香港輻射防護學會
Hong Kong Radiation Protection Society

Hong Kong Institute of Occupational and Environmental Hygiene
香港職業及環境衛生學會 A member of IOHA and HKFMS

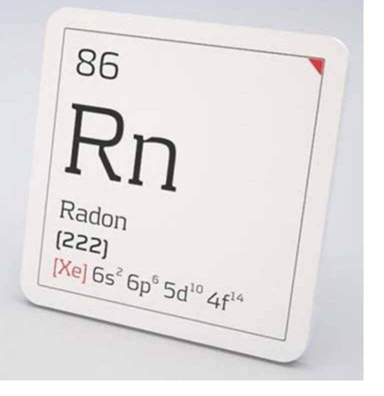
Radon and Building Materials: Safety Standards and Measurements

Presented by ST Yip

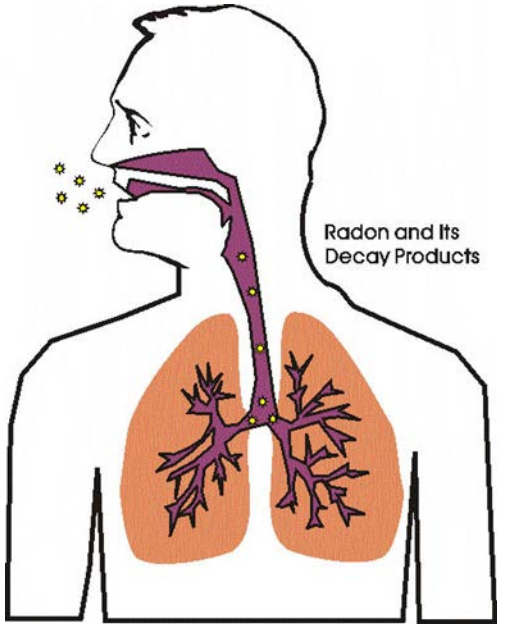
on 28 June 2016

Contents

- Radon
- Radiation Protection on Naturally Occurring Radioactive materials (NORM) and reference levels
- Standards on Building Materials for Radon
- Measuring of Radon

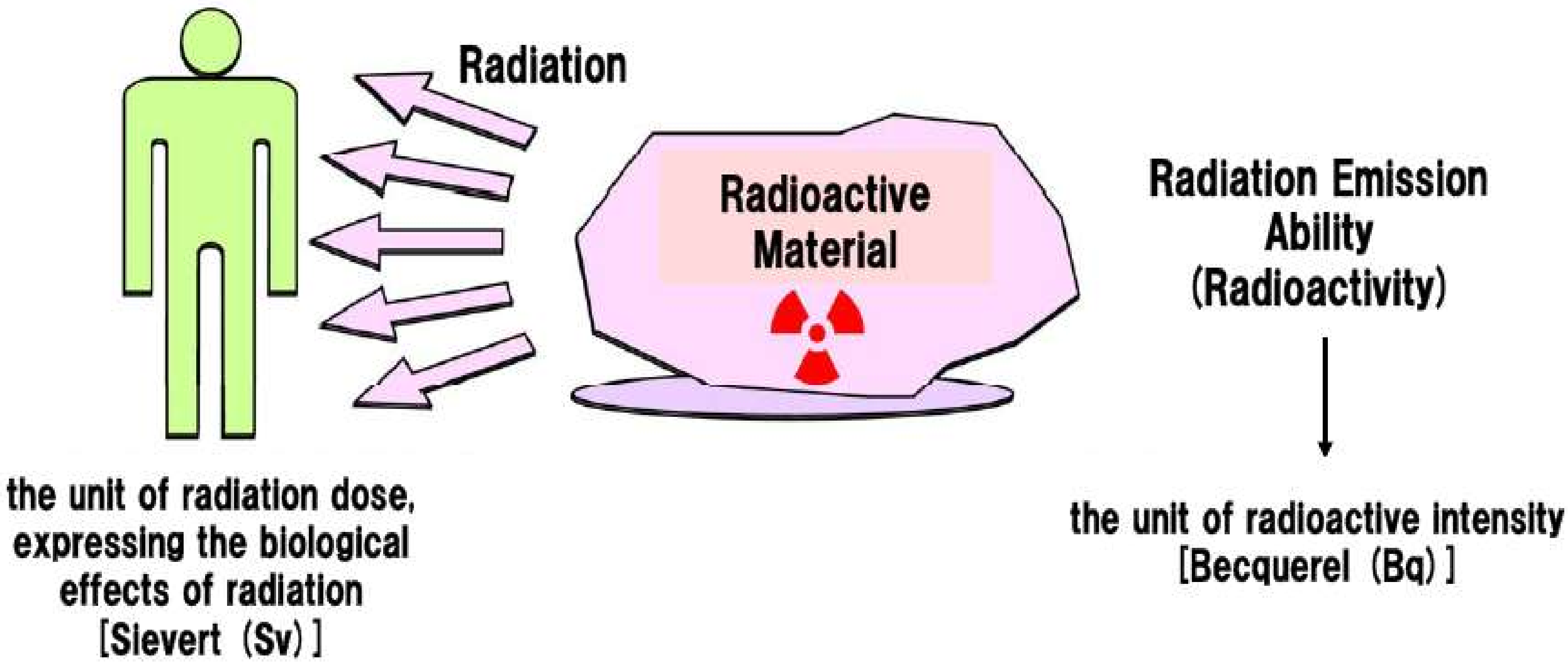


Introduction

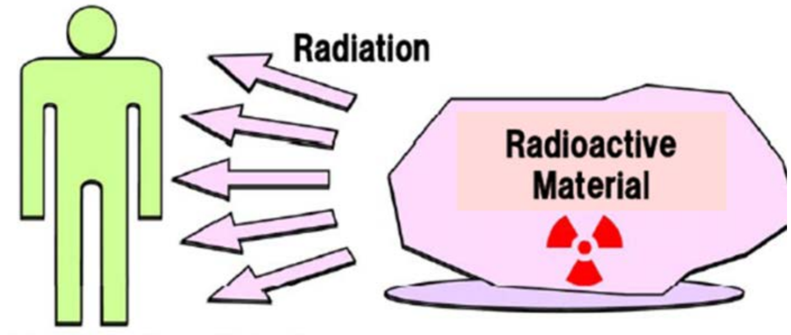


- Radon
  - Radioactive gas in air
  - One of the IAQ parameters
    - For dwellings
    - For offices and public areas
  - Major source of our radiation dose
  - From U and Th in soil and rocks: building materials (Naturally Occurring Radioactive Materials: NORM)

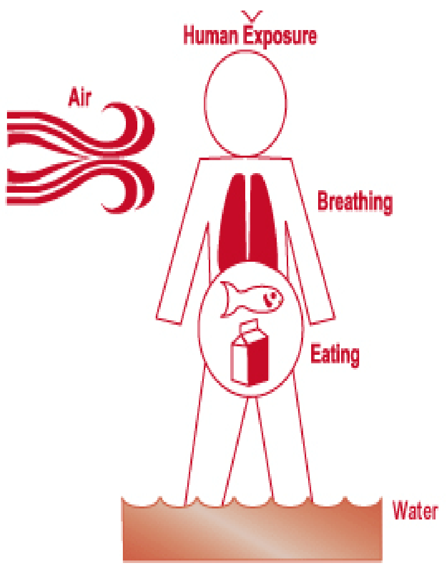
Dose, radiation and Radioactivity



Hazards/Dose



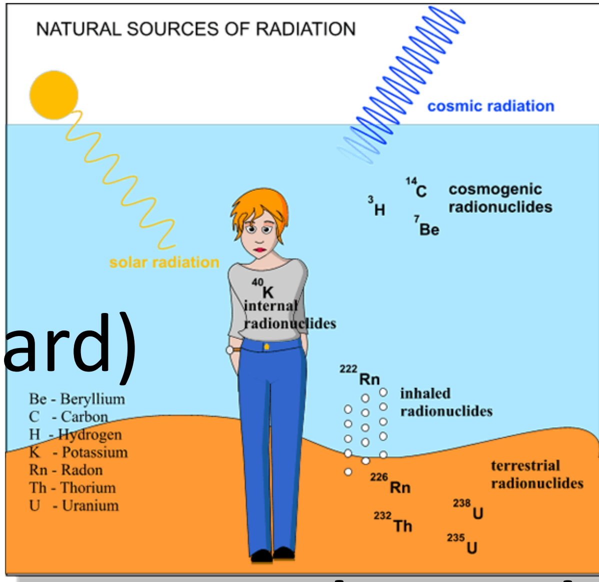
- External hazards/dose
  : Irradiated by radiation
  – **Radon** emits **alpha** that cannot passes through the dead layer of skin; **NO External Hazard**.
- Internal hazards/dose
  : Intake of Radioactive materials
  – Inhalation of **Radon**: dose to the lung



Radon

- An element of atomic number 86
- a colourless and odourless radioactive gas.
- Emits alpha rays.
- It occurs naturally as a decay product of radium. Present in most soil and rocks, granite in particular, it decays further into a series of short-lived radioisotopes that take the form of very tiny particles.
- Epidemiological studies show that exposure to radon or its decay products may increase the incidence of lung cancer.
- Quoted from 'Control of Radon Concentration in New Buildings' EPD ProPECC PN 1/99.

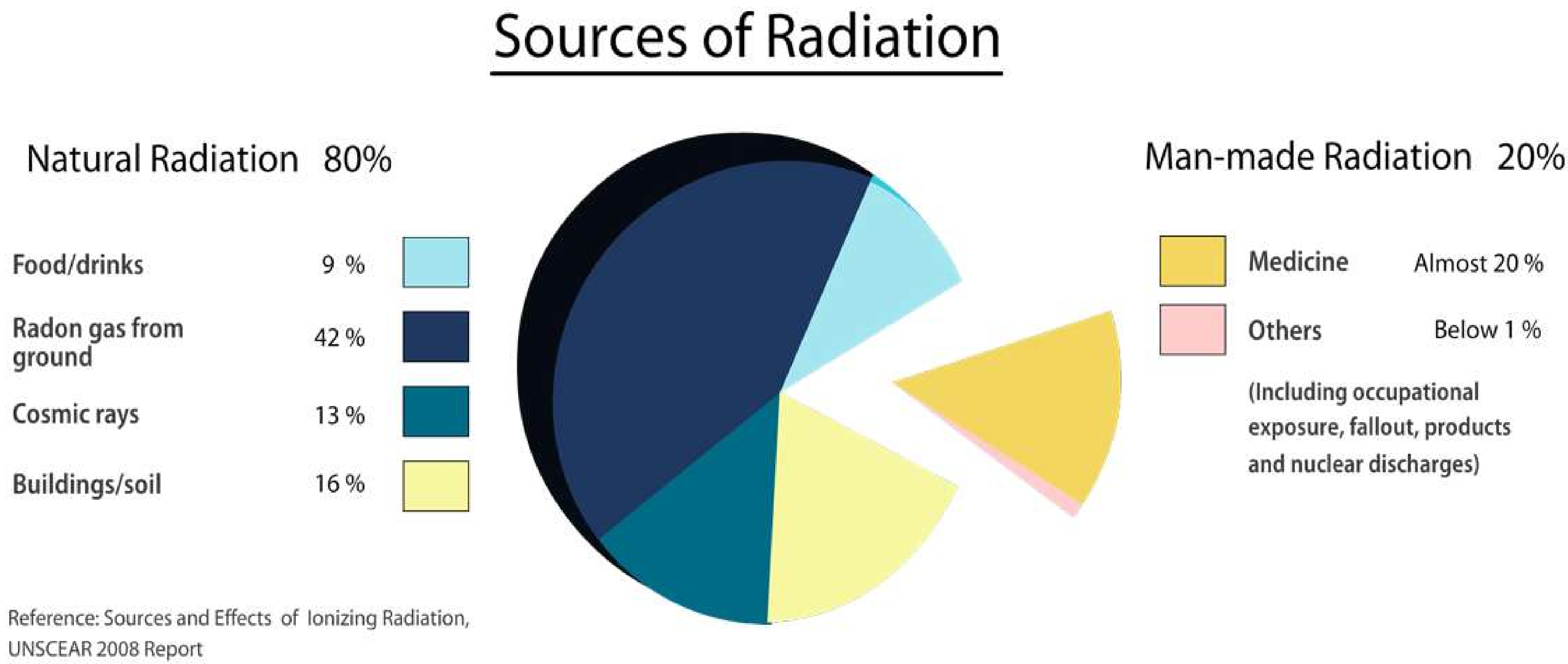
Natural Radiation sources in our environment



- radon, (internal hazard)
- food and drink, (internal hazard)
- cosmic ray, (external hazard)
- gamma ray from building materials and soil/rock(external hazard)
- On average, a person in Hong Kong receives a radiation dose of about 2.5 mSv/a from all natural sources of radiation

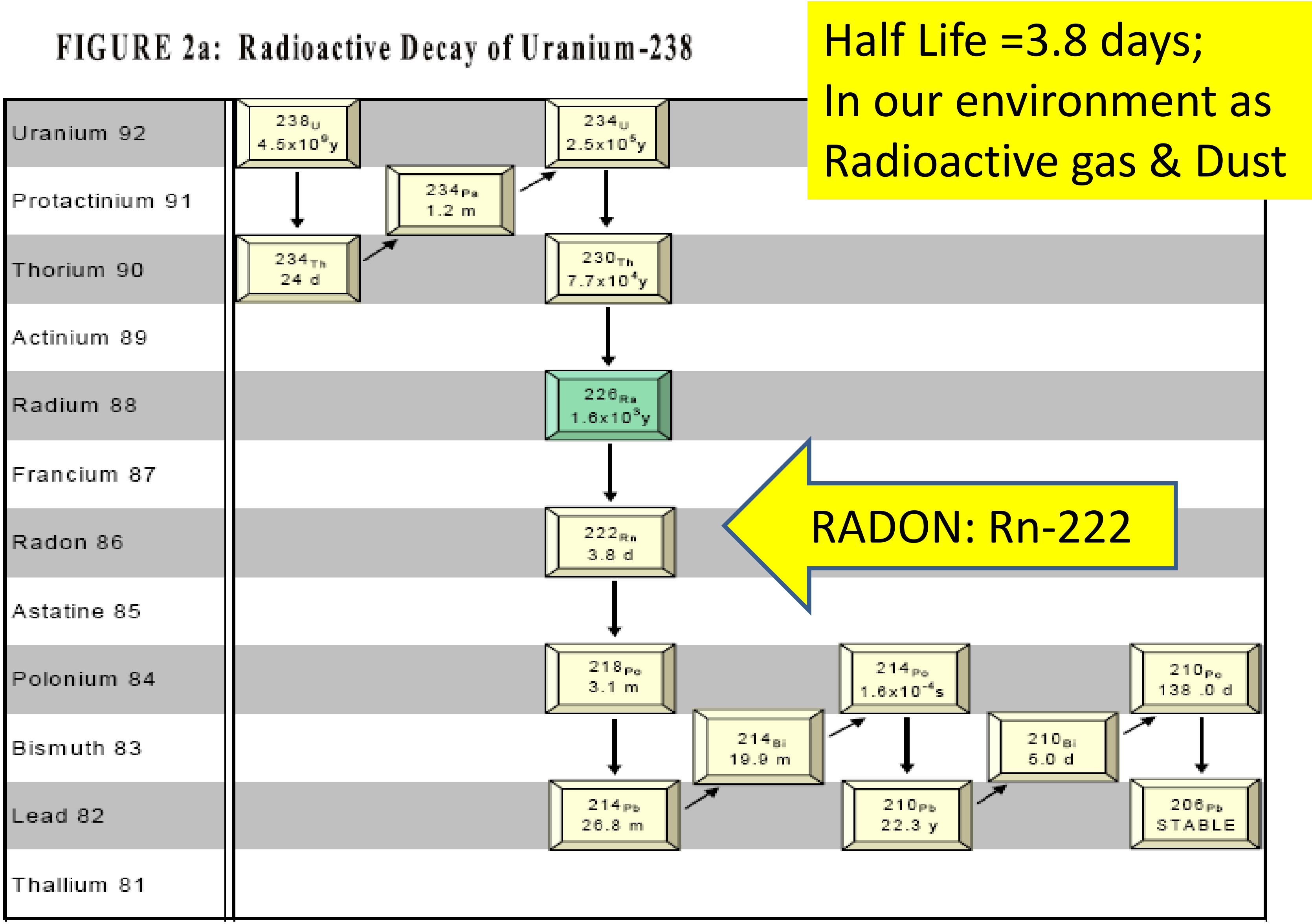
source of information: www.weather.gov.hk/blog/en/archives/00000099.htm

Radon and our radiation dose



Adopted from www.dbcp.gov.hk/eng/safety/knowledge_clip_image003.jpg

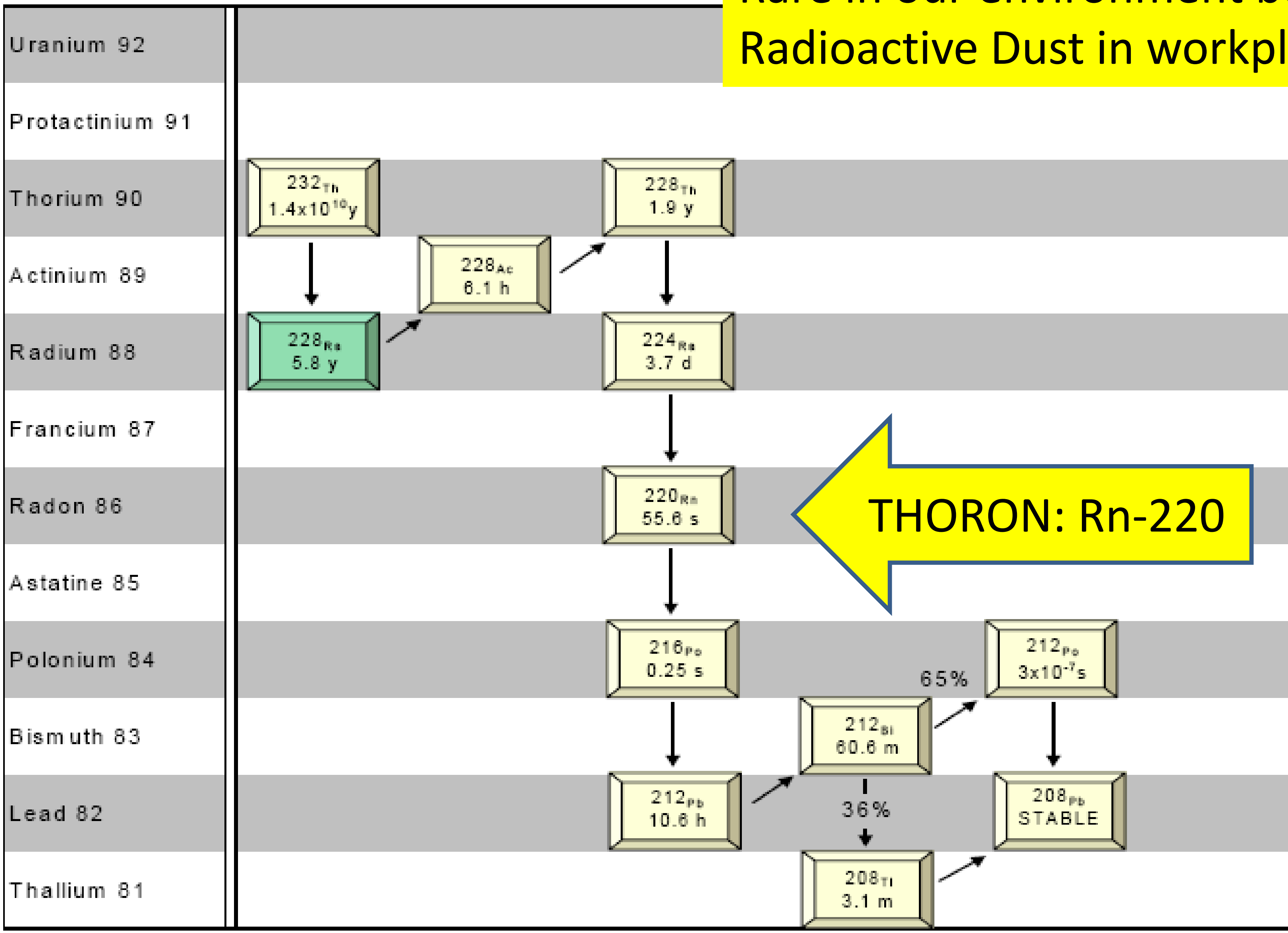
Annual Dose due to Radon: Worldwide average 2.4 mSv; 25% <1 mSv; 65% in 1-3 mSv; 10% >3mSv



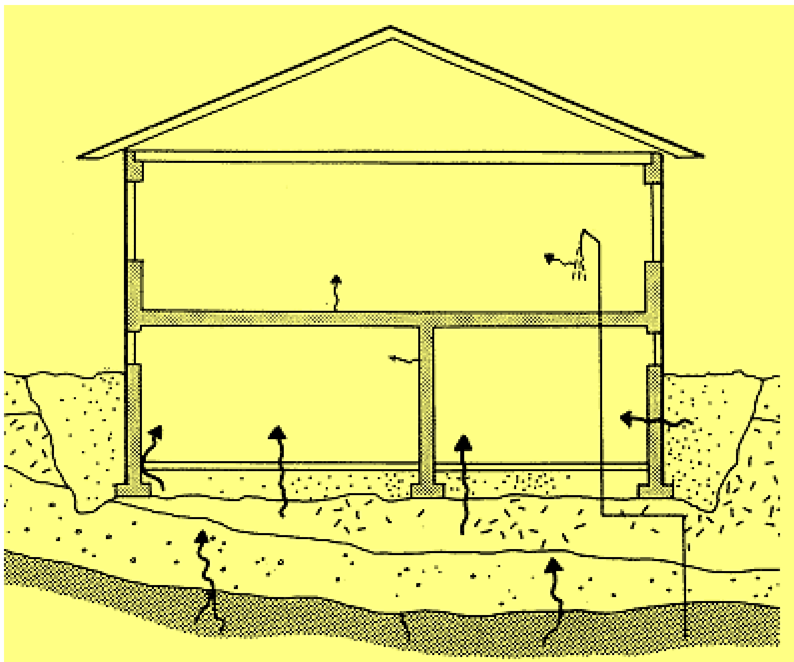
Source: Technical Report on Management of Naturally Occurring Radioactive material in waste 2005, Draft report

Half Life =55.6s;
Rare in our environment but
Radioactive Dust in workplace

FIGURE 2b: Radiaocative Decay of Thorium-232



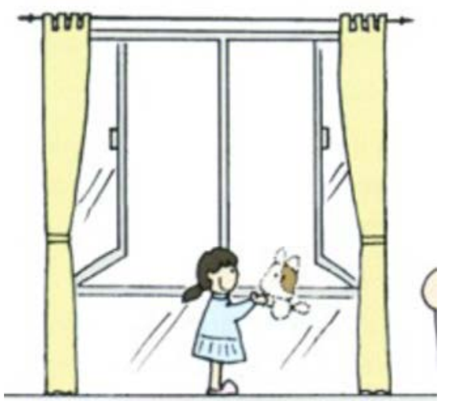
Houses, Basements and high rise Buildings



Radon from soil gas and building materials.

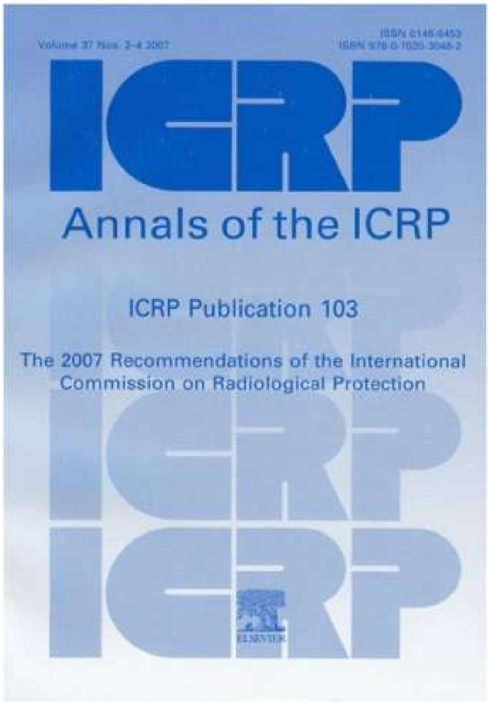
Radon and Radon Progeny

- Radon emits alpha
- Decay to fine radioactive particles (radon progeny)
- Indoor concentrations depends on
  - Rate of soil gas entry
  - building materials'
    - Radium contents
    - Emanate rate of radon
  - Rate of exchange with fresh Air



International Commission on Radiation Protection Recommendations

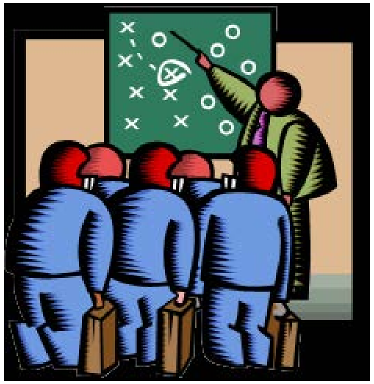
- Three Principles of Protection
  – Justification
  – Optimization of protection (ALARA)
  – Application of Dose Limits



Do they apply to Natural Occurring Radioactive Materials such as U, Th, K-40 and radon??

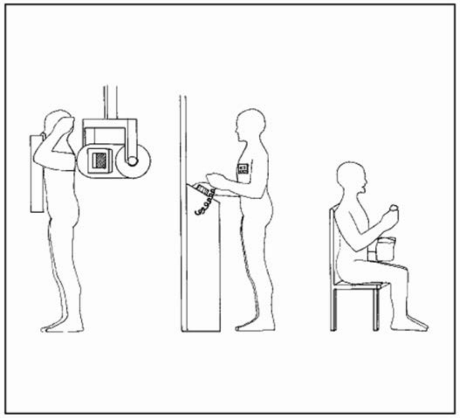
ICRP 103

ICRP recommendations 2007



- Three Exposure situations
  - Planned
  - Existing
  - Emergency

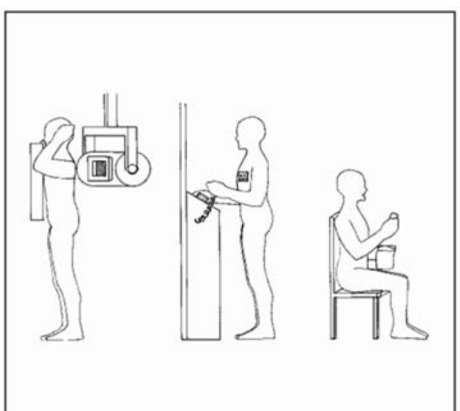
- Three categories of exposures
  - Medical
  - Occupational
  - Public

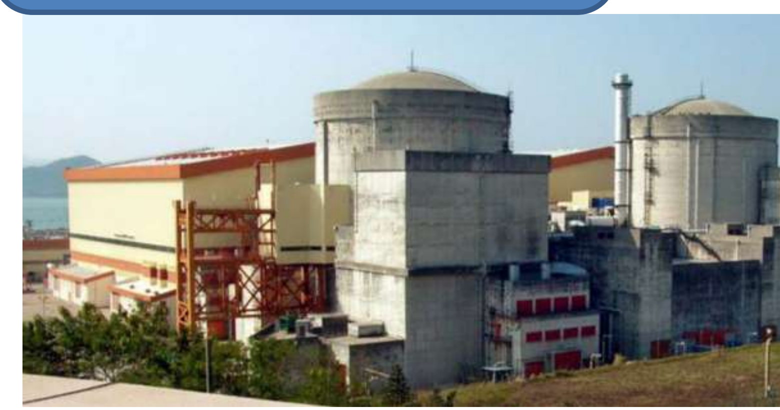


ICRP's system of protection

Type of Situation	Occupational Exposure	Public Exposure
Planned Exposure	**Dose Limit** **Dose Constraint**	**Dose Limit** **Dose Constraint**
Emergency Exposure		
Existing exposure		

Controlled by regulation





ICRP's system of protection

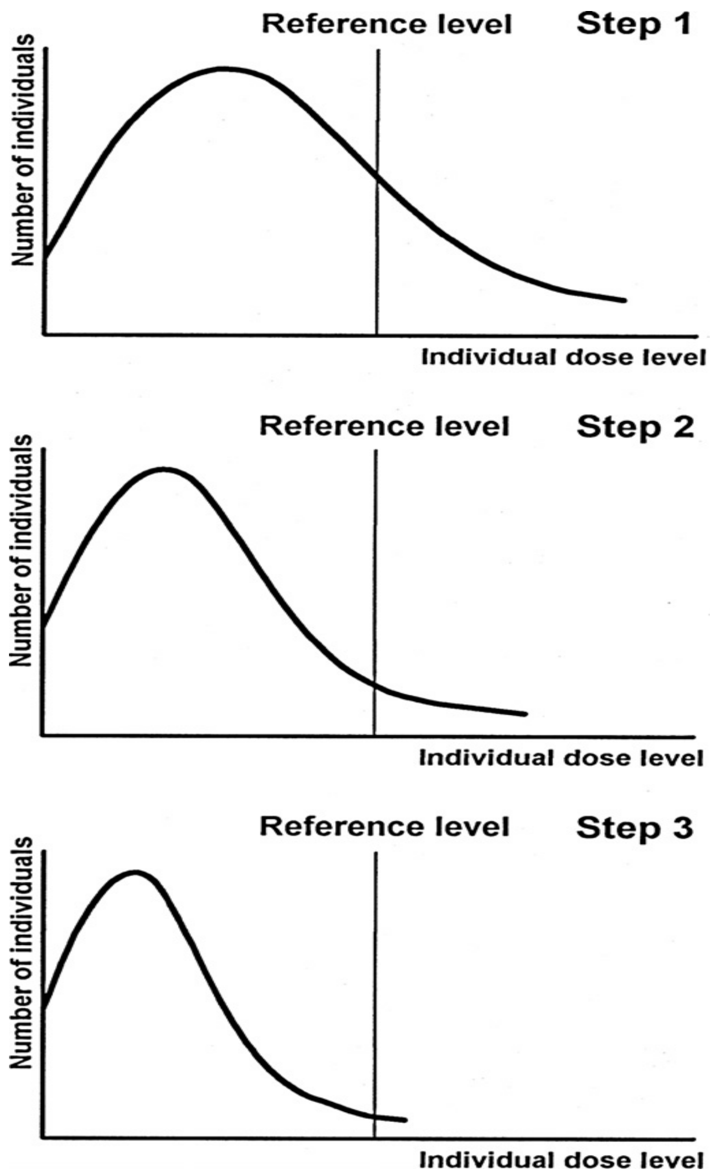
Type of Situation	Occupational Exposure	Public Exposure
Planned Exposure	Dose Limit Dose Constraint	Dose Limit Dose Constraint
Emergency Exposure	**Reference Level**	**Reference Level**

ICRP's system of protection

Type of Situation	Occupational Exposure	Public Exposure
Planned Exposure	Dose Limit Dose Constraint	Dose Limit Dose Constraint
Emergency Exposure	Reference Level	Reference Level
Existing exposure	**N.A.**	**Reference Level**

NOT a safe/hazardous Level beyond which health problems must occur.

Reference level in existing exposure situation



- The use of a reference level in an existing exposure situation and the evolution of the distribution of individual doses with time as a result of the optimization process.

  [Fig 4. Cap 6 ICRP 103]

Existing exposure situations – reference levels (ICRP)

- General reference levels (applicable to both natural and artificial sources):
  - Normally in the range 1–20 mSv/a
  - Commodities: ≤1 mSv/a
- Radon:
  - in terms of radon activity concentration in air
  - ≤300 Bq/m^3 in homes
  - ≤1000 Bq/m^3 in workplaces
  - These values are roughly equivalent to 10 mSv/a

IAEA BSS* Requirement 50:
Public exposure due to radon indoors

- The government shall provide information on levels of radon indoors and the associated health risks and, if appropriate, shall establish and implement an action plan for controlling public exposure due to radon indoors.
- Reference level for 222Rn for *dwellings and other buildings with high occupancy factors for members of the public* will *not exceed* an annual average activity concentration due to 222Rn of 300 Bq/m^3 (corresponding to 10 mSv)

*Basic Safety Standards for Protection against Ionising Radiation and for the Safety of Radiation Sources, IAEA, 2011

For implementation of ICRP recommendations

IAEA
International Atomic Energy Agency

IAEA BSS Requirement 52: Exposure due to radon in Workplaces

- The regulatory body shall establish a strategy for protection against exposure due to 222Rn in workplaces, including the establishment of an appropriate reference level for 222Rn.
- The reference level for 222Rn shall be set at a value that does not exceed an annual average activity concentration of 222Rn of 1000 Bq/m^3.

[56] On the assumption of an equilibrium factor for ^{222}Rn of 0.4 and an annual occupancy rate of 2000 hours, the value of activity concentration due to ^{222}Rn of 1000 Bq/m^3 corresponds to an annual effective dose of the order of 10 mSv.

IAEA BSS on NORM

- Exposure to natural sources – normally considered as an existing exposure situation
- However, certain exceptions : If the activity concentration of any of the radionuclides in the U and Th decay chain is above 1 Bq/g, apply requirements for planned exposure situations.

IAEA: Reference levels for radionuclides in commodities

Commodities (para 5.22):

- construction material
- food (FAO/WHO Codex)
- drinking water (WHO)

of reference level 1 mSv /a

Reference level for building materials

- Annual effective dose to the representative person generally that does not exceed a value of about 1 mSv.
- An activity concentration index for screening

- $$I = \frac{C_{Ra}}{300\ \mathrm{Bq/kg}} + \frac{C_{Th}}{200\ \mathrm{Bq/kg}} + \frac{C_K}{3\,000\ \mathrm{Bq/kg}}$$
- C_{Ra} is activity concentration of ^{226}Ra, C_{Th}:^{232}Th, C_K :^{40}K
- $I < 1$ for bulk materials or $I < 6$ for superficial materials (e.g. tiles), then annual effective dose less than reference level of 1 mSv

*Protection of the Public against Exposure Indoors due to Radon and Other Natural Sources of Radiation, SSG-32, IAEA 2015.

COUNCIL DIRECTIVE 2013/59/EURATOM

- to establish *reference levels* for **indoor radon** concentrations and for **indoor gamma radiation** emitted from **building materials**,
- and to introduce requirements on the ***recycling of residues*** from industries processing naturally-occurring radioactive materials into **building materials**.

Reference Level for Radon

The reference level for the annual average activity concentration in air shall not be higher than 300 Bq m^{-3} , unless it is warranted by national prevailing circumstances.

Apply to both dwellings and workplaces

EC Radiation Protection 112

- Radiological Protection Principles concerning The Natural Radioactivity of Building Materials
- Investigation Levels

Dose Criterion	0.3 mSv/a	1 mSv/a
Materials used in bulk amt. e.g. Concrete	$I \leq 0.5$	$I \leq 1$
Superficial and other materials with restricted use: Tiles, boards etc	$I \leq 2$	$I \leq 6$

GB 6763: 2000

建筑材料产品及建材用工业废渣放射性物质控制要求

4.1　建筑材料产品

4.1.1　建筑材料产品中的放射性核素镭—226、钍—232、钾—40的比活度应同时满足式(1)和式(2)要求：

$$\frac{C_{Ra}}{370}+\frac{C_{Th}}{260}+\frac{C_{K}}{4\ 200}\leqslant 1 \quad \cdots\cdots (1)$$

$$C_{Ra}\leqslant 200 \quad \cdots\cdots (2)$$

式中：C_{Ra}——建筑材料产品中的镭—226的放射性核素比活度，$Bq\cdot kg^{-1}$；

C_{Th}——建筑材料产品中的钍—232的放射性核素比活度，$Bq\cdot kg^{-1}$；

C_{K}——建筑材料产品中的钾—40的放射性核素比活度，$Bq\cdot kg^{-1}$。

GB6763: 2000

4.1.2　空心建筑材料制品

当空心建筑材料制品的空心率大于25%，或质量厚度小于8 g/cm^2 时，其放射性核素镭—226、钍—232、钾—40 的比活度的限值可适当放宽，但应同时满足式(3)和式(4)要求：

$$\frac{C_{Ra}}{410}+\frac{C_{Th}}{290}+\frac{C_K}{4\ 600}\leqslant 1 \quad \cdots\cdots (3)$$

$$C_{Ra}\leqslant 200 \quad \cdots\cdots (4)$$

式中：C_{Ra}——空心建筑材料制品中的镭—226 的放射性核素比活度，$Bq \cdot kg^{-1}$；

C_{Th}——空心建筑材料制品中的钍—232 的放射性核素比活度，$Bq \cdot kg^{-1}$；

C_K——空心建筑材料制品中的钾—40 的放射性核素比活度，$Bq \cdot kg^{-1}$。

GB 6763: 2000

4.2 建材用工业废渣

利用工业废渣生产建筑材料产品或空心建筑材料制品时，工业废渣中的放射性核素镭—226、钍—232、钾—40 的比活度的控制要求按下列条款执行。

4.2.1 若工业废渣中的放射性核素比活度同时满足式(1)和式(2)或式(3)和式(4)时，其使用量不受限制。

4.2.2 若工业废渣中的放射性核素比活度不满足式(1)和式(2)或式(3)和式(4)时，必须考虑工业废渣的掺量，使其产品的放射性核素比活度能同时满足式(1)和式(2)或式(3)和式(4)。

4.2.3 若利用含碳工业废渣(如煤矸石、粉煤灰、煤渣等)生产烧结建材制品时，工业废渣的放射性核素比活度应进行烧失量校正，在除以(1—B)后(B 为含碳工业废渣在 1 050℃的烧失量，%)，应满足 4.2.1 或 4.2.2 的要求。

4.3 室内装饰材料

室内装饰材料放射性物质控制要求按 4.1.2 执行。

GB 6566 2001
Limit of radionuclides in Bldg Materials

外照射指数　external exposure index

本标准中外照射指数是指:建筑材料中天然放射性核素镭-226、钍-232 和钾-40 的放射性比活度分别除以其各自单独存在时本标准规定限量而得的商之和。

$$表达式为:I_{\gamma}=\frac{C_{Ra}}{370}+\frac{C_{Th}}{260}+\frac{C_{K}}{4\ 200}$$

内照射指数　internal exposure index

本标准中内照射指数是指:建筑材料中天然放射性核素镭-226 的放射性比活度,除以本标准规定的限量而得的商。

$$表达式为:I_{Ra}=\frac{C_{Ra}}{200}$$

GB 6566 2001
Limit of radionuclides in Bldg Materials

3.1 **建筑主体材料**

当建筑主体材料中天然放射性核素镭-226、钍-232、钾-40 的放射性比活度同时满足 $I_{Ra} \leqslant 1.0$ 和 $I_{\gamma} \leqslant 1.0$ 时，其产销与使用范围不受限制。

对于空心率大于 25%的建筑主体材料，其天然放射性核素镭-226、钍-232、钾-40 的放射性比活度同时满足 $I_{Ra} \leqslant 1.0$ 和 $I_{\gamma} \leqslant 1.3$ 时，其产销与使用范围不受限制。

3.2 装修材料

3.2.1 **A 类装修材料**

装修材料中天然放射性核素镭-226、钍-232、钾-40 的放射性比活度同时满足 $I_{Ra} \leqslant 1.0$ 和 $I_{\gamma} \leqslant 1.3$ 要求的为 A 类装修材料。A 类装修材料产销与使用范围不受限制。

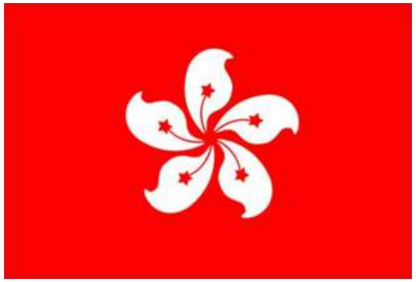
3.2.2 **B 类装修材料**

不满足 A 类装修材料要求但同时满足 $I_{Ra} \leqslant 1.3$ 和 $I_{\gamma} \leqslant 1.9$ 要求的为 B 类装修材料。B 类装修材料不可用于 I 类民用建筑的内饰面，但可用于 I 类民用建筑的外饰面及其他一切建筑物的内、外饰面。

3.2.3 **C 类装修材料**

不满足 A、B 类装修材料要求但满足 $I_{\gamma} \leqslant 2.8$ 要求的为 C 类装修材料。C 类装修材料只可用于建筑物的外饰面及室外其他用途。

3.2.4 $I_{\gamma} > 2.8$ 的花岗石只可用于碑石、海堤、桥墩等人类很少涉及到的地方。

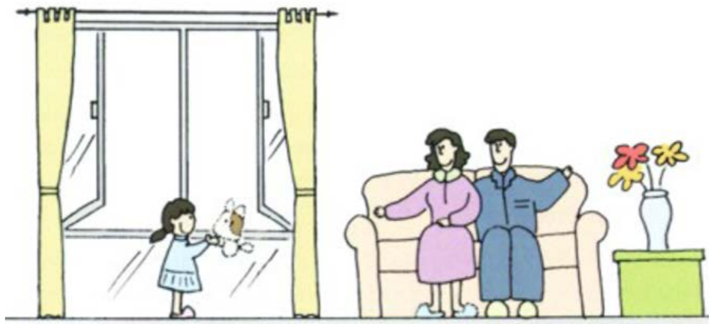


How about Hong Kong

Current situations and challenges

Building materials in HK

- Building materials:
  - A lot of concrete and granite
  - Industrial by-products added
  - Imported



Control of Building Materials

- Legislation/Regulation/Guide
  - Radiation Ordinance
    - Control of Radioactive substances 75 Bq/g;
    - Dose limits for member of public: 1 mSv/a

  Comparing to Reference Levels from IAEA
    - Ra-226: 300Bq/kg = 0.3 Bq/g
    - Th-232: 200Bq/kg = 0.2 Bq/g
    - K-40: 3000Bq/kg = 3.0 Bq/g
  - Hong Kong Green Council: Product Environmental Criteria for Building Products using Recycled Materials (GL-008-009): Gamma dose Rate < 0.5 uSv/h

Radon in Hong Kong

- Promotion of Public Awareness on radon
  - EPD: *IAQ Certification Scheme:*

    150 and 200 Bq/m3
  - EPD: *Control of Radon Concentration in New Buildings*: 100 Bq/m3
  - Building Department: *Comprehensive Environmental Performance Assessment Scheme for Buildings*
  - CEDD: *Caisson and Tunnel Construction Manual*

More information

- IAEA Basic Safety Standards
- CE COUNCIL DIRECTIVE 2013/59/EURATOM
- WHO Radon Handbook
- Radiological Protection Principles Concerning the Natural Radioactivity of Building Materials, Radiation Protection 112, Europe Commission
- Protection of the Public against Exposure Indoors due to Radon and Other Natural Sources of Radiation, SSG-32, IAEA 2015
- Chinese National Standards
  - GB 6763 2000 Bldg materials and by-products
  - GB 6566 2001 Limit of radionuclides in bldg materials

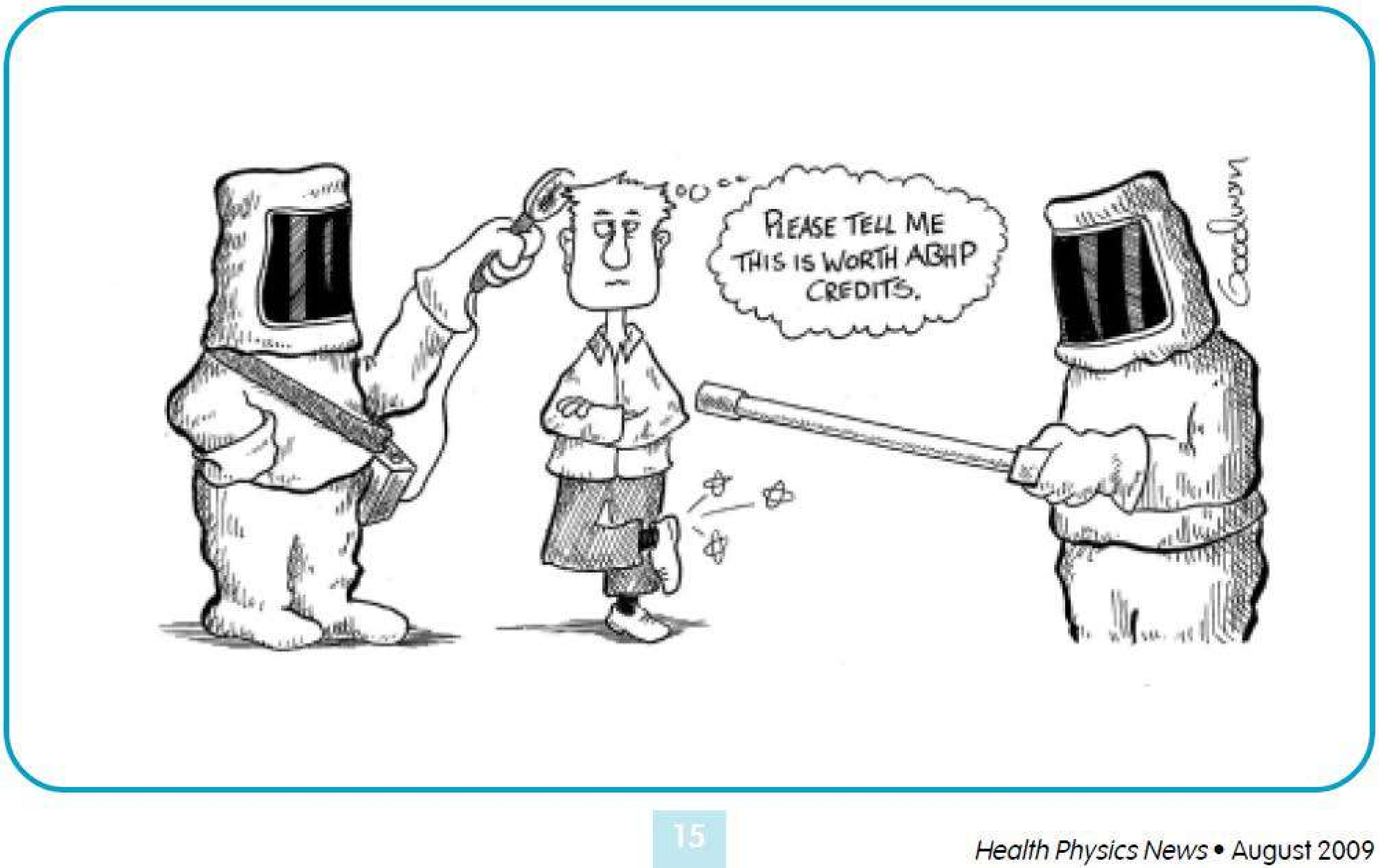
about HK situation

- A lot of studies and papers by Prof. W.M.Y. Tso and Prof J. Leung of HKU, Prof. P. Yu of City U, HK Government and many others.

Table 3 Comparison of natural radioactivity levels in soil and air-absorbed dose at different locations of Hainan Province (China) with those in other countries as given in UNSCEAR (2000).

Locations	Radioactivity concentration ($Bq\ kg^{-1}$)						Absorbed dose rate in air ($nGy\ h^{-1}$)	
	^{226}Ra		^{232}Th		^{40}K			
	Mean	Range	Mean	Range	Mean	Range	Average	Range
United States	40	8–160	35	4–130	370	100–700	47	14–118
India	29	7–81	64	14–160	400	38–760	56	20–1100
Japan	33	6–98	28	2–88	310	15–990	53	21–77
Malaysia	67	38–94	82	63–110	310	170–430	92	55–130
Thailand	48	11–78	51	7–120	230	7–712	77	2–100
China	32	2–440	41	1–360	440	9–1800	62	2–340
-Hong Kong SAR	59	20–110	95	16–200	530	80–1100	87	51–120
- Hainan Province	26	3–67	24	1–72	366	5–1381	42	2–127
Median	35	17–60	30	11–64	400	140–850	57	18–93

Ionising Radiation Monitoring and Radon monitoring

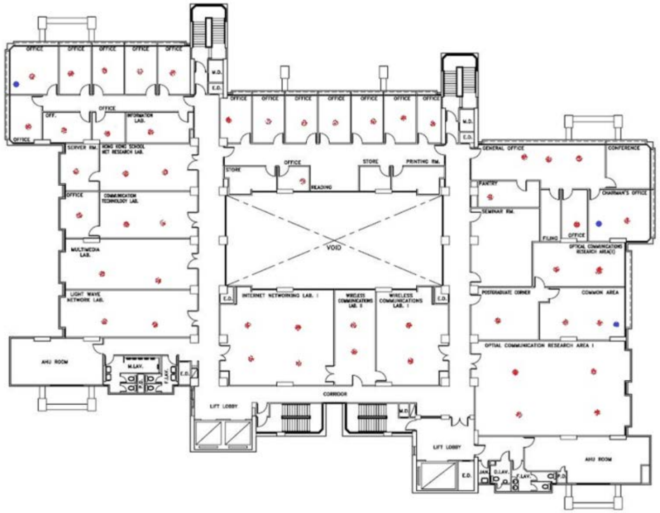


Radon measurement in Hong Kong

– Accreditation
– Instrumentation
– Calibration
– Works under high humidity condition (>70% R.H.)

measuring IAQ and Radon

- Problem: measuring radon in a Bdg. with limited time



EPD's Guidance Notes for IAQ

Guidance Notes for the Management of
Indoor Air Quality in Offices and Public Places

Table 3-2: IAQ Objectives for Office Buildings and Public Places

Parameter	Unit	8-hour average [a]	
		Excellent Class	**Good Class**
Room Temperature	°C	20 to < 25.5 [b]	< 25.5 [b]
Relative Humidity	%	40 to < 70 [c]	< 70
Air movement	m/s	< 0.2	< 0.3
Carbon Dioxide (CO_2)	ppmv	< 800 [d]	< 1,000 [e]
Carbon Monoxide (CO)	$\mu g/m^3$	< 2,000 [f]	< 10,000 [g]
	ppmv	< 1.7	< 8.7
Respirable Suspended Particulates (PM_{10})	$\mu g/m^3$	< 20 [f]	< 180 [h]
Nitrogen Dioxide (NO_2)	$\mu g/m^3$	< 40 [g]	< 150 [h]
	ppbv	< 21	< 80
Ozone (O_3)	$\mu g/m^3$	< 50 [f]	< 120 [g]
	ppbv	< 25	< 61

EPD's Guidance Notes for IAQ

Guidance Notes for the Management of
Indoor Air Quality in Offices and Public Places

Table 3-2: IAQ Objectives for Office Buildings and Public Places

Parameter	Unit	8-hour average [a]	
		Excellent Class	Good Class
Formaldehyde (HCHO)	μg/m³	< 30 [f]	< 100 [f, g]
	ppbv	< 24	< 81
Total Volatile Organic Compounds (TVOC)	μg/m³	< 200 [f]	< 600 [f]
	ppbv	< 87	< 261
Radon (Rn)	Bq/m³	< 150 [i]	< 200 [f]
Airborne Bacteria	cfu/m³	< 500 [j, k]	< 1,000 [j, k]

Legends:

a. In some cases, it may not be practical to take 8-hour continuous measurement. In these circumstances, surrogate measurement (i.e. an intermittent measurement strategy based on the average of half-an-hour measurements conducted at four time-slots) is also accepted.

But half-an-hour is NOT sufficient for radon monitoring !!

Air Monitoring of Radon vs vapours

Radon Concentration

$100\ Bq/m^3$

$=100$ dps / 1000 L

$=0.1$ dps (of radon)/L

$=6$ dpm in one litre

Solvent vapours

1 ppm

$\approx 6 \times 10^{23} / 10^{6} / 22$ L

$= 2.7 \times 10^{16}$ molecules

in one litre

dps: decay per second

dpm: decay per minute

Radon monitoring

- Efficiency of radiation detection < 0.5
- Size of sample (less than 1 L)
- Random nature of radiation →

  statistical uncertainty in counts : i.e. $N \pm \sqrt{N}$;

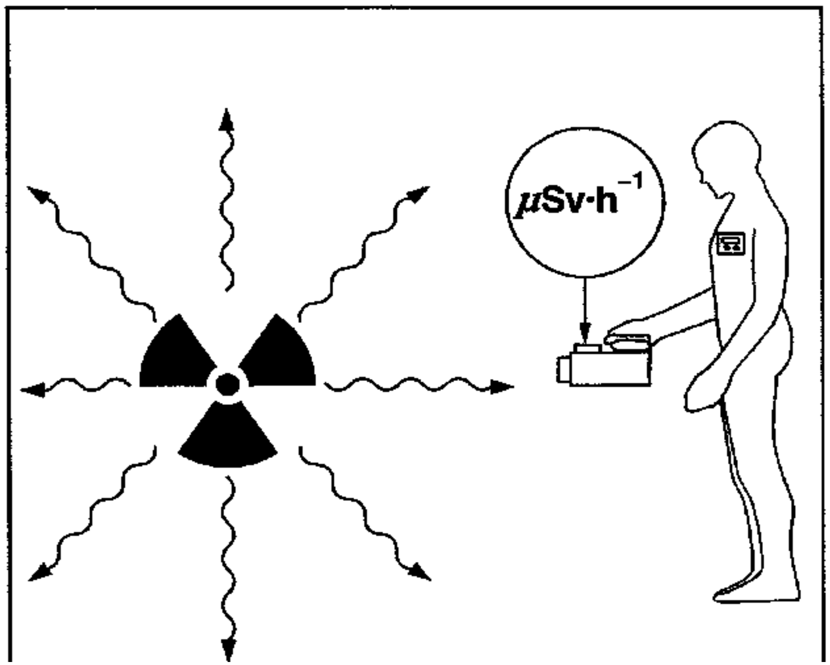
  e.g. 1 ± 1; 100 ± 10; 10000 ± 100.

That is why radon

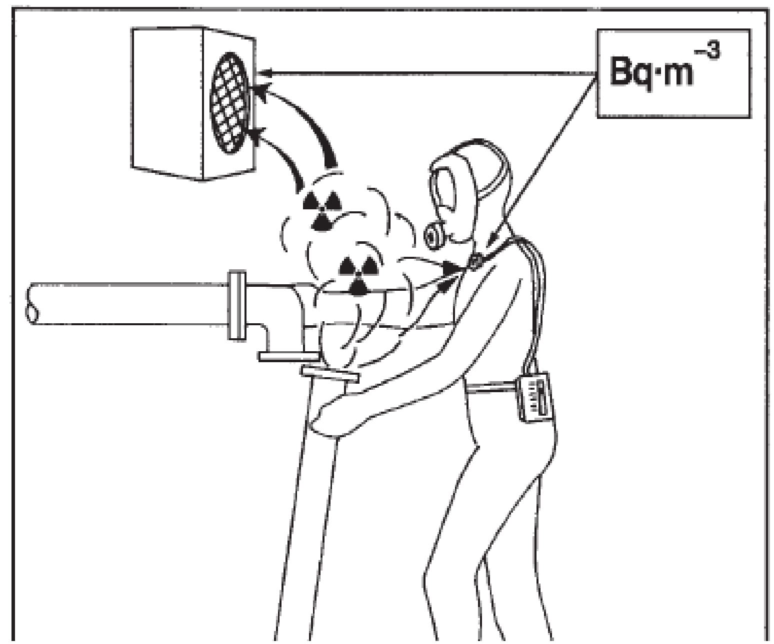
- *cannot be measured accurately within a few minutes;*
- *is NOT suitable to be measured in half-an-hour!!*
- *is measured over hours, days, weeks even months.*

radiation monitors

Dose rate meter/GM counter
For external dose assessment



Airborne contamination monitor
For internal dose assessment



detecting α β γ radiation or radon??

Source: WORKPLACE MONITORING FOR RADIATION AND CONTAMINATION, IAEA, 2004

Some direct reading Radon Monitors

A Typical Radon Monitor

Specifications

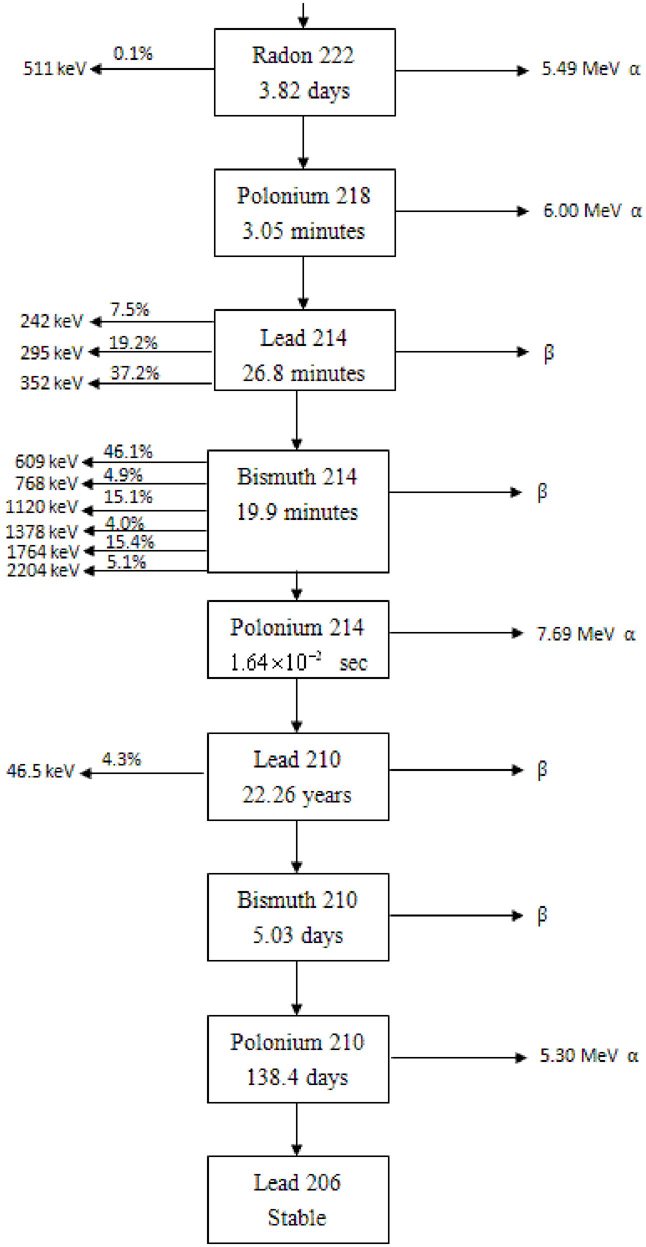
- Measurement Type: Continuous Radon Monitor (CRM)
- Sampling Method: Passive air diffusion
- Output Reading: Radon gas concentration (Rn-222)
- Detector: Solid state alpha detector, ion-implanted silicon
- Dynamic Range: 0 to 10 MBq/m3
- Units: Bq/m3 or pCi/L (1 pCi/L = 37 Bq/m3)
- Sensitivity: 0.108 CPH per Bq/m3 nominal (4 CPH per pCi/L)
- Response Time: 120 minutes to 95% of final value
- Accuracy: +/-10% + statistical uncertainty

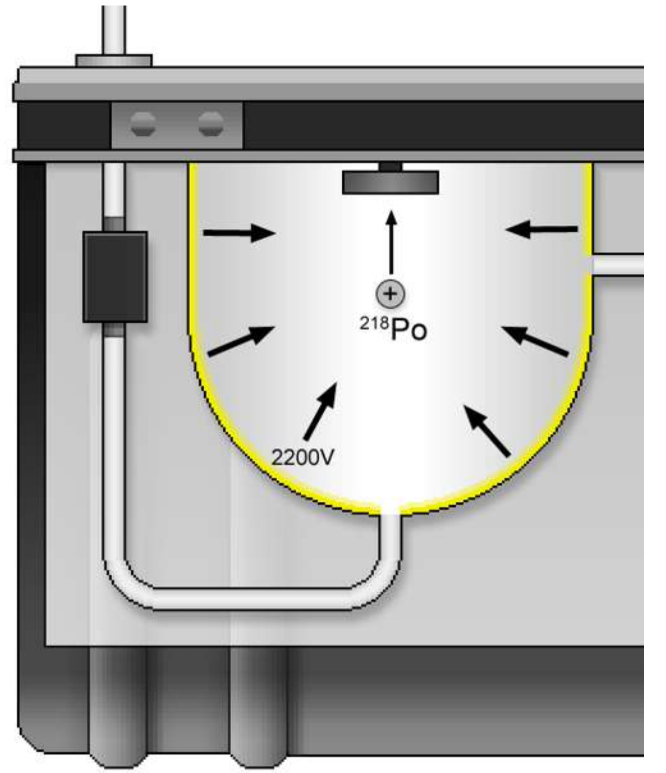
RAD7 radon monitor

Specifications

- Output Reading: Radon gas concentration (Rn-222)
- Measurement Type: Continuous Radon Monitor (CRM)
- Sampling Method: active: pump:
  Flow rate typically 800mL/min
- Detector: Solid state alpha detector, ion-implanted silicon
- Dynamic Range: 4 to 750,000 Bq/m3
- Units: Bq/m3 or pCi/L (selectable)
- Sensitivity: SNIFF 0.4 CPH per Bq/m3
  Nominal 0.78 CPH per Bq/m3
- Accuracy: +/-5% + statistical uncertainty
- Response Time: 120 minutes to 95% of final value

Detector in RAD 7



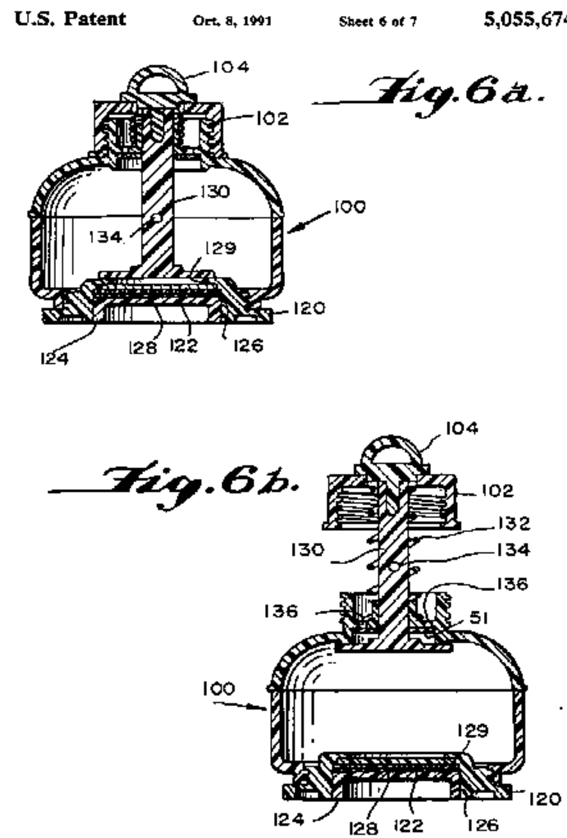


SNIFF mode counts Po-218 decays

NORMAL mode counts Po-218 and Po-214 decays

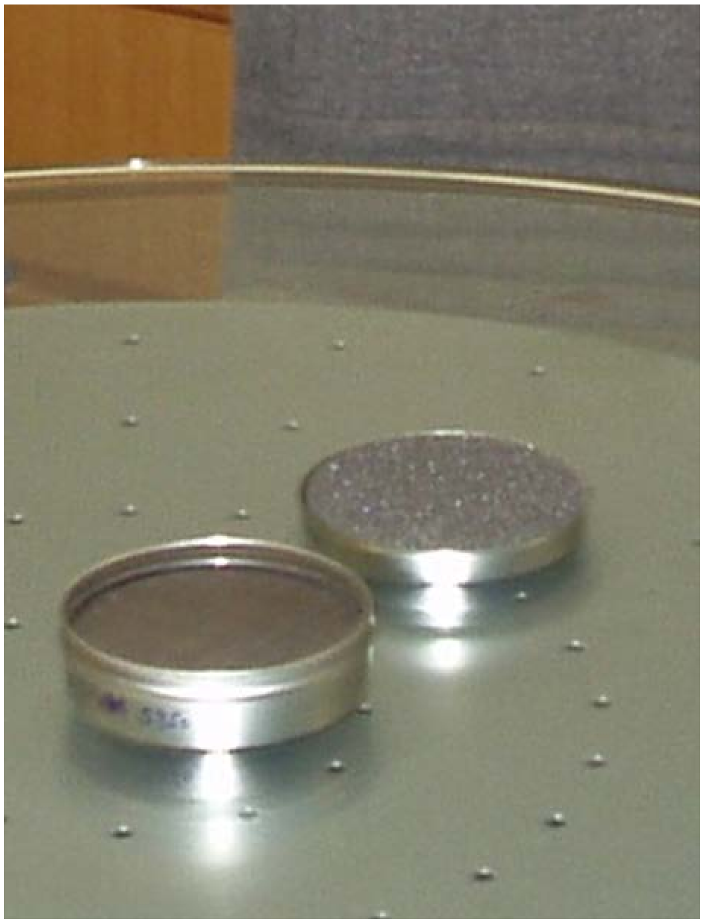
Data Source: "LBNL Isotopes Project - LUNDS Universitet", http://ie.lbl.gov/toi/index.asp

E-perm radon monitor



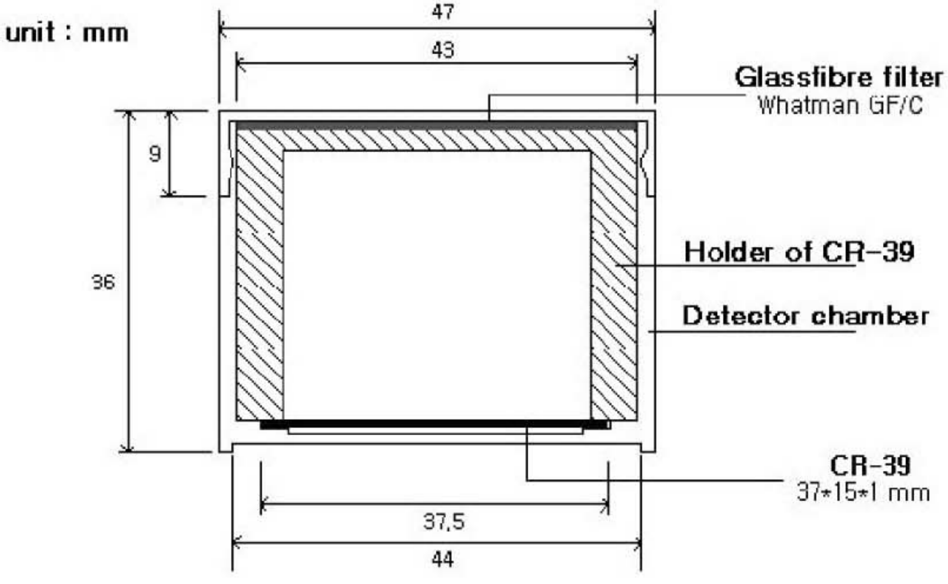
An ionization chamber
Reading has to be corrected against background gamma radiation; and may be against high humidity??

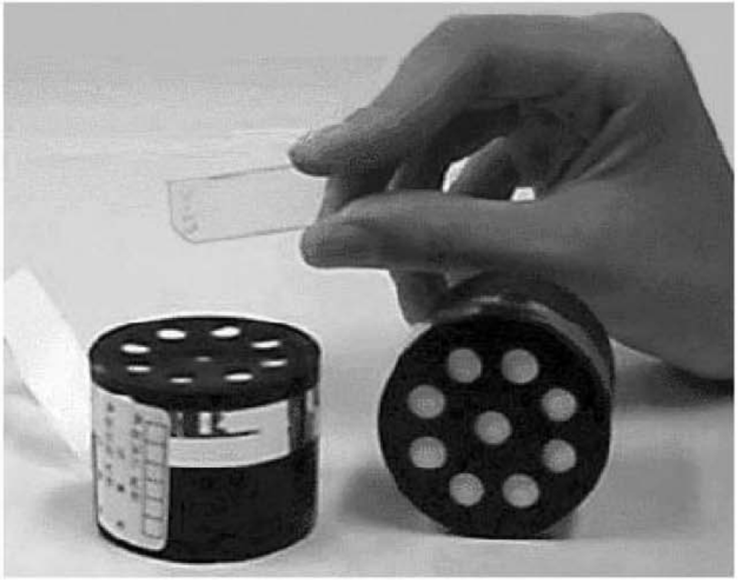
Charcoal canister



- Humidity
- Calibration required
- Has to be returned to laboratory and be in a short time.

Alpha track radon detector





Simple and cheap device for monitoring radon for a few days to months.

Disclaimer

- Equipment shown in this talk is for discussion and for sharing ideas only.
- Speaker, including HKRPS and HKIOEH, has no intention to recommend or against using the equipment.