Aerosols Containing Natural Radionuclides in Coal-Fired Power Plant

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Background and Study Objectives

Introduction

- **Coal-fired power plant is a typical way to generate electricity:**
  - About 45% of gross generation in Korea (1st)

- **Coal-fired power plant generates residues in progress of coal combustion:**
  - Fly ash, Bottom ash
  - FGD (Flue-gas desulfurization) gypsum

- **Residues contain natural radionuclides:**
  - U-238, U-235 and Th-232 series
  - Low activities concentration
  - However, it may cause not-trivial radiation dose to workers due to mainly inhalation of airborne particles

❖ Management of natural radionuclides in Korea

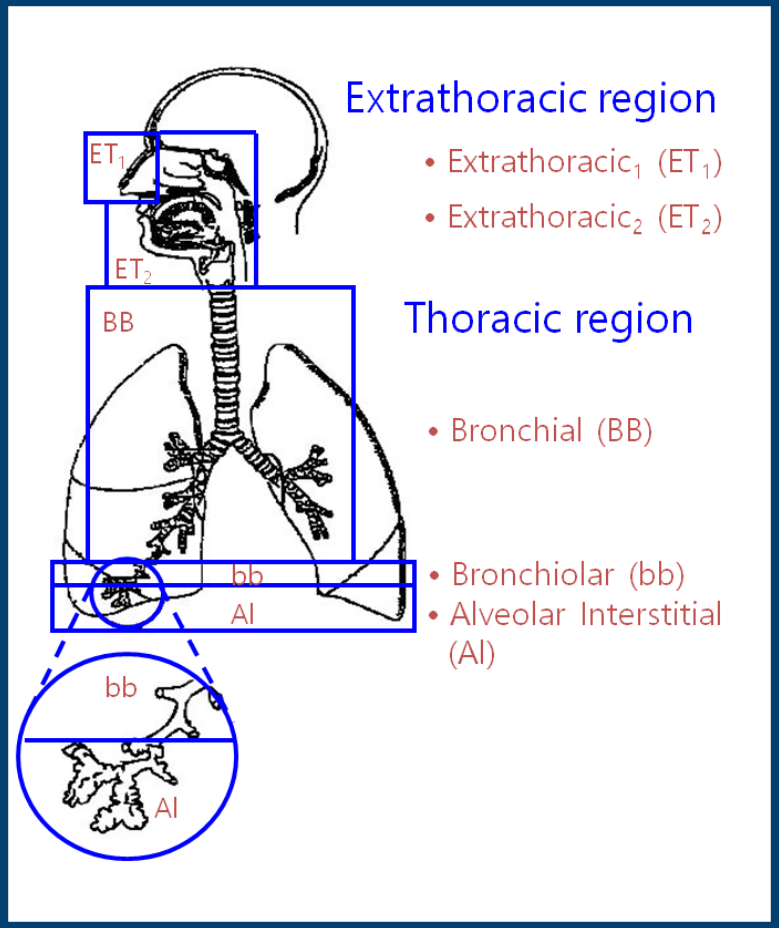
- Enforced “Act on Safety Control of Radioactive Rays around Living Environment” (2012) by a government agency, NSSC (Nuclear Safety and Security Commission)

❖ NSSC has worked to protect the public from NORM.

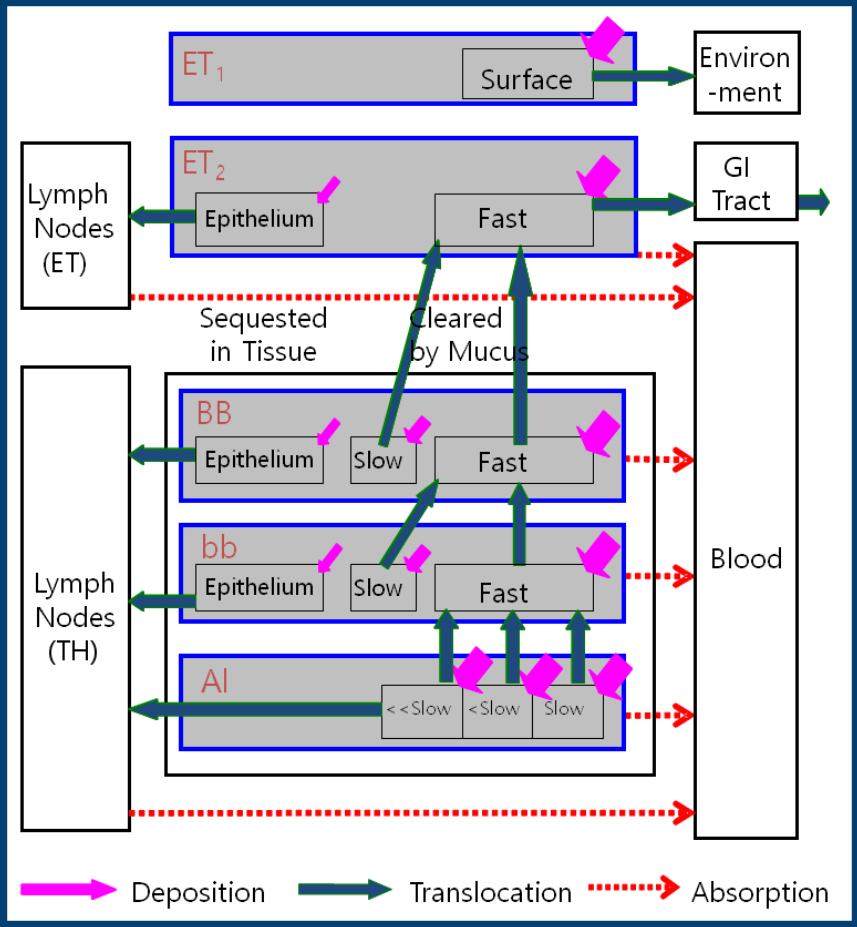
- Current status of NORM in the country (raw materials, residues, the products, etc.)
- Production process of the industry and flow of the NORM in the process
- Working environment of the workers
- Characterization of the NORM (radioactivity concentration, airborne particle properties, others for radiation protection)
- Radiation dose assessment

❖ ICRP 66 Human Respiratory Tract Model (HRTM)

- ✓ Radiation dose due to particle inhalation can be estimated by ICRP 66 HRTM.



Respiratory tract morphometry

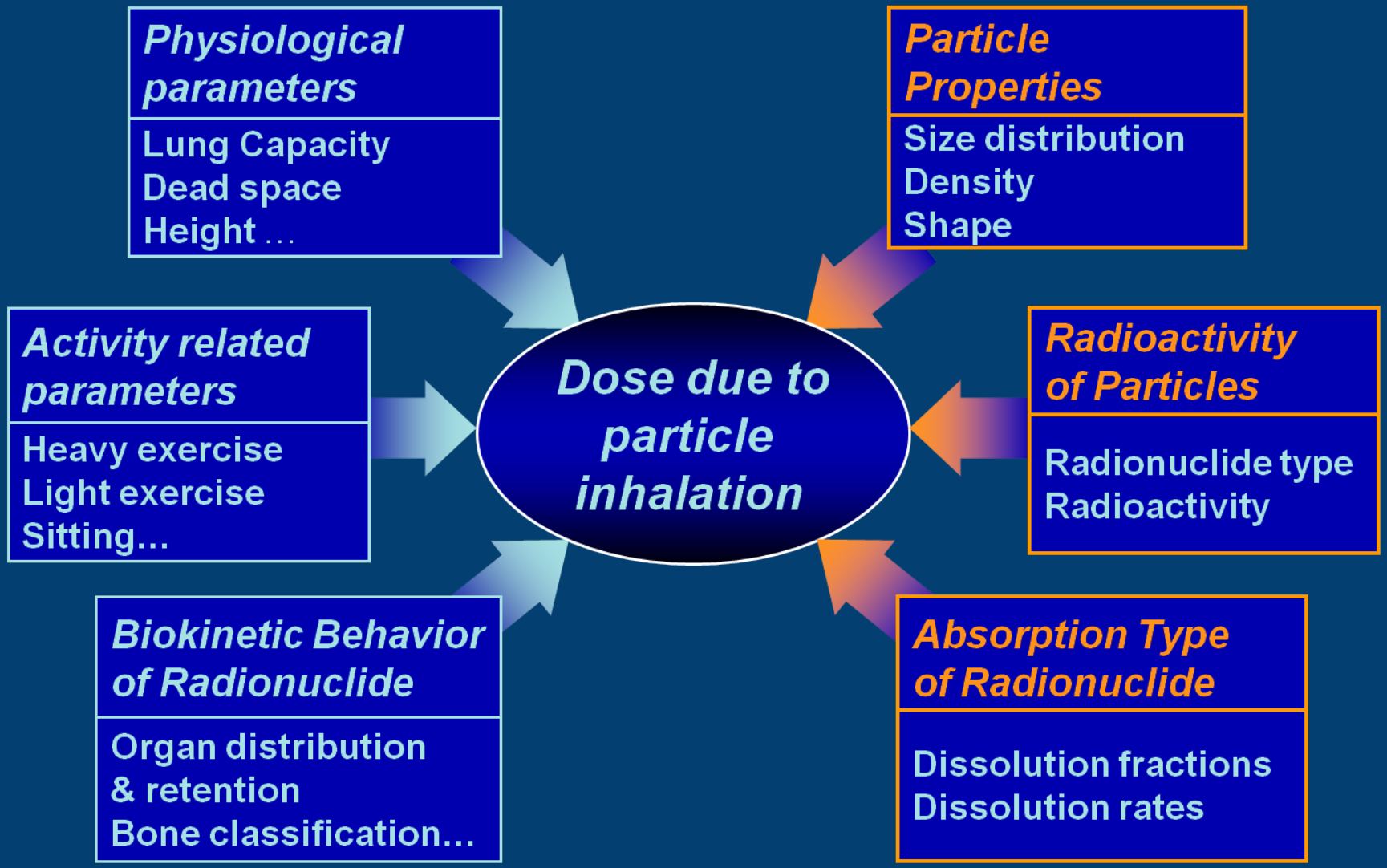


Deposition & clearance compartment model

❖ ICRP 66 Human Respiratory Tract Model

- ✓ HRTM for radiological protection
- ✓ Contents
  - Morphometry
  - Respiratory physiology
  - Radiation biology
  - Deposition model
  - Clearance model
  - Dosimetry model
- ✓ Advantages
  - Ability to explicitly consider particle properties
  - (eg) particle size distribution, shape, density, etc.

❖ Parameters Influencing Inhalation Dose



Objectives

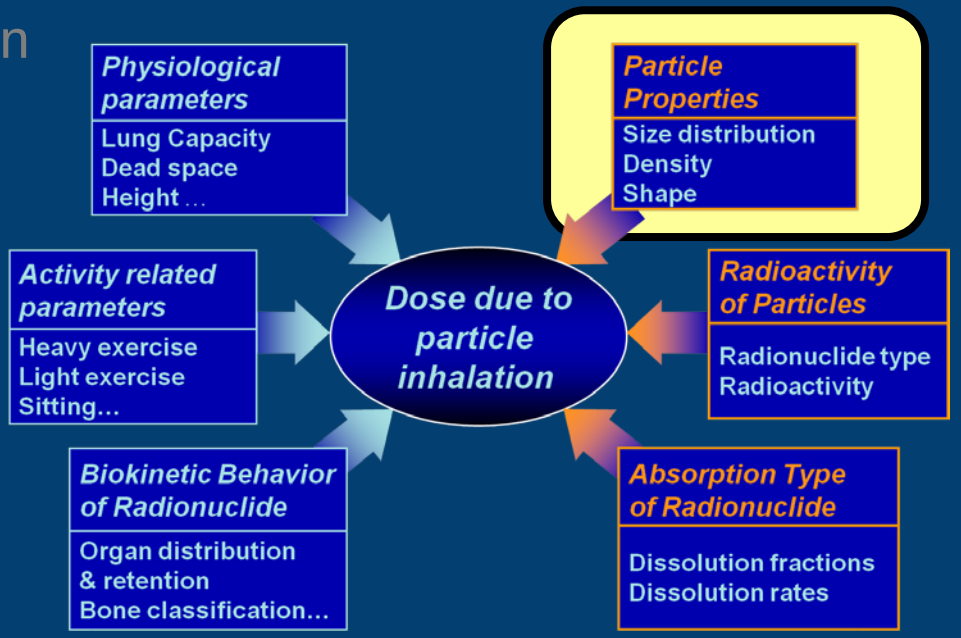
- **To characterize airborne particles containing natural radionuclides in the coal-fired power plants**
  - **To study sensitivity of inhalation dose to particle properties**
  - **To establish a database of particle properties, including particle size distribution, shape, and density.**
  - **To establish a database of radionuclide concentrations in the NORM.**

☞ **The database will be used for site-specific assessment of radiation doses to workers.**

Dose Sensitivity to Particle Properties

Particle Properties Influencing Dose

- **Airborne particle properties necessary for internal dosimetry**
  - Particle size distribution
  - Particle density
  - Particle shape
  - Radioactivity concentration
  - Solubility in the lung

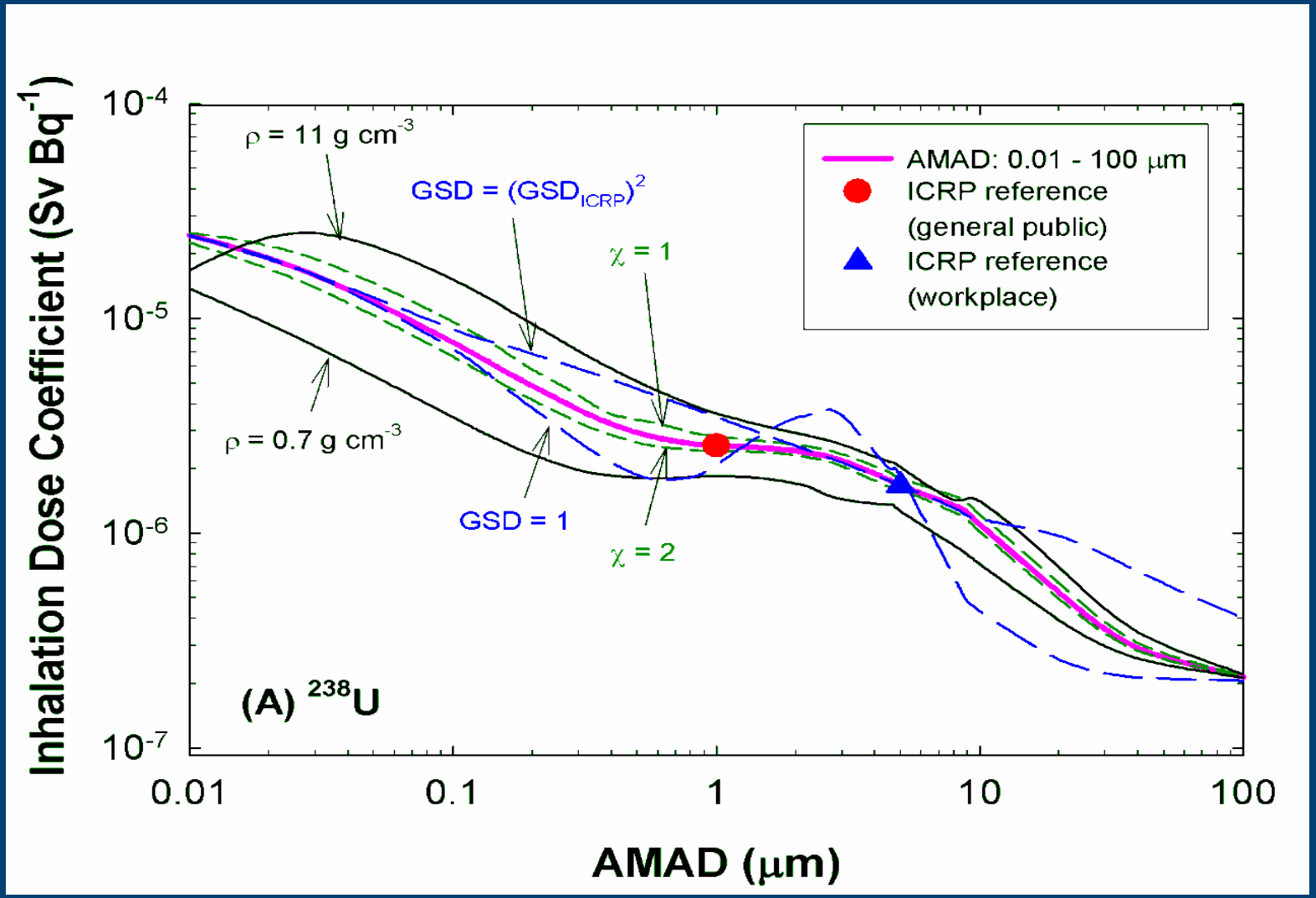


Input Parameters for Dose Sensitivity Study

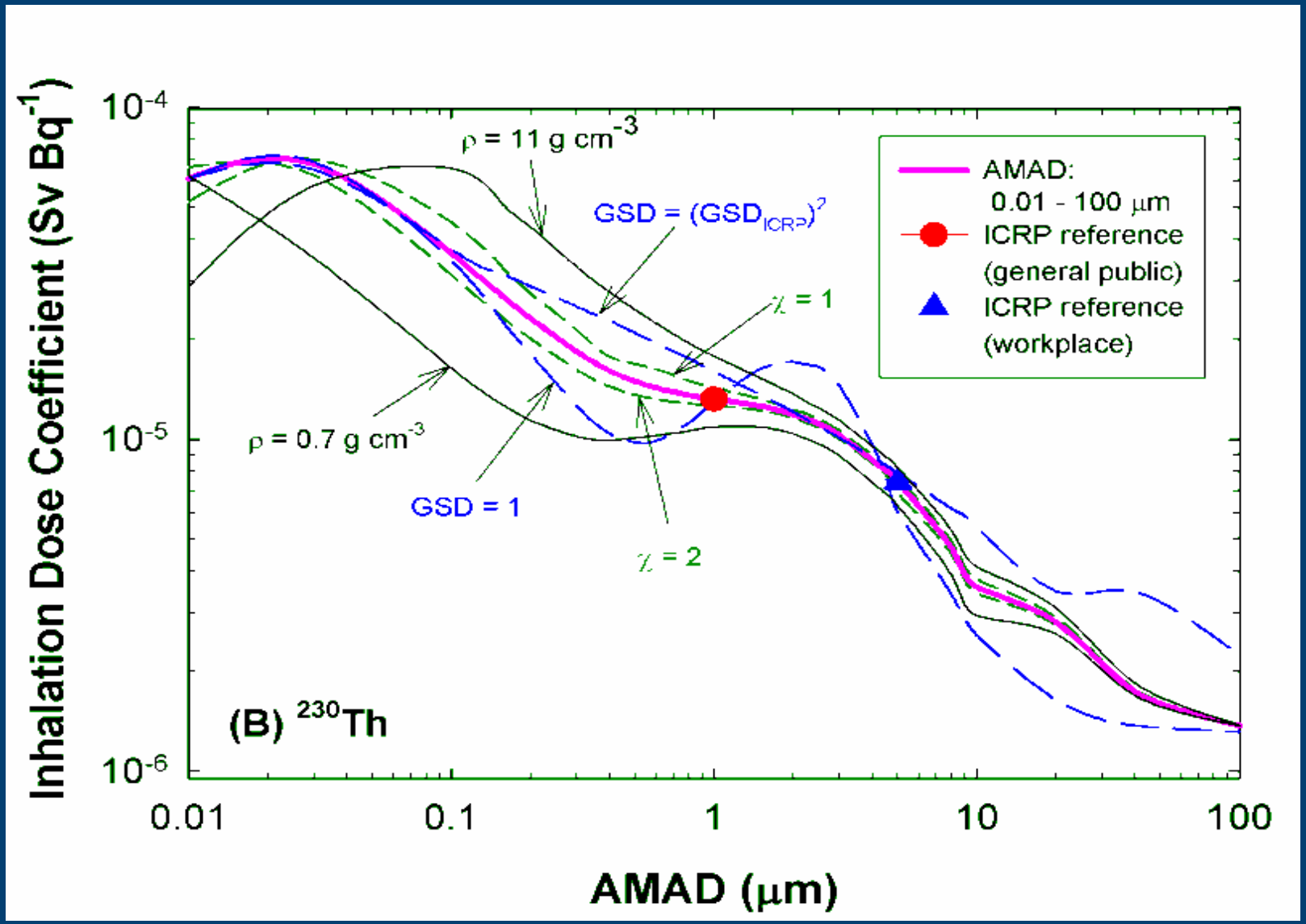
Aerosol Parameters	ICRP 66 Reference Values	Input Parameters
AMAD	5 μm (workplace) 1 μm (general public)	0.01 – 100 μm
GSD	2.5 (5 μm AMAD) 2.47 (1 μm AMAD)	1 and GSD_{ICRP66}^{2}
Density	3 g/cm	0.7 and 11 g cm^{-3}
Shape factor	1.5	1 and 2
Absorption type	type M (^{238}U) type S (^{230}Th)	type M (^{238}U) type S (^{230}Th)

Dose Sensitivity to Particle Properties

- U-238



❖ Th-230


Inhalation Dose Coefficient (Sv Bq^{-1})
10^{-4}
10^{-5}
10^{-6}
0.01
0.1
1
10
100
AMAD (μm)
ρ = 11 g cm^{-3}
GSD = (GSD$_{ICRP}$)^2
χ = 1
ρ = 0.7 g cm^{-3}
GSD = 1
χ = 2
(B) ^{230}Th
AMAD:
0.01 - 100 μm
ICRP reference
(general public)
ICRP reference
(workplace)

Properties of Airborne Particles

Airborne Particle Concentration and Size Distribution

Sampling Facilities & Concerning Areas

- 2 coal-fired power plants

Plant	Sampling Location
Coal-fired plant A	Coal yard (exterior) Fly-ash silo
Coal-fired plant B	Unloading dock of anthracite coal Coal yard (interior) Fly-ash silo

Coal yard (exterior)

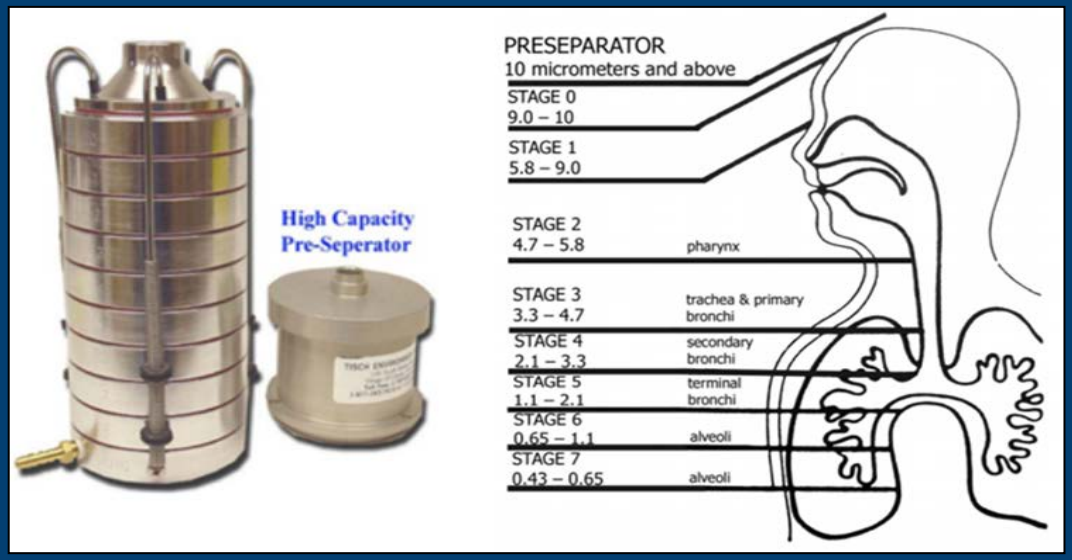
Unloading dock

Coal yard (interior)

Fly-ash silo

Air Sampling

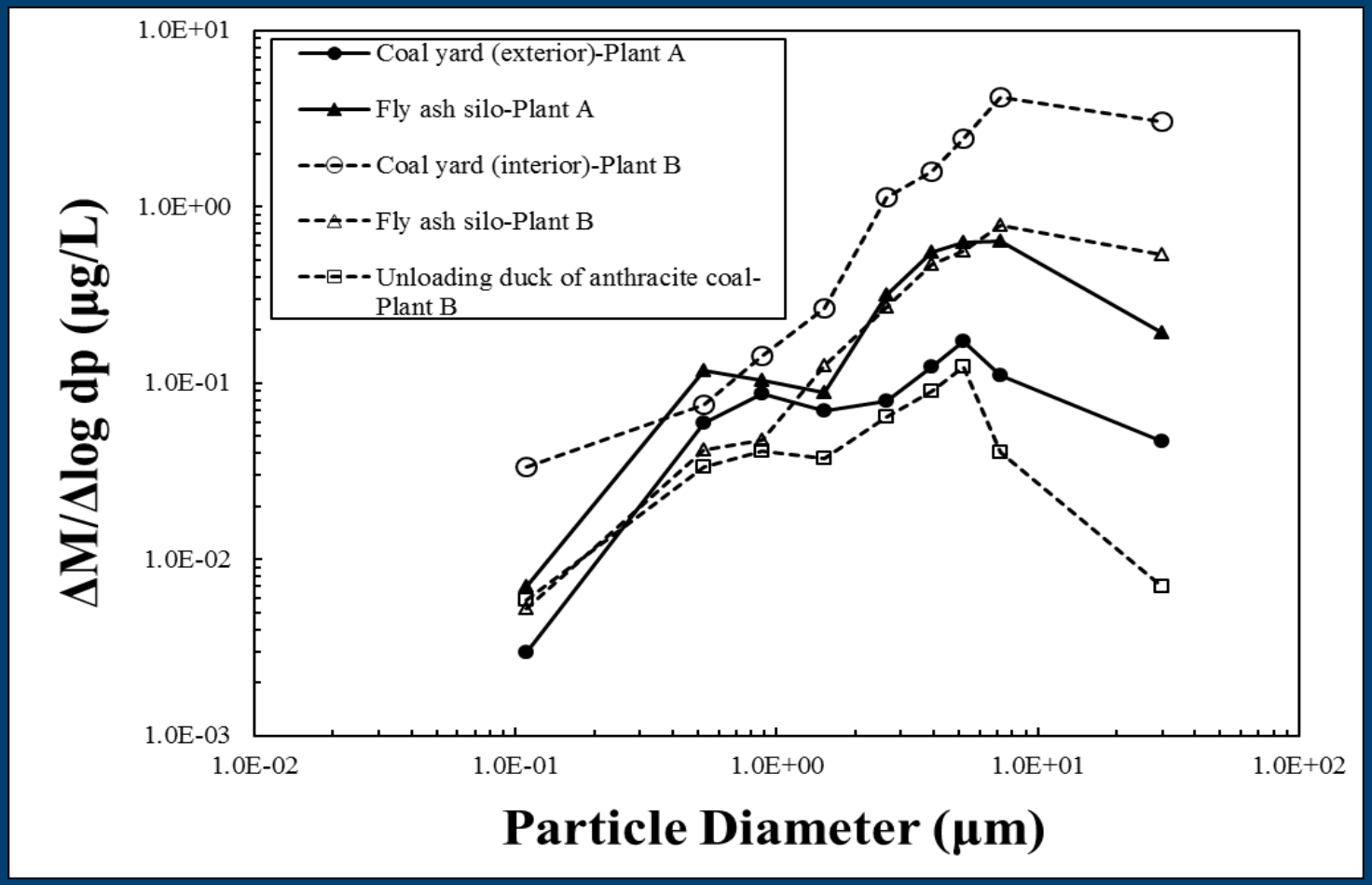
- 8-stage cascade impactors



Stage	Range of Collected Aerosols (μm)	Geometric mean of Aerosols (μm)
0	9.00-100	30.00
1	5.80-9.00	7.22
2	4.70-5.80	5.22
3	3.30-4.70	3.94
4	2.10-3.30	2.63
5	1.10-2.10	1.52
6	0.65-1.10	0.88
7	0.43-0.65	0.53
filter	0.03-0.43	0.11

Particle Size Distribution

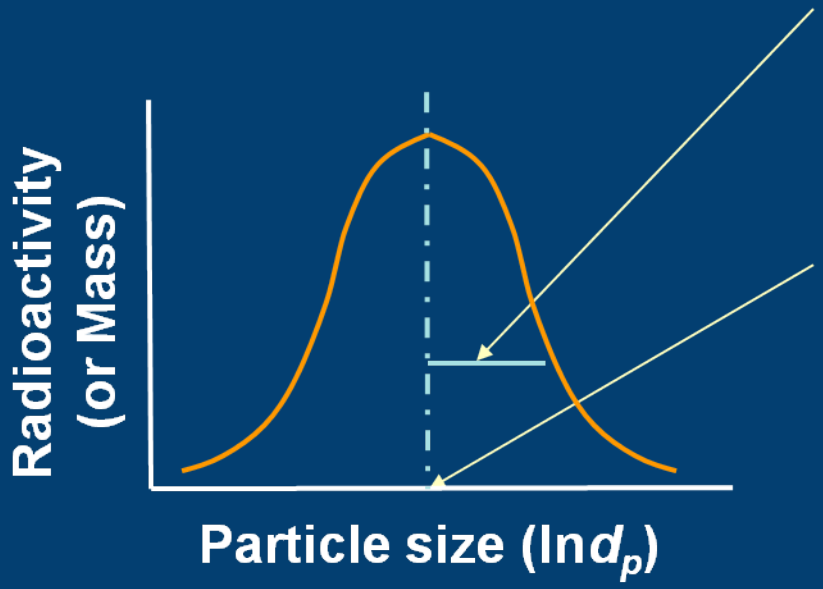
- Range : 0.03-100 μm
- Highest concentration : 4.7-5.8 & 5.8-9.0 μm



- Various with processing area
- Similar distributions were shown at same processing area from Coal-fired plant A & B.
- Different distributions at coal yard
  - Due to the difference of storage facilities
  - Exterior storage (A) and interior storage (B)

Reference Aerosol Parameters in ICRP 66

- In the absence of particle information, ICRP 66 HRTM suggests reference aerosol parameters.
- Reference aerosol parameter



✓ **Size distribution**

- Log-normal distribution
- GSD = 2.5 (5 μm AMAD)
- GSD = 2.47 (1 μm AMAD)

✓ **Median particle size (AMAD)**

- Occupational exposure : 5 mm
- Environmental exposure : 1 mm

✓ **Shape factor (χ):**

- 1.5

✓ **Mass density:**

- 3 g/cm^3

Airborne Particle Shape and Density

Particle Deposition Model in ICRP 66

- Filtration efficiency (η)
  - Function of aerodynamic diameter (d_{ae}) and thermodynamic diameter (d_{th})

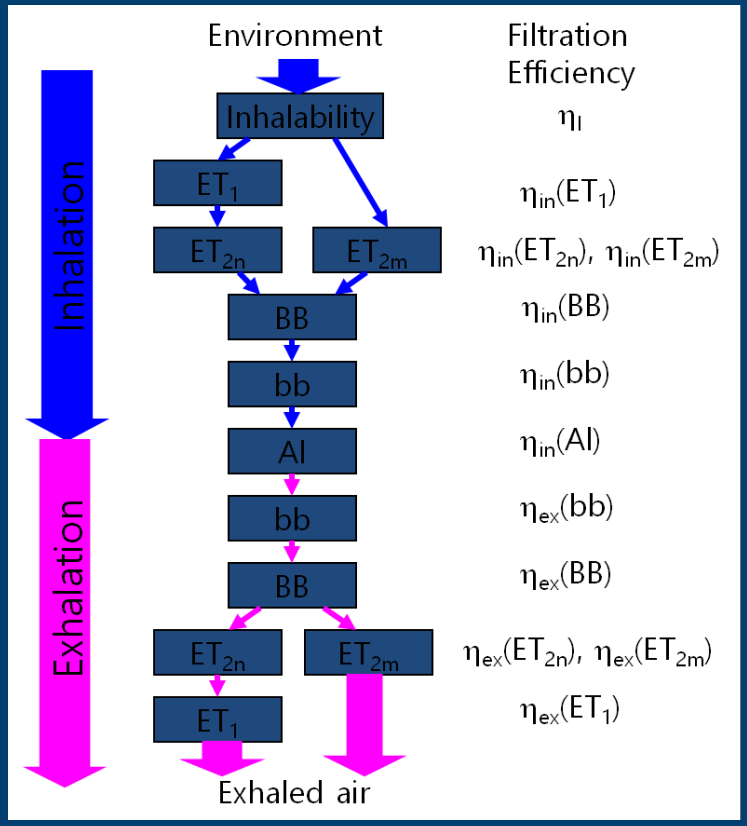
- Relation d_{ae} & d_{th}

$$d_{th} = d_{ae}\sqrt{\frac{\chi\rho_0}{\rho}\times\frac{C(d_{ae})}{C(d_{th})}}$$

χ : shape factor

ρ : particle density

C : slip correction factor



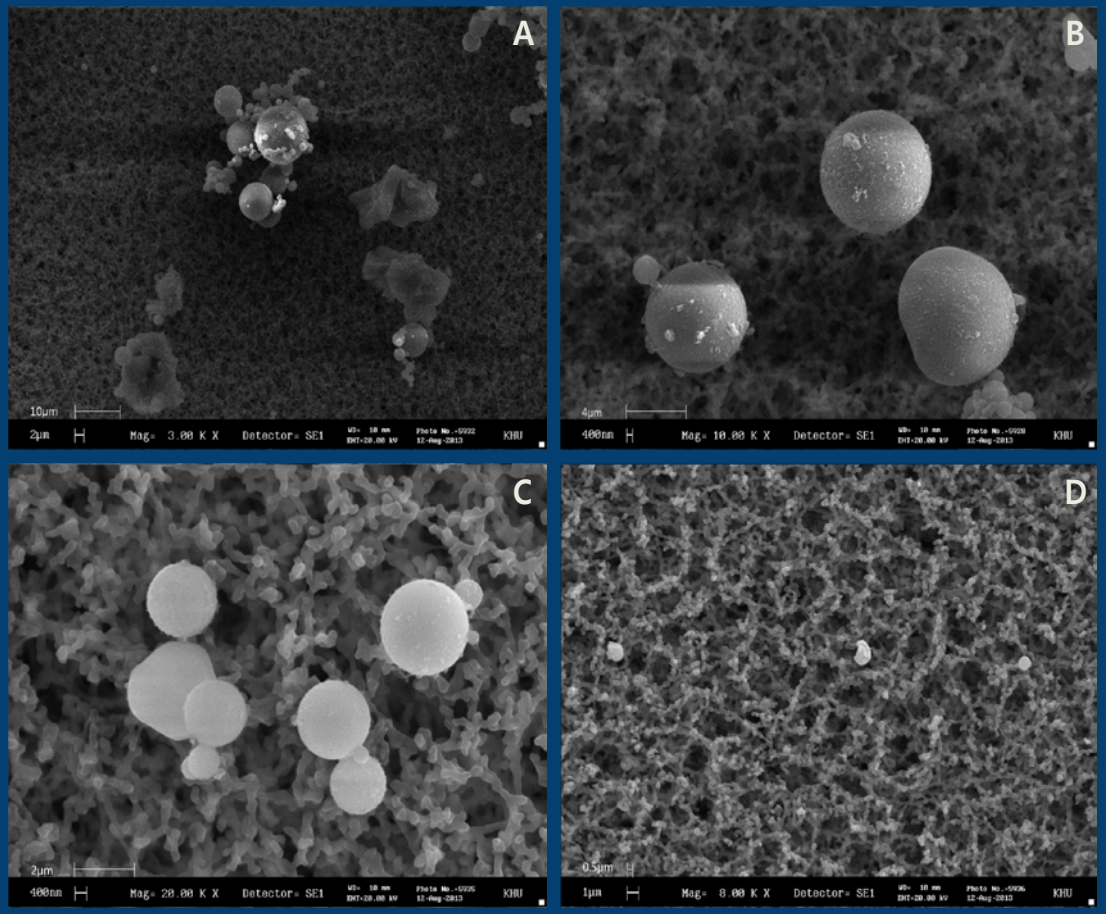
Shape and Density Analysis

- 12 samples of raw-materials and residues
- Analysis
  - SEM
  - Pycnometer

Shapes of Airborne Particles

- Spherical particles were shown at all stages

  → Particle shape factor (χ) : 1



(A) 0 stage

(B) 3 stage

(C) 5 stage

(D) 7 stage

Mass Density of Particles

Plant	Location	Sample	Density (g/cm^3)
Plant A	Coal yard (exterior)	Bituminous coal (Australia) Bituminous coal (Canada) Bituminous coal (Indonesia) Bituminous coal (Russia) Bituminous coal (U.S.A.)	1.4 ± 0.01 1.4 ± 0.01 1.4 ± 0.02 1.4 ± 0.03 1.5 ± 0.01
	Fly-ash silo	Fly ash	2.4 ± 0.01
	Bottom-ash landfill	Bottom ash	1.5 ± 0.04
	FDG gypsum storage	FDG gypsum	2.4 ± 0.02
Plant B	Unloading dock of bituminous coal	Bituminous coal (Russia)	1.5 ± 0.05
	Unloading dock of anthracite coal	Anthracite coal (Domestic)	2.1 ± 0.03
	Fly-ash silo	Fly ash	2.5 ± 0.03
	Bottom-ash landfill	Bottom ash	2.9 ± 0.05

❖ Coal

- Bituminous coal : 1.4 - 1.5 g/cm3
- Anthracite coal : 2.1 g/cm3

❖ Ash

- Fly ash : 2.4 - 2.5 g/cm3
- Bottom ash
  - . 1.5 g/cm^3 (Plant A) ~ 2.9 g/cm^3 (Plant B)
  - . Plant A : Use of only bituminous coal
  - · Plant B : Use of bituminous coal and anthracite coal

❖ FDG (flue-gas desulfurization) gypsum

- 2.4 cm3

Radionuclide Concentrations

Radioactivity Measurement

- HPGe

Radionuclide Concentration

- Ra-226, 228 : under 1 Bq/g

  → Exemption level

- Plant A

Location	Sample	Activity Concentration (Bq/kg)		
		Ra-226	Ra-228	K-40
Coal yard (exterior)	Coal (Australia)	18 ± 5	16 ± 3	77 ± 5
	Coal (Canada)	8 ± 2	5 ± 1	23 ± 3
	Coal (Indonesia)	7 ± 1	13 ± 2	33 ± 3
	Coal (Russia)	20 ± 3	14 ± 2	66 ± 4
	Coal (USA)	18 ± 3	12 ± 2	88 ± 5
Fly-ash silo	Fly ash	151 ±14	123 ± 10	325 ± 17
Bottom-ash landfill	Bottom ash	103 ± 10	94 ± 9	455 ± 23
FDG gypsum storage	FDG gypsum	6 ± 1	2 ± 1	27 ± 2

❖ Plant B

Location	Sample	Activity Concentration (Bq/kg)		
		Ra-226	Ra-228	K-40
Unloading dock of bituminous coal	Coal(Russia)	22 ± 3	24 ± 3	59 ± 4
Unloading dock of anthracite coal	Coal(Domestic)	59 ± 6	75 ± 7	489 ± 24
Fly-ash silo	Fly ash	87 ± 9	99 ± 8	388 ± 20
Bottom-ash landfill	Bottom ash	83 ± 8	100 ± 9	536 ± 26

Summary

Summary

- Radiation dose due to particle inhalation greatly depends on particle properties

  - Dose assessment without such information may distort radiation dose to unrealistic value.

- A database of airborne particle properties were established at 2 coal-fired power plants

  - The properties including airborne particle concentration and size distribution, shape, mass density, and radionuclide concentrations

- The findings can be used as a basic data for development of safety standard and guide and for practical radiation safety management.

Always we keep watching
our Radiation Safety

Thank You

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