Dose Assessment in Emergency Situation

KINS-IAEA Workshop on Radiation Safety and Emergency Response in the Medical or Industrial Use of Radiation

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HYUNGJOON YU

hjryu@kins.re.kr

한국원자력안전기술원
KINS KOREA INSTITUTE OF NUCLEAR SAFETY

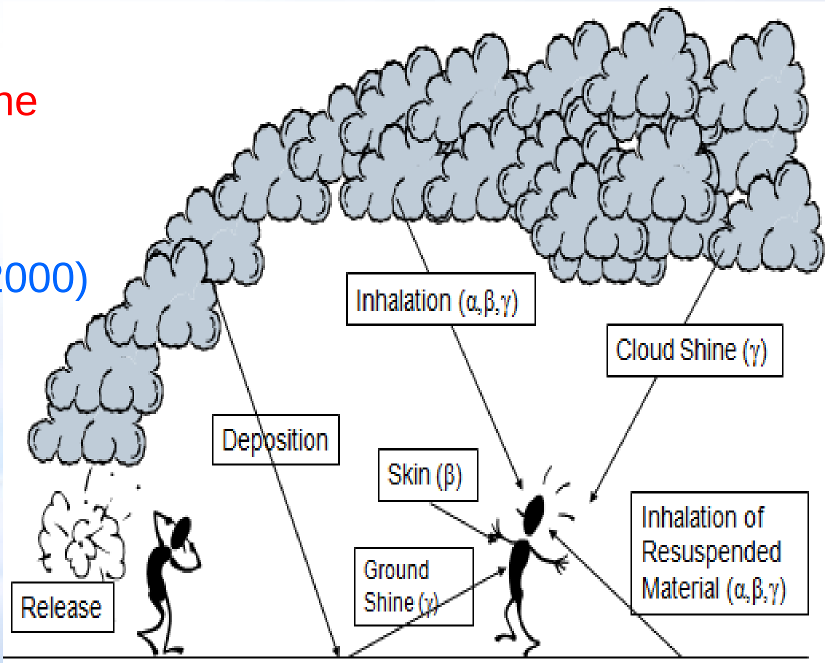
Dose Assessment Overview

❑ Radiological Dose Assessment

- estimating dose already received or anticipated dose to members of the public and emergency workers following a radiological incident
- These estimations can help guide protective actions or remediation
- Dose estimates may only be a part of comprehensive emergency management
- A body can receive an external and/or internal dose from a variety of isotopes and types of radiation

❑ This Lecture

- provides generic procedures for estimating the dose to emergency worker and/or public by radiological assessor
- is consistent with the IAEA-TECDOC-1162(2000)



Dose Assessment Overview

❑ Total Effective Dose

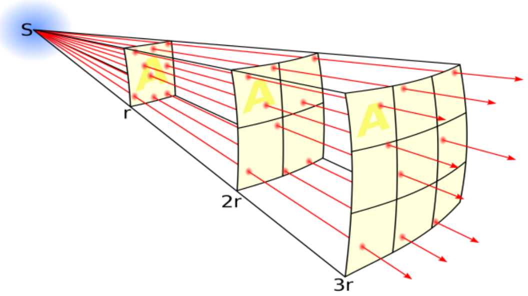
- Estimation of Total Effective Dose is generally the goal
- Total effective dose can be calculated by taking into account all dominant routes
- General dose equation: $E_T = E_{ext} + E_{inh} + E_{ing}$
  - E_T = *Total effective dose*
  - E_{ext} = *Effective dose from external radiation*
  - E_{inh} = *Committed effective dose from inhalation*
  - E_{ing} = *Committed effective dose from ingestion*

❑ Assemble and assess the dosimetric information directly available

- direct readings from EPDs, dose assessments from PRD such as film badges or TLDs
- inhalation may have occurred, nose blows should be taken using material suitable for assessing the activity removed
- ingestion may have occurred, the need to collect urine and fecal samples should be considered;
- Inhalation & ingestion case: whole body or thyroid monitoring should be considered
- if total effective dose limit may have been exceeded, a medical responder should be consulted about obtaining a blood sample for cytogenetic analysis.

Dose from external exposure (point source)

❑ Effective Dose



- effective dose at a certain distance from a point source:
  - E_{ext} = *Effective dose from a point source [mSv]*
  - *A = Source activity [kBq]*
  - T_e = *Exposure duration [h]*
  - CF_6 = *Conversion factor [(mSv/h)/(kBq/m²)]*
  - *X = Distance from the point source [m]*
  - $d_{1/2}$ = *Half value layer [cm]*
  - *d = Shielding thickness [cm]*

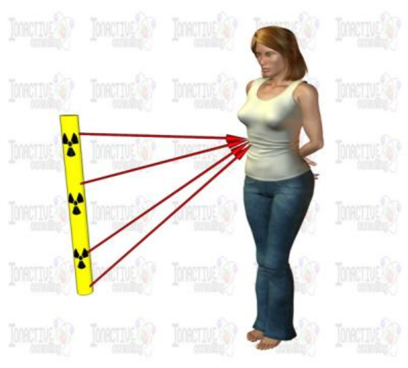
$$E_{ext} = \frac{A \cdot CF_6 \cdot T_e \cdot (0.5)^{\frac{d}{d_{1/2}}}}{X^2}$$

❑ Dose rates

- Absorbed dose rate in air at a certain distance from a point source:
  - *D = Dose rate [mGy/h]*
  - CF_7 = *Conversion factor [(mGy/h)/(kBq/m²)]*
  - *A = Source activity [kBq]*
  - *X = Distance from the point source [m]*
  - $d_{1/2}$ = *Half value layer [cm]*
  - *d = Shielding thickness [cm]*

$$\dot{D} = \frac{A \cdot CF_7 \cdot (0.5)^{\frac{d}{d_{1/2}}}}{X^2}$$

Dose from external exposure (line source)



Effective Dose

- effective dose from a line(pipe) source:
  - *X = Distance from the line source (pipe) [m]*
  - *E_{ext} = Effective dose [mSv]*
  - *CF_6 = Conversion factor [(mSv/h)/(kBq)]*
  - *A_l = Activity per 1 m [Bq/m]*
  - *T_e = Time of exposure [h]*

$$\boxed{E_{ext} = \frac{\pi \cdot CF_6 \cdot A_1 \cdot T_e}{X}}$$

Dose rates

- Absorbed dose rate in air at a distance x from a line source (pipe):
  - *D = Dose rate [mGy/h]*
  - *CF_7 = Conversion factor [(mGy/h)/(kBq)]*
  - *A_l = Activity per 1 m [Bq/m]*
  - *X = Distance from the line source (pipe) [m]*

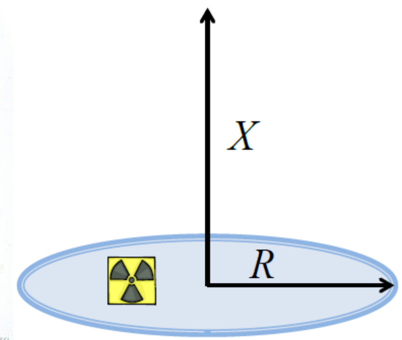
$$\boxed{\dot{D} = \frac{\pi \cdot CF_7 \cdot A_1}{X}}$$

Dose from external exposure (disk source)

❑ Effective Dose

- effective dose from disk source (spill):
  - *X = Distance from the centre of the disk [m]*
  - *R = Disk(spill) radius [m]*
  - *E_{ext} = Effective dose [mSv]*
  - *CF_6 = Conversion factor [(mSv/h)/(kBq)]*
  - *A_s = Activity of the spill [Bq/m^2]*
  - *T_e = Time of exposure [h]*

$$E_{ext} = 2\pi \cdot CF_6 \cdot A_s \cdot T_e \cdot \ln \frac{X^2 + R^2}{X^2}$$



❑ Dose rates

- Absorbed dose rate in air at a distance x from a disk source (spill):
  - *D = Dose rate [mGy/h]*
  - *CF_7 = Conversion factor [(mGy/h)/(kBq)]*
  - *A_s = Activity of the spill [Bq/m^2]*
  - *X = Distance from the centre of the disk [m]*
  - *R = Disk(spill) radius [m]*

$$\dot{D} = 2\pi \cdot CF_7 \cdot A_s \cdot \ln \frac{X^2 + R^2}{X^2}$$

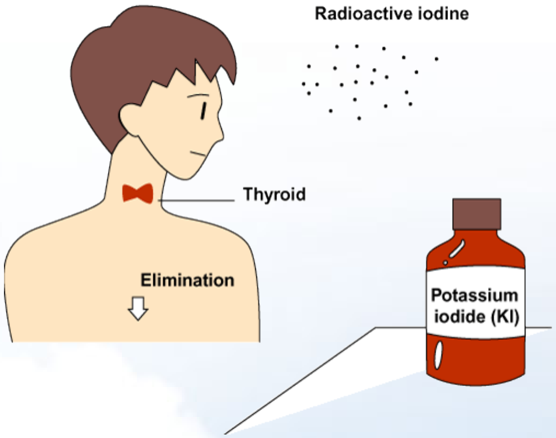
Dose from internal exposure (inhalation)

Committed Effective Dose

- Committed effective dose from inhalation:
  - E_{inh} = *Committed effective dose from inhalation [mSv]*
  - *C = Average concentration of radionuclide i in air [kBq/m^3]*
  - $CF_{2,i}$* = *Conversion factor for radionuclide i*
  - T_e = *Time of exposure to plume [h]*

**a breathing rate of 1.5 m^3/h is assumed as recommended by ICRP for an adult performing light activities*

$$E_{inh} = \sum_{i=1}^{n} \overline{C}_{a,i} \cdot CF_{2,i} \cdot T_e$$



Committed Equivalent Dose

- Committed equivalent dose to the thyroid from inhalation
  - H_{thy} = *Committed equivalent dose to the thyroid [mSv]*
  - *C = Average concentration of radionuclide i in air [kBq/m^3]*
  - $CF_{1,i}$* = *Thyroid conversion factor for radionuclide i*
  - T_e = *Time of exposure to plume [h]*

**a breathing rate of 1.5 m^3/h and 1.12 m^3/h is assumed as recommended by ICRP for an adult and a 10 years old child performing light activities*

$$H_{thy} = \sum_{i=1}^{n} \overline{C}_{a,i} \cdot CF_{1,i} \cdot T_e$$

Dose from internal exposure (ingestion)

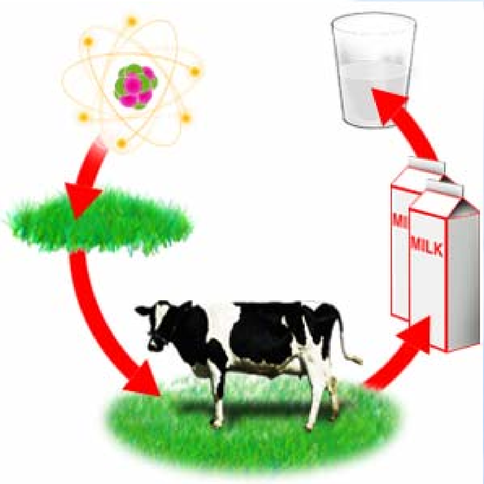
Committed Effective Dose

- Committed effective dose from consumption of food or soil:
  - E_{ing} = *Committed effective dose from ingestion of food f [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 [kg/d or L/d]*
  - $CF_{5,i}$ = *Conversion factor committed effective dose from ingestion per unit intake of radionuclide I [mSv/kBq]*
  - $DI_{f,i}$ = *Days of intake[d]; the period food is assumed to be consumed;*

For soil ingestion, maximum adult ingestion is about 100 mg/d with an average of about 25 mg/d maximum consumption for a child is 500 mg/d with an average of 100 mg/d

if $T_{1/2}$ > 21 days use 30 days,
if $T_{1/2}$ < 21 days use the mean life (T) of the radionuclide $T_m = T_{1/2}$ x1.44

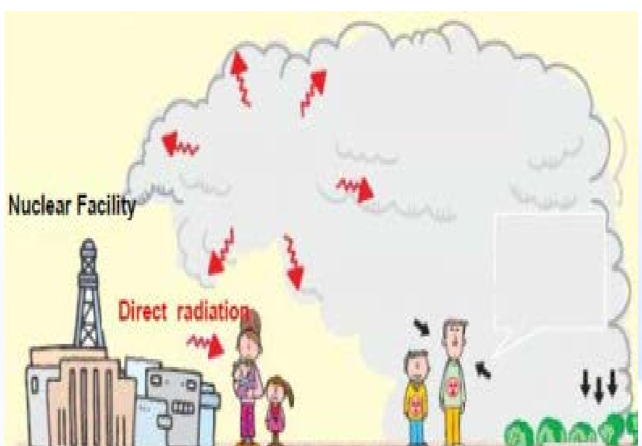
$$\boxed{E_{ing} = \sum_{i=1}^{n} C_{f,i} \cdot U_f \cdot DI_{f,i} \cdot CF_{5,i}}$$

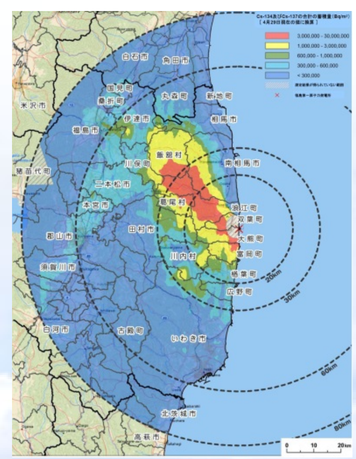


Dose from contamination (ground)

Effective Dose from exposure to ground contamination

- includes external dose and committed dose from inhalation (resuspension) resulting from remaining on contaminated ground for the period of concern
- large-scale contamination is often of more concern than discreet sources
- Calculation of Effective Dose is based on what you know about the contamination
- Obtain radionuclide concentrations on ground and ambient dose rate
- Contamination could be single isotope or a mixture
- Deposition is not uniform
  - *Wind-driven plume deposits varying amounts of contamination*
  - *Rain can produce heavier deposits from a plume*





Dose from contamination (ground)

Effective dose from deposition

- Based on comprehensive radionuclide concentrations on ground:
  - E_{ext} = *Effective dose from deposition for the period of concern [mSv]*
  - $C_{g,i}$ = *Average deposition (ground) concentration of radionuclide i [kBq/m²]*
  - $CF_{4,i}$ = *Conversion factor [(mSv/kBq/m²)]**
  - *n = Number of radionuclides*

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

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

: specific for a particular time frame (first month, second month, 50 year) That is, the time of exposure is incorporated into the conversion factor

- The mix of RI could initially be determined from gamma spectroscopy. Refinement comes from sample analysis (soil, air, etc.)
- Once the mix is known at one point (isotopes and concentrations), it can be used for “representative” concentrations for calculating dose at another point.
- Based on ambient dose rate and “represntative”:
  - $\dot{H}_g^*$ = *Ambient dose rate at 1 m above ground contamination [mSv/h]*
  - $CF_{3,i}$ = *Conversion factor [(mSv/h)/(kBq/m²)]*
  - $CF_{4,i}$ = *Conversion factor [(mSv/kBq/m²)];*
  - $C_{g,I}^{rep}$ = *Representative deposition (ground) concentration of radionuclide i [kBq/m²]*

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

$CF_{3,i}$:ambient dose rate at 1 m above ground level per unit of deposition for radionuclide i

Dose from contamination (ground)

Effective dose from deposition

- If representative concentrations are known for the deposition, effective dose at any point can be calculated using the measured concentration of a single isotope at that point
- The single isotope is known as a "marker isotope"
- This technique assumes the relative concentrations remain the same everywhere in the deposition
- Based on marker radionuclide concentration levels:
  - $CF_{4,i}$ = *Conversion factor [(mSv/kBq/m²)];*
  - $C_{g,j}^{sam}$ = *concentration of marker radionuclide j in depostion sample [kBq/m²]*
  - $C_{g,j}^{rep}$ = *Representative deposition (ground) concentration of marker radionuclide j [kBq/m²]*
  - $C_{g,I}^{rep}$ = *Representative deposition (ground) concentration of radionuclide i [kBq/m²]*

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

Dose from contamination (ground)

Effective dose from deposition

- Adjust Effective Dose by taking into account shielding and partial occupancy
- assumes buildings(shelter) are sealed and no contamination has entered inside.
  - *E_{ext}^{po} = Effective dose from deposition for the period of concern assuming shielding and partial occupancy [mSv]*
  - *SF = Shielding factor from measurements during occupancy*
  - *OF = Occupancy fraction; fraction of time in the building (default; 0.6)*

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

TABLE E4. 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 - one-story, less than 1 m of basement wall exposed - two story, less than 1 m of basement wall exposed	 0.1 0.05	 0.03–0.15 0.03–0.07
Three or four story structures (500 to 1000 m^2 per floor)[(b)] - first and second floor - basement	 0.05 0.01	 0.01–0.08 0.001–0.07
Multi-story structures (> 1000 m^2 per floor)[(b)] - upper floors - basement	 0.01 0.005	 0.001–0.02 0.001–0.15

Dose from contamination (air)

Effective dose from air immersion

- Effective dose from external exposure to γ radiation from the plume (cloud shine)
  - E_{ext} = *Effective dose from external exposure due to immersion in contaminated air [mSv]*
  - $C_{a,I}$ = *Average concentration of radionuclide i in air [kBq/m³]*
  - $CF_{9,I}$ = *Conversion factor for radionuclide i from*
  - T_e = *Exposure duration [h]*

$$E_{ext} = T_e \cdot \sum_i \overline{C}_{a,i} \cdot CF_{9,i}$$

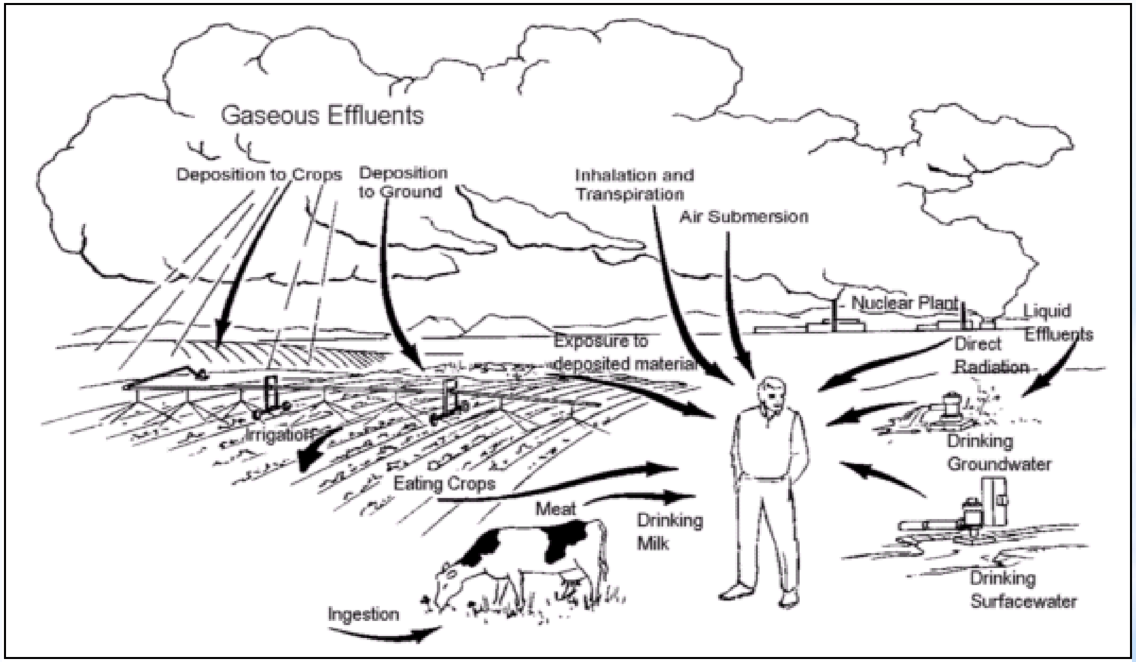


Figure 4. Pathways to exposure from contamination

Data Interpretation & Reporting

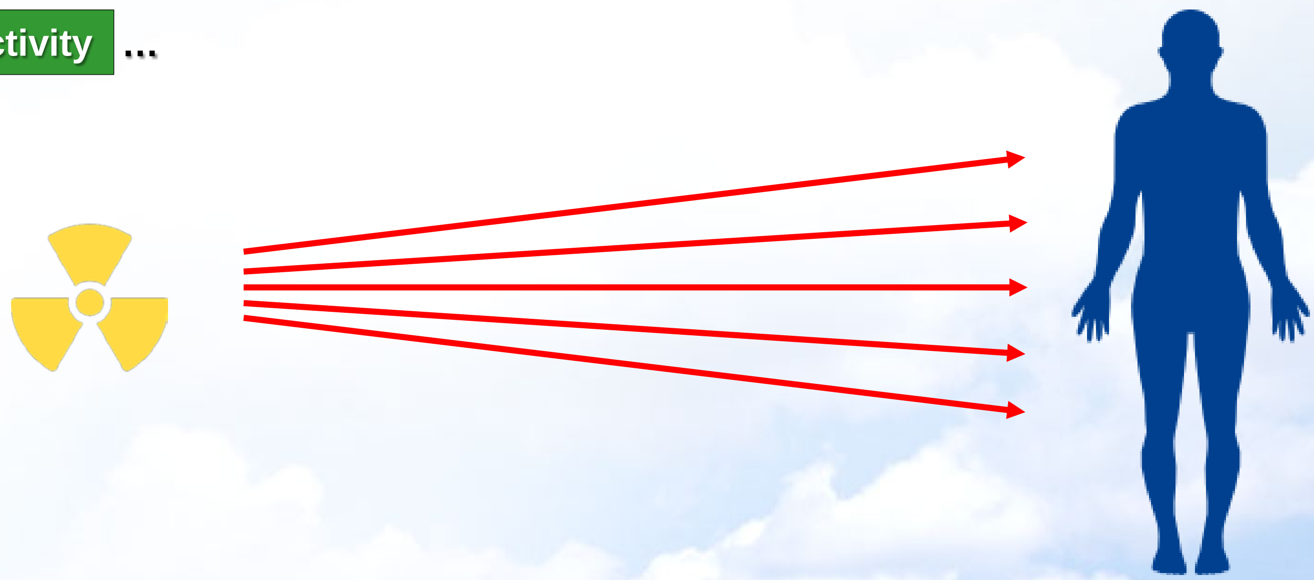
- Keep track of calculations
- Know the assumptions and boundary conditions
- Conservative assumptions are generally used
- Remember total effective dose must be calculated (all isotopes and all pathways)
- Action decisions are generally made on the most restrictive effective dose (whole body, single organ)
- Separate calculations may need to be done for emergency workers and the public
- The use of personal protective equipment (e.g. respirators) will modify the calculations presented here

Exercise of Dose Assessment in Emergency Situation

Review of Dose Assessment

❑ Basic concepts

Source	Pathways	Exposed Individual
Type of Radiation	External exposure	Sex, Ages
Physical Form	Internal exposure	Posture, Time
Chemical Form	Distance, Shielding …	Height, Weight …
Activity …		



Exercise 1

❑ Dose Assessment of External Exposure

- NDT(Non Destructive Test) worker has worked during 10 minutes.
- The distance between the source and worker was 5 m without any shield.
- The radioactive source was Ir-192 with 1.85 TBq.
- ✓ **Calculate effective dose to worker.**
- ✓ **Calculate the effective dose when the 6 mm lead plate existed between them.**

$$\boxed{E_{ext} = \frac{A \cdot CF_6 \cdot T_e \cdot (0.5)^{\frac{d}{d_{1/2}}}}{X^2}}$$

(ref. IAEA-TECDOC-1162(2000))

➢ Useful references of external dosimetry
- ICRP Publication 74(1996)
- ICRP Publication 116(2010)
- ICRP Publication 119(2011)

Ir-192

5 m

Exercise 2

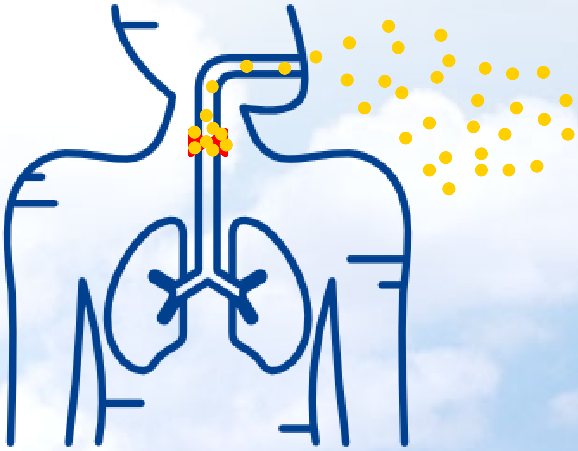
❑ Dose Assessment of Internal Exposure

- In the hospital, assessment of effective dose to the worker who products I-131 nuclear medicine should be performed.
- The results of measurement, concentration of air due to I-131 was 0.1 [kBq/m3].
- The worker used to work 2 hours a day, 5 days a week.

✓ **Calculate annual effective dose to worker due to inhalation of I-131.**

$$\boxed{E_{inh} = \sum_{i=1}^{n} \overline{C}_{a,i} \cdot CF_{2,i} \cdot T_e}$$

(ref. IAEA-TECDOC-1162(2000))



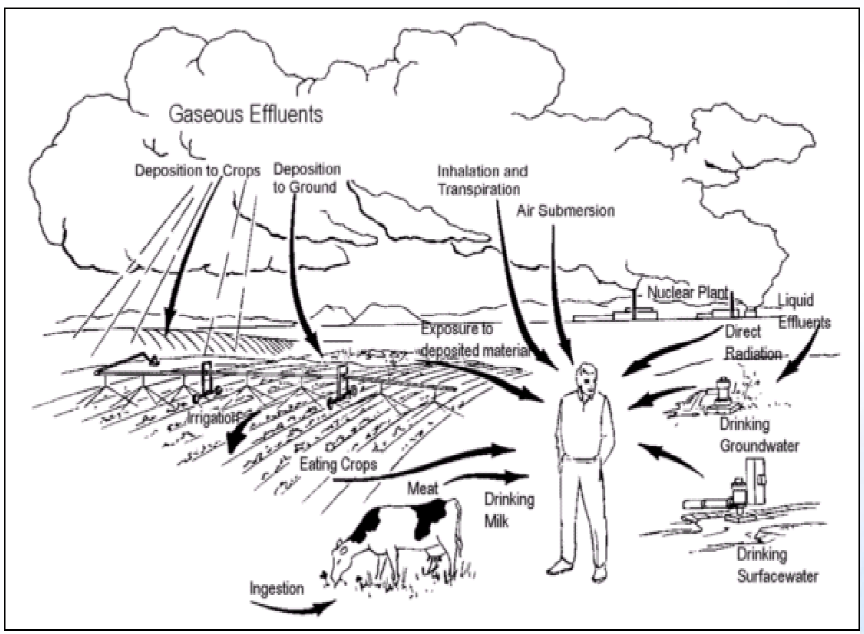
➢ Useful references of internal dosimetry
- ICRP Publication 72(1995)
- ICRP Publication 68(1994)
- ICRP Publication 100(2006)
- ICRP Publication 119(2011)
- U.S. NRC Reg.Guide 1.3(1974)
- U.S. NRC Reg.Guide 1.4(1974)

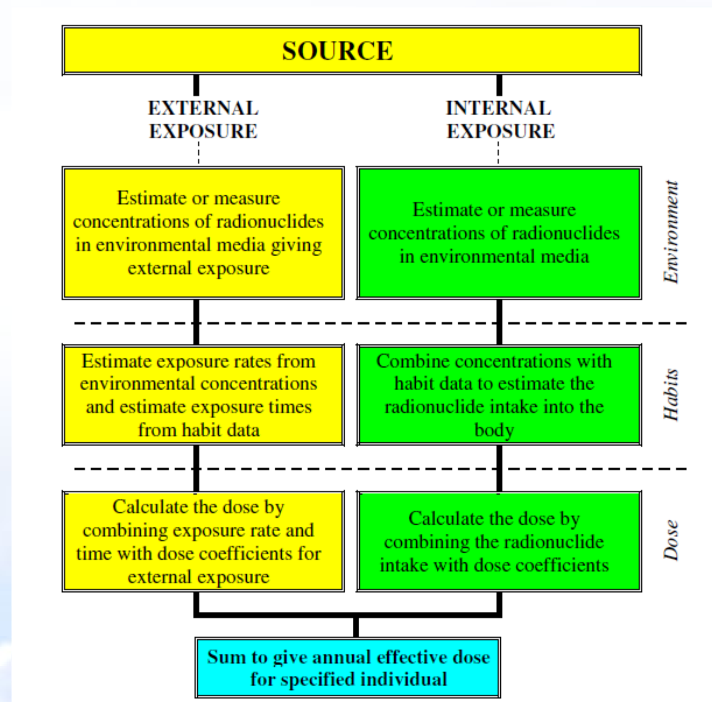
Exercise 3

❑ Dose Assessment for Contamination

- Due to the accident of nuclear power plant, radioactive materials were released and moved to a coastal village along the wind.

✓ **After few weeks from the accident, in order to evaluate the annual dose to the people who live in the village what matters should be considered?**





Exercise 3

Dose Assessment for Contamination (cont.)

- After few weeks later, at some point in the village, average radiological concentration of Cs-137 in air was measured as 0.5 kBq/m^3.

✓ **Calculate an annual effective dose to person who lives in village from air immersion with concentrated by Cs-137.**

  - *Assume that the village people used to work outside for 8 hours a day and they are not affected from the radiation when they were inside of houses or buildings.*

$$\boxed{E_{ext} = T_e \cdot \sum_i \overline{C}_{a,i} \cdot CF_{9,i}}$$

(ref. IAEA-TECDOC-1162(2000))

➢ Useful references of dosimetry of environmental contamination
- U.S. EPA FGR 12(1993)
- U.S. NRC NUREG-0017(1985)
- U.S. NRC Reg.Guide 1.109(1977)
- U.S. NRC Reg.Guide 1.111(1977)
- U.S. NRC Reg.Guide 1.113(1977)
- Nina Petoussi-Henss, et al. Phys.Med.Biol. 57, (2012)

Always we keep watching our Atomic Power

Thank You

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