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DOSE CONVERSION FACTORS

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DISCLAIMER

SUBJECT OF PRESENTATION

(1) Concepts and quantities used in calculating radiation dose from internal and external exposure.

(2) Tabulations of dose conversion factors for internal and external exposure to radionuclides.

Dose conversion factors give dose per unit intake (internal) or dose per unit concentration in environment (external).

Intakes of radionuclides for internal exposure and concentrations of radionuclides in environment for external exposure are assumed to be known.

Intakes and concentrations are obtained, e.g., from analyses of environmental transport and exposure pathways.

Differences between dosimetry methods for radionuclides and hazardous chemicals are highlighted.

CONCEPTS AND QUANTITIES

IN RADIATION DOSIMETRY

LIMITATIONS ON APPLICABILITY OF CONCEPTS AND QUANTITIES

(1) Most concepts and quantities discussed were developed for purposes of radiation protection, i.e., control of exposures.

Some concepts and quantities may not be appropriate for purposes of dose assessment or dose reconstruction.

(2) Most dose conversion factors for internal and external exposure were developed for reference young adults.

Values may not be applicable to other age groups in general population.

(3) Most dose conversion factors for internal exposure were developed for radionuclides in the workplace.

Some values may not be appropriate for exposure to radionuclides in the environment.

ACTIVITY

Quantity of radionuclides is measured by <u>activity</u> (A). At time t -

$$A(t) = \lambda_R N(t)$$

N = number of atoms of radionuclide ($\propto$ mass)

λ_R = radioactive decay constant (1/time)

$= (\ln 2)/T_{1/2} = 0.693/T_{1/2}$

$T_{1/2}$ = half-life of radionuclide (time)

SI unit - 1 Bq = 1 dis/s

Special unit - 1 Ci = 3.7×10^{10} dis/s

Quantity of hazardous chemicals is measured by <u>mass</u>.

TYPES OF RADIATIONS

Radiation dose is delivered by ionizing radiations.

Most important radiations emitted in decay of radionuclides -

- photons;
- electrons;
- alpha particles;
- neutrons (important for few radionuclides).

Emitted radiations have energies, usually given in electron volts (eV), and intensities (number per disintegration) unique to each radionuclide.

Ionizing radiations have no analog for hazardous chemicals.

INTERNAL DOSIMETRY

Estimation of radiation dose to tissues of the body resulting from intakes of radionuclides into the body.

Most important modes of internal exposure -

- ingestion;
- inhalation;
- skin absorption (important for few radionuclides).

All ionizing radiations are taken into account in estimating internal dose.

Intakes of some radionuclides result in relatively uniform irradiation of the body (e.g., H-3, C-14, Cs-137).

Intakes of many radionuclides result in highly non-uniform irradiation of the body (e.g., Sr-90, I-131, Ra-226, actinides).

Modes of internal exposure also apply to hazardous chemicals.

EXTERNAL DOSIMETRY

Estimation of radiation dose to tissues of the body resulting from exposure to radionuclides outside the body.

Most important modes of external exposure for radionuclides in the environment -

- exposure to contaminated atmospheric cloud;
- immersion in contaminated water;
- exposure to contaminated ground surface or surface soil.

Only radiations that penetrate body surface (e.g., photons, higher-energy electrons, and neutrons) are important in external dosimetry.

Exposure to higher-energy photons results in relatively uniform irradiation of the body.

External exposure is not relevant for hazardous chemicals.

ABSORBED DOSE

Absorbed dose (D) is point quantity defined as energy (E) absorbed per unit mass (m) of material (e.g., tissue) -

$$D = dE/dm$$

SI unit - 1 Gy = 1 J/kg

Special unit - 1 rad = 0.01 Gy

Absorbed dose is basic physical quantity used in radiation dosimetry.

For hazardous chemicals, dose is defined as mass administered per unit mass of organism (e.g., mg/kg).

LIMITATIONS OF ABSORBED DOSE FOR RADIATION PROTECTION AND RISK ASSESSMENT

At low levels of exposure where only stochastic effects are important, absorbed dose is not sufficient to relate amount of energy absorbed to biological effect (e.g., cancer induction).

For same absorbed dose delivered at same rate, some types of radiation may produce more pronounced biological effects than others.

Biological effects for given absorbed dose also depend on density of ionization or linear energy transfer (LET), defined as energy imparted per unit path length.

DOSE EQUIVALENT

Dose equivalent (H) is defined as absorbed dose modified by quality factor (Q) representing biological effectiveness of radiation -

$$H = DQ$$

SI unit - 1 Sv = 1 J/kg

Special unit - 1 rem = 0.01 Sv

If exposure involves more than one radiation type -

$$H = \sum_i D_i Q_i, \quad i = \text{index for radiation type}$$

Dose equivalent is basic radiation protection quantity relating absorbed energy to stochastic biological effects.

Dose equivalent is not appropriate for describing nonstochastic (deterministic) effects at high doses.

Dose equivalent has no analog for hazardous chemicals. Biological effectiveness per unit dose administered is incorporated in slope (risk) factor for each chemical.

QUALITY FACTORS

Quality factor is prescribed function of LET, e.g., see ICRP Publications 26 and 60.

Value depends on type of radiation and its energy.

Average quality factors for different radiation types recommended for use in radiation protection -

$\bar{Q}$ = 1 for photons and electrons (low-LET);

$\bar{Q}$ = 5 for thermal neutrons (high-LET);

$\bar{Q}$ = 20 for alpha particles, other neutrons (high-LET).

Values of $\bar{Q}$ are used for any energy of radiations of particular type.

Dose equivalent calculated from Q vs. LET or from $\bar{Q}$ may not be appropriate for use in dose assessment or dose reconstruction.

Dose equivalent is usually not used in radiation biology or epidemiology.

New "radiation weighting factor" (w_R) in ICRP Publication 60 replaces average quality factor ($\bar{Q}$).

DOSE RATE AND DOSE

For internal and external exposure, dose is received at rate which generally varies with time, e.g., due to changes in concentrations of radionuclides in environment, dietary and living habits of exposed individuals.

Dose-equivalent rate, $dH(t)/dt$, is denoted by $\dot{H}(t)$.

Dose received over time t is time-integral of dose rate -

$$H(t) = \int_0^t \dot{H}(\tau)d\tau$$

DOSES IN ORGANS OR TISSUES

Dose equivalents (H_T) in various organs or tissues (T) are quantities of interest in radiation protection.

Doses to all organs or tissues at risk from radiation exposure are considered.

Absorbed dose and dose equivalent in any organ or tissue usually are computed as average values, i.e., from total energy absorbed in tissue divided by total tissue mass.

For purposes of radiation protection, average absorbed dose and dose equivalent in tissues may not be appropriate for alpha particles and low-energy electrons (Auger).

For hazardous chemicals, only single organ or tissue at risk is considered.

EFFECTIVE DOSE EQUIVALENT

Effective dose equivalent (H_E) is defined as weighted sum of dose equivalents to different organs or tissues (T) -

$$H_E = \sum_T w_T H_T, \quad \sum_T w_T = 1$$

Weighting factor w_T is ratio of stochastic risk for tissue T to total stochastic risk for all tissues when body is irradiated uniformly.

H_E takes into account all tissues at risk.

Effective dose equivalent is intended to be proportional to stochastic risk for either uniform or non-uniform irradiations of the body.

Exposures with equal effective dose equivalents are assumed to result in equal risks regardless of distribution of dose among different organs or tissues.

Effective dose equivalent is intended for use only in radiation protection.

EFFECTIVE DOSE EQUIVALENT

(continued)

Weighting factors (w_T) for different organs or tissues used in defining effective dose equivalent (ICRP Publication 26) -

Gonads	0.25
Breast	0.15
Red marrow	0.12
Lungs	0.12
Thyroid	0.03
Bone surfaces	0.03
Remainder	0.30

"Remainder" includes five other organs (excluding skin, lens of the eye, and body extremities) receiving highest doses, and each organ is assigned weighting factor of 0.06.

Weighting factor for gonads represents stochastic risk of hereditary effects (first two generations only).

All other weighting factors represent stochastic risk of fatal cancers.

For hazardous chemicals, risk (slope) factors for single organs or tissues apply to cancer incidence.

EFFECTIVE DOSE

New "effective dose" (ICRP Publication 60) incorporates revised tissue weighting factors -

Gonads	0.20
Red marrow	0.12
Colon	0.12
Lungs	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Esophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surfaces	0.01
Remainder	0.05

Prescription for calculating contribution from "remainder" is different from effective dose equivalent.

New weighting factors take into account non-fatal cancer incidence as well as fatal cancers and hereditary effects (all future generations).

MODELS FOR CALCULATION OF INTERNAL DOSE

BASIC ELEMENTS OF CALCULATION OF INTERNAL DOSE PER UNIT ACTIVITY INTAKE OF RADIONUCLIDES

(1) Anatomical representation of reference individuals of different ages, sexes, and ethnic groups

Locations, shapes, masses, and elemental compositions of body organs and tissues.

(2) Absorption of inhaled or ingested radionuclides into blood (transfer compartment)

Task Group Lung Model for inhalation.

GI-tract model with absorption fraction f_1.

(3) Deposition of absorbed radionuclides in different organs or tissues

(4) Retention of radionuclides deposited in organs or tissues

(5) Organ dosimetry - dose to target organs per decay of radicnuclides in source organs (sites of deposition)

Term "metabolic" or "biokinetic" model is used to describe absorption, deposition, and retention.

For hazardous chemicals, absorption, deposition, and retention, as well as possible chemical transformations following absorption, are considered.

RETENTION OF DEPOSITED ACTIVITY

Models for retention of radionuclides describe fraction of activity deposited at time zero (i.e., from acute intake) remaining after time t.

Biological retention following acute intake often is described by a sum of exponential terms -

$$R(t) = \sum_i a_i \exp(-\lambda_{Bi} t)$$

λ_B = biological removal rate constant

$$\sum_i a_i = 1$$

Constants a_i and λ_{Bi} can be obtained by fitting observed retention or excretion over time or by solving system of differential equations describing biokinetics.

Constants depend on chemical form of element.

If removal by radioactive decay is included, effective retention following acute intake is given by -

$$R_e(t) = R(t)\exp(-\lambda_R t)$$

DOSE RATE AND DOSE FROM ACUTE INTAKE OF RADIONUCLIDES

If effective retention following acute intake is given by a single exponential term -

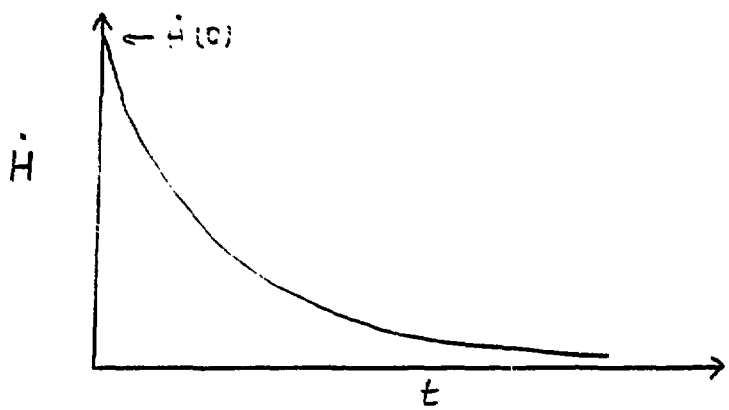
$$R_e(t) = \exp(-\lambda t)$$

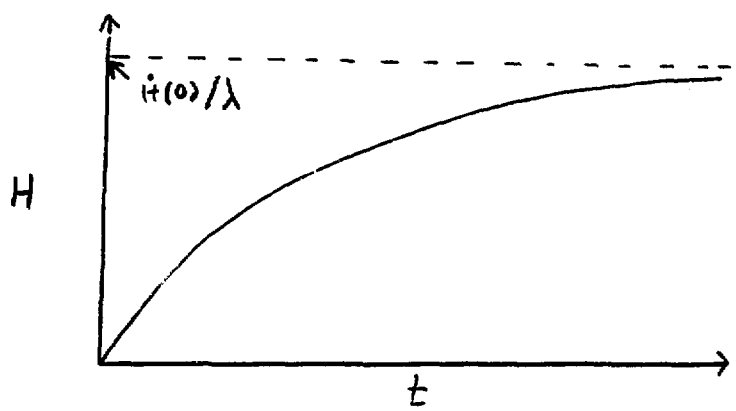
$$\lambda = \lambda_B + \lambda_R ,$$

then dose rate, $\dot{H}(t)$, and dose, $H(t)$, following acute intake of radionuclide at time zero are given by -

$$\dot{H}(t) = \dot{H}(0)R_e(t) = \dot{H}(0)\exp(-\lambda t)$$

$$H(t) = [\dot{H}(0)/\lambda][1 - \exp(-\lambda t)]$$





COMMITTED DOSE FROM INTERNAL EXPOSURE

For internal exposure, acute intakes of radionuclides commit individual to receiving doses over future times, even with no further intakes, until activity is removed from body by biological elimination or radioactive decay.

Definition of internal dose conversion factor -

- Committed dose equivalent per unit activity intake of radionuclide by specified exposure mode.

Internal dose conversion factors usually are calculated as 50-year committed dose equivalents, i.e., dose equivalents received to age 70 following acute intake at age 20.

For exposures of the public, ICRP has calculated committed dose equivalents to age 70 for any age at intake, taking into account age-dependence of dosimetry and metabolism.

Internal dose conversion factors for a given radionuclide take into account dose resulting from decay of any radioactive progeny produced by decay of the radionuclide in the body.

Both internal and external exposures at any time commit individual to some level of risk over future times.

COMMITTED DOSE FROM INTERNAL EXPOSURE

(continued)

Limits on annual committed dose equivalents are used for control of internal exposures, e.g., in ICRP recommendations.

Practice ensures that total dose equivalent received over a lifetime will not exceed sum of committed dose equivalents from intakes in each year.

For radionuclides with short half-lives or retention times in body, most of committed dose equivalent from acute intake is received within first year after intake.

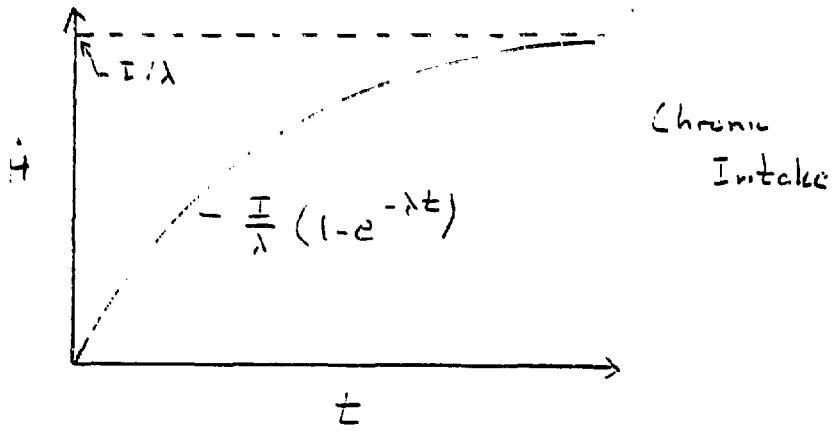
For radionuclides with long half-lives and retention times in body, use of committed dose equivalent apportions acceptable intakes into equal yearly increments.

COMMITTED DOSE FROM INTERNAL EXPOSURE

(continued)

Important property of committed doses -

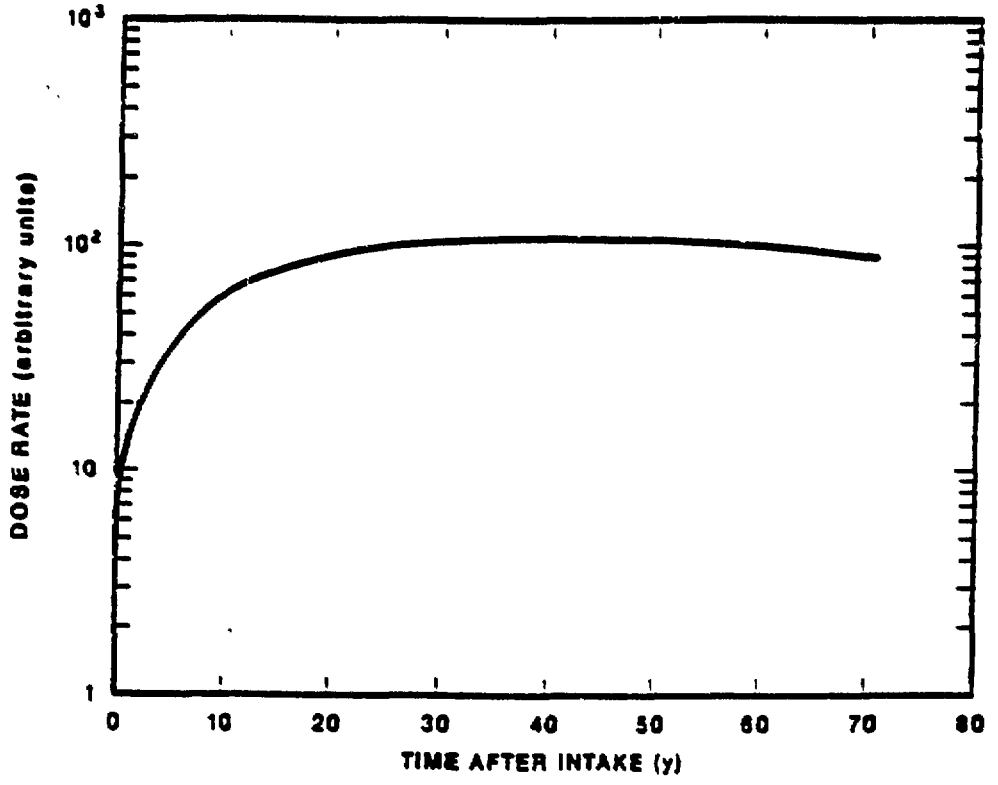
Committed dose over time t (years) following acute intake of activity (e.g., I Bq) is equal to dose rate at time t resulting from constant intake (e.g., I Bq/y).



DOSE RATE FROM ACUTE INTAKE OF PU-241

Pu-241 ($T_{1/2}$ = 14 y) emits only low-energy electrons. Decay product Am-241 ($T_{1/2}$ = 430 y) emits mostly high-energy alpha particles.

Dose rate as a function of time from acute intake of Pu-241 shows importance of committed dose in radiation protection.



RECENT DEVELOPMENTS IN INTERNAL DOSIMETRY

(1) Physiologically-based models for transfer and retention of absorbed activity in tissue compartments of body.

Models replace previous empirical approach of obtaining retention functions by fitting retention or excretion data over time.

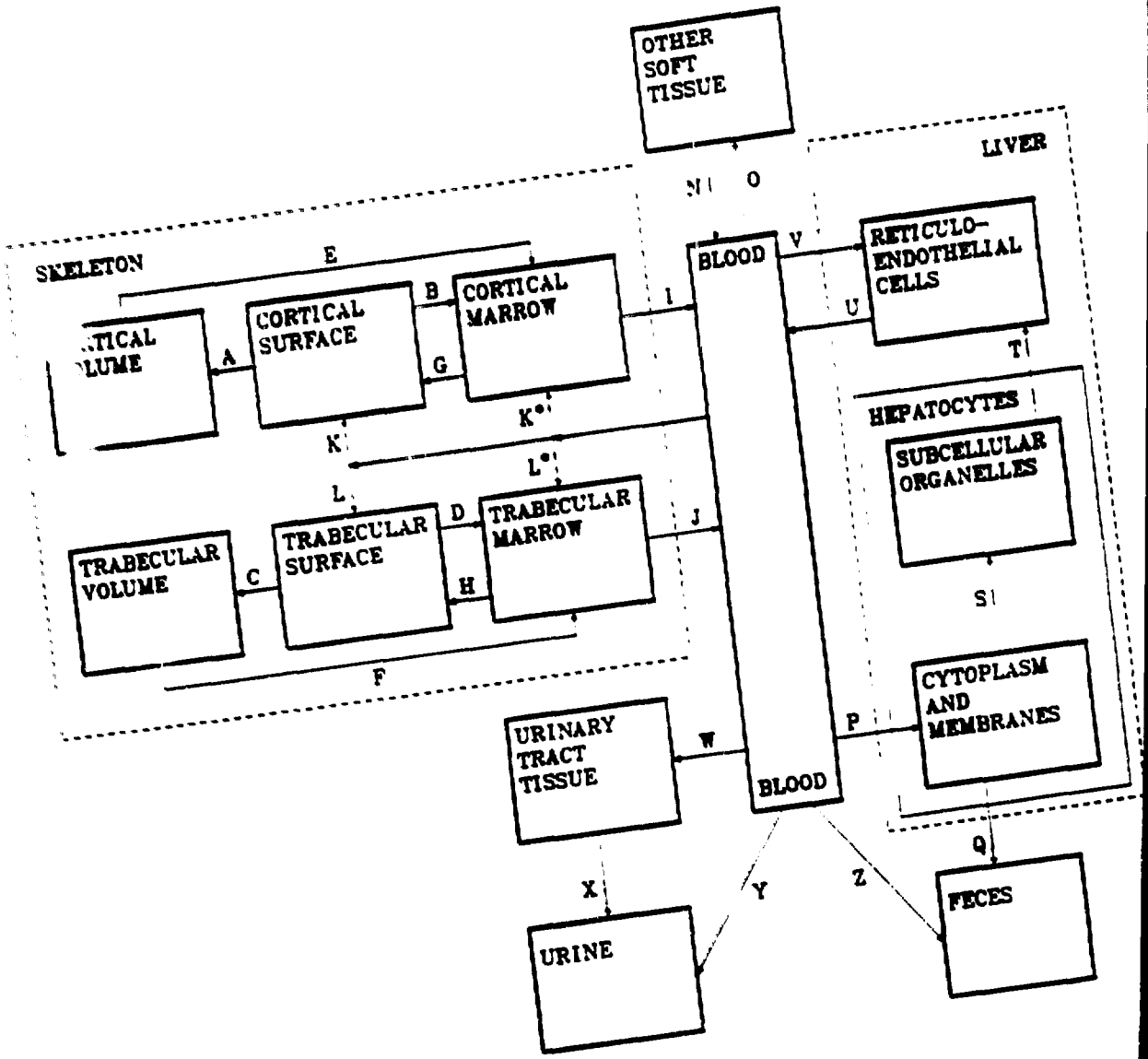
(2) Age-dependent models

Anatomical description of exposed individuals, biokinetics of absorbed radionuclides, and organ dosimetry from radionuclides in body are age-dependent.

Age dependence of dose from decay of radioactive progeny also is taken into account.

PHYSIOLOGICALLY-BASED

COMPARTMENT MODEL FOR PLUTONIUM



MODELS FOR CALCULATION OF EXTERNAL DOSE

BASIC ELEMENTS OF CALCULATION OF EXTERNAL DOSE PER UNIT CONCENTRATION OF RADIONUCLIDES IN ENVIRONMENT

(1) Anatomical representation of reference individuals of different ages, sexes, and ethnic groups

(2) Distribution of radionuclides in source region

Simple source configurations (e.g., uniform distributions in air, water, on ground surface, or in soil) are often assumed.

(3) Transport of penetrating radiations from source region to body surface of exposed individual

(4) Transport of penetrating radiations incident on body to specific organs or tissues

(5) Energy absorbed in organs or tissues

EXTERNAL DOSE CONVERSION FACTORS

For standard, simplified source configurations, dose rate in tissue T at time t is estimated by -

$$H_T(t) = \chi(t) \times DRF_T$$

χ = radionuclide concentration (uniform)

DRF_T = dose rate in tissue T per unit radionuclide concentration

Definition of external dose conversion factor (DRF) -

- Dose-equivalent rate per unit activity concentration of radionuclide in specified source region.

Dose received from external exposure is time integral of external dose rate.

Dose rate varies with time due to changes in radionuclide concentrations and may depend greatly on location in environment.

ENVIRONMENTAL DOSE COMMITMENT

Concept of environmental dose commitment refers to external and internal exposure over time following acute release of radionuclides to environment.

Formulation of concept is same as for committed internal dose from intakes of radionuclides.

As example, for activity concentration of radionuclide deposited on ground surface at time zero, external dose received over time t with no further depositions is given by -

$$H(t) \propto (1/\lambda)[1 - \exp(-\lambda t)],$$

where λ is total removal rate constant from ground surface taking into account physical removal processes (weathering) and radioactive decay.

Total (time-integrated) intakes of radionuclides over time following acute deposition would exhibit similar time dependence.

TABULATIONS OF DATA FOR

INTERNAL AND EXTERNAL DOSIMETRY

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