Thoron in the environment

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- **Characteristics of thoron (^{220}Rn)**
- **Technical issues of radon (^{222}Rn) measurements due to presence of thoron**
  - **National indoor radon survey (Japan)**
  - **Epidemiological study for residential radon and lung cancer (China)**
- **How much thoron activity concentration is in the environment? What is its resulting dose?**
  - **Comprehensive dose assessment of radon and thoron in high background radiation areas (HBRA)**

Glossary

Equilibrium Equivalent Concentration (EEC) $C_{eq\text{-}Tn}$

Thoron activity concentration C_{Tn}, in equilibrium with the progeny that have the same potential alpha energy concentration (PAEC) as the actual present compound of thoron and their short-lived progeny that are not in equilibrium. Unit: Bq m^{-3}

Equilibrium factor F

The ratio of the equilibrium equivalent concentration $C_{eq\text{-}Tn}$ to the thoron activity concentration C_{Tn}.

Potential Alpha Energy (PAE)

Sum of the alpha energy of Rn-220 and their short-lived progeny in radioactive equilibrium. Unit: J

Potential Alpha Energy Concentration (PAEC)

Alpha energy emitted from due to thoron activity concentration C_{Tn} when Rn-220 decays through to Pb-208 in air volume V as a result of a random compound of short-lived Rn-220 progeny. Unit: J m^{-3}

Glossary

Unattached fraction

The fraction of potential alpha energy concentration of short-lived thoron progeny not attached to ambient aerosols.

Working Level (WL)

Working level (WL) is the unit used for every combination of Rn-220 and their short-lived progeny in a liter of air which emits a potential alpha energy of 1.3×10^5 MeV.

Working Level Month (WLM)

WLM is a unit for the thoron exposure a worker receives during a month (170 working hours) at 1 WL.

Comparison between radon (^{222}Rn) and thoron (^{220}Rn)

Isotope	Radon	Thoron
Half life	3.8 days	55.6 sec
Origin of nuclide	^{238}U	^{232}Th
Components of PAEC/EEC (short-lived progeny)	^{218}Po, ^{214}Pb, ^{214}Bi(^{214}Po)	^{212}Pb, ^{212}Bi(^{212}Po)
Significant alpha energy	6.0 MeV (^{218}Po) 7.7 MeV (^{214}Po)	6.1 MeV (^{212}Bi) 8.8 MeV (^{212}Po)
Equilibrium factor indoors	0.4 (Typically) 0.2 to 0.6 (Range)	None
Epidemiological data	Mines and homes	None
DCF in ICRP Publication 137	10 mSv/WLM (20 mSv/WLM)	5 mSv/WLM
EEC equivalent to 1WL	3,700 Bq/m^3	275 Bq/m^3

Calculation of EEC

- EERC (radon)

  $EERC=0.106C_{Po-218}+0.513C_{Pb-214}+0.381C_{Bi-214}$

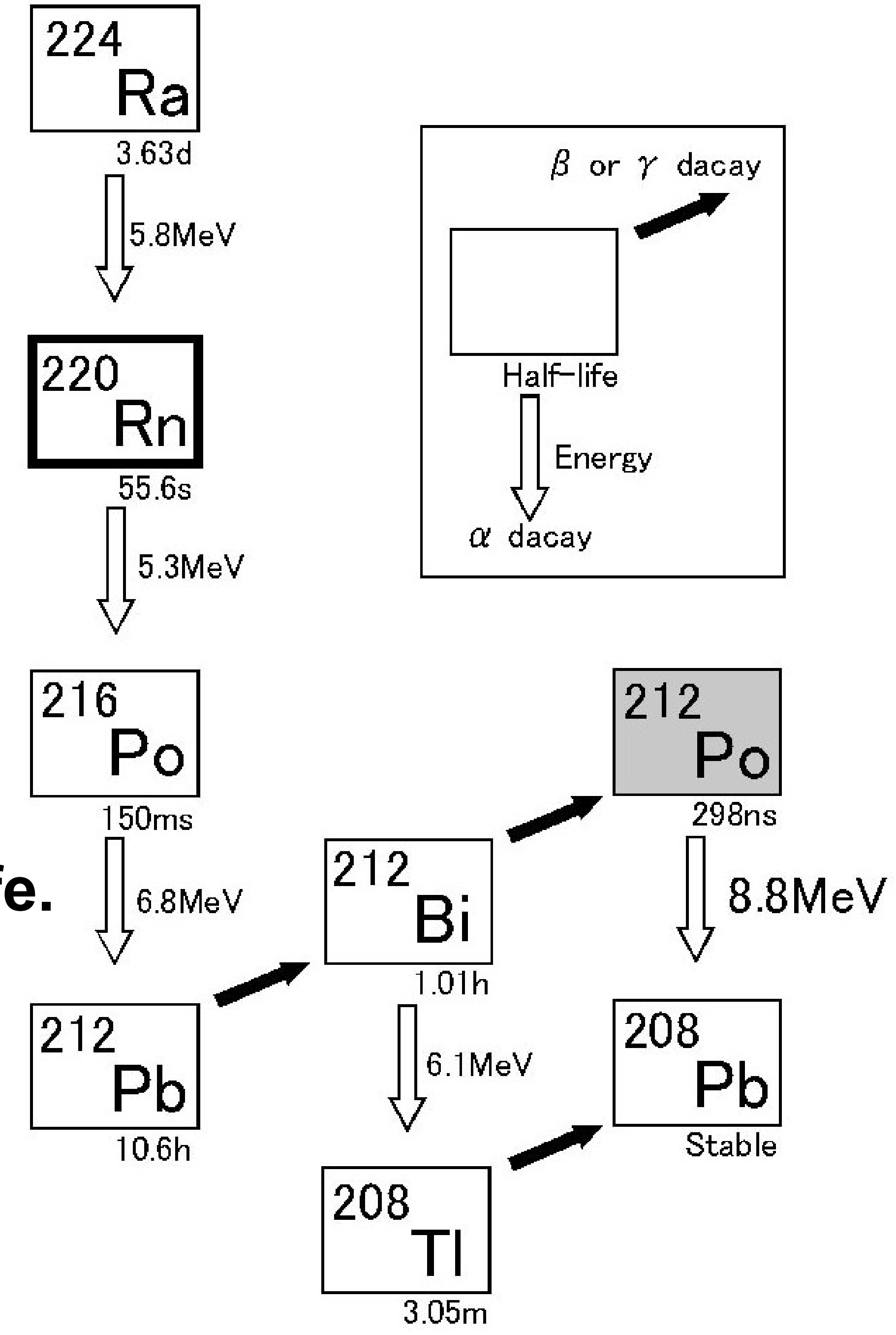
- EETC (thoron)

  $EETC=0.913C_{Pb-212}+0.087C_{Bi-212}$

Decay chains of thoron

- Thoron: inert gas, half life of **55.6 s**
- Thoron progeny: solid particles: direct cause of internal exposure due to inhalation
- Key radionuclide: ^{212}Pb, ^{212}Bi(^{212}Po)

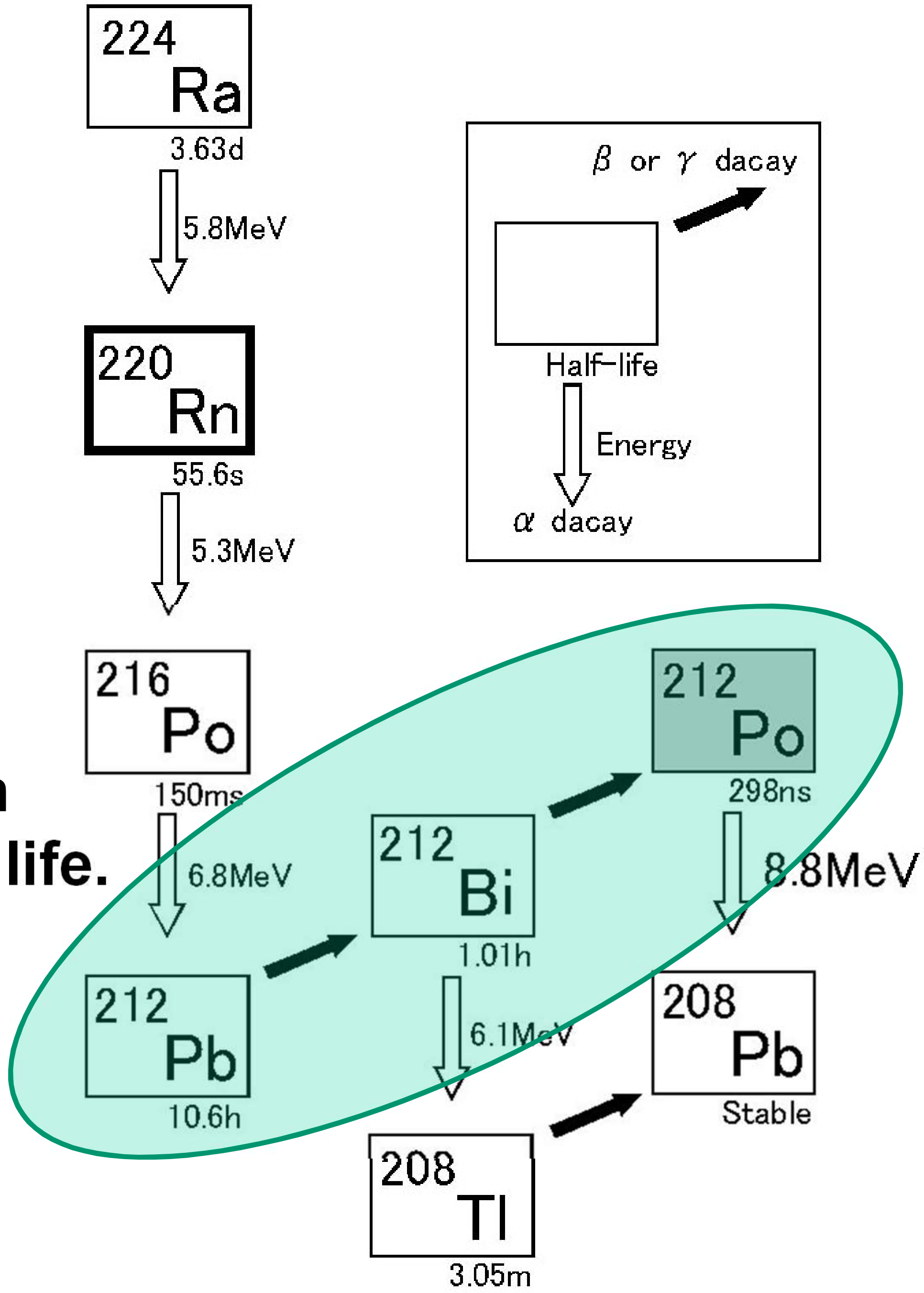
^{216}Po behaves together with ^{220}Rn due to very short half life.



Decay chains of thoron

- Thoron: inert gas, half life of 55.6 s
- Thoron progeny: solid particles: direct cause of internal exposure due to inhalation
- Key radionuclide: ^{212}Pb, ^{212}Bi(^{212}Po)

^{216}Po behaves together with ^{220}Rn due to very short half life.



Source of indoor radon and thoron

- **Radon**
  - **Ground soil from a few meters depth**
  - **(Partially) building materials (radium-rich, etc.)**
- **Thoron**
  - **Building materials from a few centimeters thickness**

**Even with a small quantity of thoron source,
a significantly high concentration might be given.**

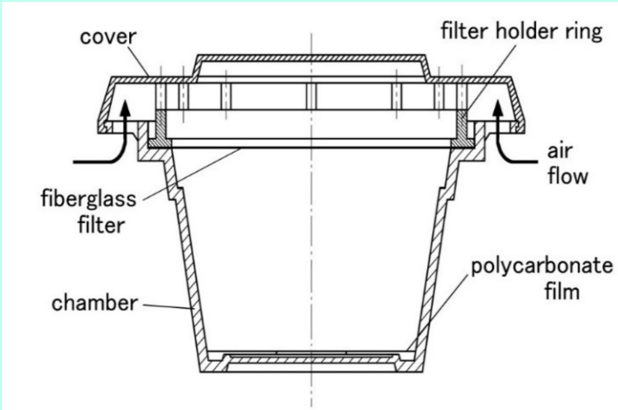
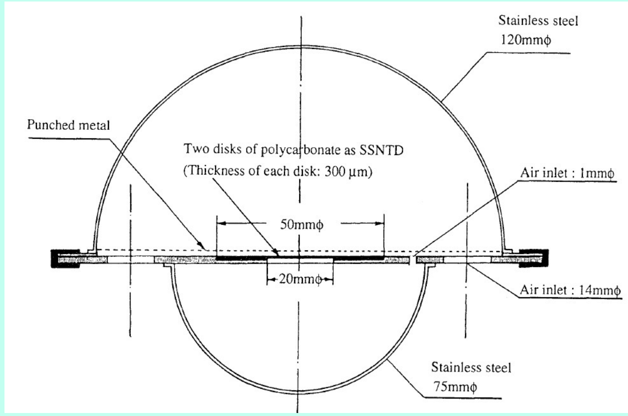
Thoron interference in radon measurements

1. **National indoor radon survey in Japan**
2. **Epidemiological study for residential radon and lung cancer in China**

Nation-Wide Surveys in Japan

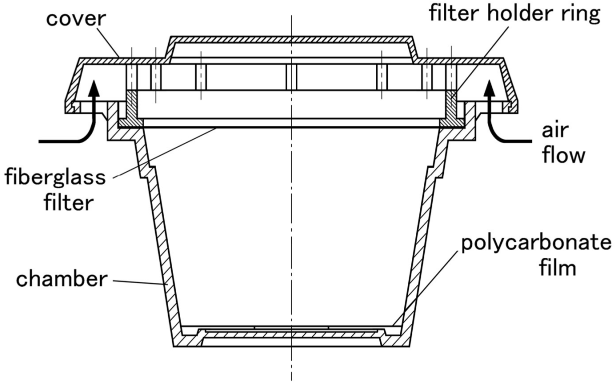
- In Japan, nation-wide radon surveys were conducted in the late 1980s and early 1990s.

Table Summary of past nation-wide radon survey

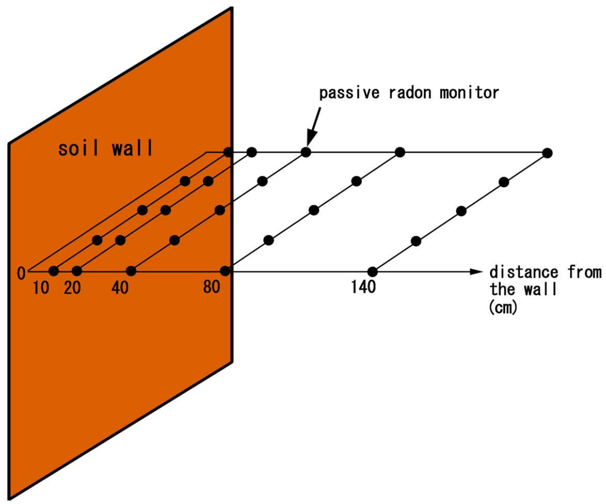
Publication	UNSCEAR 1993	Sanada et al[1)]
Survey year	1985-1991	1992-1996
Number of houses	6000	899 (about 20 in each prefecture)
Detector		
Annual average of radon conc. (Bq/m³)	29	16

1) T. Sanada et al., *J. Environ. Radioact.*, 45: 129-137 (1999)

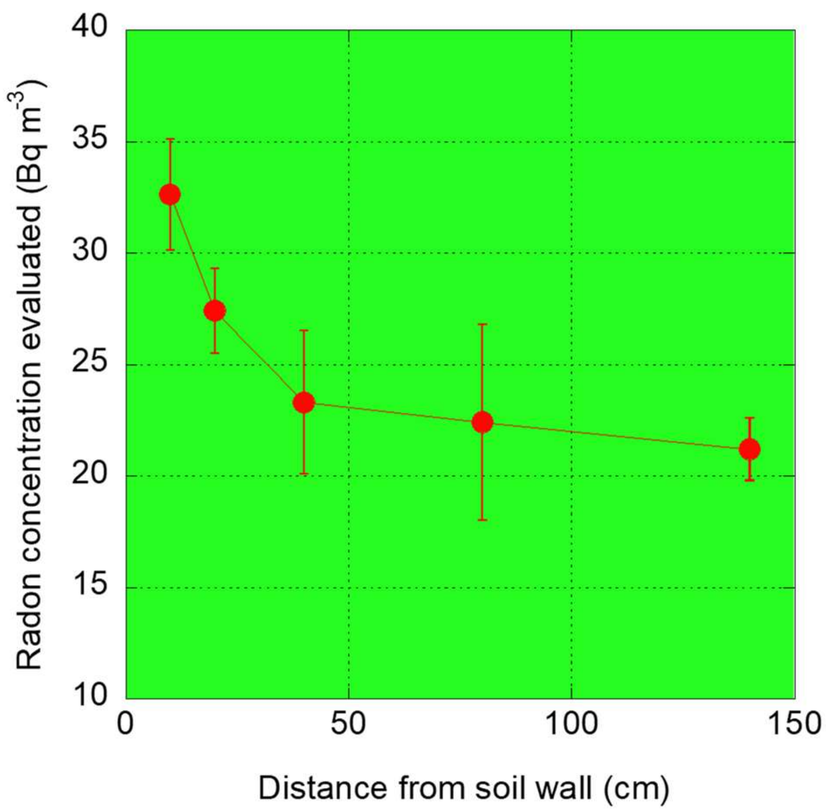
Measurement of radon without discrimination (1st national survey in Japan)



Passive radon monitor (KfK monitor)



Geometric arrangement of the monitor



Detection response of the monitor

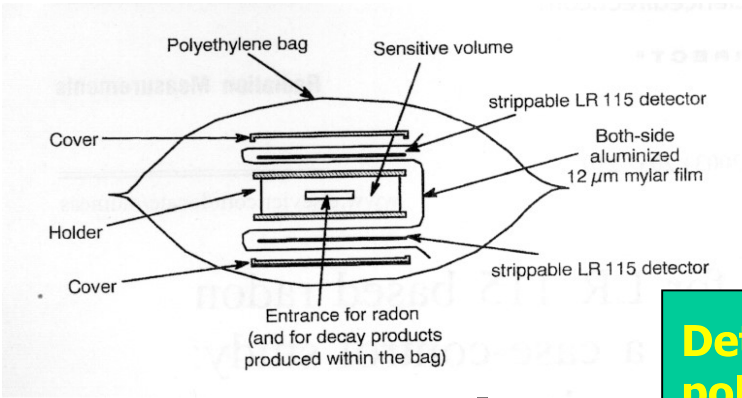
Passive radon detectors used in major epidemiological surveys

Germany, Czech, Sweden
UK, North America(Radrak)
: closed chamber

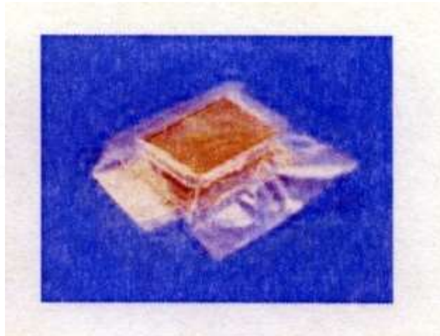
LR-115, France

Open detector

Closed detector

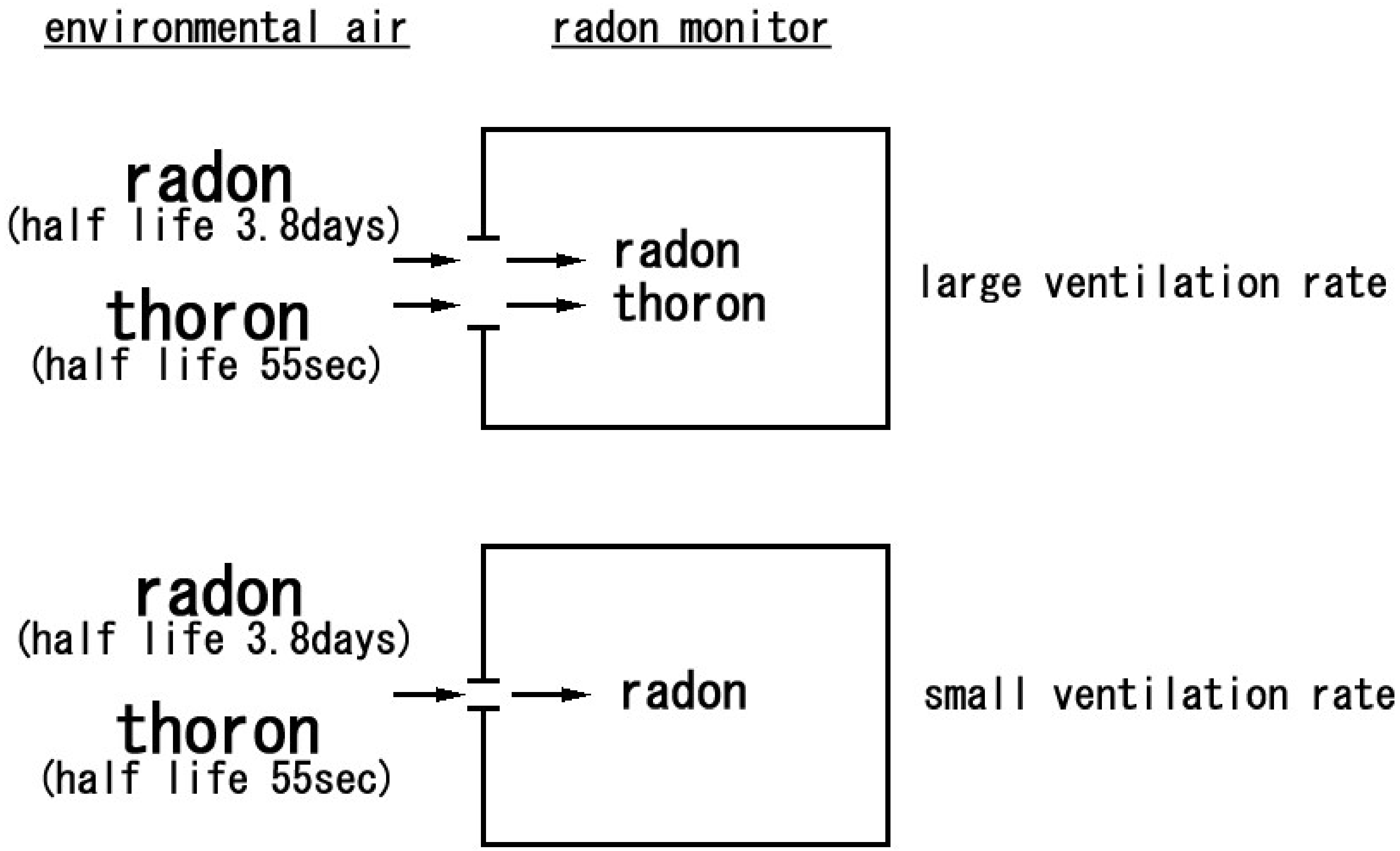


LR-115, Italy

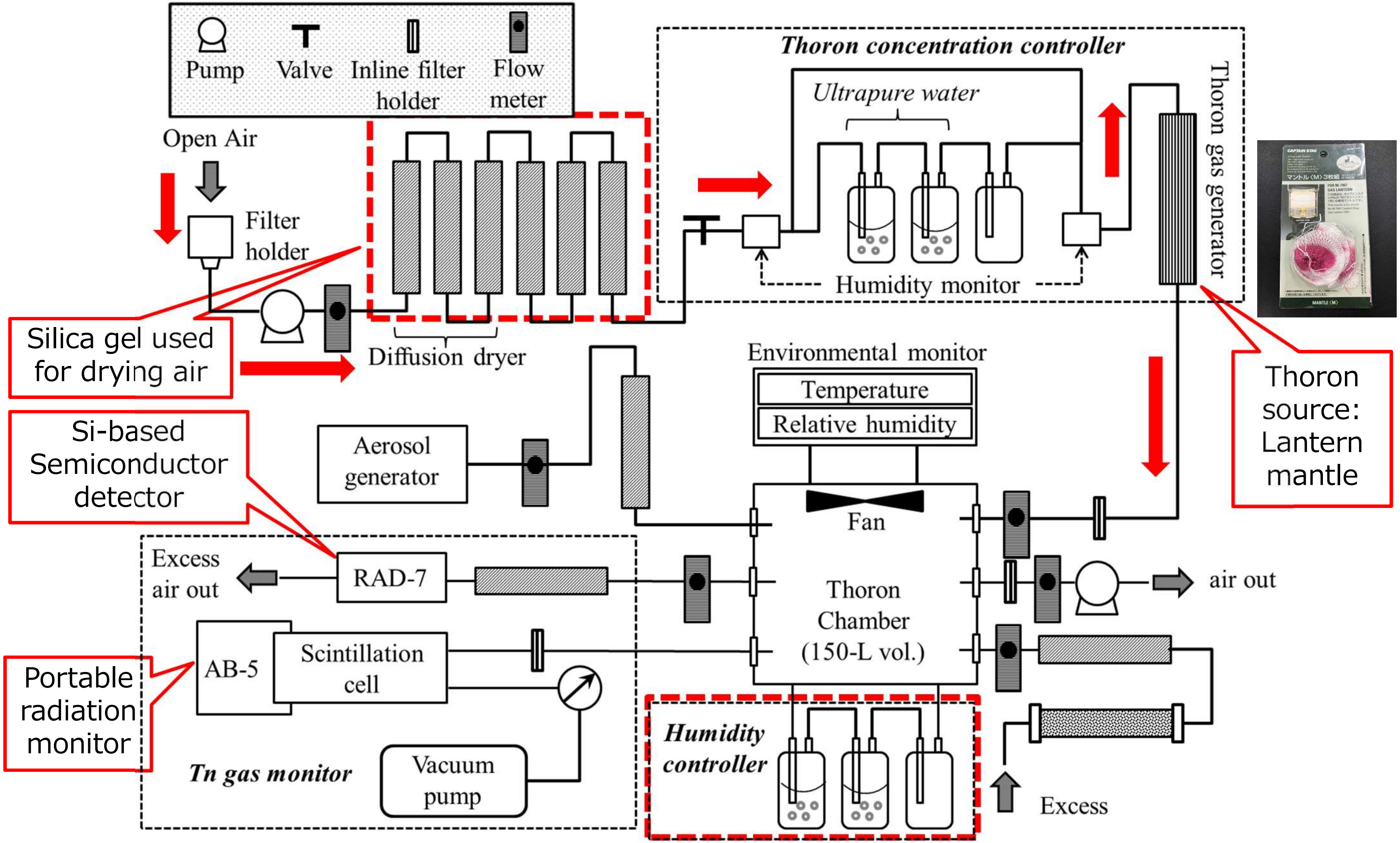


Detectors sealed with polyethylene bag for thoron entry control

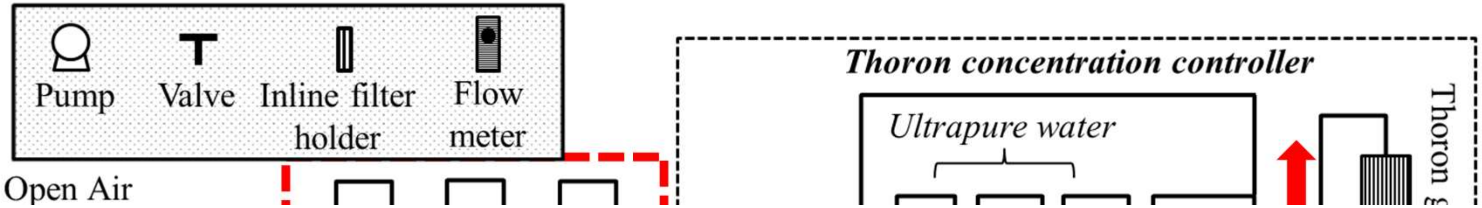
Control of air exchange rate in radon monitor



Structure of thoron exposure chamber

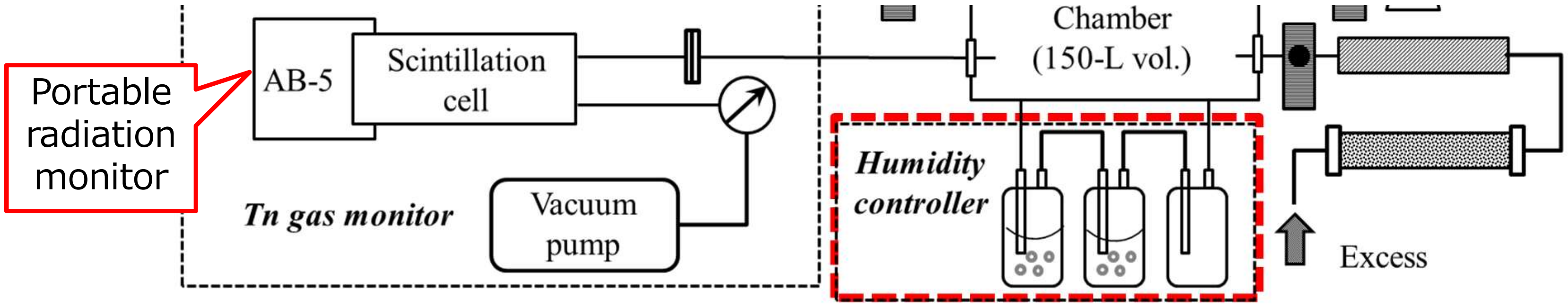


Structure of thoron exposure chamber



Key points of thoron calibration:

- Stability of thoron activity concentration
  - ✓ Continuous supply of thoron gas
- Homogeneity of thoron activity concentration
  - ✓ Stirring by fan is necessary but far from static air condition



Thoron monitoring devices

Continuous radon-thoron monitor
Silicon semi-conductor detector based on electrostatic collection method.
<u>Radon and thoron concentrations can be automatically measured by continuous air sampling</u> (~1 L/min).

RAD7 (Durridge, USA)

Intermittent radon-thoron monitor
<u>Standard device </u>based on a single scintillation cell method (Tokonami, Rev. Sci. Instrum., 2002).

- Monte Carlo calculation of counting efficiencies for radon
- Comparison with experimental results to verify results based on MC calculation
- Radon concentration is traceable
- Application to counting efficiencies for thoron with verified Monte Carlo calculation

300A & AB-5 (Pylon, Canada)

Relative sensitivities of passive radon monitors

Measuring device	Relative sensitivity		Remarks
	Radon	Thoron	
KfK monitor[a] (Germany)	1	0.78	Tokonami et al. (2001)
Radtrak[b] (USA)	1	0.68	Tokonami et al. (2001)
NRPB/SSI (UK, Ireland, Sweden)	1	0.05	Tokonami (2005)
E-PERM (USA)	1	0.03	Sorimachi et al. (2009)
ISS monitor (Italy)	1	<0.01	Bochicchio et al. (2009)
Pill bottle monitor (Canada)	1	0.02	Chen et al. (2010)

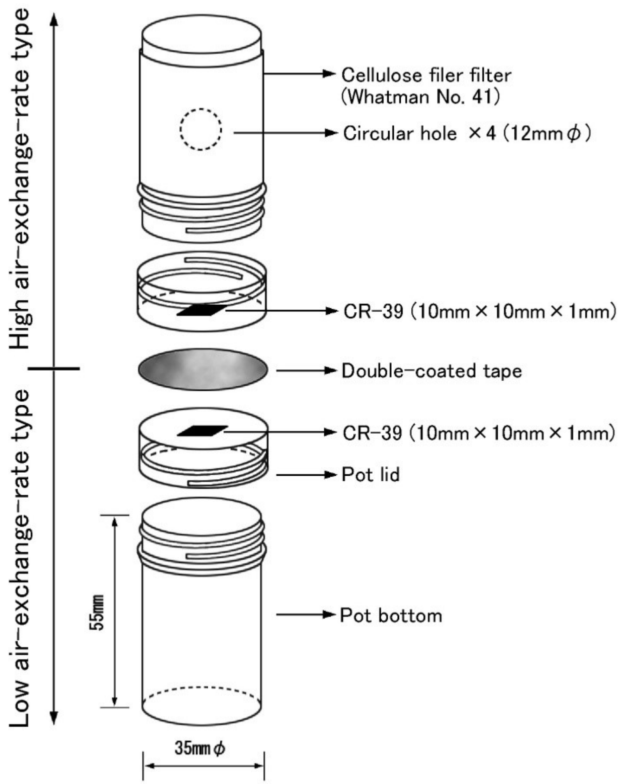
[a]Urban and Piesch (1981). [b]Pearson and Spangler (1991).

Overestimate of radon concentration

- ***Observed Radon conc. = Actual Radon conc. + Relative Sensitivity(Thoron) x Thoron conc.***
  - ***For example, when actual radon conc. and detected thoron conc. are 100 Bq/m^3, respectively, radon concentration observed by Radtrak(US) will be estimated to be 168 Bq/m^3.***

Concept: Combination of two different diffusion chambers

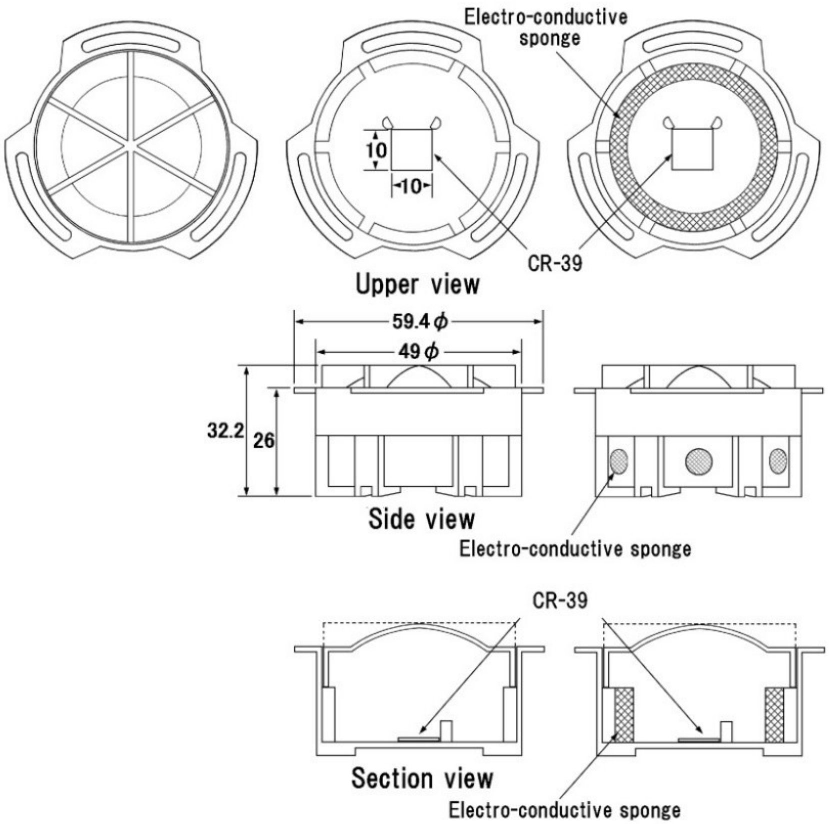
Measuring device	Relative sensitivity		Remarks
	Radon	Thoron	
Ordinary RADOPOT (Low diffusion)	1	0.05	Zhuo et al. (2002)
Modified RADOPOT (High diffusion)	1	0.59	Tokonami et al. (2003)



Prototype of RADUET

Concept: Combination of two different diffusion chambers

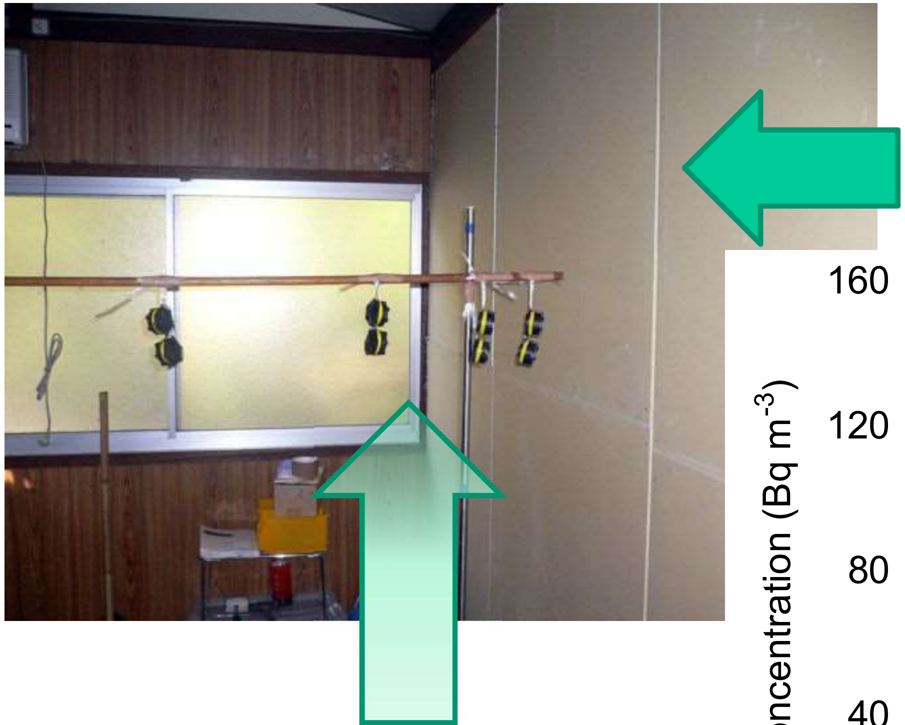
Measuring device	Relative sensitivity		Remarks
	Radon	Thoron	
RADUET(Low Diffusion)	1	0.02	Tokonami et al. (2005)
RADUET(High Diffusion)	1	0.90	



- Detecting material: CR-39
- Two chambers used with different air exchange rates: thoron contamination eliminated
- Material: electro-conductive plastic
- Enhanced porosity: use of electro-conductive sponge

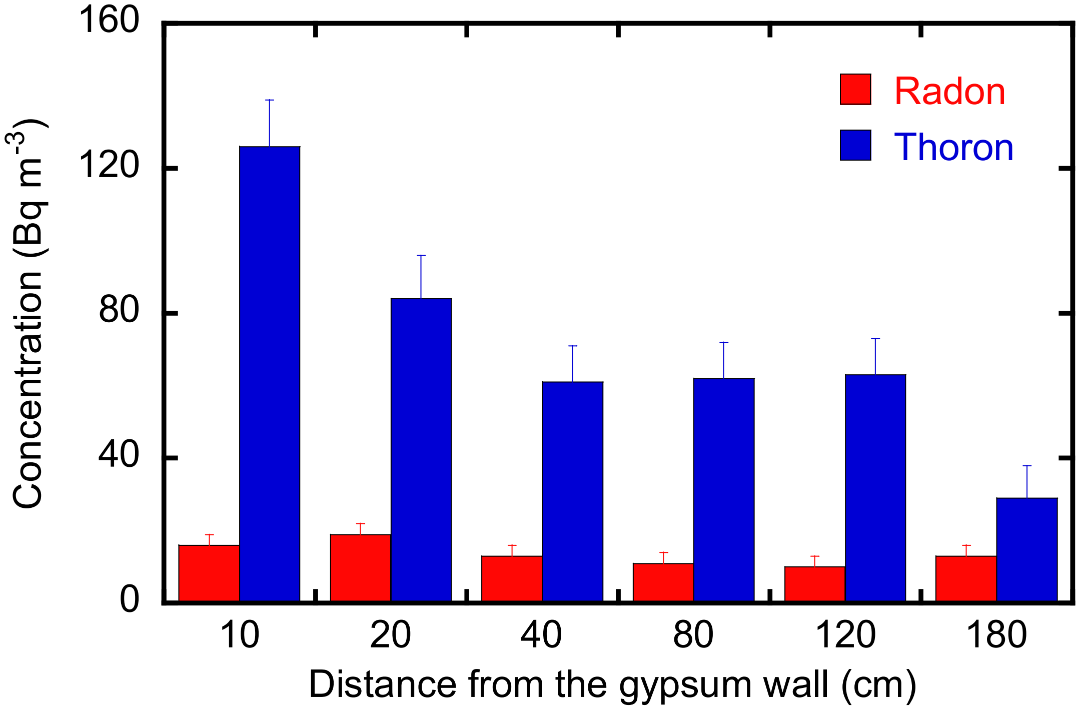
Spatial distribution of radon and thoron concentrations in a model house with gypsum wall (under static condition)

^{238}U: 163+/- 5 Bq/kg
^{232}Th: 522+/- 15 Bq/kg
^{40}K: 31+/- 14 Bq/kg



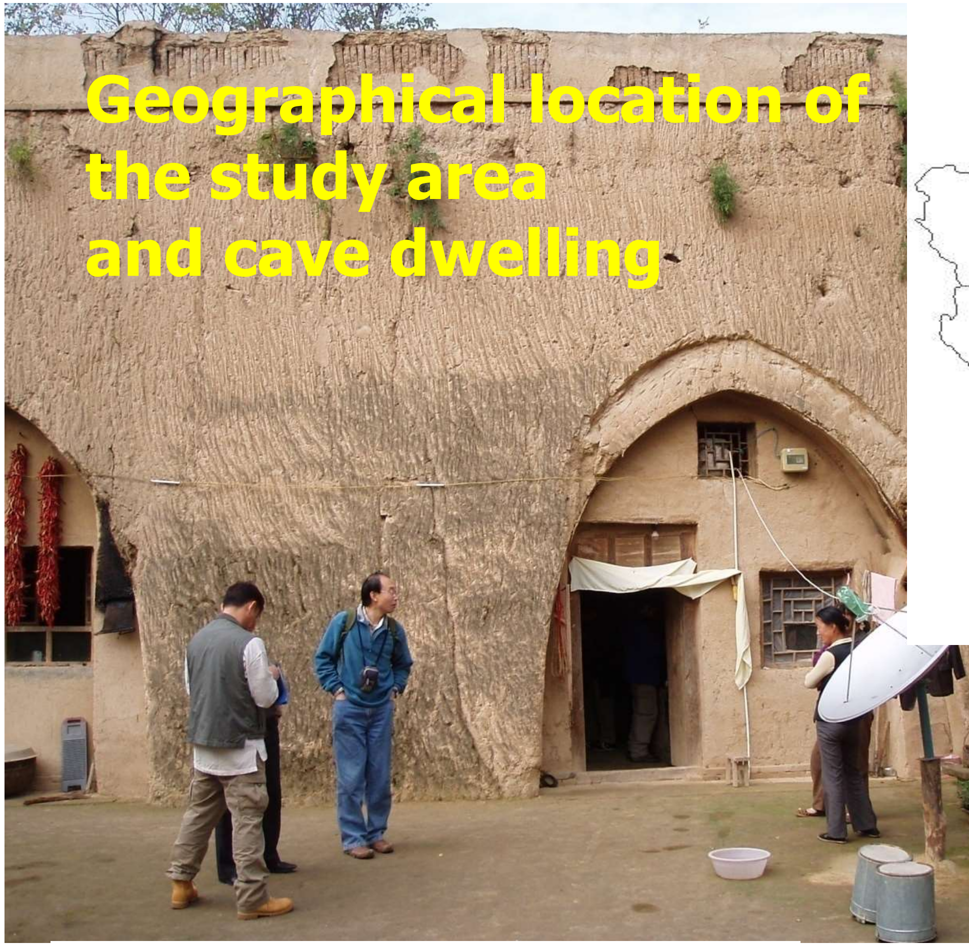
Gypsum wall

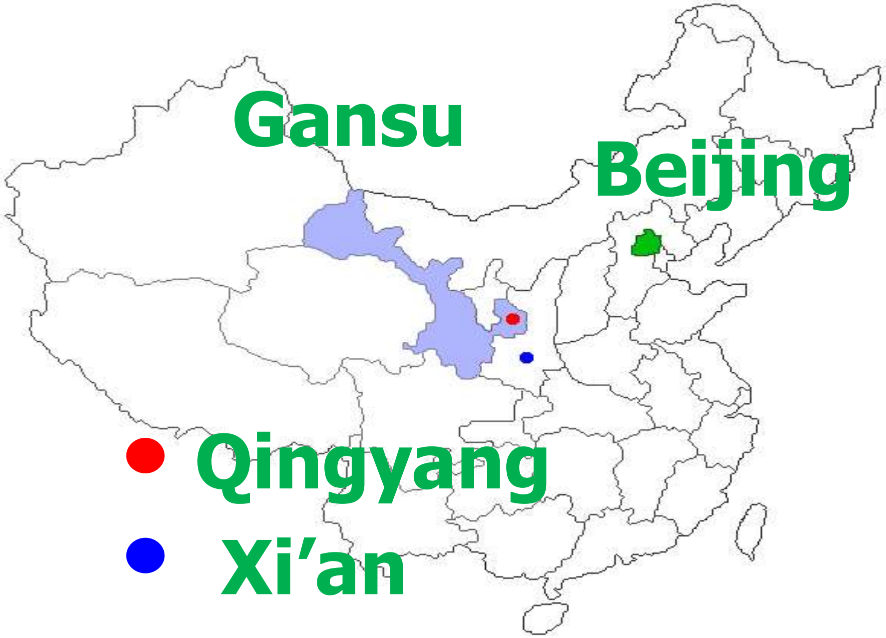
Raduet

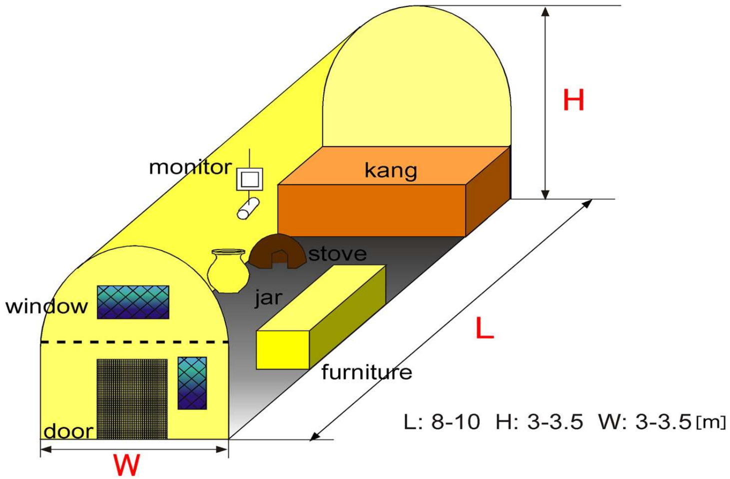


Radon : constant
Thoron: decreased

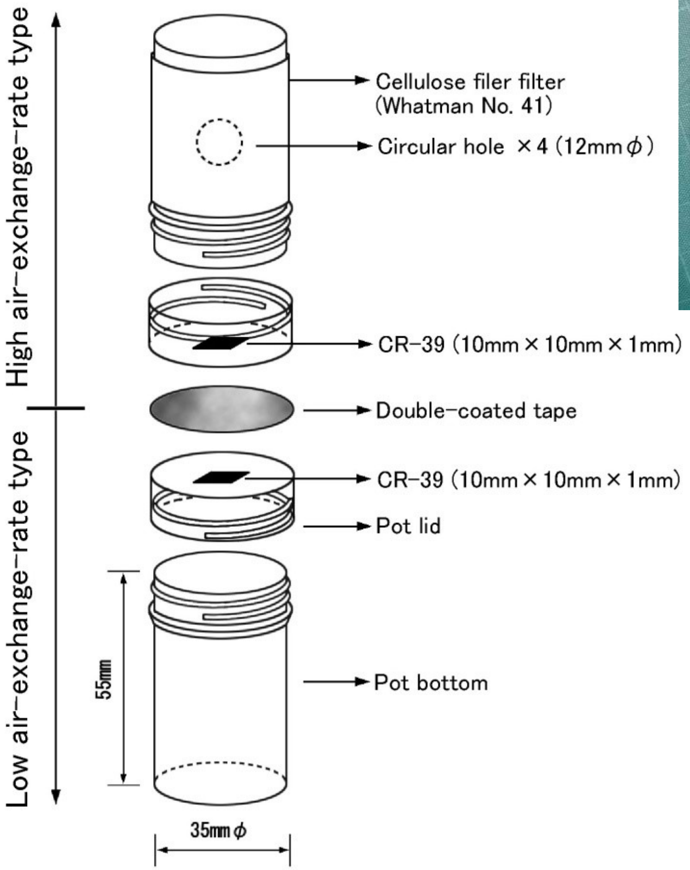
Geographical location of the study area and cave dwelling



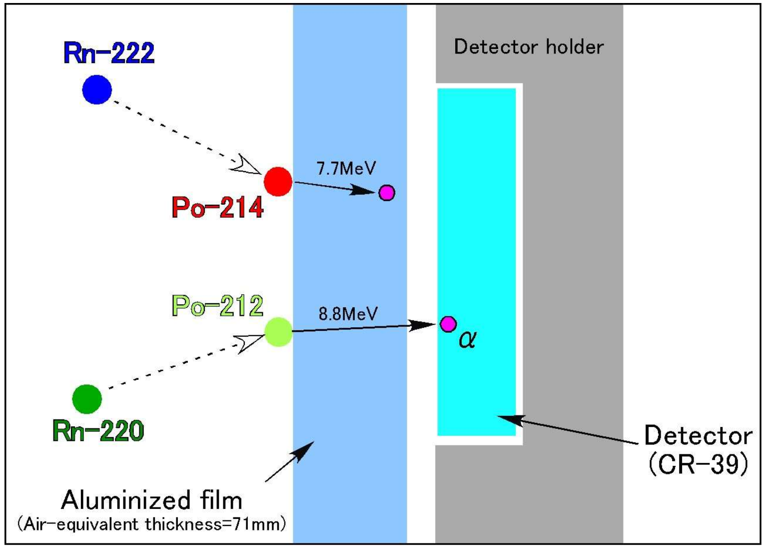


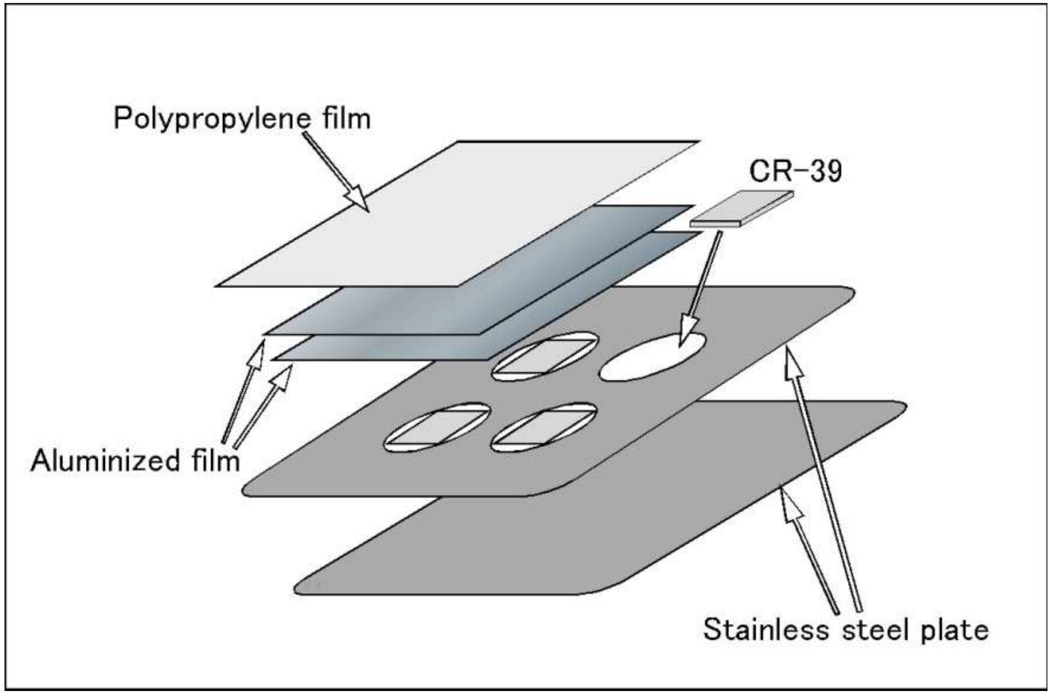


Detectors for dose assessment



Radon-thoron discriminative detectors (Prototype of RADUET)

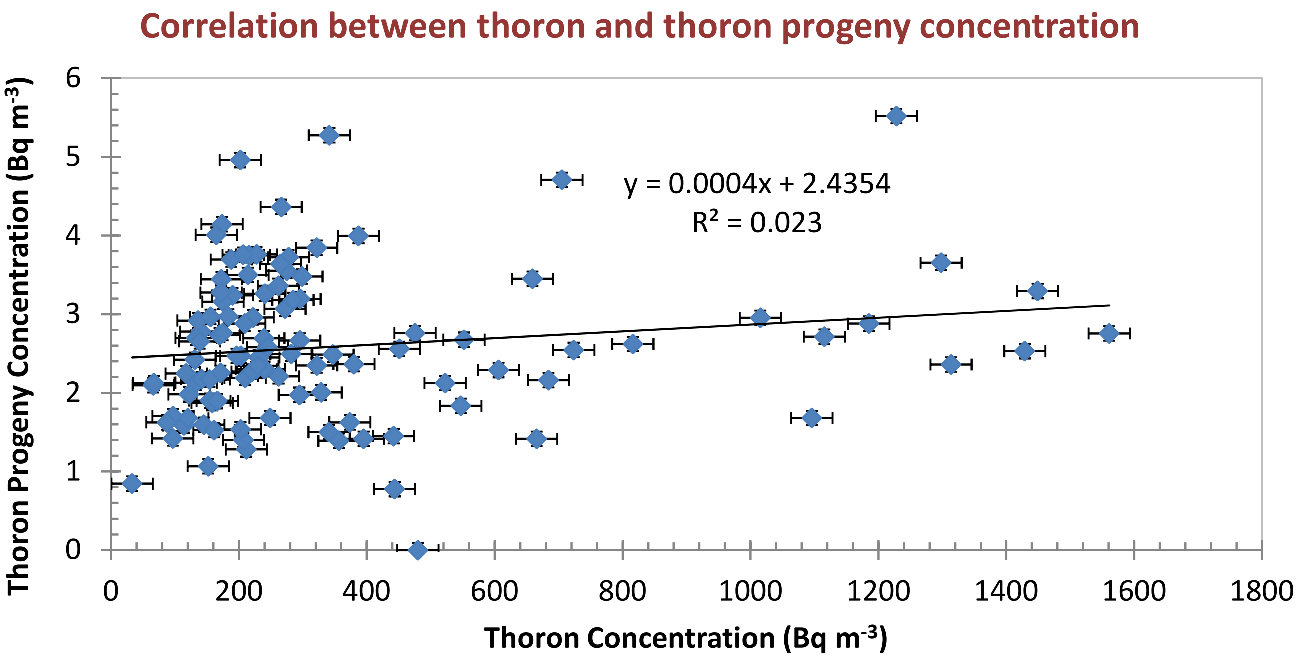




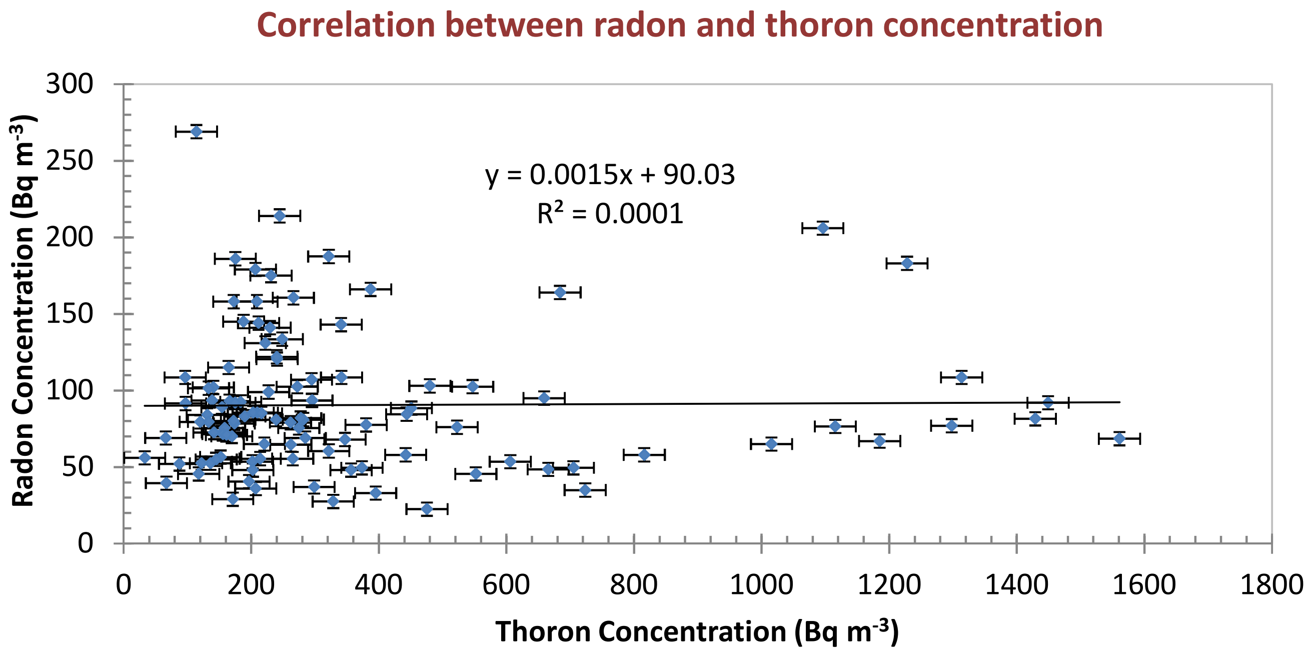
Detector for current concentrations of thoron decay products (Po-212)

Comparison of our survey result with the previous study

Subject	Wang et al. (2002)	Yamada et al. (2006)
Radon (Bq m^{-3})	223	87
Thoron (Bq m^{-3})	none	289
EETC (Bq m^{-3})	none	2.6
Odds ratio (Lung cancer risk)	0.19 at 100 Bq m^{-3} (95%CI:0.05,0.47)	none



Correlation between thoron and thoron progeny concentration
y = 0.0004x + 2.4354
R² = 0.023
Thoron Progeny Concentration (Bq m-3)
Thoron Concentration (Bq m-3)
0
1
2
3
4
5
6
0
200
400
600
800
1000
1200
1400
1600
1800



Correlation between radon and thoron concentration
y = 0.0015x + 90.03
R² = 0.0001
Radon Concentration (Bq m-3)
Thoron Concentration (Bq m-3)
0
50
100
150
200
250
300
0
200
400
600
800
1000
1200
1400
1600
1800

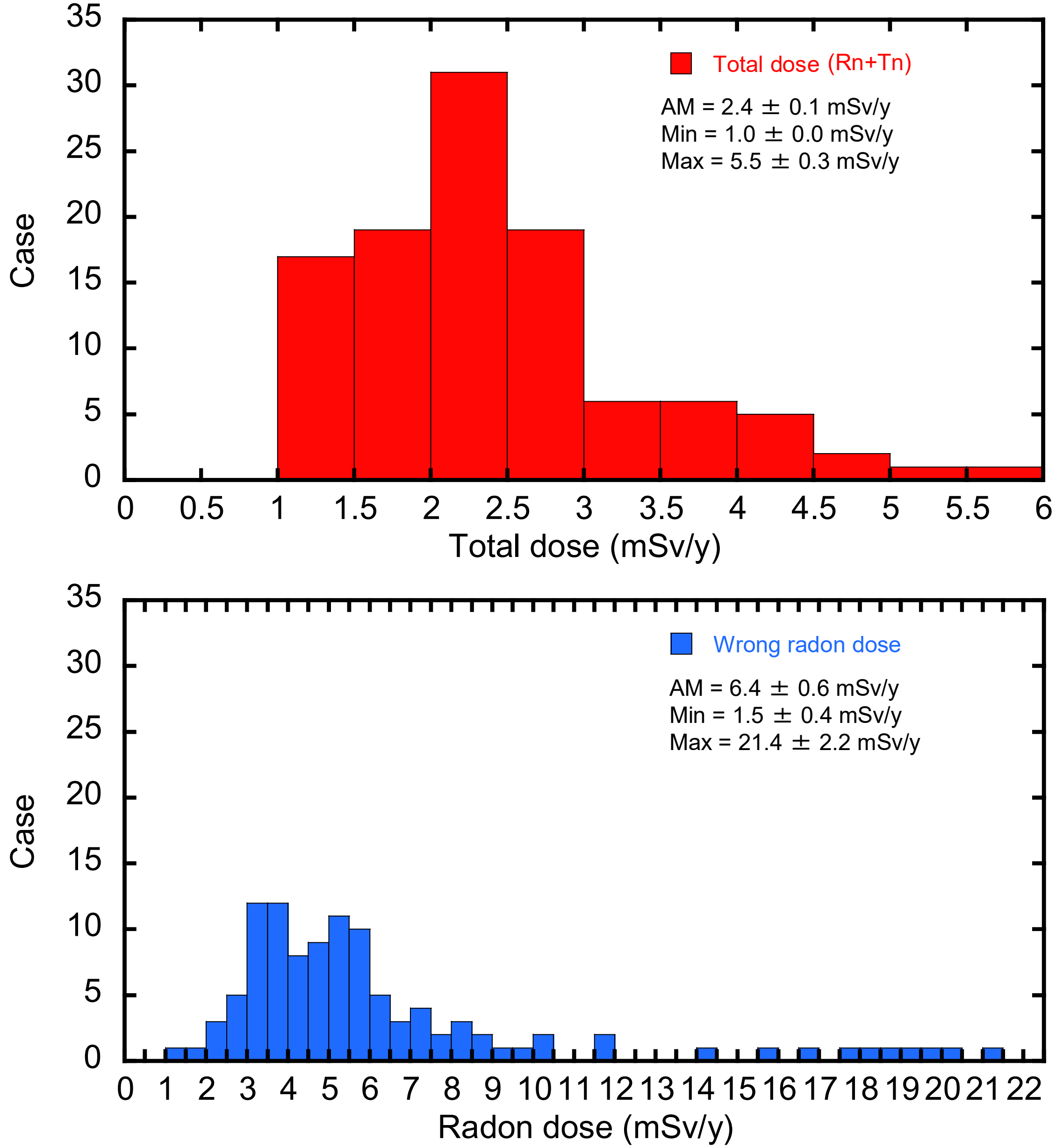
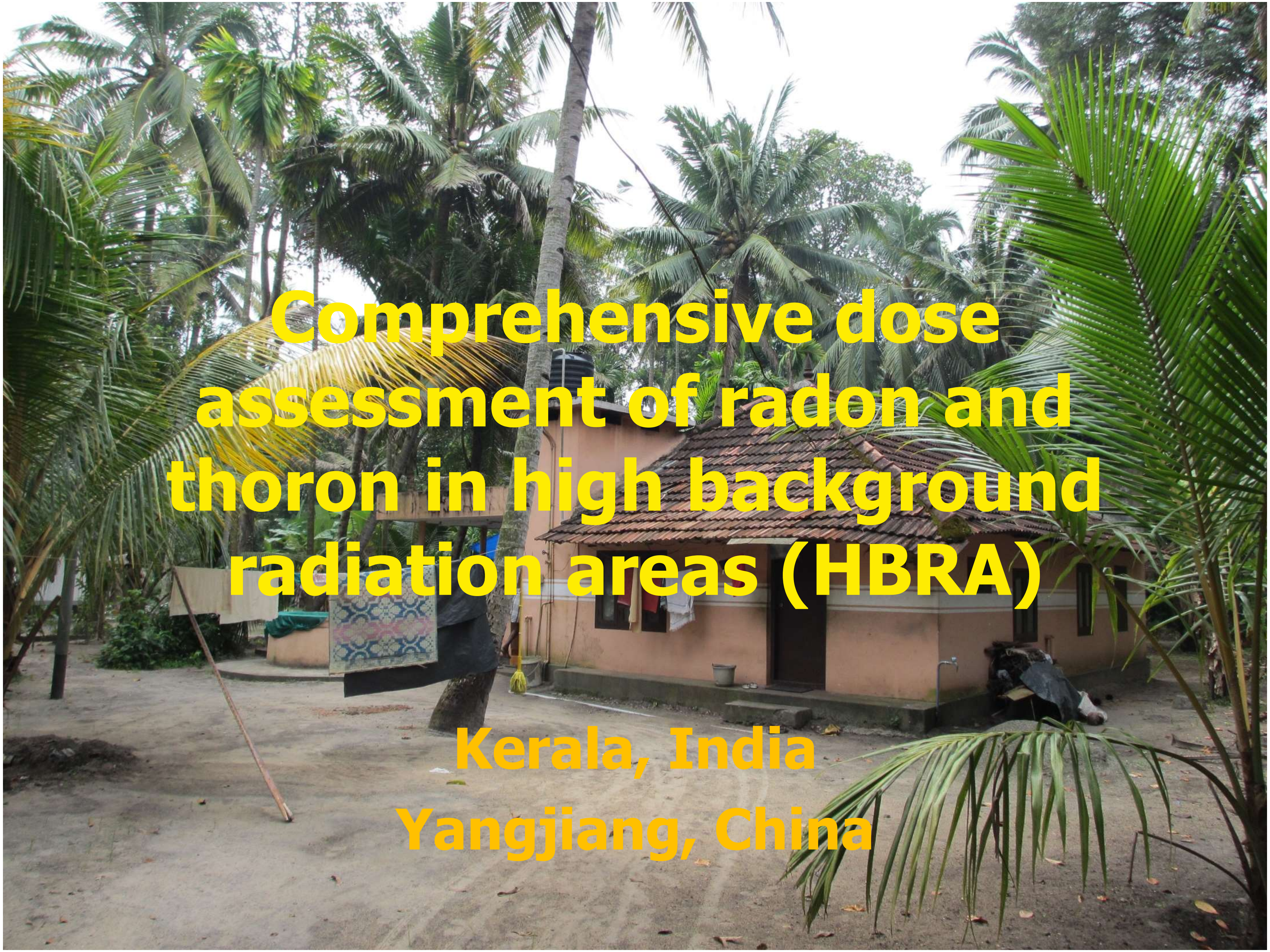


Figure: Distributions of effective dose due to inhalation between our study and the previous study

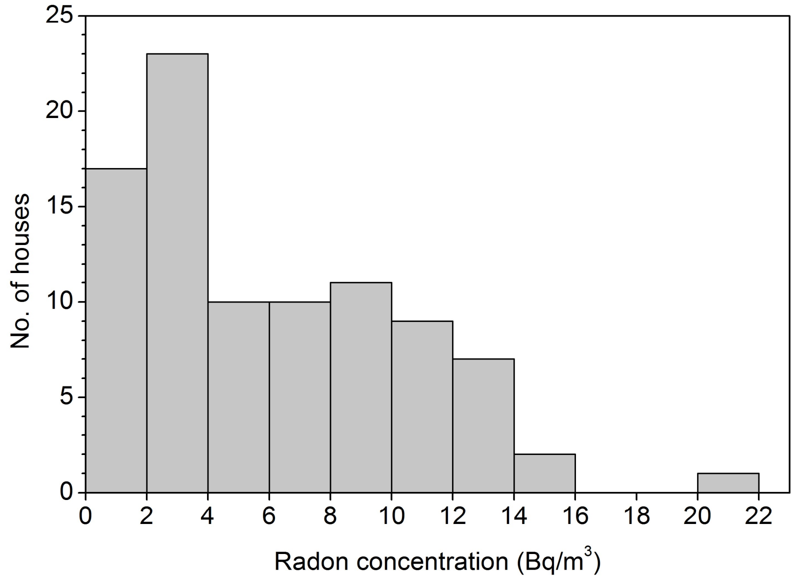
New implication of radon risk based on our Gansu study

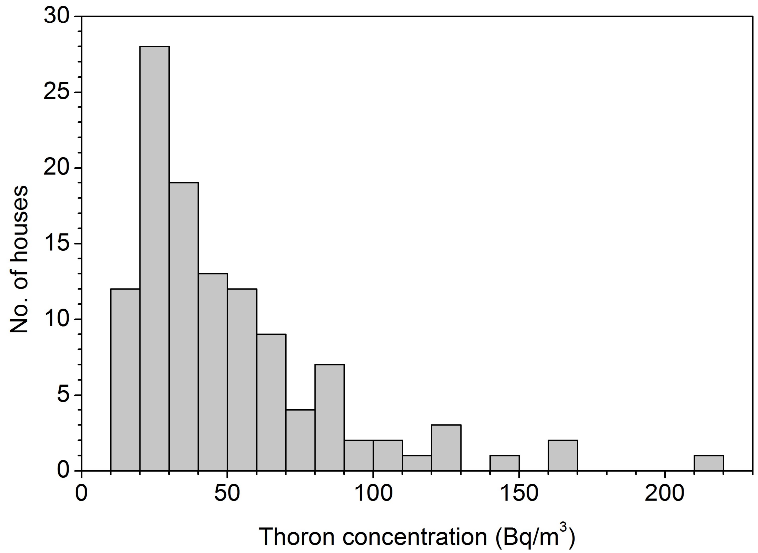
Thoron interference on radon measurements may result in incorrect risk estimates in several epidemiological studies on residential radon.


Comprehensive dose assessment of radon and thoron in high background radiation areas (HBRA)
Kerala, India
Yangjiang, China

Geographical location of HBRA

Results of radon, thoron and EETC in Kerala, India





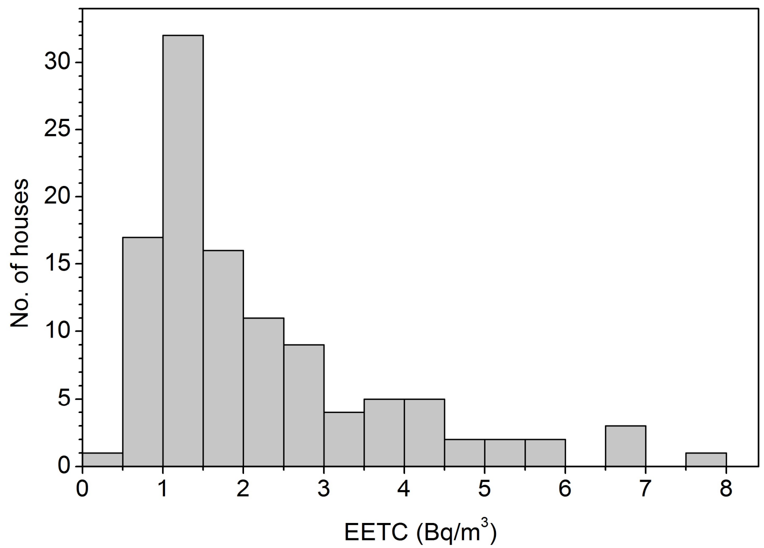
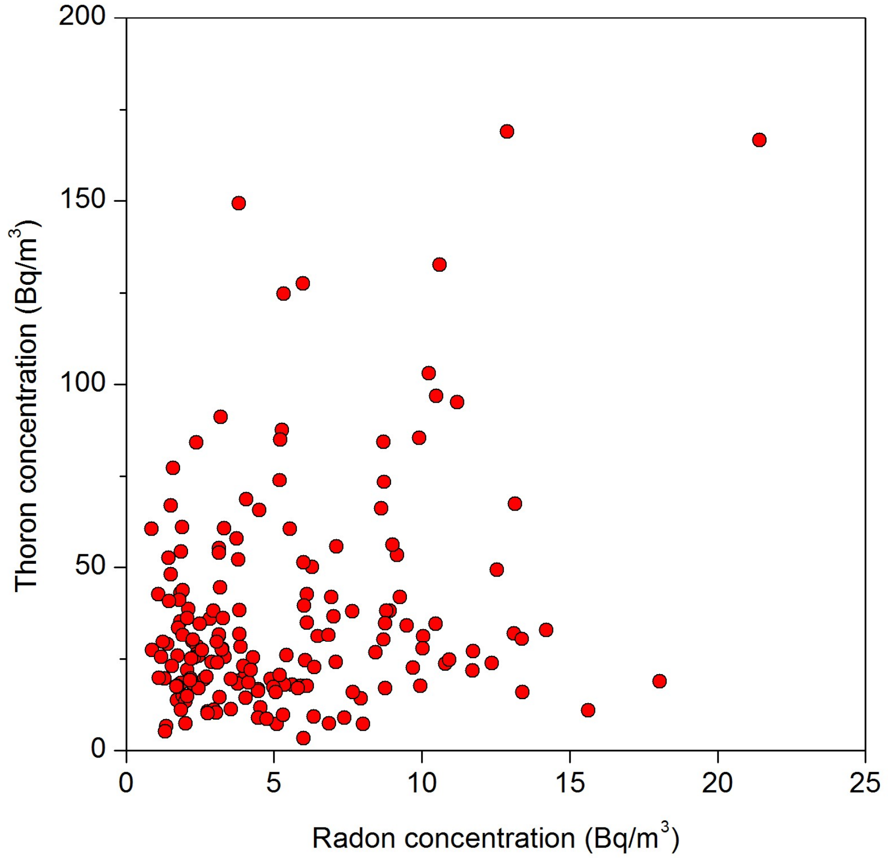


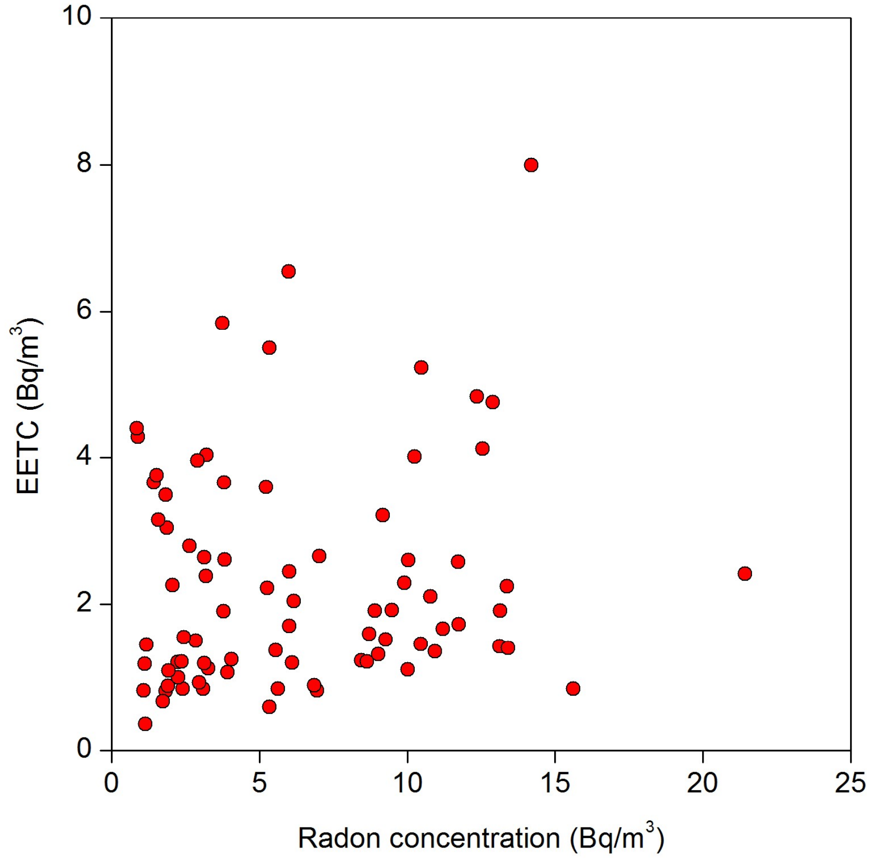
Table Result of 125 houses (75 in HBRA and 50 in CA)

	houses (NA[1])	mean (Bq/m^3)	median (Bq/m^3)	range (Bq/m^3)
HBRA				
Radon	53 (22)	5 ± 3	4	1-13
Thoron	68 (7)	53 ± 28	46	15-128
EETC	66 (9)	2.15 ± 1.57	1.48	0.59-6.72
CA				
Radon	37 (13)	8 ± 5	9	1-21
Thoron	48 (2)	47 ± 44	31	11-212
EETC	44 (6)	2.32 ± 1.51	1.91	0.36-8.00

NA: Not Assessed

Correlation between radon, thoron and thoron progeny concentrations





- **All the data were obtained by a long-term measurement with passive monitors.**
- **No correlations among any parameters.**

Dose assessment of radon

Radon
[Bq m^{-3}]

↓ ×Equilibrium factor(F)

EERC
[Bq m^{-3}]

↓ ×Exposure period [h]

Time-integrated EERC
[Bq h m^{-3}]

↓ ×Dose conversion factor
[mSv (Bq h m^{-3} $)^{-1}$]

Effective dose
[mSv]

Dose assessment of thoron

(1) Indirect method

Thoron
[Bq m^{-3}]

↓

F=0.02
(Typically?)
UNSCEAR 2006

EETC
[Bq m^{-3}]

↓ × Exposure period [h]

Time-integrated EETC
[Bq h m^{-3}]

↓ × Dose conversion factor [mSv (Bq h^{-1} m^{3})$^{-1}$]

Effective dose
[mSv]

(2) Direct method

EETC
[Bq m^{-3}]

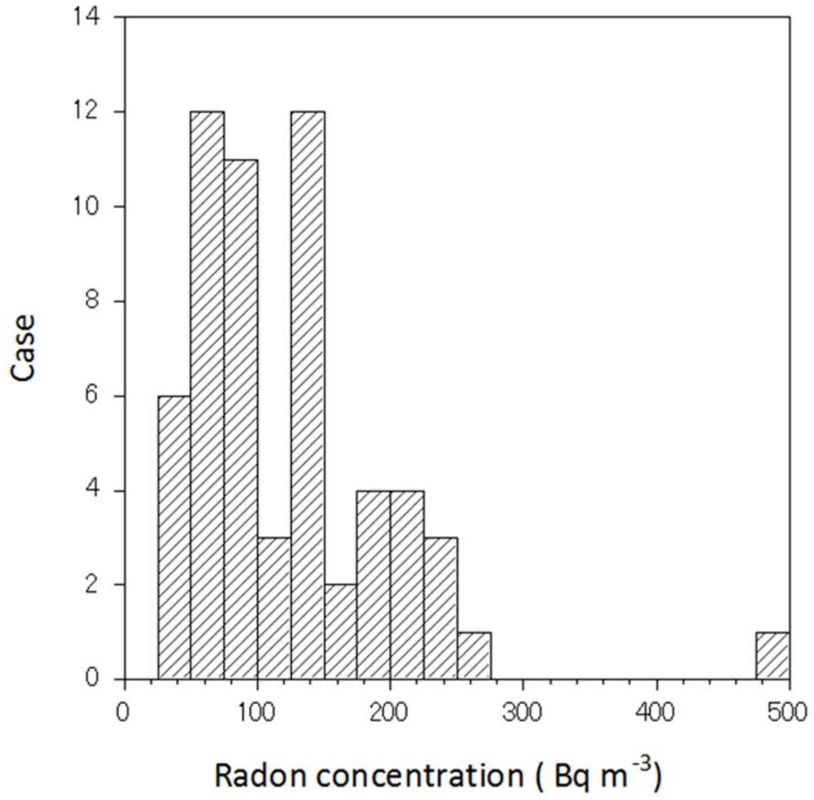
↓ × Exposure period [h]

Time-integrated EETC
[Bq h m^{-3}]

↓ × Dose conversion factor [mSv (Bq h^{-1} m^{3})$^{-1}$]

Effective dose
[mSv]

Histograms of radon and thoron concentrations in Yangjiang, China



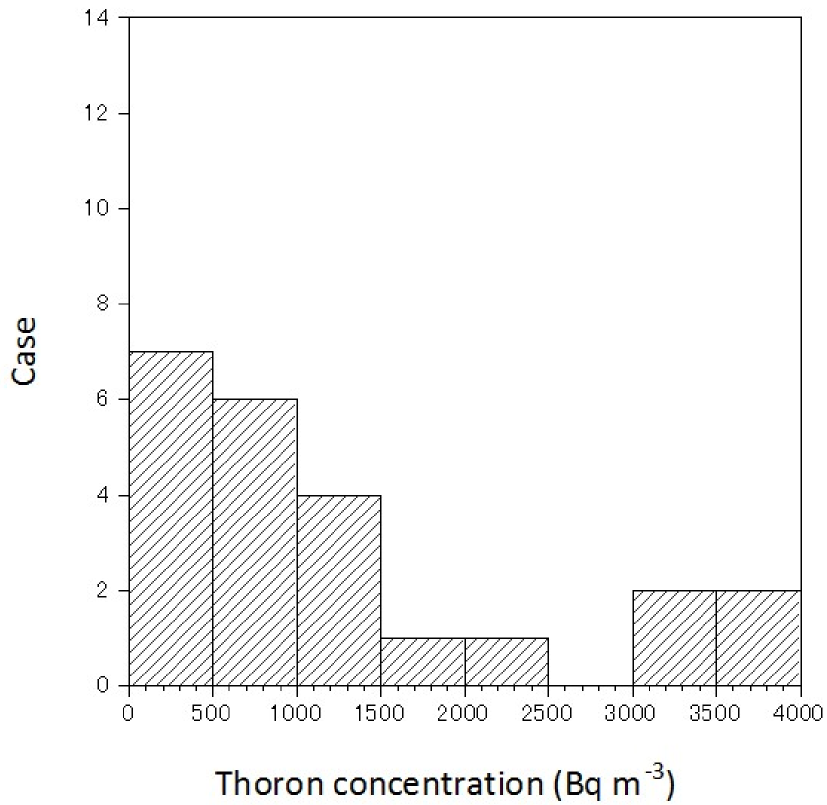
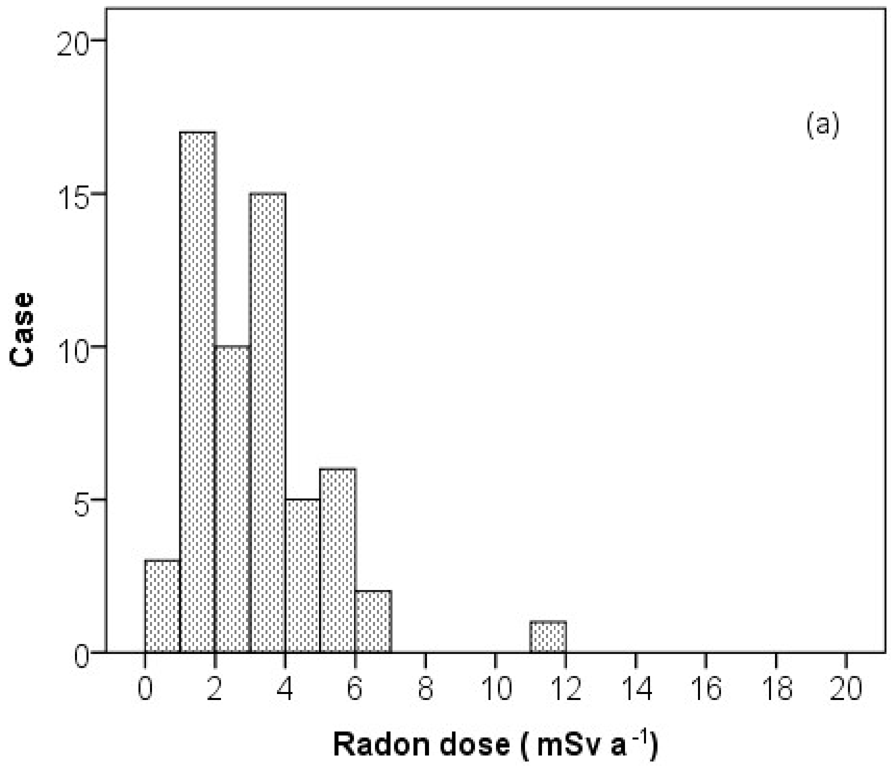


Table: Results of 60 houses

	Houses (ND)	Mean (Bq m^{-3})	Median (Bq m^{-3})	Range (Bq m^{-3})
Radon	59 (0)	124 ± 78	115	27-476
Thoron	23 (36)	1247 ± 1189	859	65-3957
EETC	59 (0)	7.8 ± 9.1	4.2	0.6-36.2

Internal dose due to inhalation of radon and thoron in Yangjinag, China



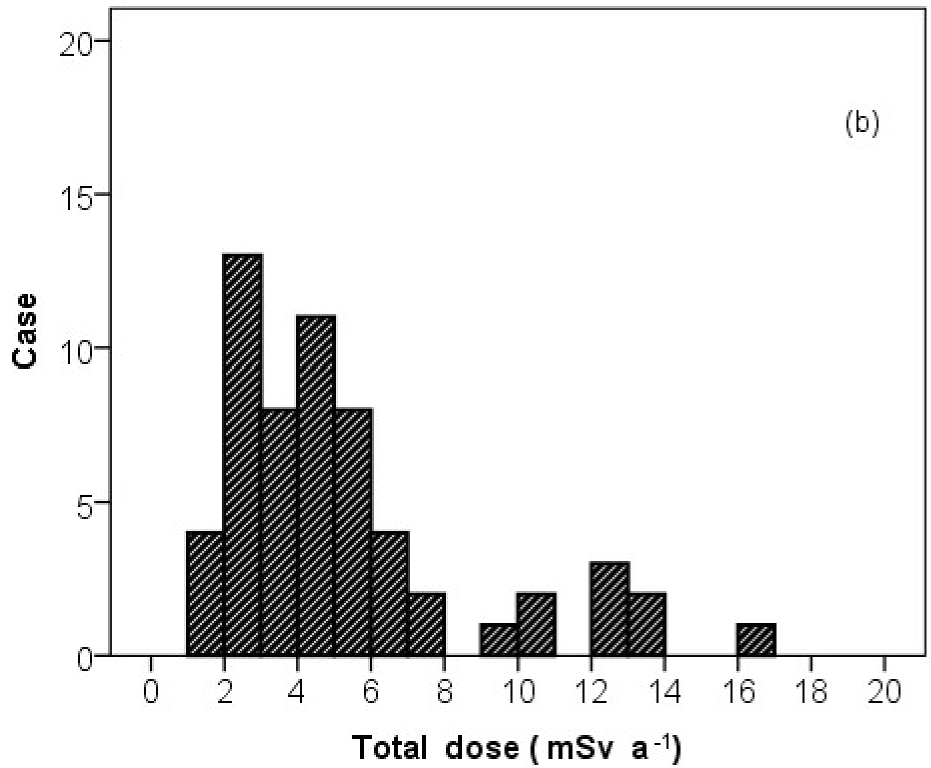


Table: Result of 60 houses

	Houses (ND)	Mean ($mSv\ a^{-1}$)	Median ($mSv\ a^{-1}$)	Range ($mSv\ a^{-1}$)
Radon	59 (1)	3.1 ± 2.0	2.9	0.7-12
Thoron	59 (1)	2.2 ± 2.5	1.2	0.2-10.1
Total	59 (1)	5.3 ± 3.5	4.4	1.5-16.4

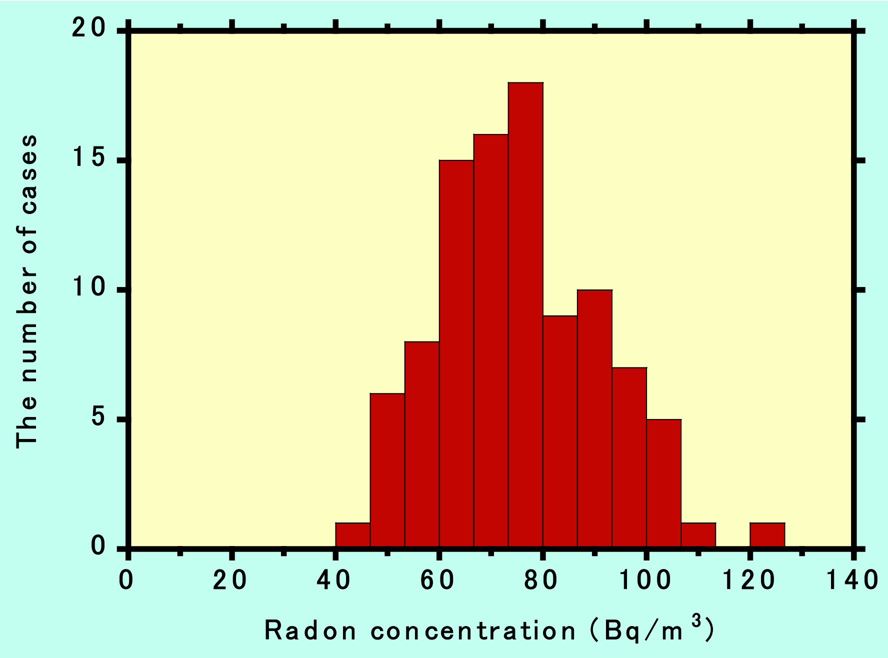
Equilibrium Factor of Thoron

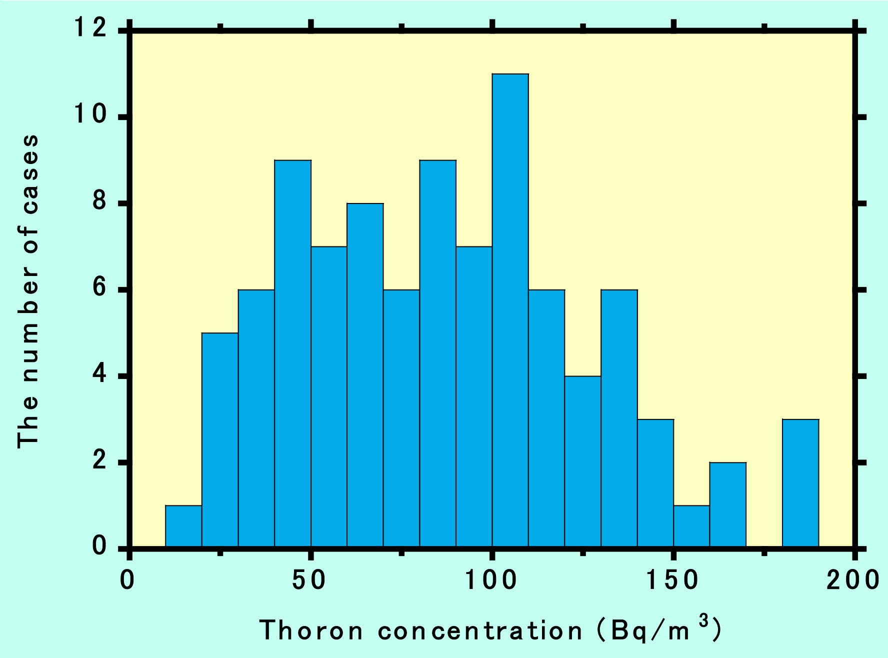
Study	Samples	Field	Range	AM±SD	GM
Kudo (2015)	23	Yangjiang (China)	0.0027-0.110	0.019±0.242	0.011
Chen (2011)	113	Canada	0.0001-0.209	0.036±0.028	0.022
UNSCEAR (2006)	-	-	-	-	0.02

New findings from our studies

- There are no correlations among three activity concentrations such as radon, thoron and EETC.
- Such non-correlations will result in non-availability of the equilibrium factor of thoron for dose assessment.
- In our HBRA studies, the thoron dose could not be ignored.

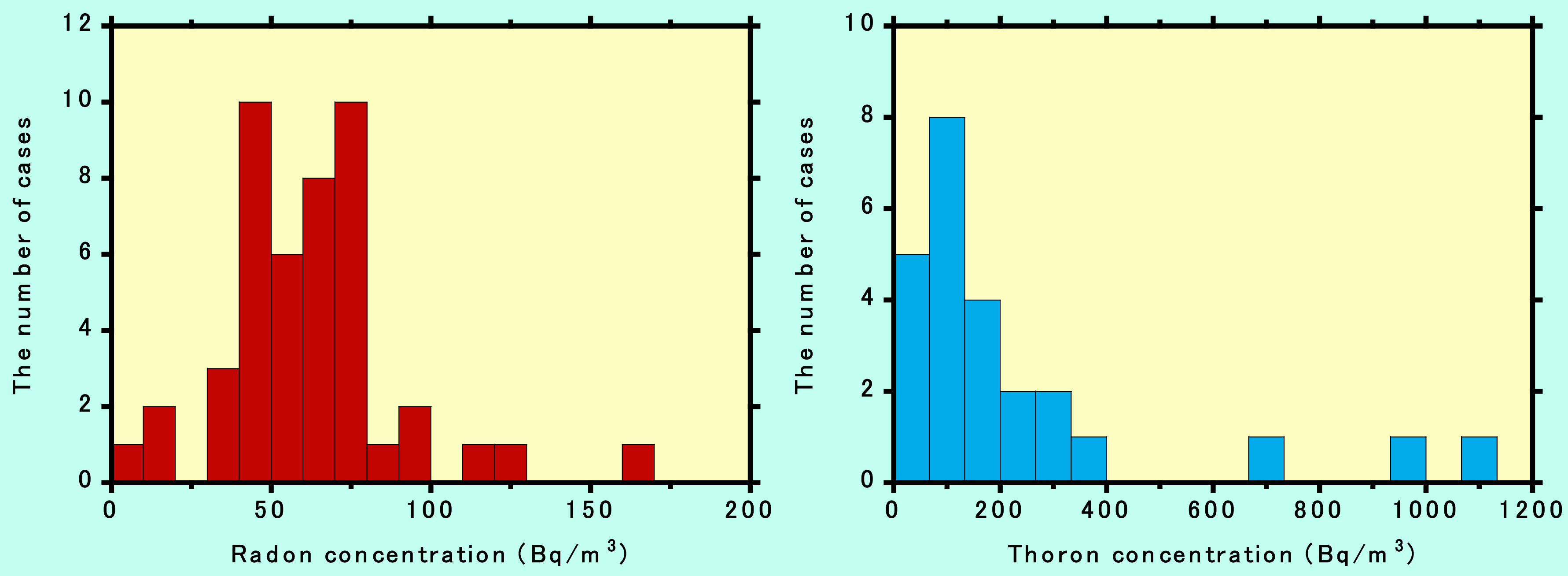
Results of radon and thoron in Cameroon





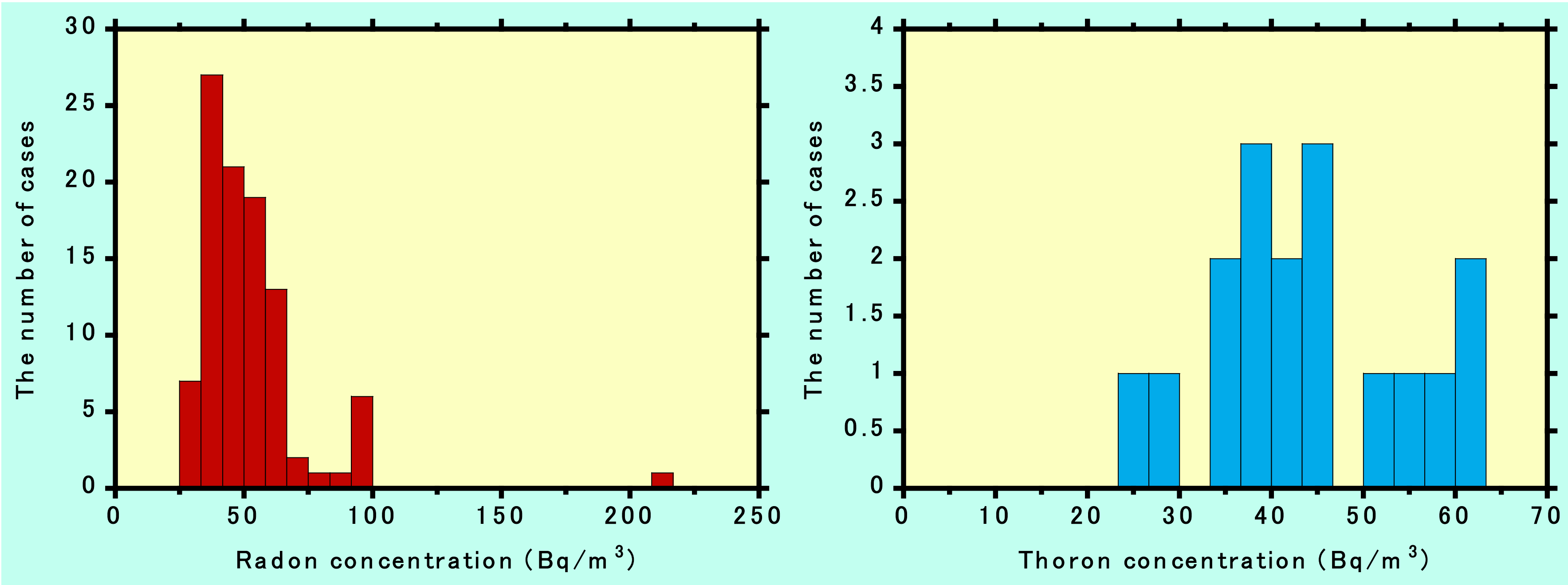
	Number of survey points (NA)	Mean (Bq/m^3)	Median (Bq/m^3)	Range (Bq/m^3)
Radon	97	76 ± 16	74	46 – 121
Thoron	94 (3)	87 ± 40	85	17 – 184

Results of radon and thoron in Kenya



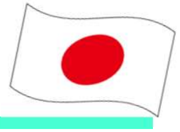
	Number of survey points (NA)	Mean (Bq/m³)	Median (Bq/m³)	Range (Bq/m³)
Radon	46	62 ± 28	63	1 – 163
Thoron	25 (21)	237 ± 287	113	42 – 1130

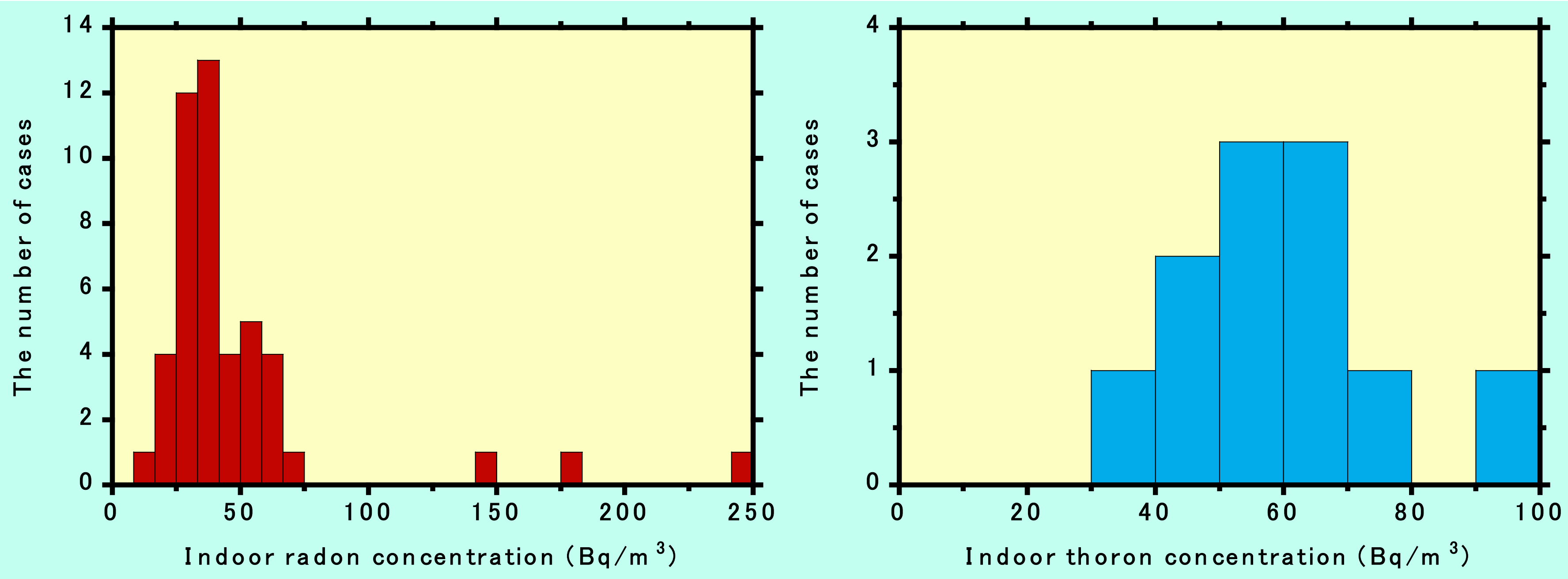
Results of radon and thoron in Thailand



	Number of survey points (NA)	Mean (Bq/m^3)	Median (Bq/m^3)	Range (Bq/m^3)
Radon	98	53 ± 23	49	29 – 209
Thoron	17 (81)	44 ± 11	43	26 – 61

Results of indoor radon and thoron in Fukushima





	Number of survey points (NA)	Mean (Bq/m^3)	Median (Bq/m^3)	Range (Bq/m^3)
Radon	47	48 ± 40	38	16 – 242
Thoron	11 (36)	59 ± 17	57	34 – 97

Summary of Presentation

- Thoron is present everywhere.
- Nobody knows how much thoron is present unless thoron concentration is measured.
  - no correlations among activity concentrations
- Thoron progeny concentrations should be directly measured.
  - Thoron concentration cannot be applied to determination of its progeny concentration using the equilibrium factor.
  - More data need to be accumulated for radiation protection purposes.
- Thoron interference can be regarded as one of major uncertainties of radon measurements in indoor radon studies.
- Any measurements for evaluation of health effects without discriminative detection of radon isotopes may result in highly uncertain risk estimates.

INTERNATIONAL STANDARD

ISO 16641

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Thank you very much for your attention.

Measurement of radioactivity in the environment — Air — Radon 220: Integrated measurement methods for the determination of the average activity concentration using passive solid-state nuclear track detectors

Mesurage de la radioactivité dans l'environnement — Air — Radon 220: Méthode de mesure intégrée pour la détermination de l'activité volumique moyenne avec des détecteurs passifs solides de traces nucléaires

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