doses were determined in accordance with the most recent recommendations of the International Commission on Radiological Protection (ICRP), namely effective dose as defined in ICRP Publication 60 (5) and the dose coefficients presented in ICRP Publication 72 (6). The critical group doses to members of the public represent the dose an individual would receive in the 50th year following continuous discharges at the same level for 50 years. The collective doses presented are for a single year's discharge truncated at 500 years, rather than integrated to infinity.

### 4.3 Methodology for Estimating Doses to Members of the Public from Discharges

132. Assessments of doses were undertaken using PC CREAM 98[1] and BIOS[2]. PC CREAM 98 is a software package for the assessment of routine and continuous discharges of radionuclides to atmosphere, and to aquatic environments. PC CREAM was developed by the NAB under contract to the European Commission DGXI. The package is an implementation of the models and methods detailed in European Commission Radiation Protection 72 report: Methodology for assessing the radiological consequences of routine releases of radionuclides to the environment (3). BIOS is the NRPB biosphere transport model capable of modeling discharges of radionuclides to rivers and the subsequent calculation of collective doses.

### Discharges to Atmosphere

133. For the calculation of doses from discharge to atmosphere PC CREAM uses a standard guaussian plume dispersion model. A uniform windrose meteorological data file, set up to represent 60% category D conditions was used to represent meteorological conditions at all of the sites in this assessment. A single stack of 30m effective release height was used for all but the mining and milling stages of the assessment. The venting of radon from mill tailings was represented by five stacks set at equal distances to represent an idealised heap of tailings. The central stack having an effective release height of 30m, whilst the four outer stacks were set to 10m. The area of the tailings heap was taken to be 100 hectares ( $1.10^6$ $m^2$), see Figure B1 of Annex B. General assumptions used in calculating doses from releases to atmosphere are given in Table 15.

134. In all cases the critical group was defined as living at a distance of 1km from the atmospheric discharge point. With the exception of uranium mining and milling, critical group doses were calculated for the following exposure pathways: inhalation of the plume, external exposure from radionuclides in the plume and deposited on the ground, ingestion of terrestrial foodstuffs, and

inhalation of resuspended material. Critical group doses for uranium mining and milling were estimated for inhalation of radon-222 only; it was assumed that the area immediately surrounding the facility was unlikely to support extensive production of terrestrial foodstuffs.

135. The critical group food intake rates are given in Table 14, and were taken from information supplied by Germany and from reference 4. The intakes of milk and root vegetables were assumed to be taken entirely from a reference production point 1 km from the discharge point, whilst 50% of the intake of the remaining foods were taken from 1 km. The other 50% of the intake were assumed to be from locations unaffected by the discharge. Adults were assumed to spend 30 % of their time outside whilst infants were assumed to spend only 10% see Table 15.

136. The assessment of collective doses from atmospheric discharges made use of actual population and agricultural distribution data for Europe for all but the mining and milling stage. The assessment took account of the same exposure pathways as were considered for critical group doses. Where appropriate the contributions from global circulation of radionuclides were included. For the assessment of collective doses from mining and milling a uniform density population grid representing 1 person per km$^2$ was produced to give results for two separate distance bands, from 0 to 100 km and from 100 to 2000 km. Such separation will enable the impact of various population density patterns to be assessed. In this way, collective doses were calculated for inhalation of radon-222. However, it is possible that doses could also be delivered via foodchain pathways following deposition of daughter radionuclides of radon-222 onto soils and crops. The significance of this route of population exposure will depend upon the agricultural productivity of the surrounding region. In the absence of detailed information on this, an upper estimate of the collective doses from foodchain pathways was obtained by assuming the release occurred from a site in England using European agricultural production data.

### Discharges to the Aquatic Environment

137. For discharges directly into the marine environment PC CREAM 98 was used whilst discharges to rivers were modeled using BIOS. These are compartment models where the dispersion of radionuclides is modelled by first order kinetics between defined compartments that represent particular sectors of the environment. The interaction of radionuclides with suspended and river or seabed sediments is modelled. For discharges to the marine environment, doses via the following exposure pathways were calculated: ingestion of fish, crustaceans and molluscs; external exposure from occupancy of beaches; and inhalation of seaspray and of resuspended beach material. In the case of discharges to freshwater systems doses from ingestion of fish and drinking water, and from occupancy of riverbanks were estimated. In estimating critical group doses, all intakes of seafoods were taken from the local marine compartment, which is the model compartment that receives the discharges and where the estimated radionuclide concentrations will be highest; external exposure from occupancy of beaches was also assumed to occur on the beaches bordering the local marine compartment. Except for uranium mining and milling, all freshwater fish and drinking water intakes were taken from the first river compartment downstream of the discharge point. For the uranium mining and milling calculations, the typical concentrations of radionuclides measured in freshwater bodies near uranium mining facilities were taken (see Table 2). Details of the intake rates are provided in Table 14, whilst river bank and beach occupancy rates are given in Table 15. In estimating collective doses, calculated concentrations of radionuclides in environmental materials were combined with estimates of seafood catches and of coastine lengths (see reference 3).

## 4.4 The Methodology Used to Estimate Doses to Workers.

138. Doses to workers were taken from information published by operators, national authorities and international organisations, except for disposal of radioactive waste where estimates were made. *[To be completed. ]*

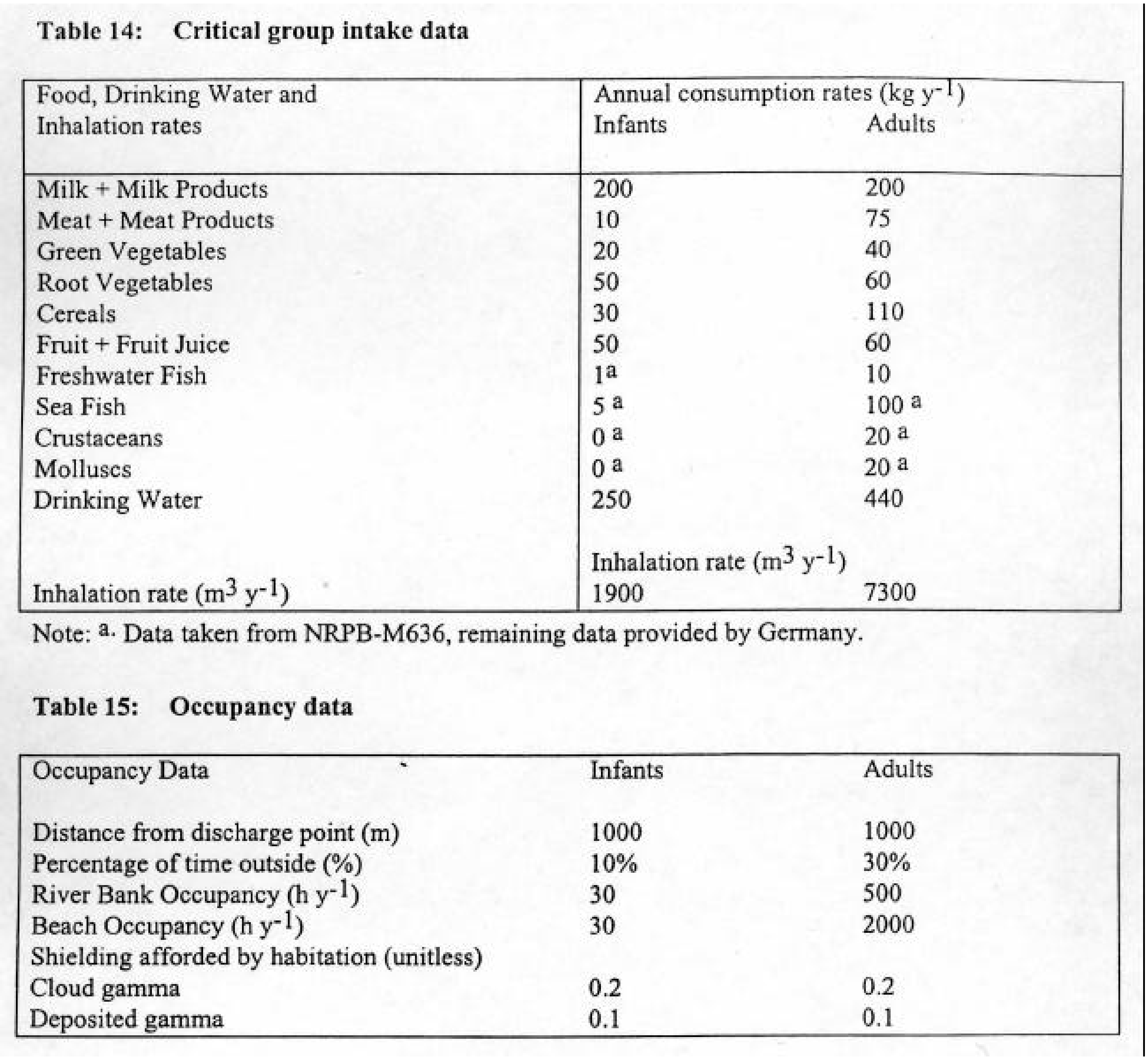

**Table 14: Critical group intake data**

| Food, Drinking Water and Inhalation rates | Annual consumption rates (kg $y^{-1}$)<br>Infants | <br>Adults |
|---|---|---|
| Milk + Milk Products | 200 | 200 |
| Meat + Meat Products | 10 | 75 |
| Green Vegetables | 20 | 40 |
| Root Vegetables | 50 | 60 |
| Cereals | 30 | 110 |
| Fruit + Fruit Juice | 50 | 60 |
| Freshwater Fish | 1[a] | 10 |
| Sea Fish | 5 [a] | 100 [a] |
| Crustaceans | 0 [a] | 20 [a] |
| Molluscs | 0 [a] | 20 [a] |
| Drinking Water | 250 | 440 |
| | Inhalation rate ($m^3$ $y^{-1}$) | |
| Inhalation rate ($m^3$ $y^{-1}$) | 1900 | 7300 |

Note: [a]. Data taken from NRPB-M636, remaining data provided by Germany.

**Table 15: Occupancy data**

| Occupancy Data | Infants | Adults |
|---|---|---|
| Distance from discharge point (m) | 1000 | 1000 |
| Percentage of time outside (%) | 10% | 30% |
| River Bank Occupancy (h $y^{-1}$) | 30 | 500 |
| Beach Occupancy (h $y^{-1}$) | 30 | 2000 |
| Shielding afforded by habitation (unitless) | | |
| Cloud gamma | 0.2 | 0.2 |
| Deposited gamma | 0.1 | 0.1 |