GUIDE NO. AERB/NF/SG/S-5

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GOVERNMENT OF INDIA

AERB SAFETY GUIDE

METHODOLOGIES FOR ENVIRONMENTAL RADIATION DOSE ASSESSMENT

ATOMIC ENERGY REGULATORY BOARD

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METHODOLOGIES FOR ENVIRONMENTAL RADIATION DOSE ASSESSMENT

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Mumbai - 400 094
India

March 2005

Price:

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FOREWORD

Activities concerning establishment and utilisation of nuclear facilities and use of radioactive sources are to be carried out in India in accordance with the provisions of the Atomic Energy Act 1962. In pursuance of the objective of ensuring safety of members of the public and occupational workers as well as protection of environment, the Atomic Energy Regulatory Board has been entrusted with the responsibility of laying down safety standards and framing rules and regulations for such activities. The Board has, therefore, undertaken a programme of developing safety standards, codes of practice and related guides and manuals for the purpose. While some of these documents cover aspects such as siting, design, construction, operation, quality assurance and decommissioning of nuclear and radiation facilities, other documents cover regulation aspects of these facilities.

Codes of practice and safety standards are formulated on the basis of internationally accepted safety criteria for design, construction and operation of specific equipment, structures, systems and components of nuclear and radiation facilities. Safety codes establish the objectives and set minimum requirements that shall be fulfilled to provide adequate assurance for safety. Safety guides elaborate various requirements and furnish approaches for their implementation. Safety manuals deal with specific topics and contain detailed scientific and technical information on the subject. These documents are prepared by experts in the relevant fields and are extensively reviewed by advisory committees of the Board before they are published. The documents are revised when necessary, in the light of experience and feedback from users as well as new developments in the field.

The Code of Practice on 'Safety in Nuclear Power Plant Siting (AERB/SC/S)' states the requirements to be met during siting of nuclear power plants in India. This safety guide provides guidance on methodologies for radiation dose computation from radioactivity concentrations in environment.

Consistent with the accepted practice, 'shall', 'should' and 'may' are used in the guide to distinguish between a firm requirement, a recommendation and a desirable option, respectively. Appendices are an integral part of the document, whereas Annexures, references and list of participants are included to provide information that might be helpful to the user. Approaches for implementation different to those set out in the guide may be acceptable, if they provide comparable assurance against undue risk to the health and safety of the occupational workers and the general public, and protection of the environment.

For aspects not covered in this guide, applicable and acceptable national and international standards, codes and guides should be followed. Non-radiological aspects of industrial safety and environmental protection are not explicitly considered in this guide. Industrial safety is to be ensured through compliance with the applicable provisions of the Factories Act, 1948 and the Atomic Energy (Factories) Rules, 1996.

This guide has been prepared by specialists in the field drawn from Atomic Energy Regulatory Board, Bhabha Atomic Research Centre, Nuclear Power Corporation of India Limited and other consultants. It has been reviewed by the relevant AERB Advisory Committee on Codes and Guides and the Advisory Committee on Nuclear Safety. AERB wishes to thank all individuals and organisations who have prepared and reviewed the draft and helped in its finalisation. The list of persons, who have participated in this task, along with their affiliations, is included for information.

(S. K. Sharma)
Chairman AERB

DEFINITIONS

Accident Conditions

Substantial deviations from operational states, which could lead to release of unacceptable quantities of radioactive materials. They are more severe than anticipated operational occurrences and include design basis accidents as well as beyond design basis accidents.

Atomic Energy Regulatory Board (AERB)

A national authority designated by the Government of India having the legal authority for issuing regulatory consent for various activities related to the nuclear and radiation facility and to perform safety and regulatory functions including enforcement for the protection of the site personnel, the public and the environment against undue radiation hazards.

Design Basis Accidents (DBAs)

A set of postulated accidents which are analysed to arrive at conservative limits on pressure, temperature and other parameters which are then used to set specifications to be met by plant structures, systems and components, and fission product barriers.

Emergency

A situation which endangers or is likely to endanger safety of the site personnel, the nuclear/radiation facility or the public and the environment.

Emergency Planning Zone (EPZ)

The zone defined around the plant upto 16 km radius providing a basic geographic framework for decision making on implementing measures as part of a graded response in the event of an off-site emergency.

Nuclear Power Plant (NPP)

A nuclear reactor or group of reactors together with all the associated structures, systems, equipment and components necessary for safe generation of electricity.

Nuclear Safety

The achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of site personnel, the public and the environment from undue radiation hazards.

Site

The area containing the facility defined by a boundary and under effective control of facility management.

SYMBOLS

Parameter	Unit	Symbol
1. Concentration of radionuclide in air	Bq/m^3	χ
2. Concentration of radionuclide in water	Bq/m^3	C_w
3. Distribution coefficient of radionuclide in sediment	ml/g	K_d
4. Radioactive decay constant for radionuclide, i	d^{-1}	λ_i
5. Concentration of radionuclide in vegetation	Bq/kg	C_v
6. Fraction of deposition of activity intercepted by vegetation as a result of wet and dry deposition	-	R
7. Yield of standing crop	kg/m^2	Y
8. Rate constant for reduction of concentration of materials deposited on vegetation due to processes other than radioactivity decay (weathering rate constant)	d^{-1}	λ_w
9. Rate constant for reduction of concentration of materials deposited on in root zone of soil due to processes other than radioactivity decay	d^{-1}	λ_s
10. Effective rate constant for reduction of activity concentration of radionuclide from vegetation	d^{-1}	λ_e (v)
11. Effective rate constant for reduction of activity concentration of radionuclide from root zone of soil	d^{-1}	λ_e (s)
12. Effective surface density for the effective root zone of soil	kg(dry soil)/m^2	P
13. Concentration factor (CF) for uptake of radionuclide from soil by edible parts of crops	Bq/kg plant per Bq/kg dry soil	B_v
14. Concentration factor for uptake of radionuclide from soil by forage plants	Bq/kg dry vegetation per Bq/kg dry soil	B_{v1}
15. Concentration factor for uptake of radionuclide from soil by food crops	Bq/kg fresh food per Bq/kg dry soil	B_{v2}
16. Fraction of animal's daily intake of radionuclide that appears in each litre of milk at equilibrium	d/L	F_m
17. Fraction of animal's daily intake of radionuclide that appears in each Kg of flesh at equilibrium	d/kg	F_f

SYMBOLS (Contd.)

Parameter	Unit	Symbol
18. Amount of dry feed consumed by animal per day	kg/d	Q_f
19. Bioaccumulation Factor – Equilibrium ratio of the concentration of radionuclide in aquatic food to its concentration in water (Bq/g/Bq/ml)	ml/g	B_p (also known as CF)
20. Depositional velocity is the ratio of amount of material deposited on the surface per unit time to the ground level concentration of air ($Bq/m^2/s/Bq/m^3$)	m/s	V_g
21. Washout Coefficient 'Λ' is a fraction of precipitation rate (I) by the relation $\Lambda=\alpha I$ where α is the proportionality constant	s^{-1}	Λ
22. Breathing rate of man (20 m^3/day for adult and 3.6 m^3/day for child)	m^3/d	B
23. Annual consumption of drinking water	m^3/y	I_{ev}
24. Irrigation rate is quantum of water used for irrigation per unit area of field per day	$m^3 d^{-1} m^{-2}$	I_r
25. Occupancy factor is number of hours in a year the person spends his time in contaminated ground	h/y	U_P
26. Annual consumption of vegetation by man	kg/y	I_v
27. Mean energy of β radiation per disintegration	Mev	E_β
28. Fractional energy of β radiation of that particular energy	-	F_β
29. Maximum energy of gamma radiation per disintegration	Mev	E_γ
30. Fractional intensity of gamma radiation of that particular energy	-	F_γ
31. Resuspension Factor, K is ratio of the resuspended air concentration of the nuclide and surface deposit	m^{-1}	K_o
32. Resuspension Factor, K_∞ is the value of K as applicable for nuclides having long-term effective removal constants	m^{-1}	K_∞
33. Dispersion Factor is the ratio of concentration of a radionuclide (χ) at a specified location due to a continuous unit release rate of the same radionuclide (Bq/s)	s/m^3	χ/Q

Note: Unless otherwise specified in the text, units mentioned above are generally applicable.

CONTENTS

1. INTRODUCTION

1.1 General

Radionuclides released from nuclear facilities such as nuclear power plants (NPPs) during normal operating conditions and under accident conditions eventually reach man through various pathways. This guide elaborates the procedure for dose computation from various pathways and radioactive concentrations in different compartments of environment viz. air, land and water. Methodologies for computation of doses from both internal and external exposures are given. It is recognised that the potential consequences due to accident conditions are always of overriding importance and are provided for in the design of NPP. As stated in the code of practice on safety in Nuclear Power Plant Siting [1], a site is acceptable if there are technical solutions to the site-related problems, which give assurance that the proposed plant can be built and operated with an acceptably low risk to the population of the region.

The International Commission on Radiological Protection (ICRP) has recommended dose limits and dose levels for the exposure of the public during normal releases and intervention levels for accident conditions respectively [2,3]. Atomic Energy Regulatory Board (AERB) has stipulated similar dose limits and intervention levels of doses for the public [4] on the lines of ICRP recommendations. This guide deals with:

- Description of environmental and dosimetric models
- Methodologies for computation of dose
- Environmental transfer factors and dosimetric factors required for dose estimation

1.2 Objective

This guide describes the various pathways leading to radiation exposures and presents the methodologies for estimating the doses received by members of the public based on the concentration of a radionuclide present in different compartments of the environment.

1.3 Scope

This guide is applicable for radioactivity releases from nuclear facilities. The dose received by an individual depends primarily on the concentrations of various radionuclides present in different compartments of the environment. The concentrations of radionuclides in the environment in turn depend on the amount of radioactivity released from the nuclear facilities and many other environmental parameters. AERB safety guides on meteorological dispersion [5], hydrological dispersion [6] and hydrogeological aspects [7] deal with methodologies for computing concentrations in air, surface water and ground-water respectively and are relevant to this guide.

1.4 Structure of the Document

The requirements and availability of data for the evaluation of dose are described in section 2. The methods of computing doses from atmospheric and aquatic releases are given in section 3. The transfer parameters required for computing doses from various pathways are identified in section 4. In the absence of actual estimates, the default values for different transfer parameters are also discussed in this section. The regulatory guidelines for conforming to derived limits are presented in section 5. Though there exist many potential pathways of exposure to a member of the public, all the pathways may not be relevant during site selection or site evaluation stages for a particular site. The application of dose evaluation procedure for different stages of NPP siting is described in section 6.

2. DOSE EVALUATION CRITERIA FOR DIFFERENT STAGES OF NUCLEAR POWER PLANT

2.1 General

Information needed for the estimation of dose to members of public depends on the stages/states of NPP (e.g. site selection, normal operating conditions and potential accident conditions). It is adequate to use critical pathway-critical nuclide concept for the assessment of dose during siting stage whereas all the relevant pathways for various radionuclides have to be employed during normal operating conditions in order to ensure compliance with dose limits specified by the Regulatory Body. The mode of computing dose requires measurement (or prediction) of concentration of radionuclides in aquatic, atmospheric and terrestrial media . The concentrations of the radionuclides in various matrices of the environment are routinely measured by Environmental Survey Laboratories (ESLs). For larger distances the concentrations of radionuclides are predicted using mathematical models. The prediction of spatial and temporal concentrations of radionuclides in the respective media (water/atmosphere/land) requires various input parameters (e.g. transport velocity, dispersion coefficients, release rate etc.). The reliability of the model prediction is dependent on the use of realistic parameter values. The Concentration Factor (CF) approach can be used to derive the concentration in a particular compartment from the concentration in other compartments. Data on the usage of various compartments are also required in detail for the different stages of dose calculation.

2.2 Site Selection

At site selection stage, data related to the usage of environment in the vicinity of NPP are taken either from the state or national data. At this stage, data on source term and environmental dispersion characteristics may not be available. The data on source terms under normal operating conditions can be taken from the past experiences of a similar facility. Since site specific meteorological data may not be available at this stage, representative data from nearby meteorological stations should be used. Dose calculations based on critical pathway-critical nuclide concept is adequate for this stage.

2.3 Design and Commissioning Stage

In the intervening period between the selection of site and commissioning of the facility, detailed site specific investigations on meteorological, hydrological as well as geohydrological parameters are undertaken. These data will be collected round the year to cover all the seasons. Compilation of data on the consumption of agricultural and aquatic produce and identification of critical population groups and pathways will be completed prior to commissioning stage. Data on source term will also be available at this stage. The type and the quality of data needed in various stages of NPP are described in the safety guide dealing with population distribution and analysis in relation to siting of NPPs [8].

2.4 Normal Operating Conditions

During normal operating conditions of NPPs, data on environmental transfer factors and the source terms in terms of release rates will be known. The dose to a member of the critical group has to be evaluated to ensure compliance with the regulatory limit.

During normal operating conditions, the radioactive materials will enter the atmosphere through stack from gaseous release and surface water body through liquid effluent discharges. The impact of liquid effluent releases to the surface water body is minimised by pre-dilution. This is confirmed through monitoring of aquatic environment for radioactivity levels in different matrices in order to compute the resulting dose to man from liquid effluent discharges. The annual dose data at an NPP site resulting from stack releases to the atmosphere are generated in order to assess the performance of various safety features incorporated in the reactor system for release control measures. This involves computation of annual average concentrations of specific radionuclides at the exclusion distance boundary of the NPP site [9] based on the diffusion climatology generated from hourly meteorological data collected at the site.

While estimating the annual dose, as far as possible, all the relevant environmental pathways should be considered. The relevant site specific transfer parameters and consumption rates of various food items for a member of the critical group, generated by Environmental Survey Laboratories (ESL) at the site, should be used for dose calculations.

The methodologies for deriving dose estimates based on the concentrations in various environmental compartments are described in section 3.

2.5 Accident Conditions

As the time and duration of an accident cannot be predicted, the dose estimations for such situations cannot be evaluated apriori. However, a guideline on dose distribution can be arrived at using the maximisation approach. Since the accidental release is assumed to last for a few hours to extended periods, the data needed for estimating the concentration of radionuclides in environmental compartments will be based on on-line meteorological data collected during the release. Combinations of various meteorological parameters [e.g: predominant wind direction, minimum wind speed, stability category (Pasquill stability class E & F), exclusion of deposition velocity for plume dose and inclusion of deposition velocity for ground exposure] leading to maximisation of the concentration can be used for generating the guideline values. However, the combinations of the parameters must be realistic. For example, consideration of ground release under weather stability condition 'F' will yield maximum concentrations in air. However this situation can not be employed when the releases are expected to persist for long periods of time. In such cases, annual average persistence of weather stability classes need to be employed. The concentration distributions generated in this way can then be used for evaluating the dose using the procedures described in section 3.

2.6 Dose Evaluation Procedures

During normal operating conditions of NPPs, the evaluation of dose to a member of the critical group is needed to ensure compliance with the regulatory limits. This is achieved using the annual average concentration of radionuclides present in various environmental compartments.

In an accident conditions, the evaluation of total dose is needed for the type of accident. The main difference in dose computation for accident condition from that for normal operating conditions lies in evaluating the total dose received by a member of public from the Time Integrated Concentration (TIC) of the environmental compartment along with occupancy/usage of environmental compartments by the individuals in the public domain.

The dose from terrestrial food intake during an accident situation should consider the TIC and the total vegetation yield in the domain of consideration for the collective dose or alternatively as a product of TIC, individual intake and the total population in the domain. The dose prediction during an accident will enable initiation of various intervention actions as well as assessment of the consequences due to the accident in terms of population dose.

2.7 Critical Pathways/Critical Nuclides/Critical Group

There may exist many exposure pathways leading to exposure of a member of public, but the dosimetric models indicate only a few of them to be really significant. These are known as critical pathways and are site-dependent.

Though the releases through liquid (e.g. ^{3}H, fission and activation nuclides like ^{134}Cs, ^{137}Cs, ^{131}I, ^{60}Co etc.) and gaseous effluents (e.g. fission product noble gases, activation gases, ^{41}Ar, ^{3}H, iodine and particulates) contain a large number of radionuclides, most of them may not lead to significant doses to man due to their short half-lives. A radionuclide which leads to a predominant dose through a pathway is often termed as the critical nuclide and the corresponding pathway as critical pathway. Among radio-iodines, I-131 specifically leads to significant dose through grass-cow-milk pathway and hence it is often considered as critical nuclide for grass-cow milk pathway.

The actual doses received by a member of the public will vary depending on many factors such as age, metabolism, dietary habits as well as usage of the environment, intertidal fishing and recreational activities. It is a normal practice in radiological protection to account for this variability by identifying an appropriate critical group. This group should be representative of a group of individuals in the population expected to receive the highest dose from the source of radiation under consideration (routine or accidental). The group should be small and homogeneous with respect to age, diet and other habits that influence the dose received. During the operation stage, the critical group should be identified from the population dwelling in the vicinity of an NPP. For example the fisher-folk dwelling near an NPP are generally considered as the critical group for the aquatic releases from the plant at a coastal site. Similarly infants whose main diet is milk are often considered as a critical group for radioactive iodine releases. Once the dose to a member of critical group is limited, the dose to the member of the public will be automatically limited.

3. PATHWAYS AND METHODOLOGIES OF DOSE COMPUTATIONS

3.1 General

Radioactive materials are generated in solid, liquid and gaseous forms during the normal operation of the reactors. Gaseous activity released into atmosphere gets dispersed depending on the atmospheric conditions and the height of release. This has been discussed in detail in safety guide on atmospheric dispersion [5]. The radioactive liquid effluents will normally be discharged into nearby water body and the dispersion of radioactive materials in this media is discussed in safety guide on Hydrological Dispersion [6]. The solid radioactive waste generated in various facilities is normally stored after treatment in near surface disposal facilities such as earth trenches, concrete vaults or tile holes depending on the level and form of activity. The multi barrier systems of near surface disposal facility, such as concrete top cover, waste form, canister, backfill, bottom cover of the facility and geosphere, retard the migration of most of the radionuclides [having low values of half lives and high distribution coefficients in soil (K_d)] from the facility and allow them to decay prior to reaching the environment. However the radionuclides having high distribution coefficients (K_d) with very long half lives may show up in the environment in extremely low concentration after a long period. The hydro-geological considerations during siting of an NPP are dealt with in safety guide on Hydrogeology [7].

The safety guides on atmospheric dispersion and hydrological dispersion [5,6] deal with methodologies for computing concentration in air and water respectively for the releases into the atmosphere and aquatic system. Dose computation methodologies herein employ the concentration of a radionuclide in air (Bq/m^3) or in water (Bq/L) as the starting point. The relevant formulae for assessing dose to an individual through different pathways are presented in this section along with identification of different environmental transfer parameters and dosimetric factors.

3.2 Air Route

3.2.1 Exposure Pathways

The major exposure pathways to an individual from release of radionuclides into the atmosphere are:

(i) Plume/Cloud dose
(ii) Immersion dose
(iii) Inhalation dose

The basic input data needed for all these pathways is the average annual or daily concentration of the radionuclide in air. The diffusion climatology of the site determines the atmospheric dispersion factor and the basic data needed for deriving diffusion climatological table are hourly wind direction, speed, insolation and cloud cover. The diffusion climatological table is generated from these data based on monthly, quarterly or annual data and this would give information on (a) number of occurrences of wind direction in a sector and stability class (in hours) and (b) values of $\sum_{i=1}^{m} N_i(1/U_i)$ where U_i is the wind velocity (kmph) for the wind classes i and N_i is the number of hours of occurrences for the respective wind class in a particular wind directional sector and atmospheric stability class and m is the number of wind classes. Using this diffusion climatology, direction dependent meteorological dispersion (dilution) factor χ/Q, for a particular sector and downwind distance is computed from the relation:

$$\chi / Q = \sum_{j} \{\sum_{i=1}^{m} N_i [1 / U_i]\} . \chi_{0,j} \qquad ....(1)$$

where $\chi_{o,j}$ represents atmospheric stability (j) dependent ground level concentration of radionuclide (Bq/m^3) for a unit release rate (Bq/s) for a unit wind speed (m/s). The annual average χ/Q (dispersion factor, s/m^3) for a sector is then obtained based on total number of observations in that sector over a year which in turn can be translated to site χ/Q at a specified downwind distance. The dispersion factor is a function of downwind distance and release height. However, for a fixed downwind distance, the variations in χ/Q reflect the variation in meteorological parameters such as wind speed, direction and stability class. The χ/Q values are used as multiplicative factors for arriving at the ground level concentration of radionuclides at a particular location when average release rate to the atmosphere is known. The concentration of radionuclides can then be translated into dose (inhalation or submersion) using respective dosimetric factors.

3.2.2 Plume or Cloud Dose

Radionuclides released into the atmosphere continuously at an elevation will travel downwind and undergo dispersion forming a standing plume. In case of an instantaneous release, it will form a puff which will travel in the downwind direction and disperse. Gamma emitting radionuclides will cause exposure at the ground level even if the plume or cloud does not touch the ground. This contribution is termed as cloud gamma or plume dose. Alpha and beta emitting radionuclides in the plume or cloud will not contribute to the dose at the ground level as their energies are dissipated within their range over a short distance in air medium. The plume dose computation involves volume integration as given below:

$$D(x, y, z) = 5 \times 10^{-4} E_\gamma \, \mu_a \int_0^\infty \int_{-\infty}^\infty \int_0^\infty \left[\frac{1 + k\,\mu R}{4\pi R^2}\right] e^{-\mu R} \chi(x, y, z)\, dxdydz \qquad ...(2)$$

where

D(x, y, z) = plume dose rate(μSv/h),
χ(x, y, z) = concentration of radionuclide (Bq/m^3) at x,y,z co-ordinates, within the volume element dx dy dz,
E_γ = gamma energy in MeV,
R = the distance of the volume element from the receptor (m),
μ_a = attenuation coefficient in air for the gamma energy(m^{-1}),
(1+ k μ R) = build up factor [$k= (\mu-\mu_a)/\mu_a$],
μ = total attenuation coefficient in air (m^{-1}),
x = downwind direction (m),
y = cross wind direction (m),
z = vertical direction (m), and
R^2 = $(x-x_i)^2+(y-y_i)^2+(z-z_i)^2$
x, y, z = location coordinates of receptor
x_i, y_i, z_i = location coordinates of volume element dxdydz
x, y, z are with respect to stack bottom (origin of co-ordinate system)

The plume doses at various down-wind distances for different weather categories, wind speed, different gamma energies and different release heights have been computed using equation-2 and compiled by Hukkoo et al [9] . The dose received from the plume can be obtained for actual releases using this compilation for a particular radionuclide. It should be noted that plume/cloud dose includes immersion dose contribution of gamma radiation.

3.2.3 Immersion Dose

A receptor at the ground will be completely immersed in the radioactive cloud when it touches the ground. This will give the immersion dose. The β radiations of the radionuclides mainly contribute to this route. Beta rays have a range of only a few metres in air and thus the β submersion dose is directly proportional to the activity concentration in the air at the point under consideration. Because of long mean free path of γ-rays in air, use of semi-infinite model can lead to considerable error close to discharge point and under poor dispersion conditions, particularly for elevated releases. At larger distances or closer distances, under favourable conditions for dispersion (Pasquill stability categories A, B), for prediction of submersion γ dose, γ submersion dose factors may be employed.

The immersion dose estimation is carried out by estimating dose at the centre of an infinite hemispherical cloud with the assumption that the concentration is uniform in this volume . As the range of beta radiation in air is limited, the effective infinite thickness will be comparatively small and the assumption of uniform concentration distribution is valid. The immersion dose rate (Sv/y) due to an infinite cloud emiting β or γ radiation can be estimated using the formula given below:

$$D_\beta(\infty) = \chi .DCF \qquad ......(3)$$

where $D_\beta(\infty)$ is the annual dose in a cloud of infinite dimension (Sv/y), and χ is the annual average concentration (Bq/m^3) at the specified location computed for the average annual release from the reactor and DCF is the dose conversion factor (Sv/y per Bq/m^3).

The dose from a finite cloud emiting β radiation is obtained from the relation:

$$D_\beta(o) = 2D_\beta(\infty)\,[1 - \exp(-\mu_a \rho_a r)] \qquad ....(4)$$

where

$D_\beta(o)$ = annual β submersion dose for finite plume (Sv/y),
μ_a = mass energy attenuation coefficient (m^2/g),
ρ_a = density of air (g/m^3) and
r = radius of finite hemispherical cloud. (In case of a room full of β emitting radioactivity in air, r can be computed from radius of a hemisphere having the same volume as the room and this equal to 2.9 m, 4.9 m and 6.2 m for room volumes of 100 m^3, 500 m^3 and 1000 m^3 respectively) [17].

For a semi infinite cloud extending only in positive z direction, the infinite dose will be ½ of that defined by equation (2). These dose factors can be employed for the computation of dose through this pathway employing appropriate concentration at the centre of the plume. The dose conversion factors, DCF (Sv/h per Bq/m^3), for β and γ radiations for some of the important radionuclides are given in Appendix-IA and Appendix-IB respectively [10,11,13].

3.2.4 Inhalation Dose

The radionuclides present in air at the ground level will lead to internal exposure through inhalation. A part of radionuclides will be retain ed in the body and the residence time of the radionuclide in the body will be governed by the effective turnover rates in the body (s^{-1}). The deposition of the radionuclide in different parts of the lung and its transfer to other parts of the body is determined by the particle or aerosol size and chemical properties of the element. The dose resulting from resident activity of the radionuclides deposited in the body due to inhalation of air is termed as inhalation dose. The fraction of noble gases retained in the body is insignificant and hence the internal dose due to inhalation of noble gases need not be considered.

The intake of radioactivity through inhalation can be estimated using the breathing rate and the concentration of respective radionuclide in air. The breathing rates vary depending on the age structure. For this purpose, two groups are generally identified viz: infant and adult.

The values of inhalation dose coefficient (DF_{inh}) for different radionuclides have been based on unit intake of radionuclide through inhalation, for different age groups of population including infant and adult compiled in IAEA document [12]. DF_{inh} gives the committed effective dose for the life time of the individual due to unit intake of radioactivity. These dose coefficients referred to by IAEA are based on ICRP recommendations. These are recommended in this guide for the computation of annual inhalation dose (Sv/y) using annual average radionuclide concentration in air at ground level and breathing rate as given below:

$$D_{inh} = C_a \cdot B \cdot DF_{inh} \quad \text{.... (5)}$$

where

D_{inh} = annual effective inhalation dose (Sv/y)
C_a = annual average concentration of radionuclide in air (Bq/m^3),
B = breathing rate (m^3/y), and
DF_{inh} = inhalation dose coefficient for a radionuclide (Sv/Bq).

The inhalation dose coefficient, $DF_{inh,}$ for some important radionuclides and for three lung absorption classes are given in Annexure-IA [12].

3.3 Terrestrial Route

3.3.1 Deposition Processes

During plume transit, the radionuclides present therein will be removed by impaction of the plume with the underlying surface over which it is traveling. In addition the particulate aerosol activity can get deposited onto the ground or any surfaces by gravitational settling or by washout with rain droplets.

The former process is known as dry deposition and the latter is called as wet deposition. The dry deposition flux ($Bq/m^2\,s$) can be computed as the product of radionuclide concentration in the plume near the surface (Bq/m^3) and deposition velocity, V_g (m/s), specific for the nuclide. The correction for wet deposition is generally made in the source term itself by a factor, $\exp(-\Lambda x/u)$, where Λ is the wet deposition rate coefficient (s^{-1}), x is the distance (m) at which concentration is measured and u is the mean wind velocity (m/s). The procedures for calculating deposited activity are described in the safety guide on atmospheric dispersion [5]. The ground deposited radionuclides can cause exposure to a member of the public through the following pathways:

(i) External dose from ground surface

(ii) Ingestion dose from intake of terrestrial food stuff

(iii) Ingestion dose from intake of drinking water

(iv) Ingestion dose from grass-cow-milk pathway

(v) Inhalation dose from resuspension of particulates

3.3.2 External Exposure from Ground Surface

Radioactivity deposited onto the ground surface acts as an area source resulting in external exposure from β, γ radiations to the person standing on the ground. This is termed as external dose from ground surface.

The dose contribution from ground surface is generally computed at a distance of one meter above the contaminated surface level. This is obtained as the product of concentration of the radionuclides deposited on the surface (Bq/m^2) and the β, γ dose conversion factor DCF_β or DCF_γ ($Sv\,h^{-1}/Bq\,m^{-2}$). These dose conversion factors have been compiled [11] for some important radionuclides for unit surface concentration, C ($Bq.m^{-2}$) of the radionuclide. The dose factors for some important radionuclides, are given in Annexure-IIA and Annexure-IIB from their β and γ radiation contributions, respectively.

3.3.3 Ingestion Dose

The radionuclides deposited on the soil, especially water soluble components are taken up by the vegetation through their roots and get distributed in different parts of the vegetation. The consumption of these terrestrial food products (eg. rice, wheat, vegetables etc.) by an individual leads to internal exposure and this is termed as ingestion dose.

In case the radioactivity is deposited on the foliage of the plant, then direct consumption of these foliage plants i.e. leafy vegetables may lead to internal dose. Similarly the animals grazing on these foliage plants incorporate the radionuclides in their body. The consumption of animal products such as meat, milk by an individual may lead to internal exposure as these products may contain some fraction of the radionuclides ingested by them.

The contamination of the terrestrial food products may occur either from atmospheric deposition process or due to irrigation of the plants with potentially active water.

3.3.3.1 Uptake through Root System

The uptake through root system to the edible part of the plant depends on physico-chemical characteristics of the radionuclides. The radioactivity taken up through the root system may concentrate differentially in different parts of the plant. However, emphasis is given to the concentration of radionuclides in edible parts of the plant. The factor, which gives the fractional activity present in edible parts of the plant with respect to the activity present in the soil is termed as soil to vegetation transfer factor (B_v). The amount of radioactivity accumulated in the vegetation (Bq/kg) is computed from the relation:

$$C_v = \{C_a V_g B_v [1 - \exp(1 - \lambda_e(s)\, t_1)] / P\lambda_e(s)\} \exp(-\lambda_1 t_2) \qquad .....(6)$$

where

C_v = radionuclide concentration in vegetation (Bq/kg),
C_a = annual average concentration of radionuclide in air (Bq/m^3),
V_g = deposition velocity (m/s),
B_v = concentration factor for uptake radionuclide by vegetation [kg(soil)/kg(plant)],
P = effective surface soil density up to root zone (kg/m^2),
$\lambda_e(s)$ = effective decay constant of the radionuclide for the vegetation, $[\lambda_i + \lambda_s]$ (s^{-1}),
λ_i = radioactive decay constant of the radionuclide (d^{-1}),
λ_s = rate constant for reduction of radioactivity in soil other than radioactivity decay (d^{-1}),
t_1 = time up to which plants are exposed during growth (d), and
t_2 = hold up time between harvest and consumption (d).

The concentration factors, 'B_v' of a radionuclide in a crop plant vary in a complex manner with soil texture and other soil properties such as cation exchange capacity, pH, exchangeable cations, organic matter and the physico-chemical form of the radionuclide in soil. In addition, B_v varies with crop types e.g. B_{v1} is the concentration factor in forage plants (pasture vegetation) and B_{v2} is the concentration factor for food crops such as leafy vegetables, root vegetables, grams etc.

The food materials are generally washed or cooked prior to direct consumption which decreases the amount of radioactivity present in the food stuff. For conservative purpose, the effect of washing or cooking in depleting the radionuclide concentration is not taken into consideration while computing the annual effective dose from the food products. The ingestion dose (Sv/y) due to consumption of food is obtained from the relation:

$$D_{ing} = C_v . I_v . DF_{ing} \quad .....(7)$$

where

D_{ing} = annual effective ingestion dose (Sv/y),
C_v = radionuclide concentration in food materials (Bq/kg),
I_v = annual food intake (kg/y), and
DF_{ing} = ingestion dose coefficient for a radionuclide (Sv/Bq).

The ingestion dose coefficients for some important radionuclides are given in Annexure-IB [12].

3.3.3.2 Foliar Deposition

Activity deposited on the leafy surface of the green vegetables and other vegetations is estimated when the surface area and the interception factors are known (R/Y). This consists of two factors. The first factor, namely density of the edible part of the foliage surface per unit surface of the ground will give the fractional activity intercepted by the foliage (R). The second factor is the yield, kg/m^2 (Y) in terms of wet weight of the edible part of the foliage per unit soil surface area. A ratio of these two factors will give effective surface area of the edible part per one kg of edible part by wet weight. The concentration of radionuclides in vegetation is estimated based on deposition flux and the above mentioned factors (R/Y) using the relation:

$$C_v = \{C_a V_g R\, [1- \exp(- \lambda_e(w)\, t_1)] / (Y.\lambda_e(w))\}[\exp(-\lambda_1 t_2)] \quad ....(8)$$

where R/Y(m^2/kg) is the ratio of interception factor to forage yield, and $\lambda_e(w)=\lambda_i+\lambda_w$. λ_w is the rate constant for reduction of radioactivity in vegetation other than radioactivity decay. The other terms have already been defined with equation-6.

The concentration of a radionuclide in food crops is generally computed both through the root uptake and foliar deposition modes. It is known that washing the green vegetables prior to consumption will remove some fraction of the labile (easily washable) radioactivity. No credence is generally given to this aspect as a conservative estimate. However, for realistic estimation, the fractional elimination through these processes is to be incorporated while computing the committed effective dose to man.

3.3.3.3 Grass-Cow-Milk Route

Atmospheric radioactivity deposited onto the grass is consumed by bovine animals. A fraction of this activity reflects in the lactated milk as well as in the meat of the animal. The consumption of the milk or milk products and the meat will lead to internal exposure to man. As this route plays an important role for assessing the dose from radioactive iodines, it is treated separately as dose from grass-cow-milk route.

Various factors such as density of grass grown, consumption of grass by animal, partition of the radioactivity between milk and grass and consumption rate of milk by man are the important factors required for the computation of ingested radioactivity by an individual. The product of ingested activity and the dose conversion factors (DF_{ing}) will yield the dose received by an individual through this route. The annual dose to an individual (Sv/y) through grass-cow-milk pathway is obtained from the relation:

$$D_{ing} = C_v \cdot Q_f \cdot F_m \cdot I_m \cdot DF_{ing} \qquad .....(9)$$

where

C_v = radionuclide concentration in animal feed (Bq/kg)
Q_f = forage intake rate for the animal (dry weight) (kg/d),
F_m = fraction of animal daily intake that appears in each litre of milk (d/L),
I_m = milk intake rate by man (L/y), and
DF_{ing} = ingestion dose coefficient for a radionuclide (Sv/Bq).

The credit for fresh forage intake and stored food intake by the animal can be introduced using the factors such as f_f and f_p which represent fraction of daily feed that is fresh forage (dimensionless) and fraction of the year that animals consume fresh pasture vegetation (dimensionless).

The dose due to ingestion of meat can be obtained by replacing F_m and I_m with F_f and I_f where F_f represent fraction of animal daily intake that appears in each kg of meat (d/kg) and I_f is the annual consumption of meat (kg/y).

3.3.4 Resuspension

The plume of the radioactive aerosol eventually reaches the ground. The deposited activity may get dispersed back into air by the turbulent wind conditions existing near the surface. This resuspension process is characterised by the resuspension factor (K_O, m^{-1}) which is the ratio of the suspended air concentration of the aerosol (Bq/m^3) and the surface deposited activity on a unit area (Bq/m^2) under equilibrium conditions. A default value of 1.0E-9 m^{-1} is adopted for K^1_∞. The form of time dependence of K_O may be represented by a two component exponential viz: K_O=A exp($-\lambda_1 t$) +B exp($-\lambda_2 t$) where A and B are constants and λ_1 and λ_2 are short term and long term effective removal rates respectively. Reference values are $10^{-5} m^{-1}$ and $10^{-9} m^{-1}$ for A and B respectively and $10^{-2} d^{-1}$ and $2x10^{-5} d^{-1}$ for λ_1 and λ_2 respectively. The value of K_O for long term effective removal rates (especially for transuranics) is represented by K_∞. This exposure pathway is generally insignificant except for α emitters and other radionuclides having high K_d for soil.

The dose due to inhalation of resuspended materials depends on the concentration of a radionuclide in the suspended materials, its deposited activity on surface soil (Bq/m^2) and the dust load (g/m^3) prevalent at site. The ratio of surface soil activity and surface soil density will yield activity concentration in soil. The inhalation dose D_{inh} (Sv/y) due to radioactivity present in resuspended aerosol particulates (sediment/soil laden or salt laden air) is obtained from the relation:

$$D_{inh} = C_s . A_d . B . U_p . DF_{inh} \quad \text{....(10)}$$

where

C_s = radionuclide concentration in resuspended aerosol (Bq/g),
A_d = dust weight load in resuspended materials (kg/m^3),
B = breathing rate (m^3/h),
U_p = occupancy factor at the site (h/y), and
DF_{inh} = inhalation dose coefficient for a radionuclide (Sv/Bq).

3.4 Water Route

3.4.1 General

Radionuclides enter the surface water body (i) due to direct discharge of liquid effluents from NPPs, (ii) through ground water flowing across near surface radioactive storage facilities, and (iii) through direct deposition of

[1] Useful only for calculating ∞ resuspension activity.

water droplets from atmosphere. The latter two cases are generally insignificant. The width of the water body is generally smaller compared to plume dimensions and hence the depostional flux is expected to be insignificant. Similarly the multi barrier systems employed in near surface disposal facility will generally contain the radioactivity within the facility and any movement of radionuclides leached from the waste matrix will be retarded by the geosphere owing to its adsorption capacity. The concentration of radionuclides in a water body and the resulting dose from its different uses are covered in this section. This route includes different types of water bodies like wells, lakes, rivers as well as sea. Dose to man results from direct consumption of water through drinking/ cooking purposes as well as from indirect use such as irrigation, swimming and recreational activities.

3.4.2 Drinking Water Route

The methodologies for predicting the concentrations in different surface water systems are dealt with in the safety guide on hydrological dispersion [6]. The direct consumption of water for drinking purposes leads to internal exposure and the annual dose D_{ing} (Sv/y) from drinking water route can be computed using the relation:

$$D_{ing} = C_w . I_w . DF_{ing} \qquad .....(11)$$

where

C_w = concentration of radionuclide in surface water (Bq/m^3),
I_w = annual consumption of water (m^3/y) for drinking, and
DF_{ing} = Ingestion dose coefficient for a radionuclide (Sv/Bq).

3.4.3 Irrigation Route

The radionuclides may reach man through consumption of food crops and vegetables grown in fields which are irrigated with surface waters receiving the liquid effluents from NPPs. The radionuclides are concentrated in food materials through root uptake. However direct deposition on leafy vegetables (sprinkler system) cannot be ruled out. The build up of radioactivity in food materials can be estimated from a knowledge of the concentrations of radionuclides in irrigation water (Bq/m^3), area irrigated and the quantity of water used. Using the transfer factors between the soil and vegetation (B_v), the concentration of radionuclides in the vegetation C_v can be computed from the relation:

$$C_v = \{C_w \cdot I_r \cdot R/Y\}[\{1 - \exp(-\lambda_e(v)t)/\lambda_e(v)\}] + \{C_w . I_r B_{v2} / P \lambda_e(s)\}[\{(1 - \exp(-\lambda_e(s) t_e) / \lambda_e(s)\}] \quad .....(12)$$

where

P	=	effective surface density up to root zone (kg/m^2),
I_r	=	irrigation rate ($m^3/d/m^2$),
$\lambda_e(v)$	=	effective decay constant for the radionuclide in vegetation, $[(\lambda_i + \lambda_w)]$ (d^{-1}),
$\lambda_e(s)$	=	effective decay constant for the nuclide in soil, $[(\lambda_i + \lambda_s)]$,
λ_i	=	radioactive physical decay constant of the radionuclide (d^{-1}),
λ_s	=	rate of reduction of radioactivity in soil other than radioactive decay,
λ_w	=	rate constant for reduction of radioactivity in vegetation other than radioactivity decay (d^{-1}),
t_e	=	period of long term deposition in the soil (d),
t	=	time upto which plants were exposed during growth (d),
B_{V2}	=	concentration factor of crops for uptake of radionuclides from soil (Annexure-VB), and
P	=	effective surface density upto root zone (kg/m^2),
C_w	=	concentration of radionuclide in surface water (Bq/m^3),
R/Y	=	interception factor (refer section 3.3.3.2)

The correction factor for the radioactivity decay in food crops prior to consumption after harvesting is introduced as multiplication factor viz $\exp(-\lambda_i t_d)$ where t_d is the delay time. The other parameters have already been defined. The values for λ_w are of the order of 4.6E-2 d^{-1} for particulate activity and 6.9E-2 d^{-1} for iodine on pasture vegetation. The retention and biological availability of radionuclides in soils will depend upon long term deposition term for activity in soil. A generic value of λ_s = 3E-5 d^{-1} for environmental rate constant for removal activity from the root zone is considered adequate.

The product of radionuclide concentration in vegetation, its annual consumption rate and dose factor yields internal dose to man through ingestion of that particular vegetation (equation-6).

3.4.4 Sea/ Fresh Water Food Route

The aquatic plants and animals living in surface waters accumulate radionuclides from the water. Some of them have special ability to concentrate large amount of specific radionuclides in their system and they are used as indicators for identifying the critical nuclide-critical pathway. The consumption of marine food (fish, benthic organisms etc.) and fresh water food leads to internal dose to man through ingestion.

The concentration of a radionuclide in aquatic species is defined by the term, Concentration Factor (CF) (also referred to as Bio-accumulation factor, B_p) which is the ratio of the concentration of radionuclide per unit mass of the species to the concentration in the water media at equilibrium. These concentration factors are species and nuclide specific and also found different for the same species in fresh and sea water. These factors can also be estimated from the concentrations of stable counterpart of the elements. The concentration factors are generally generated during the pre-operational stage of NPPs by the Environmental Survey Laboratory (ESL). The annual dose D_{ing} (Sv/y) to man due to consumption of aquatic food is estimated using concentration factor approach as shown below:

$$D_{ing} = C_w \cdot B_p \cdot I_f \cdot DF_{ing} \qquad ....(13)$$

where

C_w = concentration of radionuclide in water (Bq/m^3),
B_p = concentration factor of radionuclide for the specific food (m^3/kg),
I_f = annual consumption of the specific food (kg/y), and
DF_{ing} = ingestion dose coefficient for the radionuclide (Sv/Bq).

3.4.5 Mud-flats and Sediments

Radionuclides are accumulated to a significant extent in the suspended sediment load present in water media. The eventual deposition of this suspended sediment in the coastal bed lead to additional exposure pathways to the critical group (fishermen) dwelling near the coastal area. An important pathway is the direct external exposure from the sediment surface and this is evaluated from the relation:

$$D_s = 2.88 \times 10^{-10} C_s E\, U_p M_p \qquad .....(14)$$

where

D_s = external dose rate due to contaminated sediment (Sv/y),
C_s = concentration of radionuclide in sediment (Bq/kg),
E = mean energy of radio rays or β particles (Mev),
U_p = Occupancy factor, for a pathway, p (h/y),
M_p = modification factor for source-recipient geometry.

The constant 2.88 E-10 is the dose conversion factor [13] having a unit of ($Gy.h^{-1}/Bq.Mev.kg^{-1}$). There exists different pathways through which radiation exposure to the occupant in mud bank can occur. Typical examples for exposure pathways from beach shore are working in intertidal zones for fish catching, sunbathing on beach, handling fishing gear, swimming and boating. The geometry factor and occupancy factor can differ depending upon the pathways. The geometry factor M_p for β as equal to 1 and for γ as equal to 2 for swimming; M_p for β as equal to 1 and for γ as equal to 1 for working in intertidal regions; M_p for β as equal 1 and γ as equal 0.1 for handling fishing gears.

The second pathway results from resuspension of the sediment particulates into air which would cause inhalation exposure to fishermen who work on these mud flats and beaches. The estimation of dose through this pathway is similar to that described in Equation-10. The occupancy factor in U_p the contaminated area is an important parameter that will dictate the computed dose.

3.4.6 Recreational Activity

Recreational activities like swimming, surfing in the contaminated waters will also lead to external exposures from volume source of the water. The annual external dose from β and γ radiations of a radionuclide due to swimming is computed from the relation:

$$D_\beta = 2.88 \times 10^{-10} . C_w . U_p . \Sigma f_\beta E_\beta \qquad \text{.... (15)}$$

$$D_\gamma = 5.76 \times 10^{-10} . C_w . U_p . \Sigma f_\gamma E_\gamma \qquad \text{.... (16)}$$

where D_β is the external dose due to β radiation (Sv/y), D_γ is the external radiation due to γ radiation (Sv/y), C_w is the concentration of radionuclide in water (Bq/m^3), U_p is the occupancy factor, E_β is the energy of β-radiation of that particular radionuclide, f_β is the fractional intensity of β-radiation energy, E_γ is the energy of γ-radiation of that particular radionuclide, and f_γ is the fractional intensity of γ-radiation energy . The DCF_{swim} can be computed from these relations for β and γ emitting radionuclides for unit concentration (Bq/m^3) of the respective radionuclides with 100% occupancy. Alternatively, the dose due to swimming can be computed from the relation:

$$D_{swim} = C_w . U_p . DCF_{swim} \qquad \text{.....(17)}$$

where D_{swim} is the annual external dose due to beta and gamma radiation (Sv/y), C_w is the concentration of the radionuclide in water (Bq/m^3), and DCF_{swim} is the dose conversion factor (Sv/h per Bq/m^3). The DCF_{swim} for some important radionuclides are given in Annexure-IIC [11].

4. PARAMETERS INVOLVED IN DOSE CALCULATIONS

4.1 General

The computation of dose to man from radioactive contamination in the environment requires a large data base for a variety of parameters which can be grouped under the following categories:

(i) Transfer factors/concentration factors.

(ii) Consumption/intake rates and pattern.

(iii) Dose conversion factors.

It is preferable to generate site specific data for the parameters listed in (i) and (ii). Default values may be used when site specific data are not available.

4.2 Transfer Factors/Concentration Factors

4.2.1 Transfer Factors

The radioactivity present either in air, water or land reach man through different pathways. The relevant pathways involved are given in Fig 4.1 and Fig 4.2. Under equilibrium condition, the ratio of activity transferred to compartment-2 from the activity present in the source compartment-1 is known as transfer factor, $P_{1,2}$. Many of these parameters depend on climatic and environmental conditions, soil type and physico-chemical behavior of radionuclides. As far as possible, values of these parameters should be generated for the site under consideration. However default parameters may be used if a statistically reliable estimate of the site specific parameters is not available.

The transfer factors which play dominant role in dose computations are concentration factor for aquatic organisms (B_p), distribution coefficient for nuclides in marine and aquatic sediments (K_d), concentration factor in forage and food crops (B_v), transfer factor to milk (F_m), and transfer factor to meat (F_f). The default values of these transfer factors are given in Annexures III, IV,VA,VB, VIA and VIB [13].

4.2.2 Weathering Rate Constant (λ_w)

The radioactivity deposited in terrestrial environment can get depleted due to various natural processes like wind blowing, washout or percolation through soil. The weathering half lives are not known for many radioisotopes.

A value of λ_w as 4.6 E-2 d^{-1} is chosen as a default value for particulate radioactivity based on weathering rate of particulates on pasture vegetation. The value of λ_w for iodines is reported as 6.9 E-2 d^{-1} [13]. Since the elimination mechanisms are dependent on natural processes, these parameters could be site dependent. The site specific investigations of the retention and biological availability of radionuclides in soils are desirable especially for long-lived radionuclides when long term deposition onto soil is envisaged. For values of deposition times ≥ 10 years, a generic value λ_s (soil removal rate constant) of $1 \times 10^{-2}\ y^{-1}$ is considered for the environmental removal rate constant from the root zone. This value of λ_s is considered to provide a reasonable conservative estimate for most nuclides of concern. However for very mobile radionuclides like T_C (in pertechnetale form as $T_C\,O_4^-$) and Iodine, this default value of λ_s may substantially overestimate soil concentration even for short build up times in soil. Values of $1 \times 10^{-1} y^{-1}$ and 3.0 y^{-1} have been reported for Iodine and $T_C\,O_4^-$ respectively in literature [13].

The default values of soil density, 'P' as a function of root depth, delay period between harvest and consumption and weathering half lives alongwith vegetation density and intercept factors for some important radionuclides of interest are given in Annexure VIIA, VIIB and VIII [13].

4.2.3 Irrigation Rate (I_r)

The mode of irrigation, its rate and duration will determine the activity distribution of a radionuclide on foliage as well as in soil. Foliar uptake will be dominant for sprinkler irrigation and root uptake predominates in the case of soil irrigation. In both cases, the rate of irrigation ($m^3.d^{-1}.m^{-2}$) and the mode of irrigation are required for the computation of radiation dose through the terrestrial pathway. This parameter will indirectly influence the λ_s for soil.

4.2.4 Plant Root Depth

The radioactivity uptake by plants from contaminated soil mainly depends on root depth and soil density. For cereals, leafy vegetables and forage, roots extend only to the first few centimeters of soil. For pulses, the root depth is of the order of few tens of centimeters and for fruit bearing trees, roots can go much deeper. Thus, the radioactivity uptake by plants and related radiation dose are governed by the type of plants and soil density in their root zone and also on the chemical form of radionuclides. Default values of effective surface soil densities for various rooting zone depths and soils are given in Annexure VIIA.

4.2.5 Interception Factor (R/Y)

The ranges of values for deposition velocity, V_g, indicate functional dependence with atmospheric turbulence characteristics, particle sizes of the aerosols and reflection and adsorption capacities of receiving surfaces. Chamberlain [14] has determined the fraction of aerosol intercepted by forage, R, from an empirical relation with the crop density (Y= kg/m^2). The ratio R/Y (m^2/Kg) is given because of evidence indicating that R and Y for pasture vegetations are not independent variables and are strongly correlated. Since R includes translocation, it will vary with both crop type and nuclide. The default values are given in Annexure-VIII.

4.3 Consumption/Intake Rates

4.3.1 Consumption Rates

The intake rate of radionuclides is obtained from the consumption rate of individual food materials. These consumption rates of food are needed for both man and bovine animals since the meat/milk consumed by an individual is obtained from bovine animals who in turn consume terrestrial forage and crops .

4.3.2 Food Consumption Rate by Man

Food consumption rates are country specific and in the Indian context it could even be site specific. In view of this it is preferable to generate average statewise data base on this parameter for Indian conditions. For this purpose, the data base available with National Institute of Nutrition [15] may be utilized. The data generated from dietary survey conducted within 30 km radius area around the NPP site would be more meaningful.

4.3.3 Feed Intake Rate by Bovine Animals

The cow-milk route is an important route of exposure to child population especially in accidental situations. The concentration in foliage is converted into concentration in milk and meat using the feed intake rates by animals. It is not difficult to obtain site specific feed intake rates which can be derived from the grazing habits of animals. However, the magnitude and variation of this parameter can be obtained from various dairy farms existing in the country.

4.3.4 Delay in Consumption

Radioactivity concentration in the food/foliage will reduce due to decay during the period between harvest and consumption. This time delay

(Annexure-VIIB) coupled with the radioactive half life of a radionuclide will eventually dictate the fraction of deposited activity entering the human/ bovine body system. However, this component will be important only for short lived radionuclides.

4.4 Dose Conversion Factors

4.4.1 Dose Coefficients

The dose coefficients DF (inh. or ing.) yield committed effective dose received by a person during his life time per Bq of activity is taken through inhalation or ingestion. This factor is computed based on the energy of the radiation and the resident activity of the radionuclide in the body. The latter term is controlled by effective elimination rate constant (sum of biological and radiological decay constants). The elements, due to their differential chemical properties get distributed either throughout the body or in a specific organ. The effective dose coefficients for different radionuclides applicable to general public are given in IAEA Basic Safety Standard Series [12] and values for some important radionuclides are given in Annexures IA and IB. The corresponding dose coefficients for specific organs can be derived based on tissue weighing factors.

4.4.2 Dry Deposition Velocity, V_g

The particulate radioactive materials are removed from the plume by dry deposition. The deposition velocity, V_g ($m.s^{-1}$) is defined as the ratio of the amount of material deposited on the surface per unit time and to the ground level air concentration {For example $V_g = d/C_a$ where d is the deposition rate ($Bq.m^{-2}.s^{-1}$) and c_a is the average ground level concentration ($Bq.m^{-3}$)}. The rate at which the materials are deposited from the plume will depend on the nature of the air-borne material and the underlying surface. The default values for V_g are 0.002 m/s; 0.04 m/s and 0.0002 m/s for particulates (<4 μm), elemental iodine, and organic iodine compounds (CH_3) respectively.

4.4.3 Wash-out Coefficient (Λ)

The radioactive materials are removed from the plume by the action of rain or snow. In general, this process is assumed to remove the material uniformly throughout the entire vertical extent of the plume. The wash-out coefficient, Λ (s^{-1}), is assumed to be approximately proportional to precipitation rate I ($mm.h^{-1}$) by the relation $\Lambda = \alpha I$ where α, the proportionality constant depends on the aerodynamic particle diameter and solubility of gases in water. Reference values for α applicable to particulates, elemental iodine and organic iodine are 1.6 E-4 $h.(mm.s)^{-1}$; 1.1 E-4 $h.(mm.s)^{-1}$ and < 10^{-4} $h.(mm.s)^{-1}$ respectively. The wash-out correction is applied for those periods during which precipitation is experienced.

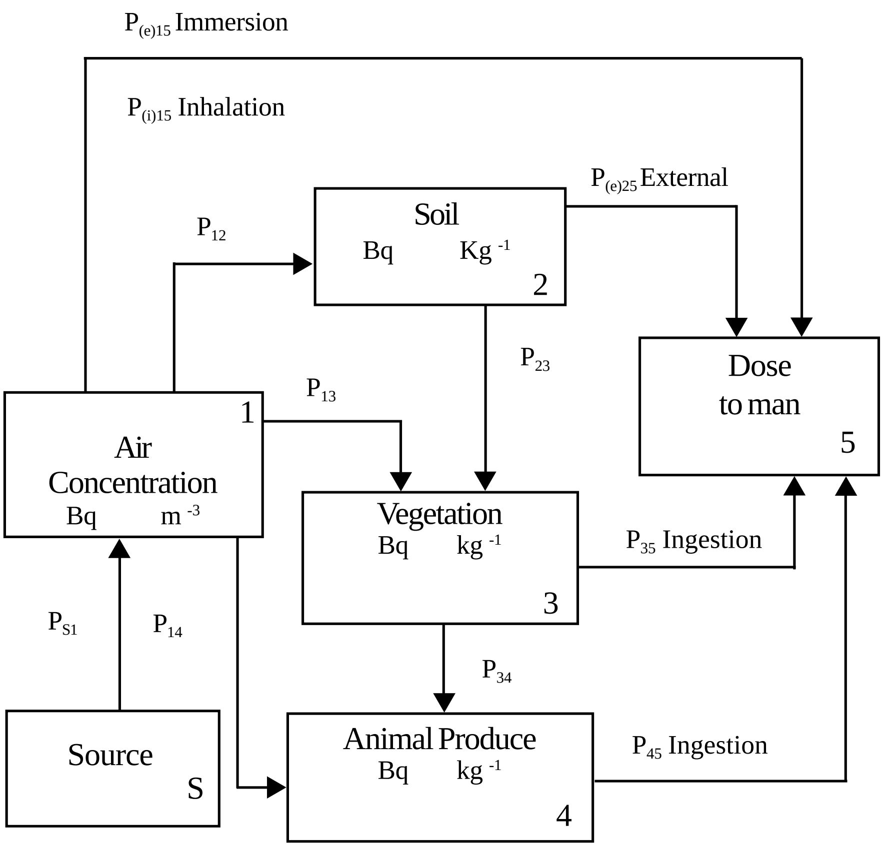

FIG 4.1: ATMOSPHERIC PATHWAYS FOR DOSE TO MAN FROM SOURCE 'S'
(Refer Table 6.1)

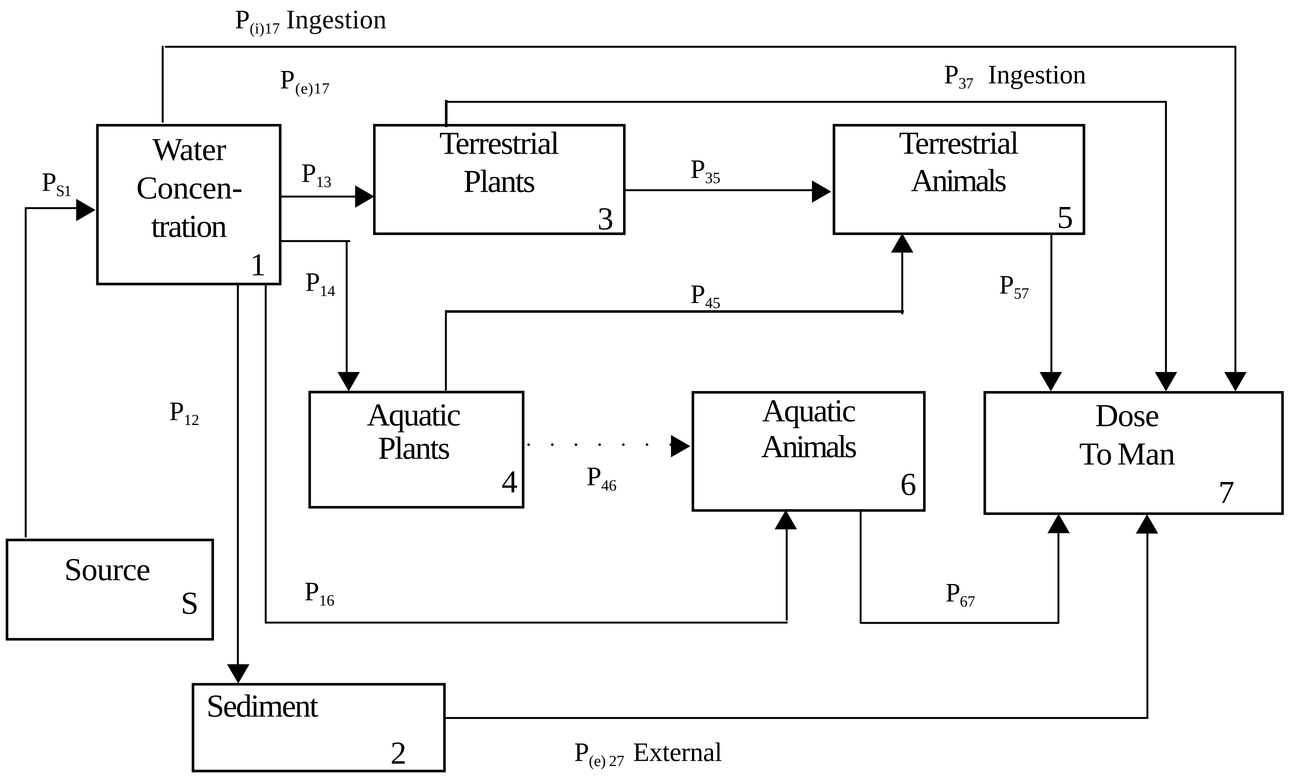

FIG 4.2 : AQUATIC PATHWAYS FOR DOSE TO MAN FROM SOURCE ‘S’ (Refer Table 6.2)

5. REGULATORY CRITERIA

5.1 General

The processes causing human exposures can be treated as a network of events and situations. Each part of the network starts from a source. Radiation or radioactive materials pass through environmental pathways which may be complex (e.g. ground accumulation, transfer to animals, then to food stuffs etc.) with some pathways being common to several sources. Eventually individuals are exposed to one or many sources of radiation. Hence the assessment of the effectiveness of radiation protection can be related to the source giving rise to the individual doses (source-related) or related to the individual dose received by a person from all relevant sources (Individual-related).

The control of exposure to a member of public in all normal situations is exercised by the application of controls at the source and the concept of dose commitment has been found to be useful for this purpose. The critical group may be exposed to radiation through different pathways and from different radionuclides owing to discharges from the same or different sources. If a limit is set for effective dose commitment to a critical group from each year of practice that continues at a constant level, the average annual individual effective dose to a member of the public will never exceed that limit.

5.2 Apportionment of Dose Limits during Normal Operation

Regulatory Body usually sets dose constraints (apportionment of dose limit) for monitoring compliance with dose limit for the public. In the concept of dose apportionment, the primary dose limit of 1mSv per year for a member of the public is apportioned among the various facilities operating and planned at the site, among atmospheric, aquatic and terrestrial pathways and also among specific radionuclides depending on the specific characteristics of the installation. A fraction of the dose limit is kept as a reserve for future expansions of the facilities at the site.

5.3 Estimation of Derived Limits

In practical radiological protection, it is often necessary to provide limits for quantities other than effective dose, effective dose commitment or intake by relating for example to environmental conditions. When these limits are related to the primary dose limit by a defined model of the situation and are intended to reflect the basic limits, they are called derived limits (DLs). Derived limits are secondary limits and may be set as derived limiting concentrations (DLCs) in different environmental matrices or derived discharge limits (DDLs) allowed for an environment under consideration. They are calculated from the resulting concentration of radionuclide in the aquatic/atmospheric medium due to unit discharge in the respective medium, environmental transfer factors and dietary habits of the critical group. The DLs for atmospheric or aquatic releases are computed using the computed dose for unit release rate of activity to the respective medium and the environmental pathways depicted in Fig 4.1 and Fig 4.2 as given below.

DL (Bq/y) = Primary dose limit (mSv y^{-1})/Computed dose per unit release rate (mS y^{-1}/Bq y^{-1}) from all pathways.

When the dose constraints or apportioned dose limits are used instead of primary dose limit, fractional derived limit (FDL) can be calculated for a specific radionuclide via specified medium.

As far as possible, the parameters applicable to Indian conditions are used in these calculations. In order to ensure that the dose to a member of the critical group is not exceeded the following additive relation for any combination of pathways and nuclides should be complied with:

$$\sum_k \sum_l \sum_m [A\,(k,l,m) / DL(k,l,m)] < 1 \qquad \text{......(18)}$$

where

A(k,l,m) = Level of activity of the nuclide k, environmental pathway l from source m

DL(k,l,m) = Derived limit of activity of nuclide k, environmental pathway l from source m which would lead to apportioned dose limit for the nuclide.

The regulatory requirement demands that the dose actually measured or predicted to a member of the critical group shall be lower than the prescribed constraints (or apportionment) provided for an installation releasing radioactive materials. In order to achieve this objective, fractional derived limits (FDLs) are calculated based on the apportioned dose for specific radionuclides (also known as technical specification limit) released through atmospheric and aquatic routes such that the following relation for any radionuclide in a specified pathway is complied with:

$$[A(k,l,m) / FDL(k,l,m)] \leq 1$$

where

A(k,l,m)	=	Level of activity of the nuclide k, in environmental pathway l from source m
FDL(k,l,m)	=	Fractional derived limit of activity of nuclide k, in envirenmental pathway l from source m which would lead to apportioned dose limit for the nuclide.

The control shall be employed at the release point such that the actual release to the environment via atmosphere or hydrosphere is far less than the respective authorised release rates based on dose constraints. As an example, if the annual apportioned dose for a NPP in a site is 0.20 mSv, the sum of the doses corresponding to various FDLs should not be more than 0.20 mSv. However it is prudent to use only those pathways and radionuclides that would contribute significantly to the dose for each source.

5.4 Regulatory Compliance

Based on these concepts a three-stage system of regulatory control and compliance is employed for radiological surveillance of effluents and the resulting exposure in the public domain arising due to NPP operations. The three-stage controls include:

- specification of discharge criteria for each facility in the form of technical specifications,
- source monitoring prior to discharge to the environment to ensure that the discharge criteria are being met with, and
- establishment of detailed environmental monitoring programme.

The basic objective of the environmental monitoring programme is to demonstrate compliance with the radiation exposure criteria set for members of the public. This requires detailed measurements of radioactivity content in different environmental matrices and the samples selected on the basis of potential exposure pathways. The number and type of samples and their sampling frequency are site-specific depending on the nature of operations, utilisation of the environment and existence of population clusters around the site. The sampling programme should cover a radial distance of 30 km and include aquatic, atmospheric and terrestrial samples.

6. APPLICATION OF DOSE CALCULATIONS TO SITING

6.1 General

Dose assessment includes consideration of the source term, types of the environmental media to which the source would be released, the characteristics of the recipient medium and human use of the environment. The radionuclide concentrations in the environmental media, viz water bodies or air media are calculated using simple conceptual hydrological models or Gaussian plume models for atmospheric dispersion coupled with appropriate depletion terms (such as deposition velocity and washout coefficients for atmospheric models and sediment pick up and radioactivity decay for hydrological models). The radiological models for atmospheric and aquatic pathways and the corresponding food chains are described here.

6.2 Concentration Factor Approach

The Concentration Factor (CF) method is most widely used for assessing the consequences from releases of radioactivity under normal operating conditions. The released radionuclides are assumed to reach equilibrium in environmental materials, and the transfer coefficients are steady state concentration ratio between one physical compartment and another. The rate of introduction of activity into any compartment is exactly balanced by its removal from that compartment. Since the comparison of the estimated dose to members of public is to be made with annual limits, averages may be taken over prolonged periods, say one year. Most of the radionuclides released into the environment will reach an equilibrium during this period and CF values available for each compartment are assumed to be applicable to equilibrium situations. The advantage of CF method is that simple multiplicative factors are used to obtain the intake of radioactivitiy by the individuals. The resulting effective dose is obtained by multiplying the intakes with committed dose per unit intake. Thus the dose resulting from a given discharge of single radionuclide may be obtained from the following relation for each environmental pathway.

$$D = [\,A\ B\ C\ DF\,]\ Q \qquad :.....(19)$$

where

D = dose to member of the critical group (Sv/y),

A = dispersion factor at the location of interest per unit discharge to atmospheric or aquatic environment (s/m^3),

B = concentration factor in the food chain (m^3/kg),

C	=	consumption rate of food stuff (kg/y),
DF	=	dose factor per unit intake (Sv/Bq), and
Q	=	release rate to the environment (Bq/s)

For the inhalation pathway, B is equal to unity and C is the inhalation rate (m^3/y).

6.3 Individual Dose from Atmospheric Route

6.3.1 Dosimetric Model and Pathways

Nuclear power plants release gaseous radioactive effluents into the atmosphere. The radioactive gas or aerosol once airborne, travels and disperses in a manner governed by its physical properties and those of the ambient atmosphere to which they are released.

There are three main pathways through which atmospherically released radioactivity reaches an individual viz: external irradiation, inhalation and ingestion through food. For noble gas releases, external irradiation from the cloud is important whereas for iodine and particulate releases external exposure from ground deposited activity as well as ingestion of food grown on the contaminated ground become the significant routes. Fig. 4.1 considers typically two external exposure pathways and two ingestion pathways and one inhalation pathway. The transfer factors P_{ij} are defined as the ratio at steady state of the relevant quantities of X_i and X_j in compartment i and j respectively, i.e. $P_{ij} = (X_j / X_i)$. It is worth mentioning that in any real application, the user must use only the relevant pathways that are appropriate for the specific prevailing conditions.

Applying CF approach, the total dose to man $X_{5(a)}$ through all concerned atmospheric pathways can be represented in a simplified form as:

$$X_{5(a)} = \{(P_{(e)\,15} + P_{(i)\,15})X_1 + P_{(e)\,25}X_2 + P_{35}\,X_3 + P_{45}\,X_4\} \qquad .....(20)$$

from compartments 1,2,3 and 4 respectively. This expression can be expanded in terms of atmospheric concentration X_1, as follows:

$$X_{5(a)} = [P_{(e)\,15} + P_{(i)\,15} + (P_{(e)\,25}\,P_{12}) + (P_{35}P_{13} + P_{35}\,P_{23}\,P_{12}) + (P_{45}\,P_{14} + P_{45}\,P_{34}\,P_{23}\,P_{12} + P_{45}\,P_{34}\,P_{13} + P_{45}\,P_{34}\,P_{23}\,P_{12})]\,X_1 \qquad ....(21)$$

The identification of individual transfer parameters as well as the compartments are given in Table 6.1 along with their units. The method of computing dose to man from each individual pathway is described in section 3 in detail.

6.3.2 Transfer Parameters for Atmospheric Route

An attempt is made to describe the individual compartments with reference to details and symbols provided in section 3. The transfer parameter, P_{si}, is related to dispersion parameter in obtaining concentration of radionuclide in air, X_1, at any point downwind of the source from the source release rate (X_s), neglecting the removal processes ($P_{si}= X_1/X_s$). The external dose from plume ($P_{(e)15}$) and ground ($P_{(e)25}$) have already been discussed in section 3. The transfer parameter for deposition on soil from radioactive plume under steady state is given by P_{12} = [$V_g/\lambda_e\ \rho$] where Vg, λ_e and P represent deposition velocity (m/s), effective removal constants from soil (s^{-1}) and surface soil density (kg(s)/m^2) respectively. Similarly the transfer parameter, P_{13}, for deposition from plume onto vegetation can be represented as P_{13}= [$Vg/\lambda_e Y$] where λ_e and Y are effective removal rate constants from vegetation(s^{-1}) and vegetation density (kg/m^2) respectively. The transfer parameter, P_{14} from atmosphere directly to the animal produce (meat or milk) due to inhalation of radioactivity material by animal is given by $P_{14} = I_a F_f$ or $I_a F_m$ where F_f or F_m is the fraction of daily intake via inhalation that appears in each kg of meat (d/Kg) or litre of milk (d/L) and I_a is breathing rate of the animal. The vegetation uptake from soil is represented by the transfer factor P_{23} which relates the concentration of a radionuclide in vegetation to that deposited on the surface of the soil ($P_{23}=B_v$). The transfer factor relating to the concentration of radionuclide in animal meat or milk to that in feed consumed by the animal is given as $P_{34} = [Q_f F_f$ or $Q_f F_m]$ where Q_f is the feed intake rate by the animal (kg/d). The transfer parameters, P_{35} and P_{45} convert ingestion of vegetation and animal produce to dose [P_{35} or $P_{45} = I_f DF_{ing}$] where DF_{ing} the ingestion dose coefficient for the radionuclide of interest for ingestion route and I_f is the consumption rate of the respective food.

6.3.3 Dose from Specific Atmospheric Pathways

Radioactive materials released to the atmospheric environment include fission product noble gases, activation gases, tritium, iodine and particulates. The dose that could be received by a member of public via inhalation, ingestion from food chains or external exposure from plume and ground contamination is given in Annexure IX (Table-IX.1) for unit concentration of each radionuclide in air. This table reflects that some specific radionuclides only contribute to the exposure of an individual through specific pathways (e.g. I-131: grass-cow-milk, noble gases: plume dose; Cs-137 and Sr-90 : ground exposure). The dose from Cs-137 and Sr-90 through ingestion of crops, meat and milk will be significantly low, indicating plume dose from noble gases as the critical nuclide-critical pathway.

6.4 Individual Dose from Aquatic Route

6.4.1 General

The radionuclides released to aquatic medium could expose an individual externally through swimming and staying on mud banks or beach and internally through consumption of drinking water and marine food stuffs. Irrigation practices also can lead to radioactivity entering the terrestrial food chains.

A conceptual compartmentalized aquatic system (Fig. 4.2) is used as example for model calculation of dose to an individual through various aquatic pathways. The total dose to an individual, $X_{7(w)}$, through aquatic pathways can be represented in a simplified form as:

$$X_{7(w)} = [P_{(i)\,17} + P_{(e)\,17}]\, X_1 + P_{(e)\,27} X_2 + P_{37} X_3 + P_{57} X_5 + P_{67} X_6 \qquad .....(22)$$

from compartments 1,2,3,5 and 6 respectively. The expression can be expanded in terms of only water concentration as given below:

$$X_{7(w)} = [\{P_{(e)\,17} + P_{(i)\,17} + P_{(e)\,27}\ P_{12} + P_{57}\, P_{13}\} \qquad .....(23)$$

$$+ \{P_{13}\ P_{35}\ P_{57} + P_{14}\, P_{45}\, P_{57}\} + \{P_{16}\, P_{67}\}]\, X_1$$

6.4.2 Transfer Parameters for Aquatic Route

The identification of individual transfer parameters are given in Table 6.2 along with with their units. The individual compartments are identified with reference to details/symbols provided in section 3. The transfer factor, P_{si}, is related, in this case to the hydrological models and the resulting concentration. The transfer parameters, $P_{(i)17}$, P_{37}, P_{57} and P_{67} are related to the intake of drinking water (or inhalation of sediment/salt laden air), terrestrial plants, terrestrial animal produce and aquatic animals, respectively (i.e. I_f DF_{ing} for freshwater or I_a DF_{inh} for seawater). $P_{(e)17}$ and $P_{(e)27}$ are the transfer factors relating to external exposure through swimming and shoreline sediment usage during intertidal fishing. The bioaccumulation factors for aquatic plants and animals are denoted by the transfer parameters P_{14} and P_{16} respectively. Similarly P_{12} represents K_d value for the sediment. The transfer parameter relating the concentration of radionuclide in vegetation with spray irrigation water is given by $P_{13} = I_r/\lambda_e Y\ [\ 1\text{-}\exp(-\lambda_e t)]$ and all the parameters have already been defined. The transfer parameters P_{35} and P_{45} relating the concentration of radionuclide in animal meat or milk to that in feed are obtained as the product of feed intake rate and the fraction of daily intake which appears in each kg of meat or litre of milk [F_f or F_m].

6.4.3 Dose from Specific Aquatic Pathways

Radionuclides discharged to the aquatic environment as liquid effluents include tritium and fission and activation nuclides. The dose to a member of public from freshwater ingestion pathways is given in Annexure-IX (Table-IX.2) for unit concentration of each radionuclide in water (Sv/y per Bq/ml). This table suggests that the ingestion of fresh water molluscs could lead to significant dose especially for Co-60. In addition, the table also suggests that the dose due to ingestion pathways through terrestrial route such as crops, meat and milk are insignificant. The actual dose received by members of the public depends on the radionuclide concentration in water and the dietary habits of the population.

The dose to a member of the public from seawater ingestion pathways is given in Annexure-IX (Table-IX.3) for unit concentration of each radionuclide in seawater (Sv/y per Bq/ml). This table suggests that the ingestion of sea water molluscs and salt could lead to significant dose, especially for Co-60.

Similarly the dose from inhalation (sediment laden or salt laden air) and external exposure (submersion in sediment laden air) pathways due to aquatic discharges are expected to be small as can be seen from Annexure-IX (Table-IX.4 & Table-IX.5). The exposure due to working in intertidal zones could become very significant. This pathway should be considered while evaluating the release rates to the aquatic system.

6.5 Dose Computation during Site Selection Stage

At the site survey stage information may or may not be available on the routine releases of radioactive materials to the environment. Even a decision may or may not have been made as to the type of NPP which will be constructed. However, it should be possible to obtain from literature some information on the quantity and the type of radioactive materials which may be released during normal operation of a reactor. UNSCEAR 2000 has compiled the quantities of different types of radioactive materials released from various kinds of reactors[16]. The normalized liquid effluent release levels have also been compiled in this UNSCEAR, based on reported discharges for each type of reactor.

It is observed that liquid effluent radioactivity releases are about three to ten times of magnitude lower than that atmospheric releases for the same of type of reactor. Thus this route, in general, may not contribute to significant exposure to the critical groups. However, for inland sites where the water bodies would be used for discharge of radioactive liquid effluents, intake of drinking water may become an important pathway for the critical group dose consideration. Similarly the intake pathway of marine food (molluscs) may become important for coastal as well as inland sites. For example Co-60 could contribute to the internal dose via ingestion of molluscs, especially that derived from fresh water systems (Annexure-IX). Thus at the site survey stage the contribution from aquatic route has to be assessed for specific pathways for specific radionuclides only.

Though there exists many pathways through which radioactivity released to atmosphere could reach man, it is adequate to use only the critical pathways (e.g. plume dose from noble gases) for exposure assessment during this stage with the use of default parameters (conservative dispersion factors).

6.6 Dose Computation during Site Evaluation Stage

The aim of the individual exposure assessment during site evaluation stage is to compare the doses that would be received by the critical group members with the source upper bounds. This necessitates information on the use of the local environment. The preliminary survey usually indicates a few pathways worthy of more detailed considerations e.g. consumption of particular food stuff, use of water as drinking water supply or for irrigation, occupancy in the mud bank zones for intertidal fish catch and these pathways will then be used in dose evaluation. As a result, appropriate pathways which may lead to exposure through the uses of the environment of the preferred site could be identified along with transfer parameters.

6.7 Dose Computation during Pre-operational Stage

The main objective of the pre-operational stage is to prepare a measurement programme at the selected site after the start of construction and before the start of operation in order to complete and refine the assessment of site characteristics. This would include verification of those parameters, that have been used in site evaluation stage (such as dispersion coefficients, deposition velocity, concentration factors etc.) through experimental measurements, wherever possible.

Pre-operational studies are necessary for providing early data for estimating the dose from the routine releases and setting limits and conditions for radioactivity releases from NPP to the environment. This begins with determination of base line levels of radioactivity in the appropriate environmental matrices which will enable assessment of the additional contribution of radioactivity due to releases from the plant. The assessment of individual dose made during site survey and site evaluation stages will be updated and refined at this stage with site specific parameters obtained through experimental surveys. A model computation would reveal that, even at this stage only a few pathways/ nuclides would lead to dose to an individual and they are maintained much below the prescribed apportioned limits as described in the beginning of this guide.

TABLE-6.1 (Refer Fig. 4.1)

TRANSFER FACTORS FOR ATMOSPHERIC ROUTE

Transfer Factor	Identification	Units
X_1	Atmospheric concentration	Bq/m^3
X_2	Soil concentration	Bq/kg
X_3	Vegetation concentration	Bq/kg
X_4	Concentration in animal produce	Bq/kg
X_5	Dose to man	Sv/y
$P_{(i)15}$	Dose factor for inhalation	Sv/y per Bq/m^3
$P_{(e)15}$	Dose factor for cloud plume	Sv/y per Bq/m^3
P_{12}	Deposition on to soil	m^3/kg
P_{13}	Deposition on to vegetation	m^3/kg
P_{14}	Inhalation of plume by animals	m^3/kg
P_{23}	CF in vegetation, Bv	kg(s)/ kg(v)
P_{34}	Vegetation intake to animal produce	kg(f)/ kg(m)
$P_{(e)25}$	External dose from soil	Sv/y per Bq/kg
P_{35}	Dose from intake of vegetation	Sv/y per Bq/kg
P_{45}	Dose from intake of milk or meat	Sv/y per Bq/kg

Parenthesis: s= soil; v= vegetation; f = animal feed; and m= meat or milk

TABLE-6.2 (Refer Fig. 4.2)

TRANSFER FACTORS FOR AQUATIC ROUTE

Transfer Factor	Identification	Units
X_1	Surface water concentration	Bq/m^3
X_2	Sediment concentration	Bq/kg
X_3	Concentration in terrestrial plants	Bq/kg
X_4	Concentration in aquatic plants	Bq/kg
X_5	Concentration in terrestrial animal produce	Bq/kg
X_6	Concentration in aquatic plants	Bq/kg
X_7	Dose for man	Sv/y
$P_{(i)17}$	Dose factor for inhalation of salt or sediment laden air or ingestion of drinking water	Sv/y per Bq/m^3
$P_{(e)17}$	External dose factor for immersion in salt cloud or in sediment cloud or swimming	Sv/y per Bq/m^3
$P_{(e)27}$	External dose factor from mud banks	Sv/y per Bq/m^3
P_{12}	CF for sediment	m^3/kg
P_{13}	Irrigation transfer	m^3/kg
P_{14}	CF for aquatic plants	m^3/kg
P_{16}	CF for aquatic animals	m^3/kg
P_{35}	Vegetation to terrestrial animal uptake	kg(v)/kg(m)
P_{45}	Aquatic plant to terrestrial animal uptake	kg(f)/kg(m)
P_{37}	Dose from intake of terrestrial plants	Sv/y per Bq/kg
P_{57}	Dose from intake of terrestrial animal produce	Sv/y per Bq/kg
P_{67}	Dose from intake of aquatic animal	Sv/y per Bq/kg

Parenthesis: s= soil; v= vegetation; f = animal feed; and m= meat or milk

APPENDIX-I A [10,11,13]

BETA SUBMERSION DOSE FACTORS FOR SKIN $DCF_{ß}$ ($Sv.h^{-1}/Bq.m^{-3}$)

Nuclide	$DCF_{ß}$ Sv/h per Bq/m^3	Nuclide	$DCF_{ß}$ Sv/h per Bq/m^3
H-3	0	Pb-214	4.79E-11
C-14	6.74E-13	Bi-210	8.11E-11
A-41	9.72E-11	Bi-214	1.48E-10
Kr-85	4.68E-11	Po-210	0
Kr-85m	4.79E-11	Rn-222	0
Kr-88	7.53E-11		
Rb-88	5.25E-10	Ra-226	3.65E-17
Sr-90	3.31E-11	Th-230	0
Y-90	2.28E-10	Th-231	5.25E-12
Zr-95	1.26E-11	Th-234	9.02E-13
Nb-95	7.88E-13	Pa-234m	1.94E-10
Tc-99	6.16E-12	U-234	3.88E-15
Ru-106	0	U-235	5.71E-13
Rh-106	3.54E-10	U-236	2.17E-15
I-129	4.00E-13	U-238	1.48E-15
I-131	2.97E-11	Pu-238	0
I-133	8.68E-11	Pu-240	0
Xe-131m	1.26E-11	Pu-241	0
Xe-133	9.36E-12	Am-241	1.71E-15
Xe-133m	2.85E-11		
Xe-135	6.16E-11		
Cs-134	2.63E-11		
Cs-137	2.63E-11		
Ba-137m	1.48E-11		
Eu-154	4.22E-11		
Pb-210	0		

APPENDIX-I B [10,11,13]

GAMMA SUBMERSION DOSE FACTORS, DCFγ ($Sv.h^{-1}/Bq.m^{-3}$)

Nuclide	DCF$_ß$ Sv/h per Bq/m^3	Nuclide	DCF$_ß$ Sv/h per Bq/m^3
H-3	0	Pb-214	3.54E-11
C-14	0	Bi-210	0
A-41	2.07E-10	Bi-214	2.40E-10
Kr-85	3.20E-13	Po-210	1.26E-15
Kr-85m	2.28E-11	Rn-222	5.59E-14
Kr-88	3.31E-10		
		Ru-226	9.47E-13
Rb-88	1.04E-10	Th-230	5.31E-14
Sr-90	0	Th-231	1.60E-12
Y-90	0	Th-234	1.06E-12
Zr-95	1.11E-10	Pa-234m	1.71E-12
Nb-95	1.14E-10		
		U-234	2.05E-14
Tc-99	7.19E-17	U-235	2.17E-11
Ru-106	0	U-236	1.60E-14
Rh-106	3.08E-11	U-238	1.37E-14
I-129	1.14E-12	Pu-238	1.26E-14
I-131	5.48E-11		
		Pu-240	1.26E-14
I-133	8.90E-11	Pu-241	0
Xe-131m	1.26E-12	Am-241	2.63E-12
Xe-133	4.79E-12		
Xe-133m	4.22E-12		
Xe-135	3.54E-11		
Cs-134	2.28E-10		
Cs-137			
Ba-137m	8.90E-11		
Eu-154	1.94E-10		
Pb-210	1.83E-13		

ANNEXURE-I A[12]

COMMITTED EFFECTIVE DOSE PER UNIT INTAKE, DF_{inh} BY INHALATION (Sv/Bq) FOR MEMBERS OF THE PUBLIC

Nuclide	DF_{inh} (Sv/Bq)		Nuclide Type	DF_{inh} (Sv/Bq)		Nuclide Type	DF_{inh} (Sv/Bq)	
	Infant	Adult		Infant	Adult		Infant	Adult
H-3 F	2.6E-11	6.2E-12	Sr-90 F	1.3E-7	2.4E-8	Ra-228 F	1.7E-5	9.0E-7
M	3.4E-10	4.5E-11	M	1.5E-7	3.6E-8	M	1.5E-5	2.6E-6
S	1.2E-9	2.6E-10	S	4.2E-7	1.6E-7	S	4.9E-5	1.6E-5
C-14 F	6.1E-10	2.0E-10	Y-90 M	1.3E-8	1.4E-9	Th-280 F	2.1E-4	1.0E-4
M	8.3E-9	2.0E-9	S	1.3E-8	1.5E-9	M	7.7E-5	4.3E-5
S	1.9E-8	5.8E-9	Zr-95 F	1.2E-8	2.5E-9	S	4.0E-5	1.4E-5
F-18 F	2.6E-10	2.8E-11	M	2.0E-8	4.8E-9	Th-232 F	2.3E-4	1.1E-4
M	4.1E-10	5.6E-11	S	2.4E-8	5.9E-9	M	8.3E-5	4.5E-5
S	4.2E-10	5.9E-11	Nb-95 F	4.1E-9	5.7E-10	S	5.4E-5	2.5E-5
Na-22 F	9.7E-9	1.3E-9	M	6.8E-9	1.5E-9	Pa-231 M	2.2E-4	1.4E-4
Na-24 F	2.3E-9	2.7E-10	S	7.7E-9	1.8E-9	S	7.4E-5	3.4E-5
P-32 F	1.2E-8	7.7E-10	Ru-103 F	4.2E-9	4.8E-10	U-238 F	1.9E-6	5.0E-7
M	2.2E-8	3.4E-9	M	1.1E-8	2.4E-9	M	1.2E-5	2.9E-6
S-35 F	5.5E-10	5.1E-11	S	1.3E-8	3.0E-9	S	2.9E-5	8.0E-6
M	5.9E-9	1.4E-9	Ru-106 F	7.2E-8	7.9E-9	Np-237 F	9.8E-5	5.0E-5
S	7.7E-9	1.9E-9	M	1.4E-7	2.8E-8	M	4.4E-5	2.3E-5
Cl-36 F	3.9E-9	3.3E-10	S	2.6E-7	6.6E-8	S	3.7E-5	1.2E-5
M	3.1E-8	7.3E-9	I-129 F	7.2E-8	3.6E-8	Pu-239 F	2.1E-4	1.2E-4
Cr-51 F	1.7E-10	2.0E-11	M	3.6E-8	1.5E-8	M	8.0E-5	5.0E-5
M	2.6E-10	3.2E-11	S	2.9E-8	9.8E-9	S	4.3E-5	1.6E-5
S	2.6E-10	3.7E-11	I-131 F	7.2E-8	7.4E-9	Am-241 F	1.8E-4	9.6E-5
Mn-54 F	5.2E-9	8.5E-10	M	2.2E-8	2.4E-9	M	7.3E-5	4.2E-5
M	7.5E-9	1.5E-9	S	8.8E-9	1.6E-9	S	4.6E-5	1.6E-5
Fe-55 F	4.2E-9	7.7E-10	Cs-134 F	1.1E-8	6.6E-9	Cm-244 F	1.5E-4	5.7E-5
M	1.9E-9	3.8E-10	M	3.2E-8	9.1E-9	M	6.2E-5	2.7E-5
S	1.0E-9	1.8E-10	S	7.0E-8	2.0E-8	S	4.4E-5	1.3E-5
Co-60 F	3.0E-8	5.2E-9	Cs-137 F	8.8E-9	4.6E-9			
M	4.2E-8	1.0E-8	M	3.6E-8	9.7E-9			
S	9.2E-8	3.1E-8	S	1.1E-7	3.9E-8			
Ni-63 F	2.3E-9	4.4E-10	Ce-144 F	3.6E-7	4.0E-8			
M	2.5E-9	4.8E-10	M	1.9E-7	3.6E-8			
S	4.8E-9	1.3E-9	S	2.1E-7	5.3E-8			
Zn-65 F	1.5E-8	2.2E-9	Po-210 F	7.4E-6	6.1E-7			

Notes:
Infant ≤ 1 y
Adults > 17 years
F-Fast, M-Moderate, S-Slow: They denote compounds absorbed from the lungs at rate characterised as Fast, Moderate and Slow.

ANNEXURE-I B [12]

COMMITTED EFFECTIVE DOSE PER UNIT INTAKE, DF_{ing} BY INGESTION (Sv/Bq) FOR MEMBERS OF THE PUBLIC

Nuclide	DF_{inh} (Sv/Bq)		Nuclide Type	DF_{inh} (Sv/Bq)		Nuclide Type	DF_{inh} (Sv/Bq)	
	Infant	Adult		Infant	Adult		Infant	Adult
H-3	6.4E-11	1.8E-11	Ag-110m	2.4E-8	2.8E-9	Pu-239	4.2E-6	2.5E-7
OBT	1.2E-10	4.2E-11	Sn-125	3.5E-8	3.1E-9	Pu-240	4.2E-6	2.5E-7
C-14	1.4E-9	5.8E-10	Sn-126	5.0E-8	4.7E-9	Pu-241	5.6E-8	4.8E-9
F-18	5.2E-10	4.9E-11	Sb-124	2.5E-8	2.5E-9	Pu-242	4.0E-6	2.4E-7
Na-22	2.1E-8	3.2E-9	Sb-125	1.1E-8	1.1E-9	Am-241	3.7E-6	2.0E-7
Na-24	3.5E-9	4.3E-10	I-129	1.8E-7	1.1E-7	Am-243	3.6E-6	2.0E-7
P-32	3.1E-8	2.4E-9	I-131	1.8E-7	2.2E-8	Am-244	4.9E-9	4.6E-10
S-35	1.3E-9	1.3E-10	I-133	4.9E-8	4.3E-9	Cm-242	5.9E-7	1.2E-8
S-35	7.7E-9	7.7E-10	I-135	1.0E-8	9.3E-10	Cm-243	3.2E-6	1.5E-7
Cl-36	9.8E-9	9.3E-10	Cs-134	2.6E-8	1.9E-8	Cm-244	2.9E-6	1.2E-7
Cr-51	3.5E-10	3.8E-11	Cs-137	2.1E-8	1.3E-8	Cm-245	3.7E-6	2.1E-7
Mn-54	5.4E-9	7.1E-10	Cs-138	1.1E-9	9.2E-11			
Fe-55	7.6E-9	3.3E-10	Ba-140	3.2E-8	2.6E-9			
Fe-59	3.9E-8	1.8E-9	La-140	2.0E-8	2.0E-9			
Co-58	7.3E-9	7.4E-10	Ce-141	8.1E-9	7.1E-10			
Co-60	5.4E-8	3.4E-9	Ce-144	6.6E-8	5.2E-9			
Ni-63	1.6E-9	1.5E-10	Pr-144	6.4E-10	5.0E-11			
Zn-65	3.6E-8	3.8E-9	Po-210	2.6E-5	1.2E-6			
Se-79	4.1E-8	2.9E-9	Ra-224	2.7E-6	6.5E-8			
Br-82	3.7E-9	5.4E-10	Ra-226	4.7E-6	2.8E-7			
Sr-89	3.6E-8	2.6E-9	Ra-228	3.0E-5	6.9E-7			
Sr-90	2.3E-7	2.8E-8	Ac-224	1.0E-8	7.0E-10			
Sr-91	5.2E-9	6.5E-10	Ac-228	7.4E-9	4.3E-10			
Y-90	3.1E-8	2.7E-9	Th-230	4.1E-6	2.1E-7			
Y-91	2.8E-8	2.4E-9	Th-232	4.6E-6	2.3E-7			
Zr-93	1.2E-9	1.1E-9	Th-234	4.0E-8	3.4E-9			
Zr-95	8.5E-9	9.5E-10	Pa-231	1.3E-5	7.1E-7			
Nb-95	4.6E-9	5.8E-10	Pa-234	5.0E-9	5.1E-10			
Mo-99	5.5E-9	6.0E-10	U-234	3.7E-7	4.9E-8			
Tc-99	1.0E-8	6.4E-10	U-235	3.5E-7	4.7E-8			
Tc-99m	2.0E-10	2.2E-11	U-238	3.4E-7	4.5E-8			
Ru-103	7.1E-9	7.3E-10	Np-237	2.0E-6	1.1E-7			
Ru-106	8.4E-8	7.0E-9	Np-239	8.9E-9	8.0E-10			

Notes:

a Infant ≤ 1 Y

b OBT-Organically Bound Tritium.

ANNEXURE-II A [13]

BETA DOSE FACTORS TO SKIN FOR GROUND CONTAMINATION ($Sv.h^{-1}/Bq\ m^{-2}$)

Nuclide	DCF$_{ß}$ $Sv.h^{-1}/Bq\ m^{-2}$	Nuclide	DCF $Sv.h^{-1}/Bq\ m^{-2}$
H-3	0	Pb-214	2.17E-12
C-14	0	Bi-210	1.26E-11
Kr-85	2.97E-12	Bi-214	2.39E-11
Kr-85m	4.11E-12	Po-210	0
Kr-88	8.79E-12	Rn-222	0
Rb-88	5.82E-11	Ra-226	0
Sr-90	5.02E-13	Th-230	0
Y-90	3.88E-11	Th-231	0
Zr-95	7.88E-14	Th-234	0
Nb-95	5.37E-14	Po-234m	3.42E-11
Tc-99	0	U-234	0
Ru-106	0	U-235	0
Rh-106	5.02E-11	U-236	0
I-129	0	U-238	0
I-131	6.62E-13	Pu-238	0
I-133	1.37E-11	Pu-240	0
Xe-131m	0	Pu-241	0
Xe-133	0	Am-241	0
Xe-133m	0		
Xe-135	6.39E-12		
Cs-134	1.14E-12		
Cs-137	8.45E-13		
Ba-137m	3.31E-12		
Eu-154	4.57E-12		
Pb-210	0		

ANNEXURE-II B [13]

GAMMA DOSE FACTORS FOR GROUND CONTAMINATION ($Sv.h^{-1}/Bq\ m^{-2}$)

Nuclide	DCF_{γ} $Sv.h^{-1}/Bq\ m^{-2}$	Nuclide	DCF_{γ} $Sv.h^{-1}/Bq\ m^{-2}$
H-3	0	Pb-214	7.53E-13
C-14	0	Bi-210	0
Kr-85	6.62E-15	Bi-214	4.11E-12
Kr-85m	5.02E-13	Po-210	2.51E-12
Kr-88	5.14E-12	Rn-222	1.14E-15
Rb-88	1.71E-12	Ra-226	2.05E-14
Sr-90	0	Th-230	2.40E-15
Y-90	0	Th-231	5.25E-14
Zr-95	2.17E-12	Th-234	2.74E-14
Nb-95	2.28E-12	Pa-234m	3.31E-14
Tc-99	1.71E-18	U-234	2.17E-15
Ru-106	0	U-235	4.68E-13
Rh-106	6.05E-13	U-236	1.94E-15
I-129	6.28E-14	U-238	1.71E-15
I-131	1.14E-12	Pu-238	2.40E-15
I-133	1.83E-12	Pu-240	2.28E-15
Xe-131m	5.14E-14	Pu-241	0
Xe-133	1.37E-13	Am-241	8.22E-14
Xe-133m	1.14E-13		
Xe-135	7.53E-13		
Cs-134	4.57E-12		
Cs-137/Ba-137m	1.83E-12		
Eu-154	3.54E-12		
Pb-210	7.88E-15		

ANNEXURE-II C [11]

EFFECTIVE DOSE RATE CONVERSION FACTORS FOR EXTERNAL EXPOSURE ($Sv.h^{-1}/Bq.m^{-3}$) DUE TO PHOTONS AND ELECTRONS FOR WATER IMMERSION

Nuclide	DCF_{swim} ($Sv.h^{-1}/Bq.m^{-3}$)	Nuclide	DCF_{swim} ($Sv.h^{-1}/Bq.m^{-3}$)
H-3	0	Tc-99	6.53E-17
C-14	7.04E-16	Ru-103	1.64E-13
N-13	3.48E-13	Rh-106	7.50E-14
N-16	1.99E-12	Ag-110m	9.59E-13
F-18	3.37E-13	Sb-124	6.72E-13
Na-22	6.91E-13	Sb-125	1.45E-13
Na-24	1.61E-12	I-129	3.37E-15
P-32	1.70E-15	I-131	1.31E-13
S-35	9.03E-18	I-132	8.03E-13
Cl-36	4.75E-16	I-135	5.66E-13
Ar-37	5.72E-19	Cs-134	5.41E-13
Ar-41	4.15E-13	Cs-137	2.39E-14
Cr-51	1.08E-14	Cs-138	8.65E-13
Mn-54	2.95E-13	Ba-140	6.47E-14
Fe-55	9.89E-18	La-140	8.34E-13
Fe-59	4.19E-13	Ce-141	2.74E-14
Co-58	3.41E-13	Ce-144	6.58E-15
Co-60	8.80E-13	Pr-144	1.52E-14
Zn-65	2.05E-13	Ra-226	2.39E-15
Kr-83m	4.04E-17		
Kr-85m	5.74E-14	Th-232	7.18 E-17
Kr-85	1.26E-15	Pa-231	1.05 E-14
Kr-87	3.05E-13	U-235	5.35 E-14
Kr-88	7.65E-13	Np-237	8.37 E-15
Kr-89	6.91E-13	Np-239	5.92 E-14
Kr-90	4.60E-13	Pu-238	3.69 E-17
Rb-88	2.48E-13	Pu-239	3.12 E-17
Sr-89	1.47E-15	Am-241	7.29 E-15
Sr-90	3.48E-16	Am-243	1.91 E-14
Y-90	2.41E-15	Cm-243	4.47 E-14
Sr-91	2.44E-13	Cm-244	3.53 E-17
Y-91	2.75E-15	Ba-137m	2.05 E-13
Zr-95	2.57E-13		
Nb-95	2.68E-13		
Mo-99	5.49E-14		
Tc-99m	4.66E-14		

ANNEXURE-III [18 TO 21]

DEFAULT VALUES OF B_P FOR VARIOUS ELEMENTS IN AQUATIC FOODS[a] ($L.kg^{-1}$)

	Fresh Water		Marine			
Element	**Fish**	**Invertebrates[b]**	**Fish**	**Crustacea**	**Molluscs**	**Seaweed**
Na	2 E+01	2 E+01	1	1	1	1
P	1 E+05	1 E+05	1 E+04	1 E+04	1 E+04	1 E+04
S	8 E+02	1 E+02	1	1	1	1
Cr	2 E+02	2 E+03	4 E+02	5 E+02	5 E+02	3 E+04
Mn	4 E+02	1 E+05	5 E+02	1 E+04	1 E+04	1 E+04
Fe	1 E+02	3 E+03	1 E+03	1 E+03	1 E+03	1 E+04
Co	3 E+02	1 E+04	1 E+02	1 E+03	1 E+03	1 E+03
Ni	1 E+02	1 E+02	5 E+02	1 E+02	1 E+02	5 E+02
Zn	1 E+03	1 E+04	2 E+03	4 E+03	1 E+05	1 E+03
Sr	6 E+01	3 E+02	1	1 E+01	1 E+01	1 E+01
Y	3 E+01	1 E+03	1 E+01	1 E+03	1 E+03	1 E+03
Zr	3 E+02	1 E+02	1 E+02[c]	1 E+02	1 E+03	5 E+02
Nb	3 E+02	1 E+02	1 E+02[c]	1 E+02	1 E+03	5 E+02
Tc	2 E+01	5	1 E+01	1 E+03	1 E+02	1 E+04
Ru	1 E+01	3 E+02	1	6 E+02	2 E+03	2 E+03
Ag	2	7 E+02	1 E+03	5 E+03	1 E+05	1 E+03
Sb	1	1 E+01	1 E+03	3 E+02	1 E+02	1 E+02
Te	4 E+02	6 E+03	1 E+03	1 E+03	1 E+04	1 E+04
I	4 E+01	4 E+02	1 E+01	1 E+02	1 E+02	1
Cs	2 E+03	1 E+03	5 E+01	3 E+01	1 E+01	1 E+03
Ba	4	2 E+02	1 E+01	1 E+02	1 E+02	5 E+01
La	3 E+01	1 E+03	3 E+01	1 E+03	1 E+03	5 E+02
Ce	3 E+01	1 E+03	1 E+01	1 E+01	1 E+01	1 E+03
Pm	3 E+01	1 E+03	1 E+02	1 E+03	1 E+03	1 E+01
Pb	3 E+02	1 E+02	3 E+02	1 E+02	1 E+02	1 E+03
Bi	2 E+01	1 E+05	2 E+01	1 E+03	1 E+03	1 E+03
Po	5 E+01	2 E+04	2 E+03	2 E+04	2 E+04	1 E+03
Ra	5 E+01	3 E+02	1 E+02	1 E+02	1 E+02	1 E+03
Th	3 E+01	5 E+02	1 E+04	1 E+03	1 E+03	1 E+02
Pa	1 E+01	1 E+02	1 E+03	1 E+01	1 E+01	1 E+03
U	1 E+01	1 E+02	1	1 E+01	1 E+01	1 E+02
Np	1 E+01	4 E+02	1 E+01	1 E+02	1 E+03	1 E+01
Pu	4	1 E+02	1	1 E+02	1 E+03	1 E+03
Am	3 E+01	1 E+03	1 E+01	2 E+02	2 E+03	2 E+03
Cm	3 E+01	1 E+03	1 E+01	2 E+02	2 E+03	2 E+03
						E+03

Notes:

[a] Values derived from the reviews of Thompson et al [18], Vanderploeq etal [19], Hoffman and Baes [20] and IAEA [21].

[b] This pathway is expected to occur only in a few site-specific cases and is not considered to be of generic importance.

[c] Values selected exercising judgement and considering private communications by Ophel and Tschurlovits.

ANNEXURE –IV [18]

CONCENTRATION FACTORS K_d FOR SEDIMENTS

Element	K_d (ml/g) Marine	Fresh Water	Element	K_d (ml/g) Marine	Fresh Water
H	0	0	Ag	10000	
C	(100)[a]	2000	Sn	10000	200
Na	(100)		Sb	10000	
P	(100)		Te	10000	300
S	(100)		I	100	30
Cl	(100)		Cs	500	200
Ca	(500)		Ce	10000	30000
Cr	(10000)	20000	Pm	10000	30000
Mn	10000	10000	Sm	(10000)	
Fe	10000	10000	Eu	10000	
Co	10000	30000	Au	10000	
Ni	10000		Pb	10000	
Zn	10000	1000	Po	10000	
Se	10000		Ra	500	
Br	(100)		Ac	10000	
Sr	500	2000	Th	5000000	
Y	10000	4000	Pa	5000	
Zr	10000	60000	U	500	
Nb	10000	100	Np	(50000)	
Tc	10000	200	Pu	50000	
Ru	10000	40000	Am	50000	30000
Pd	(10000)		Cm	(50000)	30000
			Cf	(50000)	30000

Notes:
[a] Values in parentheses indicate that these have been inferred from analogy, not experimental data.

ANNEXURE-VA [13]

DEFAULT VALUES OF B_{v1}* CONCENTRATION FACTOR IN FORAGE PLANTS[a]

Element	B_{v1}*	Element	B_{v1}*	Element	B_{v1}*
Na	2×10^{-1}(b)	Tc	2×10^{1}(f,g)	Pb	9×10^{-2}(c,j)
P	3×10^{0}(b)	Ru	9×10^{-2}(c)	Bi	5×10^{-1}(b,k)
S	2×10^{0}(b)	Ag	1×10^{0}(b)	Po	4×10^{-3}(c)
Cr	3×10^{-3}(b)	Sb	4×10^{-2}(b)	Ra	2×10^{-1}(c,j)
Mn	3×10^{-1}(c,d)	Te	2×10^{0}(c,h)	Ac	4×10^{-3}(l)
Fe	3×10^{-3}(b)	I	9×10^{-1}(c)	Th	1×10^{-3}(m,n)
Co	4×10^{-1}(c)	Cs	1×10^{-1}(c,d)	Pa	1×10^{-1}(o)
Ni	4×10^{-2}(b)	Ba	2×10^{-2}(b)	U	1×10^{-2}(c,n)
Zn	5×10^{-1}(b)	La	4×10^{-2}(i)	Np	1×10^{-1}(n)
Sr	2×10^{0}(c,d)	Ce	4×10^{-2}(c)	Pu	1×10^{-3}(m,n)
Y	1×10^{-2}(c,e)	Pm	4×10^{-2}(i)	Am	4×10^{-3}(c,n)
Zr	2×10^{-2}(c)	Sm	4×10^{-2}(i)	Cm	4×10^{-3}(l,n)
Nb	4×10^{-2}(b)	Eu	4×10^{-2}(i)		

* $Bq.g^{-1}$ dry vegetation per $Bq.g^{-1}$ dry soil..

Notes:

a The B_{v1} values in this table have been selected so that the probability of exceeding a dose limit is very low when a resulting prediction is a small fraction (< 5%) of the dose limit. If a resulting prediction is a substantial fraction of a relevant dose limit, site specific evaluations are recommended.

b Based on the ratio of the average concentrations in unassociated forage plants and soil.

c Based on the unweighted mean of the mean values observed for a crop or crop type in a single study.

d Site-specific investigations are recommended for sites where sandy soils are dominant, particularly if a resulting dose prediction is substantially greater than a small fraction of a relevant dose limit.

e Based in part on data on foliage of plants normally not used as forage.

f Based on surveillance measurements of ^{99}Tc and field studies of $^{95}Tc^{m}O_4$.

g The removal of activity from the agricultural system by harvesting must be considered when B_v is large and the accumulation time of activity in soil is long.

h In the absence of relevant data, the value selected is based on the assumption that Te is chemically similar to Se.

i Based on the B_{v1} for Ce. In the absence of relevant data the lanthanides are assumed to behave similarly.

j Based on the review of environmental transport parameters for ^{210}Pb and ^{226}Ra.

k Value associated with a large uncertainty due to the paucity of data.

l Based on the B_{v1} for Am. In the absence of relevant data the actinides whose dominant oxidation state is +3 are assumed to behave similarly.

m Adapted from maximum observed value.

n Takes into account the expected behaviour of the actinides with respect to plant uptake from soil.

o Based on the B_{v1} for Np. In the absence of relevant data, Pa is assumed to be chemically similar to Np.

ANNEXURE-VB [13]

DEFAULT VALUES OF B_{v2}* CONCENTRATION FACTOR IN FOOD CROPS[a]

Element	B_{v2}*	Element	B_{v2}*	Element	B_{v2}*
Na	5×10^{-2}(b)	Tc	5×10^{0}(c,g)	Pb	1×10^{-2}(i)
P	1×10^{0}(b)	R	8×10^{-3}(d)	Bi	1×10^{-1}(c, j)
S	6×10^{-1}(b)	Ag	2×10^{-1}(b)	Po	2×10^{-4}(d)
Cr	8×10^{-4}(c)	Sb	1×10^{-2}(c)	Ra	4×10^{-2}(e,k)
Mn	5×10^{-1}(d)	Te	6×10^{-1}(d,h)	Ac	1×10^{-3}(l)
Fe	7×10^{-4}(b)	I	2×10^{-2}(d)	Th	5×10^{-4}(d,m)
Co	3×10^{-2}(d)	Cs	3×10^{-2}(e)	Pa	4×10^{-2}(n)
Ni	2×10^{-2}(b)	Ba	5×10^{-3}(c)	U	2×10^{-3}(d,m)
Zn	4×10^{-1}(b)	La	2×10^{-3}(f)	Np	4×10^{-2}(m)
Sr	3×10^{-1}(e)	Ce	2×10^{-3}(d)	Pu	5×10^{-4}(d,m)
Y	2×10^{-3}(f)	Pm	2×10^{-3}(f)	Am	1×10^{-3}(d,m)
Zr	5×10^{-3}(c)	Sm	2×10^{-3}(f)	Cm	1×10^{-3}(l,m)
Nb	1×10^{-2}(c)	Eu	2×10^{-3}(f)		

* $Bq.g^{-1}$ dry vegetation per $Bq.g^{-1}$ dry soil..

Notes:

a The B_{v2} values in this table have been selected to yield a very low probability of exceeding a dose limit when a resulting prediction is a small fraction (5%) of the dose limit. If a resulting prediction is a substantial fraction of a relevant dose limit, site specific evaluations are recommended.

b Based on the ratio of the average concentrations in food derived from terrestrial plants and soil.

c Based on the B_{v1} for forage plants from Annexure-VA.

d Based on the unweighted mean of the mean values observed for a crop or crop type in a single study.

e Assumed at one-twentieth the maximum value observed.

f Based on the B_{v2} of Ce. Because of the absence or sparsity of relevant data, Y and the lanthanides are assumed to behave similarly.

g The removal of activity from the agricultural system by harvesting must be considered when B_v is large and the accumulation time of activity in soil is long.

h In the absence of relevant data, the value is based on the assumption that Te is chemically similar to Se.

i The value is twice the mean of the mean values estimated for ten different food crops.

j Value associated with a large uncertainty due to the paucity of data.

k Takes into account observed ratios between Ra and Ca and those between Sr and Ca.

l Based on the B_{v2} for Am. In the absence of relevant data the actinides whose dominant oxidation state is +3 are assumed to behave similarly.

m Takes into account the expected behaviour of the actinides with respect to plant uptake from soil.

n Based on the B_{v2} for Np. In the absence of relevant data, Pa is assumed to be chemically similar to Np.

ANNEXURE-VIA [13]

DEFAULT VALUES OF F_m THE TRANSFER COEFFICIENT TO MILK[a]

Element	F_m ($d.l^{-1}$)	Element	F_m ($d.l^{-1}$)	Element	F_m ($d.l^{-1}$)
Na	4×10^{-2}	Te	1×10^{-2} (d)	Pb	3×10^{-4}
P	2×10^{-2}	Ru	6×10^{-7}	Bi	5×10^{-4}
S	2×10^{-2}	Ag	3×10^{-2}	Po	1×10^{-4}
Cr	2×10^{-3}	Sb	2×10^{-5}	Ra	6×10^{-4}
Mn	3×10^{-4}	Te	2×10^{-4}	Ac	2×10^{-5} (b)
Fe	3×10^{-4}	I	1×10^{-2}	Th	5×10^{-6}
Co	2×10^{-3}	Cs	8×10^{-3}	Pa	5×10^{-6} (e)
Ni	1×10^{-2}	Ba	4×10^{-4}	U	6×10^{-4} (f)
Zn	1×10^{-2}	La	2×10^{-5}	Np	5×10^{-6} (g)
Sr	1×10^{-3}	Ce	2×10^{-5}	Pu	1×10^{-7} (h)
Y	2×10^{-5} (b)	Pm	2×10^{-5}	Am	4×10^{-7}
Zr	3×10^{-5}	Sm	2×10^{-5}	Cm	2×10^{-5} (b)
Nb	2×10^{-2} (c)	Eu	2×10^{-5}		

Notes:

a The F_m values in this table refer to approximate quantities to be expected at equilibrium. They have been selected to produce a low probability of exceeding a dose limit with model calculations using these values predict doses approaching 5% of the dose limit.

b Assumes a chemical behaviour similar to $CeCl_3$.

c Assumed maximum value as default value.

d In the absence of relevant data on Technetium, the selected value is based on the assumption that the chemical behaviour of Technetium is similar to that of Iodine.

e From a comparison of the ^{233}Pa and ^{91}Y recovered following intravenous injection in the cow.

f The value 6×10^{-4} $d.l^{-1}$ is preferred in this table because of the relative paucity of data available for uranium.

g In the absence of available data on F_m assumed to be similar to Pa based on similar behaviour following intravenous administration of Np in sheep and Pa in cows.

h Value adopted for plutonium citrate. Plutonium dioxide may be associated with an F_m as low as $4 \times 10^{-9} d.l^{-1}$.

ANNEXURE – VIB [13]

DEFAULT VALUES OF F_f TRANSFER COEFFICIENT TO BEEF[a]

Element	F_f ($d.kg^{-1}$)	Element	F_f ($d.kg^{-1}$)	Element	F_f ($d.kg^{-1}$)
Na	2×10^{-1} (b)	Te	1×10^{-2} (f)	Pb	8×10^{-4} (j)
P	8×10^{-2} (b)	Ru	2×10^{-3} (g)	Bi	2×10^{-2} (e)
S	1×10^{-1} (h)	Ag	5×10^{-3} (b)	Po	3×10^{-3} (e)
Cr	3×10^{-2} (h)	Sb	1×10^{-3} (g)	Ra	5×10^{-4} (j)
Mn	1×10^{-3} (h)	Te	2×10^{-2} (e)	Ac	2×10^{-5} (k)
Fe	3×10^{-2} (b)	I	1×10^{-2} (g)	Th	1×10^{-4} (l)
Co	3×10^{-2} (b)	Cs	2×10^{-2} (g,h)	Pa	1×10^{-3} (m)
Ni	5×10^{-3} (h)	Ba	2×10^{-4} (h)	U	3×10^{-2} (e)
Zn	2×10^{-1} (b)	La	2×10^{-3} (d)	Np	1×10^{-3} (m)
Sr	6×10^{-4} (c)	Ce	2×10^{-3} (i)	Pu	1×10^{-5} (l,n)
Y	2×10^{-3} (d)	Pm	2×10^{-3} (d)	Am	2×10^{-5} (i,n)
Zr	2×10^{-2} (e)	Sm	2×10^{-3} (d)	Cm	2×10^{-5} (k)
Nb	3×10^{-1} (e)	Eu	2×10^{-3} (d)		

Notes:

a The F_f values were selected to yield a very low probability of exceeding a dose limit when a resulting prediction is a small fraction (5%) of the dose limit. Site-specific evaluations are recommended if a resulting dose estimate is a substantial fraction of a relevant dose limit.

b Estimated from concentrations in unassociated beef and forage. To reduce the likelihood that a dose approaches a dose limit when the resulting estimate is a small fraction of the limit, the median value was adjusted upward by the factor exp(*o*) where *o* is the standard deviation of the log-transformed F_f distribution.

c Estimated from concentration in unassociated beef and forage and from radioisotope tracer data.

d Based on the F_f for Ce. In the absence of data on F_f the lanthanides and Y are assumed to behave similarly.

e Estimated from concentrations in unassociated meat and forage. Owing to the paucity of relevant data, the estimate is associated with a relatively large uncertainty.

f In the absence of relevant data, based in part on the assumption that Technetium as pertechnetate ion is chemically similar to Iodide ion.

g Based on radioisotope tracer studies.

h Mean of values estimated from radioisotope tracer studies.

i Maximum value estimated from radioisotope tracer studies.

j Value derived from concentrations in animal muscle and asssociated diet.

k Based on the F_f from Am. In the absence of relevant data, the actinides whose dominant oxidation state is +3 are assumed to behave similarly.

l Estimated from the concentration in unassociated beef and forage. The concentration in cattle muscle are estimated from that in cattle bone and the Th contents in bone and muscle of rats.

m The F_f for Pa and Np are based on the estimates for Pu and Am. The retention functions were assumed to be the same for the internally deposited nuclides, and F_f was assumed to be proportional to the gastro-intenstinal absorption factor.

n Based in part on behaviour of plutonium nitrate in chickens. The F_f for plutonium dioxide is expected to be less.

ANNEXURE-VII A [13]

DEFAULT VALUES OF EFFECTIVE SURFACE SOIL DENSITY 'P' AS A FUNCTION OF DEPTH OF THE ROOT ZONE AND SOIL CHARACTERISTICS

Effective surface soil density, P (kg. m^{-2} dry-weight soil)

Rooting zone depth	**Peat soils**	**Other soils**
0-2 cm	10	30
0-15 cm	75	200
0-30 cm	150	400

Notes:

Based on soil densities of 0.5 g.cm^{-3} for peat soils and 1.3 g.cm^{-3} for other soil types.

ANNEXURE – VII B [13]

EXAMPLE VALUES OF CROP EXPOSURE PERIOD t_e AND DELAY PERIOD FOR THE TIME BETWEEN HARVEST OF CROP AND CONSUMPTION t_h

Parameter	$t_{e(1)}$	$t_{e(2)}$	$t_{h(1)}$	$t_{h(2)}$	$t_{h(3)}$
Value (days)	30	60	0	90	14

Notes:

$t_{e(1)}$ applies to forage grasses;

$t_{e(2)}$ applies to food crops;

$t_{h(1)}$ applies to forage;

$t_{h(2)}$ applies to stored feed for animals;

$t_{h(3)}$ applies to food crops.

ANNEXURE-VIII [13]

EXAMPLE VALUES FOR ABOVE-GROUND AGRICULTURAL PRODUCTIVITY, DEFAULT VALUES FOR INTERCEPTION FACTORS FOR FORAGE PLANTS AND EDIBLE PORTIONS OF FOOD CROPS, AND DEFAULT VALUES FOR ENVIRONMENTAL REMOVAL RATES FROM CROP SOURCES

	Parameter	Example values	Default values
R_1 / Y_1	Ratio of interception factor to yield Y_1 of forage vegetation in dry weight [a]		$2.0\ m^2\ kg^{-1}$
Y_2	Yield of leafy vegetables in fresh weight [b]	$2.0\ kg\ m^{-2}$	
Y_3	Yield of other food crops consumed by humans in fresh weight [c]	$0.60\ kg\ m^{-2}$	
R_2	Other nuclides and Cesium in food crops other than grain		0.50
R_3	Cesium in grains [d,e]		0.20
λ_w	Particulates [f]		$4.6 \times 10^{-2} d^{-1}$
λ_w	Iodine on pasture vegetation		$6.9 \times 10^{-2} d^{-1}$
Q_f	Feed intake		$16\ Kg.\ d^{-1}$

Notes:

a R_1 is defined as interception factor for forage grasses and is normalised to the dry weight standing crop biomass of forage grasses because of statistical correlations of R_1 and Y_1.

b Based on average yield of leafy vegetables in the USA.

c Based on average yield of non-leafy above-ground vegetables in the USA.

d R_2 is defined as interception fraction for edible portions of food crops. This parameter includes both the fraction of depositing material that is intercepted by the surfaces of vegetation and the subsequent translocation to edible parts.

e Selected to lessen the likelihood of underestimating the contamination of grains of cesium.

f Based on the weathering rate of particulates on pasture vegetation.

ANNEXURE-IX

TYPICAL DOSE COMPUTATION FROM ATMOSPHERIC ROUTE, FRESH WATER INGESTION ROUTE, SEA WATER INGESTION ROUTE, INHALATION PATHWAYS AND EXTERNAL PATHWAYS

TABLE IX.1

TYPICAL DOSE COMPUTATION FROM ATMOSPHERIC ROUTE

Nuclides	Dose (Sv/y) for unit air concentration (Bq/m^3)					
	Inhalation	Ingestion			External	
		Crops	Meat	Milk	Plume	Ground
H-3	1.24E-7	1.22E-8	1.22E-10	6.66E-8	NA	NA
C-14	4.64E-8	2.52E-4	3.94E-6	5.38E-6	5.89E-9	NA
A-41	NA	NA	NA	NA	3.40E-6	NA
Kr-85	NA	NA	NA	NA	4.10E-7	NA
Sr-90	2.56E-3	3.26E-3	1.03E-5	1.20E-4	2.89E-7	1.20E-3
I-131	6.49E-5	1.15E-3	7.31E-6	2.02E-4	7.39E-7	4.76E-5
Xe-133	NA	NA	NA	NA	1.23E-7	NA
Cs-137	6.30E-5	1.38E-3	1.20E-4	3.38E-4	1.00E-9	6.60E-3

crop intake= 240 kg/y; milk intake= 70 kg/y;
meat intake=10 kg/y; surface soil density (P)= 240 kg/m^2
animal intake rate = 16 kg/d; occupancy =0.3; R/Y= 2 m^2/kg (forage)
NA means not applicable

Note: These are based on worked out examples and not taken from any reference.

TABLE IX. 2

TYPICAL DOSE COMPUTATION FROM FRESH WATER INGESTION ROUTE

Nuclides	Dose (Sv/y)for unit water concentration (Bq/ml) through ingestion pathways					
	Water	Fish	Mollusc	Crops	Milk	Meat
H-3	1.86E-5	NA	NA	2.44E-7	1.33E-8	2.44E-9
Co-60	7.97E-3	5.96E-2	1.98E+0	2.26E-5	2.26E-6	4.70E-6
Sr-90	4.21E-2	1.15E-2	1.15E-2	1.21E-3	2.99E-5	2.56E-6
Cs-134	2.16E-2	4.59E-2	4.59E-2	6.08E-5	5.75E-5	2.20E-6
Cs-137	1.47E-2	3.13E-2	3.13E-2	4.24E-5	4.20E-6	1.50E-6

water intake rate = 1.09 m^3/y; fish intake rate = 27.3 Kg/y; mollusc intake rate= 27.3 kg/y; irrigation rate = 4.3 L/m^2/d

Note : These are based on worked out examples and not taken from any reference.

ANNEXURE-IX (Contd.)

TABLE IX.3

TYPICAL DOSE COMPUTATION FROM SEA WATER INGESTION ROUTE

Nuclides	Dose (Sv/y) for unit water concentration (Bq/ml) through ingestion pathways		
	Fish	Mollusc	Salt
H-3	NA	NA	NA
Co-60	1.98E-7	1.98E-1	1.19E-1
Sr-90	2.10E-3	2.10E-3	6.32E-3
Cs-134	1.94E-3	5.94E-3	3.25E-3
Cs-137	4.05E-3	4.05E-3	2.21E-3

Salt intake= 5.475 kg/y

Note : These are based on worked out examples and not taken from any reference.

TABLE IX.4

TYPICAL DOSE COMPUTATION FROM INHALATION PATHWAYS

Nuclides	Dose (Sv/y) for unit air concentration (Bq/ml) through inhalation pathways		
	Sediment Laden Air	Salt Laden Air	Remarks
H-3	2.48E-6	NA	Freshwater
	2.48E-6	NA	Seawater
Co-60	1.29E-3	NA	Freshwater
	4.31E-3	1.29E-7	Seawater
Sr-90	5.12E-4	NA	Freshwater
	1.28E-4	7.68E-7	Seawater
Cs-134	2.73E-4	NA	Freshwater
	4.56E-6	2.73E-8	Seawater
Cs-137	1.89E-4	NA	Freshwater
	3.15E-6	1.89E-8	Seawater

Inhalation rate = 7.3 E3 m^3/y; sediment in air = 1E-4 g/m^3; salt in air = 1.0E-5 g/m^3

Note: These are based on worked out examples and not taken from any reference.

ANNEXURE-IX (Contd.)

TABLE IX.5

TYPICAL DOSE COMPUTATION FROM EXTERNAL PATHWAYS

Nuclides	Dose (Sv/y) for unit concentration (Bq/ml) through external pathways			
	Plume	Swimming	Ground	Remarks
H-3	NA	5.08E-7	NA	Freshwater
	NA	5.08E-7	NA	Seawater
Co-60	1.87E-5	4.32E-4	1.08E+1	Freshwater
	6.24E-6	4.41E-4	3.60E+0	Seawater
Sr-90	5.79E-8	9.50E-5	2.08E-1	Freshwater
	1.44E-5	9.50E-5	5.21E-2	Seawater
Cs-134	6.68E-8	2.75E-4	6.52	Freshwater
	1.11E-7	2.78E-4	1.08E-1	Seawater
Cs-137	3.02E-6	1.13E-4	2.42E+0	Freshwater
	5.04E-8	1.13E-4	4.04E-2	Seawater

The differences in external dose for fresh water/ seawater media arise primarily due to difference in K_d value for the nuclide in sediment
Duration of swimming = 300 h/y;
Occupancy on beach = 500 h/y

Note: These are based on worked out examples and not taken from any reference.

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Dates of meeting	:	November 10, 1997 November 17, 1997 November 25, 1999 December 10, 1999 January 7 & 27, 2000 October 10, 2001

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NOTES

AERB SAFETY GUIDE NO. AERB/NF/SG/S-5

Published by : Atomic Energy Regulatory Board
Niyamak Bhavan, Anushaktinagar
Mumbai - 400 094.
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