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**BRIN-JAEA FOLLOW-UP TRAINING COURSE ON RADIOLOGICAL EMERGENCY PREPAREDNESS AND RESPONSE**

# Calculation of Radiation Dose


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# Curriculum Vitae

## Ambar Winansi

- Education : STTN-BATAN – Nuclear Technophysics
  UI – Environmental Engineering

- Working Experience :

  2014-2020 : Environmental Radioactivity Monitoring and Emergency Section - Personnel Dose and Environmental Monitoring Division

  2021-2023 : Serpong Radiation Laboratory

  2024 : Laboratory of Energy Resources, Fuels, and Environment

  2025 : Research Center for Safety, Metrology, and Nuclear Quality Technology (PRTKMMN)

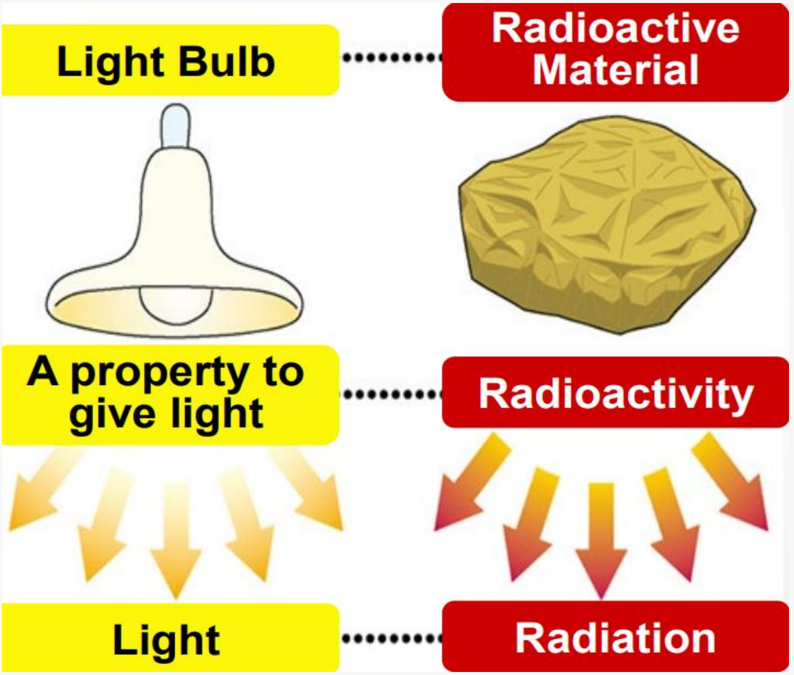
- Training
  - Advanced Instructor Training Course on Environmental Radioactivity Monitoring
  - Nuclear Technology Seminar on Nuclear Energy Officials
  - Instructor Training Course on Environmental Radioactivity Monitoring

# Contents

# Objectives

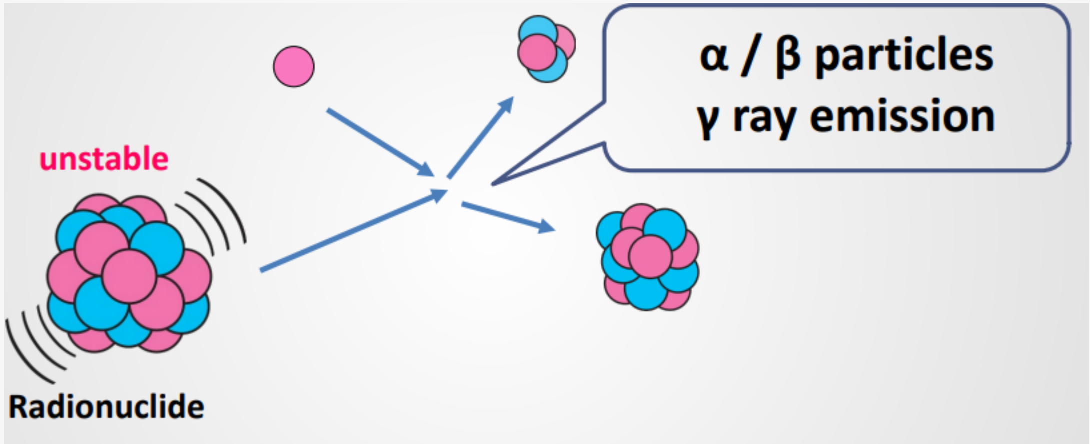
1. Understanding different radiation quantities and units commonly use in radiation protection practices
2. Understanding how to calculate individual dose, effective dose, equivalent dose, collective dose
3. Understand the concept of calculating external and internal doses from major pathways resulting from an accident at a nuclear facility.

# Radioactive Material, Radioactivity and Radiation




A material emitting radiation

The emitting property




Radionuclides emits radiations during radioactive decay

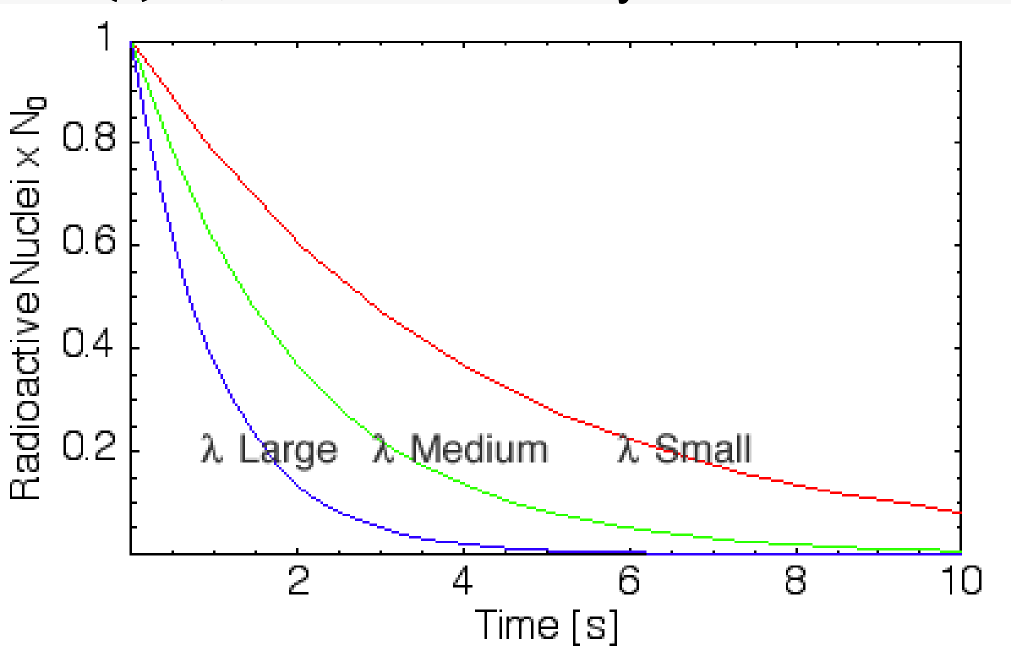
An unstable nucleus spontaneously decomposes to form a different nucleus, giving off radiation in the form of particles or high energy rays.

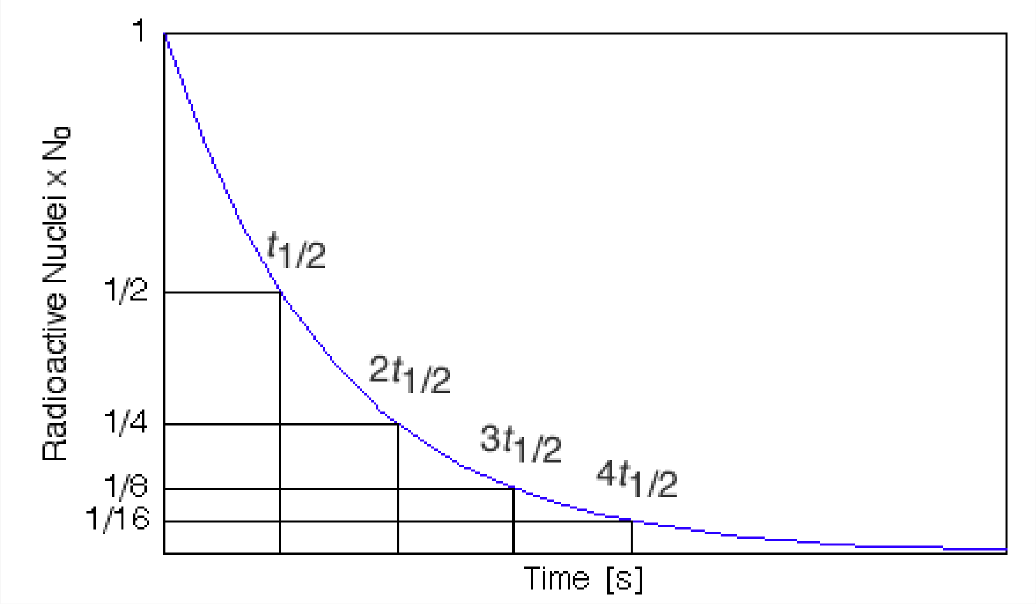
Unit to show the strength of radioactivity: becquerel (Bq)

Unit to show the degree of radiation effect: sievert (Sv)

# RADIOACTIVE DECAY

The number of atoms which decays between the time $(t)$ and time $(t + dt)$, $dN(t)$ , is given by $-\lambda N(t)dt$, where $\lambda$ is decay constant




$$-\frac{dN(t)}{dt} = \lambda N(t) \Rightarrow -\int_{N_0}^{N_t} \frac{dN}{N} = \int_0^t \lambda dt \Rightarrow \frac{N_t}{N_0} = e^{(-\lambda t)} \Rightarrow N_t = N_0 e^{(-\lambda t)}$$

The activity, is measured in Becquerels [Bq]

1 Bq = 1 decay per second [dps]

# Relation Between Half-life ($T_{1/2}$) And Decay Constant (λ)

$$\frac{N(T_{1/2})}{N_0} = \frac{1}{2} = e^{-\lambda T_{1/2}}$$

$$\lambda T_{1/2} = \ln 2$$

$$T_{1/2} = \frac{\ln 2}{\lambda}$$

$$T_{1/2} = \frac{0,693}{\lambda}$$

| | Half Life ($T_{1/2}$) | Decay Constant (λ) |
|---|---|---|
| $^{134}$Cs | 2.1 y | $1.07 \times 10^{-8}\ s^{-1}$ |
| $^{137}$Cs | 30.1 y | $7.31 \times 10^{-10}\ s^{-1}$ |
| $^{131}$I | 8 d | $1\times10^{-6}\ s^{-1}$ |

## Effective Half Life

$$\frac{1}{T_e} = \frac{1}{T_p} + \frac{1}{T_b}$$

Effective half life (Te) : the actual half life in the body

Physical half life (Tp): the half life by radioactive decay

Biological half life (Tb): the half life by metabolism and excretion

| Radionuclide | Tp (day) | Tb (day) | Te (day) |
|---|---|---|---|
| Tc-99m | 0.25 | 1 | 0.2 |
| H-3 | $4.5 \times 10^3$ =12.3 y | 12 | 12 |

# Question-1

**Calculate the elasped time that radioactivity of $^{134}Cs$ decreases to $\frac{1}{10}$**

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# Radiation Doses, Units of Radiation

## Correlation Between $D_T$, $H_T$, $H_E$

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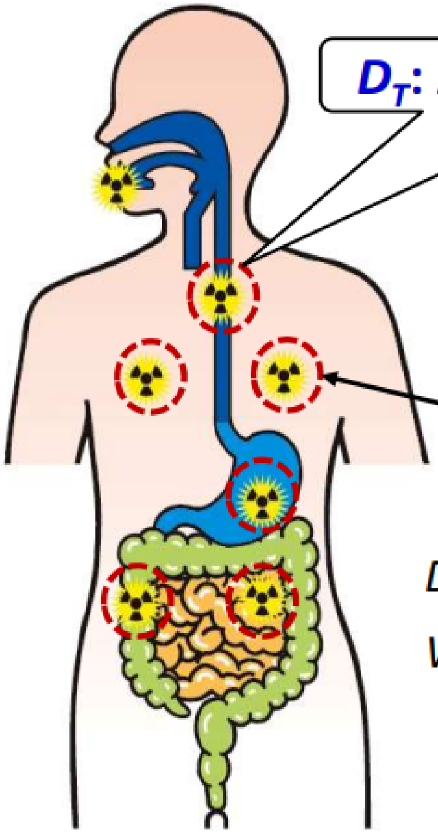
**Effective Dose ($H_E$)**

$$H_E = \sum_T (H_T \times W_T)$$

$H_T$: Equivalent Dose for Each Tissue

$W_T$: Tissue Weighting Factor

**Whole-body Exposure Dose**



**$D_T$: Absorbed Dose [Gy]**

1 J/kg =1 Gy

$$D = \frac{dE}{dm}$$

**Equivalent Dose ($H_T$)**

$$H_T = (D_T \times W_R)$$

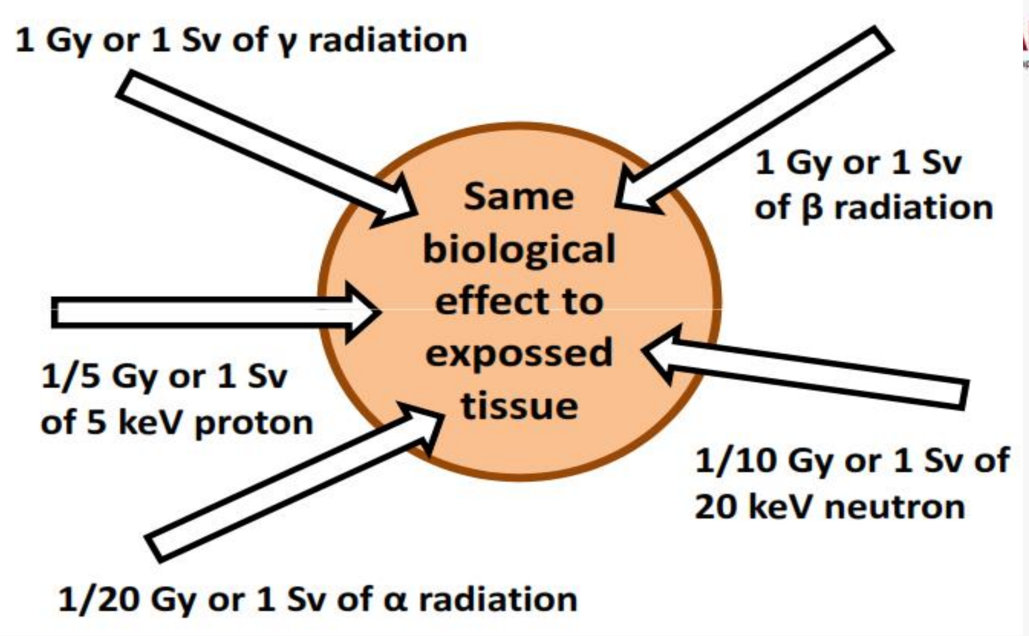
$D_T$: Absorbed Dose for Each Tissue

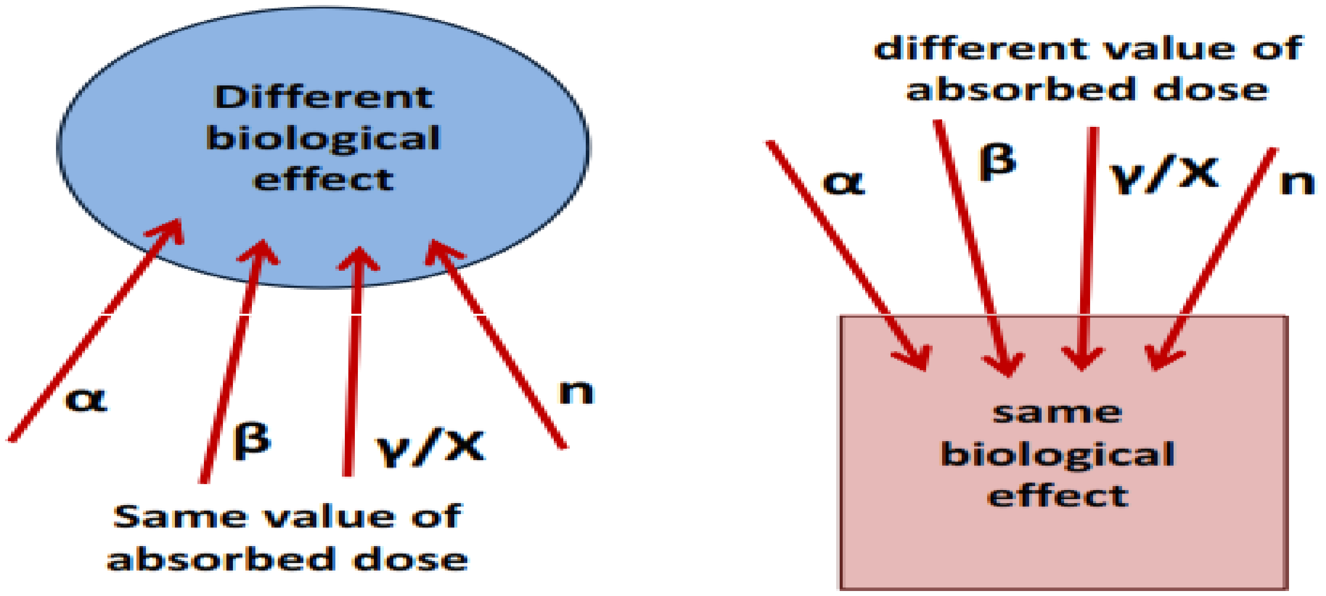
$W_R$: Radiation Weighting Factor

**Regional Exposure Dose**

for γ-ray and β-ray → 1Gy = 1Sv

| Kinds of Radiation | | Factor |
|---|---|---|
| X-ray and γ-ray | | 1 |
| β-ray | | 1 |
| Neutron* (by ICRP 1990's ≈ICRP 2007's) | <10keV | 5 |
| | >10keV>100keV | 10 |
| | >100keV>2MeV | 20 |
| | >2MeV>20MeV | 10 |
| | >20MeV | 5 |
| Proton (>2MeV) | | 5 |
| α-ray, Fission Products, Heavy Nucleus | | 20 |

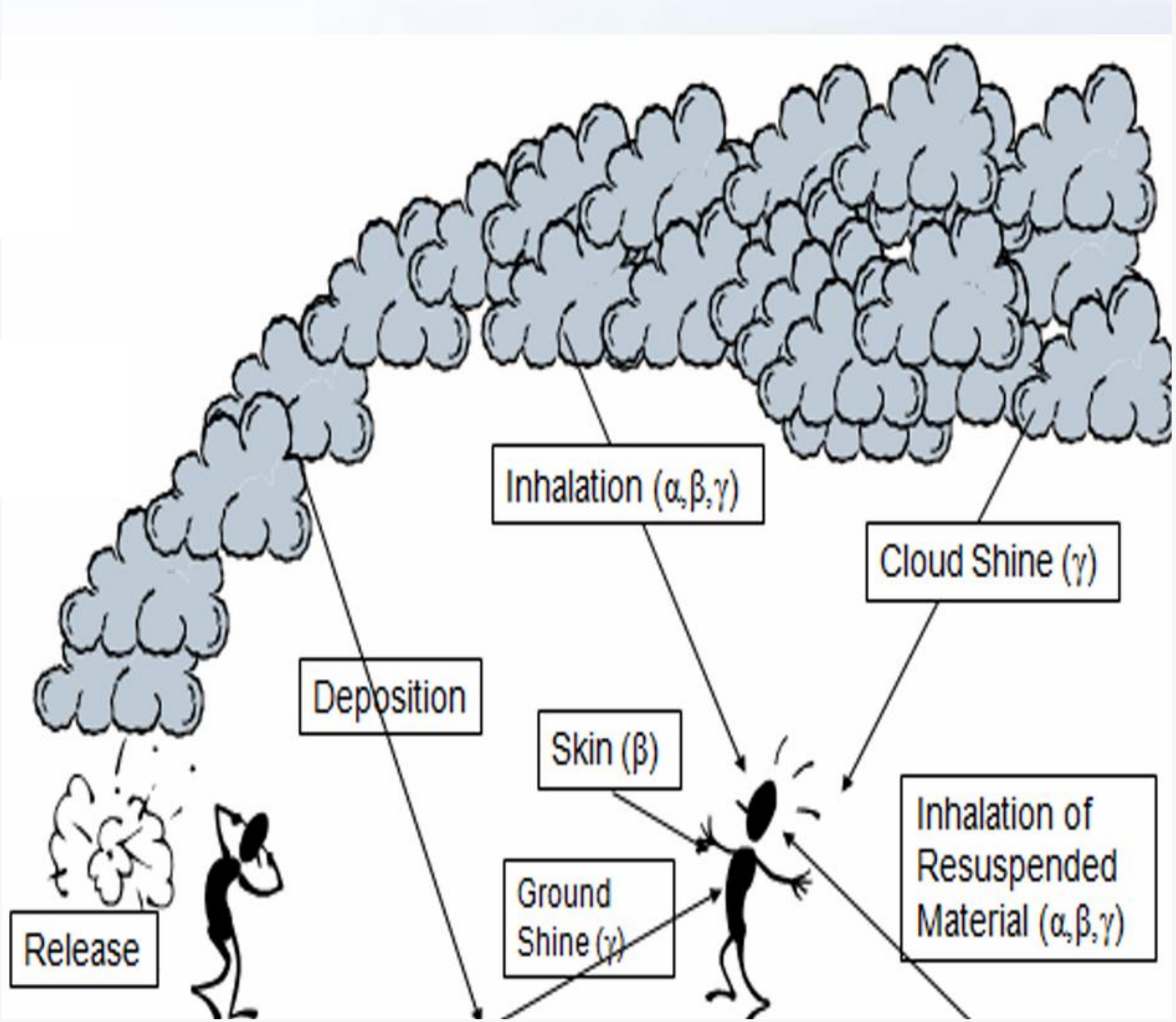


# Radionuclides of Interest in Case of a Nuclear Accident

| Type of facility | Radionuclides |
|---|---|
| Nuclear reactor facilities | $^{131}I$, $^{90}Sr$, $^{134}Cs$, $^{137}Cs$ radioactive rare gas ($^{133}Xe$, $^{85}Kr$, etc) |
| Reprocessing facilities | $^{90}Sr$, $^{137}Cs$, $^{106}Ru$,, $^{239}Pu$, $^{240}Pu$, $^{239}Pu$, $^{240}Pu$, $^{238}Pu$, $^{241}Pu$, $^{241}Am$, $^{85}Kr$ |
| Fuel fabrication facilities | $^{235}U$, $^{238}U$, $^{233}U$ |
| Radioactive waste facilities | $^{3}H$, $^{14}C$, $^{60}Co$, $^{59}Ni$, $^{63}Ni$, $^{90}Sr$, $^{94}Nb$, $^{99}Tc$, $^{129}I$, $^{137}Cs$, gross alpha |

# Exposure Pathways




**Following the NPP accident, humans were exposed to radioactive material by several pathways . The major exposure pathways were:**

- External exposure from radionuclides deposited on the ground (ground shine)
- External exposure from radionuclides in the radioactive cloud (cloud shine)
- Internal exposure from inhalation of radionuclides in the radioactive cloud (inhalation)
- Internal exposure from ingestion of radionuclides in food and water (ingestion)

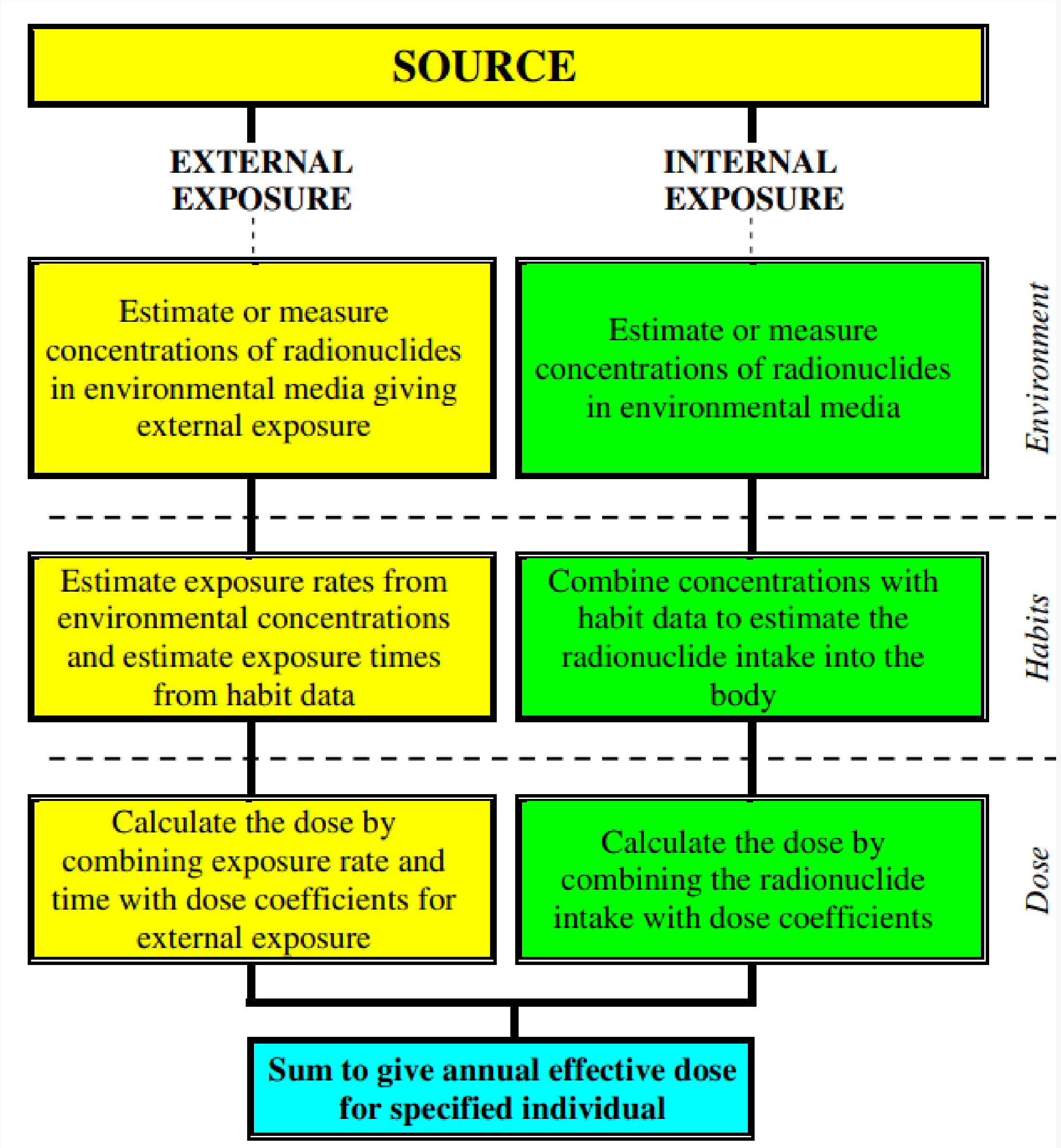
UNSCEAR, 2013 report

| | |
|---|---|
| The following input parameters for dose assessment cover the following | ➢ Source Term (RN, release rate, fate and transport)<br>➢ Concentration of RN in environmental sampel<br>➢ Consumption rates, breath rate<br>➢ Meteorological data<br>➢ Population distribution data<br>➢ Locally produced food |
| Total effective dose can be calculated by taking into account all dominant routes by which individuals were exposed in an accident | $E_T = E_{ext} + E_{inh} + E_{ing}$<br><br>$E_T$ = Total effective dose<br>$E_{ext}$ = Effective dose from external radiation<br>$E_{inh}$ = Committed effective dose from inhalation<br>$E_{ing}$ = Committed effective dose from ingestion |

Where direct means of assessing doses is available, principally the use of personal monitoring dosimeters for external exposure, this should be used. However in many cases such means may not be available or there may be a time delay in attaining the data.

Tecdoc 1162 “Dose Assessment Overview”

# Dose Assessment Process




- Stage 1 : The source of the exposure should be Characterised
- Stage 2 : environmental concentrations at various locations are obtained by measurements, by modelling the dispersion, deposition, and transport of radionuclides
- Stage 3 : combination of concentrations of radionuclides in environmental media with habit data and other information defined by exposure scenarios.
- Stage 4 : application of dose coefficients and related quantities
- Stage 5 : Summation of the contributions from internal and external exposure results in a total annual dose

ICRP Pub 101

# Assessing of Dose Rate (D) and the Effective Dose From Ground Contamination (1/4)

Estimate effective dose from deposition for the period of concern,
**Based on comprehensive radionuclide concentration on ground :**

$$E_{ext} = \sum_{i=1}^{n} \bar{C}_{g,i} \cdot CF_{4,i}$$

Where :

$E_{ext}$ : Effective dose from deposition for the period of concern

$C_{g,i}$ : Average deposition (ground) concentration of radionuclide i [kBq/m$^2$]

$CF_{4,i}$ : Conversion factor→Table E.3; effective dose per unit deposition for radionuclide i; includes external dose and committed dose from inhalation due to resuspension resulting from remaining on contaminated ground for the period of concern.

n : Number of radionuclide

IAEA Tecdoc 1162

# Assessing of Dose Rate (D) and the Effective Dose From Ground Contamination (2/4)

**Based on ambient dose rate:**

$$E_{ext} = \dot{H}_g^* \cdot \frac{\sum_{i=1}^{n} C_{g,i}^{rep} \cdot CF_{4,i}}{\sum_{i=1}^{n} C_{g,i}^{rep} \cdot CF_{3,i}}$$

Where :

$\dot{H}_g$ : Ambient dose rate at 1 m above ground level from ground contamination [mSv/h]

$CF_{3,i}$ : Conversion factor→Table E.3 ; ambient dose rate at 1 m above ground level per unit of deposition for radionuclide i

$C_{g,i}^{rep}$ : Representative deposition (ground) concentration of radionuclide i [kBq/m$^2$]

# Assessing of Dose Rate (D) and the Effective Dose From Ground Contamination (3/4)

**Based on marker radionuclide concentration levels :**

$$E_{ext} = C_{g,j}^{sam} \cdot \frac{\sum_{i=1}^{n} C_{g,i}^{rep} \cdot CF_{4,i}}{C_{g,j}^{rep}}$$

Where :

$C_{g,j}^{sam}$ : Concentration of marker radionuclide *j* in deposition samples [kBq/m$^2$]

$C_{g,j}^{rep}$ : Representative deposition (ground) concentration of marker radionuclide *j* [kBq/m$^2$]

$C_{g,i}^{rep}$ : Representative deposition (ground) concentration of radionuclide i [kBq/m$^2$]

# Assessing of Dose Rate (D) and the Effective Dose From Ground Contamination (4/4)

Adjust effective dose from deposition by taking into account shielding and partial occupancy, use the following equation :

$$E_{ext}^{po} = E_{ext} \cdot [SF.OF + (1-OF)]$$

Where :

$E_{ext}^{po}$ : Effective dose from deposition for the period of concern assuming shielding and partial occupancy[mSv]

SF : Shielding factor from measurement during occupancy or from table E4

OF : Occupancy fraction

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Table E.3. Conversion Factors For Exposure to Ground Contamination

| Radionuclide | Conversion factor $CF_3$[a] Ambient dose rate from deposition [(mSv/h)/(kBq/m$^2$)] | Conversion factor $CF_4$[b] Effective dose from deposition [(mSv/kBq/m$^2$)] | | |
|---|---|---|---|---|
| | | 1st Month | 2nd Month | 50 Year |
| H-3 | 0.0E+00 | NC | NC | NC |
| C-14 | 5.7E-11 | 5.2E-07 | 4.9E-07 | 1.0E-04 |
| Na-22 | 7.4E-06 | 3.7E-03 | 3.4E-03 | 8.4E-02 |
| Na-24 | 1.3E-05 | 2.0E-04 | 0.0E+00 | 2.0E-04 |
| P-32 | 1.0E-08 | 5.3E-06 | 1.2E-06 | 6.8E-06 |
| P-33 | 1.6E-10 | 1.1E-06 | 4.4E-07 | 1.8E-06 |
| S-35 | 5.9E-11 | 1.2E-06 | 8.7E-07 | 4.7E-06 |
| Cl-36 | 2.4E-09 | 8.1E-06 | 7.7E-06 | 1.6E-03 |
| K-40 | 5.2E-07 | 2.6E-04 | 2.5E-04 | 5.3E-02 |
| K-42 | 9.4E-07 | 1.2E-05 | 0.0E+00 | 1.2E-05 |
| Ca-45 | 1.6E-10 | 2.9E-06 | 2.4E-06 | 1.8E-05 |
| Sc-46 | 6.8E-06 | 3.0E-03 | 2.2E-03 | 1.2E-02 |

Table E.4. Shielding Factors For Surface Deposition

| Structure or location | Representative SF (a) | Representative range |
|---|---|---|
| 1 m above an infinite smooth surface | 1.0 | - |
| 1 m above ordinary ground | 0.7 | 0.47–0.85 |
| One and two story wood-frame house (no basement) | 0.4 | 0.2–0.5 |
| One and two story block and brick house (no basement) | 0.2 | 0.04–0.4 |
| House basement, one or two walls fully exposed<br>- one-story, less than 1 m of basement wall exposed<br>- two story, less than 1 m of basement wall exposed | <br>0.1<br>0.05 | <br>0.03–0.15<br>0.03–0.07 |
| Three or four story structures (500 to 1000 m$^2$ per floor)[(b)]<br>- first and second floor<br>- basement | <br>0.05<br>0.01 | <br>0.01–0.08<br>0.001–0.07 |
| Multi-story structures (> 1000 m$^2$ per floor)[(b)]<br>- upper floors<br>- basement | <br>0.01<br>0.005 | <br>0.001–0.02<br>0.001–0.15 |

# Question 2 :

In a nuclear accident, a source of **$Cs_{137}$** was released into the environment and deposited on the ground surface. It is known that the contamination on the ground surface is **30 Bq $cm^{-2}$**. Emergency Workers using PPE are estimated to be at the contaminated location for **2 hours**. If it is known that the conversion factor for the rate of exposure from radionuclide deposition in the soil for $Cs^{137}$ is **$2.1 \times 10^{-6}$ [(mSv/hour)/(kBq/$m^2$)].**

Estimated dose received by Emergency Workers while in the area?

# Assessing Radionuclide Concentration in the Air (1/2)

Committed Effective Dose from Inhalation :

$$E_{inh} = \sum_{i=1}^{n} \bar{C}_{a,i} . CF_{2,i} . Te$$

Where

$\bar{C}_{a\ i}$ : Average concentration of radionuclide i in air [kBq/m3]

$CF_{2,i}$ : Conversion factor for radionuclide i from table E.6

$E_{inh}$ : Committed effective dose from inhalation [mSv]

$T_e$ : Time of exposure to plume [h]

Committed Equivalent Dose to the Thyroid :

$$H_{thy} = \sum_{i=1}^{n} \bar{C}_{a,i} . CF_{1,i} . Te$$

$H_{thy}$ : Committed equivalent dose to the thyroid [mSv]

$CF_{1,i}$ : Thyroid conversion factor for radionuclide I from table E.7

Table E.6. Committed Effective Dose From One Hour's Inhalation of Contaminated Air- For an Adult

| Radionuclide | Conversion factor $CF_2$ [(mSv/h)/(kBq/m$^3$)] | Radionuclide | Conversion factor $CF_2$ [(mSv/h)/(kBq/m$^3$)] |
|---|---|---|---|
| Ce-143 | 1.2E-03 | Th-230 | 1.5E+02 |
| Ce-144 | 8.0E-02 | Th-231 | 5.0E-04 |
| Pr-143 | 3.6E-03 | Th-232 | 1.7E+02 |
| Pr-144 | 2.7E-05 | Th-234 | 1.2E-02 |
| Pr-144m | NC | Pa-231 | 2.1E+02 |
| Pm-145 | 5.4E-03 | Pa-233 | 5.9E-03 |
| Pm-147 | 7.5E-03 | Pa-234 | 6.0E-04 |
| Nd-147 | 3.6E-03 | U-232 | 5.6E+01 |
| Sm-147 | 1.4E+01 | U-233 | 1.4E+01 |
| Sm-151 | 6.0E-03 | U-234 | 1.4E+01 |
| Eu-152 | 6.3E-02 | U-235 | 1.3E+01 |
| Eu-154 | 8.0E-02 | U-236 | 1.3E+01 |
| Eu-155 | 1.0E-02 | U-238 | 1.2E+01 |

Table E.7. Committed Equivalent Dose to The Thyroid One Hour's Inhalation of Contaminated Air

| Radionuclide | Conversion factor $CF_1$ [(mSv/h)/(kBq/m$^3$)] | |
|---|---|---|
| | Adult | 10 years |
| Te-131m | 2.0E-02 | 3.7E-02 |
| Te-132 | 3.8E-02 | 6.8E-02 |
| I-125 | 1.5E-01 | 2.5E-01 |
| I-129 | 1.1E+00 | 1.5E+00 |
| I-131 | 2.3E-01 | 4.1E-01 |
| I-132 | 2.1E-03 | 3.8E-03 |
| I-133 | 4.2E-02 | 8.3E-02 |
| I-134 | 3.9E-04 | 7.3E-04 |
| I-135 | 8.6E-03 | 1.7E-02 |

# Assessing Radionuclide Concentration in the Air (2/2)

Estimate concentration of radionuclide i in air by using following equation :

$$C_{a,i} = \frac{Qi\ .DFm}{\bar{u}}$$

Where :

$C_{a,i}$ : Concentration of radionuclide i in air [kBq/m$^3$]

$Q_i$ : Release rate of radionuclide i [kBq/s]

$\bar{u}$ : Average wind speed [m/s]

$DF_m$ : Dilution factor, see table E8

Release Rates From a Fire

$$Q_i = \frac{A_i\ .FRFi}{T_r} \quad \longrightarrow \quad FRF = \frac{Activity\ released\ [kBq]}{Activity\ involved\ in\ fire\ [kBq]}$$

$A_i$ : Activity of radionuclide i avalable in fire [kBq]

$FRF_i$ : Fire release fraction for radionuclide i from table E11 if form compound is unknown or Table E.12 if the compound form is known

$T_r$ : Release duration [s]

# Table E.11. Fire Release Fraction (FRF) by Radionuclide

| Radionuclide | FRF[a] | Radionuclide | FRF[a] |
| --- | --- | --- | --- |
| H-3(gas) | 5.E-01 | Se-75 | 1.E-02 |
| C-14 | | Kr-85 | |
| Na-22 | 1.E-02 | Kr-85m | 1.E+00 |
| Na-24 | | Kr-87 | |
| P-32 | | Kr-88 | |
| P-33 | | Rb-86 | |
| S-35 | 5.E-01 | Rb-87 | |
| Cl-36 | | Rb-88 | |
| K-40 | | Sr-89 | |
| K-42 | | Sr-90 | |
| Ca-45 | | Sr-91 | |
| Sc-46 | | Y-90 | |
| Ti-44 | | Y-91 | |
| V-48 | 1.E-02 | Y-91m | |
| Cr-51 | | Zr-93 | |
| Mn-54 | | Zr-95 | 1.E-02 |
| Mn-56 | | Nb-94 | |
| Fe-55 | | Nb-95 | |
| Co-58 | 1.E-03 | Mo-99 | |
| Fe-59 | 1.E-02 | Tc-99 | |
| Co-60 | 1.E-03 | Tc-99m | |
| Ni-63 | | Ru-103 | |
| Cu-64 | 1.E-02 | Ru-105 | |
| Zn-65 | | Rh-106 | |
| Ga-68 | NC | Ru-106 | |
| Ge-68 | | Ag-110m | |
| Cd-109 | | Xe-138 | 1.E+00 |
| Cd-113m | | Cs-134 | |
| In-114m | | Cs-135 | |
| Sn-113 | | Cs-136 | |
| Sn-123 | | Cs-137 | |
| Sn-126 | | Cs-138 | |
| Sb-124 | | Ba-133 | |
| Sb-126 | | Ba-137m | |
| Sb-126m | 1.E-02 | Ba-140 | |
| Sb-127 | | La-140 | 1.E-02 |
| Sb-129 | | Ce-141 | |
| Te-127 | | Ce-144 | |
| Te-127m | | Pr-144 | |
| Te-129 | | Pr-144m | |
| *Te-129m | | Pm-145 | |
| Te-131 | | Pm-147 | |
| Te-131m | | Sm-147 | |
| Te-132 | | Sm-151 | |
| I-125 | 5.E-01 | Eu-152 | |
| I-129 | 5.E-01 | Eu-154 | 1.E-02 |



# Table E.12. Fire Release Fraction (FRF) by Compound Form

| Compound Form | FRF[a] |
| --- | --- |
| Noble Gas | 1.0 |
| Very Mobile Form (i.e. particle attached to flammable trash in a fire) | 1.0 |
| Volatile and combustible compounds | 0.5 |
| Carbon | 0.01 |
| Semi-volatile compounds | 0.01 |
| Non-volatile powders | 0.001 |
| Uranium and plutonium metal | 0.001 |
| Non-volatile in flammable liquids | 0.005 |
| Non-volatile in non-flammable liquids | 0.001 |
| Non-volatile solids | 0.0001 |

# Assessing Committed Effective Dose from Ingestion

Committed Effective dose from consumption of food or soil can calculate by using the equation below :

$$E_{ing} = \sum_{i=1}^{n} C_{f,i} . Uf . DIf_{,i} . CF5_{,i}$$

Where :

$Ei_{ng}$ : Committed effective dose from ingestion [mSv]

$C_{f,i}$ : Concentration of radionuclide i in food f after processing or in soil [kBq/kg]

$U_f$ : The mass of food f consumed by the population of interest per day

$CF5_{,i}$ : Conversion factor from table E.13 [mSv/kBq], committed effective dose from ingestion per unit intake of radionuclide i

$DI_{f,i}$ : Days of intake [d], the period food is assumed to be consumed;

Table E.13. Committed Effective Dose From Ingestion per Unit Intake of Radionuclide – Ingestion Dose Conversion Factors for an Adult

| Radionuclide | Conversion factor $CF_5$ [mSv/kBq] |
|---|---|
| H-3 | 1.8E-05 |
| C-14 | 5.8E-04 |
| Na-22 | 3.2E-03 |
| Na-24 | 4.3E-04 |
| P-32 | 2.4E-03 |
| P-33 | 2.4E-04 |
| S-35 org. | 7.7E-04 |
| S-35 inorg. | 1.3E-04 |
| Cl-36 | 9.3E-04 |
| K-40 | 6.2E-03 |
| K-42 | 4.3E-04 |
| Ca-45 | 7.1E-04 |
| Sc-44 | 3.5E-04 |
| Sc-46 | 1.5E-03 |
| Ti-44 | 5.8E-03 |
| V-48 | 2.0E-03 |
| Cr-51 | 3.8E-05 |
| Mn-54 | 7.1E-04 |
| Mn-56 | 2.6E-04 |
| Fe-55 | 3.3E-04 |
| Fe-59 | 1.8E-03 |
| Co-58 | 7.4E-04 |
| Co-60 | 3.4E-03 |
| Ni-63 | 1.5E-04 |
| Cu-64 | 1.2E-04 |
| Zn-65 | 3.9E-03 |
| Ga-68 | 1.0E-04 |
| Ge-68 | 1.3E-03 |
| Se-75 | 2.6E-03 |
| Kr-85 | 0.0E+00 |
| Kr-85m | 0.0E+00 |
| Kr-87 | 0.0E+00 |
| Kr-88 | 0.0E+00 |
| Zr-97 | 2.1E-03 |
| Nb-93m | 1.2E-04 |
| Nb-94 | 1.7E-03 |
| Nb-95 | 5.9E-04 |
| Nb-95m | 5.7E-04 |
| Nb-97 | 6.9E-05 |
| Mo-99 | 6.0E-04 |
| Tc-99 | 6.4E-04 |
| Tc-99m | 2.2E-05 |
| Ru-103 | 7.3E-04 |
| Ru-105 | 2.6E-04 |
| Ru-106 | 7.0E-03 |
| Rh-103m | 3.8E-06 |
| Rh-105 | 3.7E-04 |
| Rh-106 | 1.6E-04 |
| Ag-110m | 2.8E-03 |
| Cd-109 | 2.0E-03 |
| Cd-113m | 0.0E+00 |
| Cd-115 | 1.4E-03 |
| In-113m | 2.8E-05 |
| In-114m | 4.1E-03 |
| In-115 | 3.2E-02 |
| In-115m | 8.6E-05 |
| Sn-113 | 7.4E-04 |
| Sn-123 | 2.1E-03 |
| Sn-126 | 4.8E-03 |
| Sb-124 | 2.6E-03 |
| Sb-126 | 2.5E-03 |
| Sb-126m | 3.6E-05 |
| Sb-127 | 1.7E-03 |
| Sb-129 | 4.2E-04 |
| Sb-131 | 1.0E-04 |
| Te-127 | 1.7E-04 |

# Committed Effective Dose from Air Immersion

- To assess effective dose from external exposure to γ- emitting radionuclides in a radioactive plume.

$$E_{ext} = Te \sum_{i} \bar{C}_{a,i} \, . \, CF_{9,i}$$

$E_{ext}$ : Effective dose from external exposure due to immersion in contaminated air [mSv]

$\bar{C}_{a,i}$ : Average concentration of radionuclide i in air [kBq/m$^3$]

$CF_{9,i}$ : Conversion factor for radionuclide i from Table E.14 [(mSv/h)/(kBq/m$^3$)]

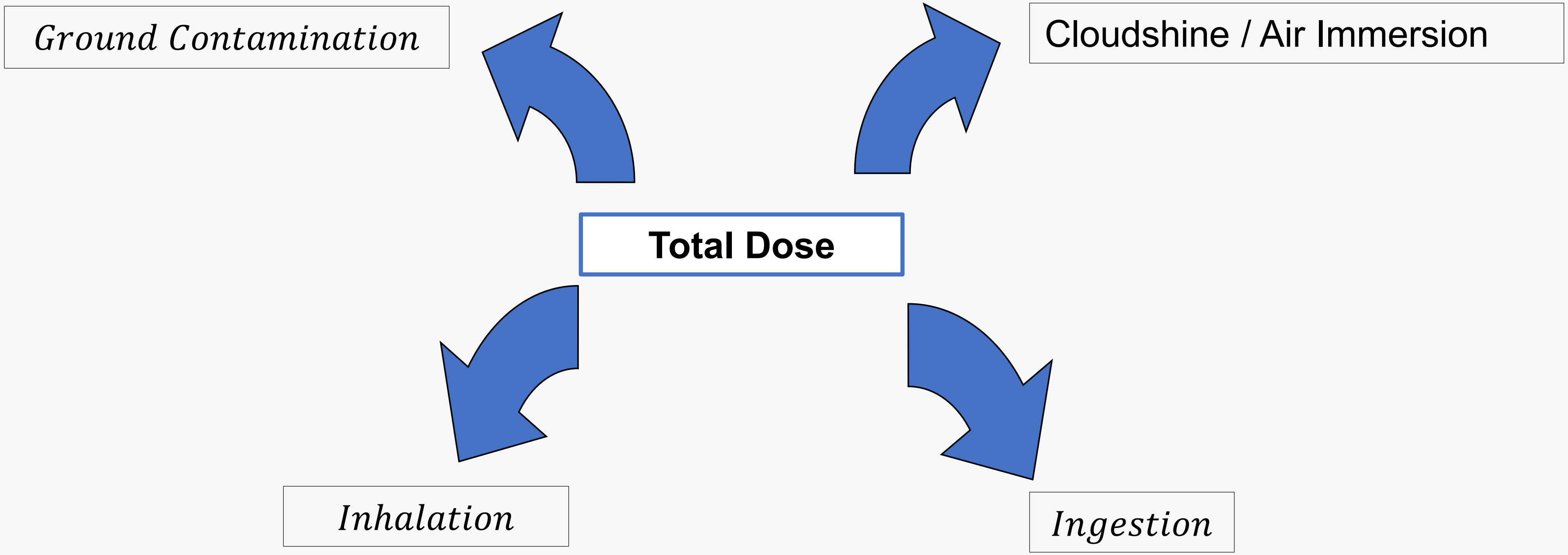
$T_e$ : Exposure duration [h]

# Table E.14. Conversion Factors for External γ Exposure Due to Immersion in Contaminated Air



| Radionuclide | $CF_9$ [(mSv/h)/(kBq/$m^3$)] | Radionuclide | $CF_9$ [(mSv/h)/(kBq/$m^3$)] |
|---|---|---|---|
| H-3 | 0.0E+00 | Tc-99m | 2.8E-05 |
| C-14 | 0.0E+00 | Ru-103 | 1.0E-04 |
| Na-22 | 4.8E-04 | Ru-105 | 1.7E-04 |
| Na-24 | 1.0E-03 | Ru/Rh-106[a] | 4.4E-05 |
| P-32 | 0.0E+00 | Pd-109 | 1.4E-07 |
| P-33 | 0.0E+00 | Ag-ll0m | 5.9E-04 |
| S-35 | 0.0E+00 | Cd-109 | 4.8E-07 |
| Cl-36 | 1.8E-12 | Cd-113m | 0.0E+00 |
| K-40 | 3.4E-05 | In-114m | 1.9E-05 |
| K-42 | 6.3E-05 | Sn-113 | 1.8E-06 |
| Ca-45 | 3.4E-15 | Sn-123 | 1.5E-06 |
| Sc-46 | 4.4E-04 | Sn-125 | 6.7E-05 |
| Ti-44 | 2.8E-05 | Sn-126 | 1.0E-05 |
| V-48 | 6.3E-04 | Sb-124 | 4.1E-04 |
| Cr-51 | 6.7E-06 | Sb-126 | 5.9E-04 |
| Mn-54 | 1.9E-04 | Sb-127 | 1.4E-04 |
| Mn-56 | 4.1E-04 | Sb-129 | 3.2E-04 |
| Fe-55 | 4.8E-09 | Te-127m | 6.7E-07 |
| Fe-59 | 2.6E-04 | Te-129 | 1.1E-05 |

# SUMMARY




$$E_{tot} = E_i^{dep} + E_i^{cl} + E_i^{inh} + E_i^{ing}$$

# PREFERENCE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# Thank You