Exposure caused by natural radionuclides in building materials: current practice, regulations and radiation protection standards development

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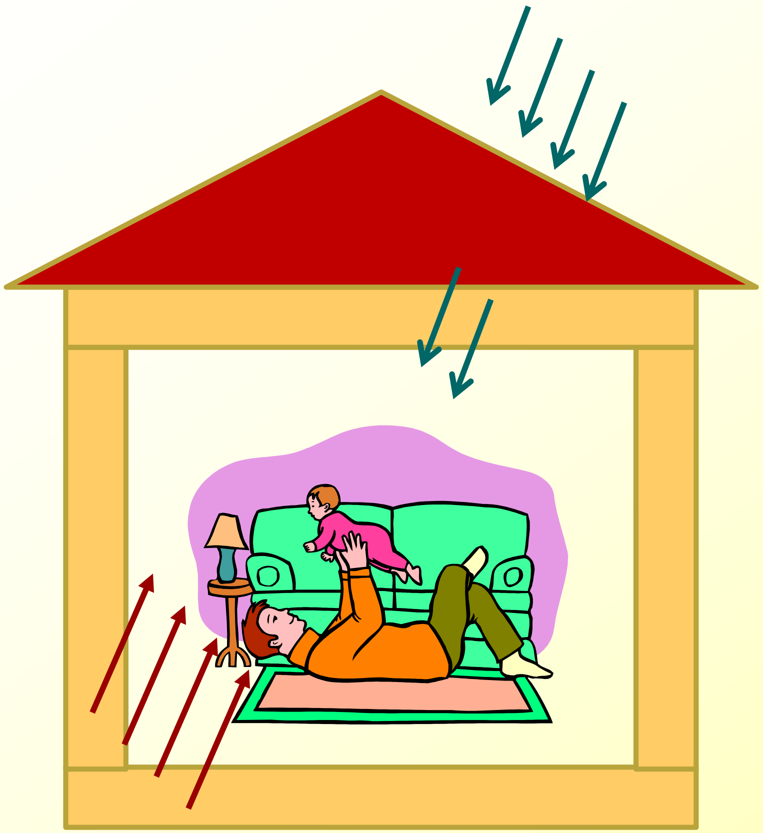
Trigger & target

- Limit the public external radiation exposure indoor due to natural radionuclides in building materials
- Key radionuclides for exposure evaluation: K-40, Ra-226, Th-232
- Additional issue: Rn exhalation from construction material and internal exposure due to Rn progenies
  → *but: main indoor Rn from building underground*
- EU: EC proposal to revised Basic Safety Standards for radiation protection (2011)
  - Excess exposure due to natural radionuclides in building materials ***E*** **< 1 mSv / year**

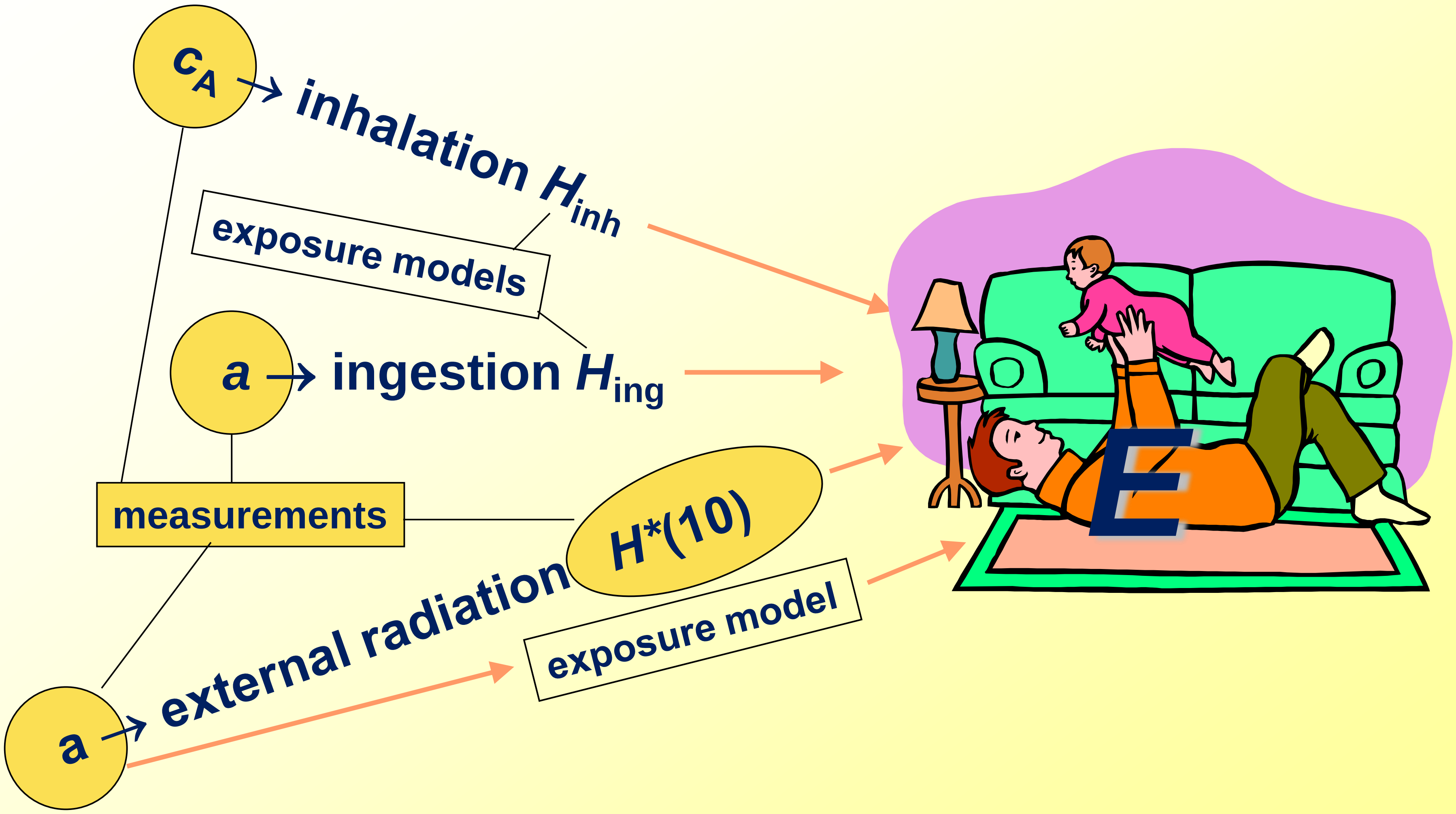
Average natural exposure situation



Radioactivity in natural building materials:
K-40 ≈ 200 … 370 … 700 Bq/kg
Ra-226 ≈ 25 … 40 … 75 Bq/kg
Th-232 ≈ 20 … 25 … 60 Bq/kg

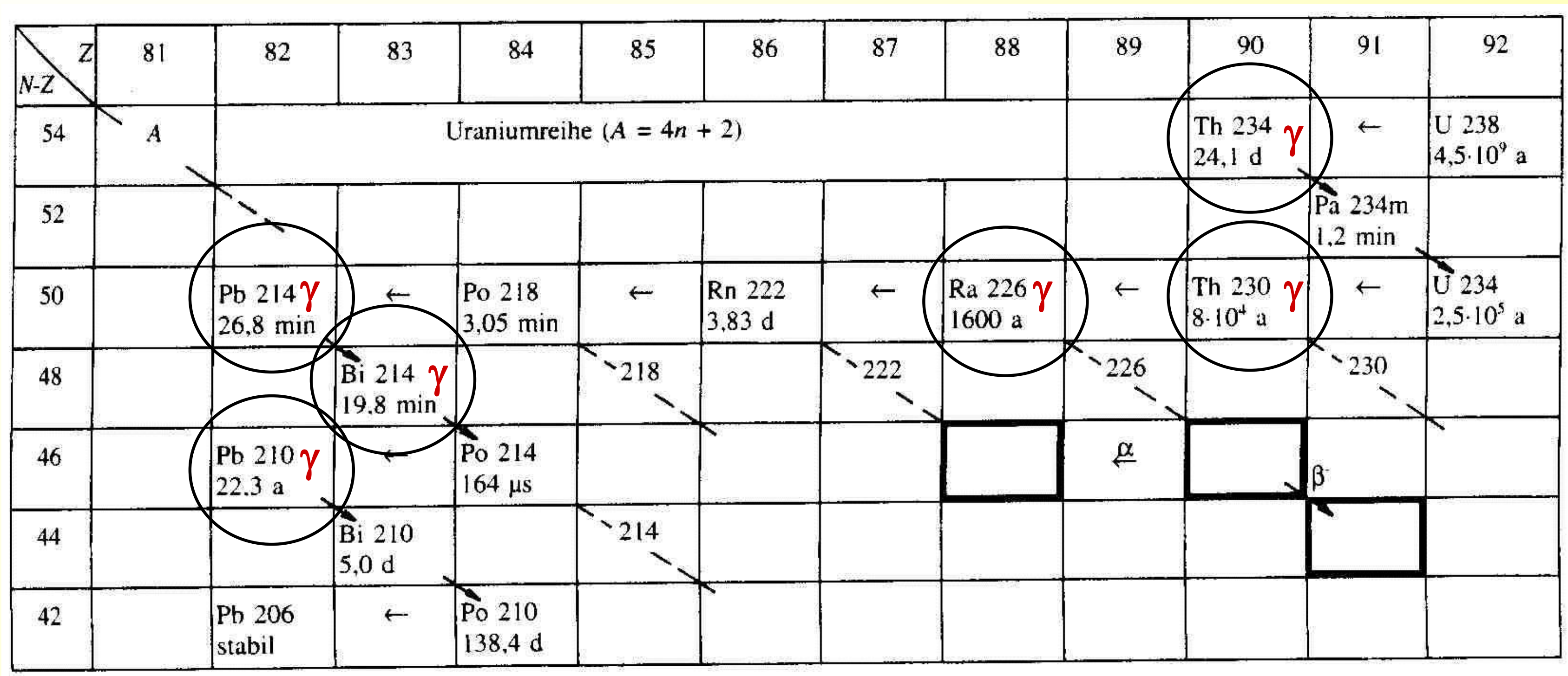
Natural exposure outdoor :
$H^*(10)$ ≈ 0,9 … 1,3 … 2,3 mSv / year
E ≈ 0,4 … 0,7 … 1,2 mSv / year

Radionuclide activity → human exposure



U-238 decay chain

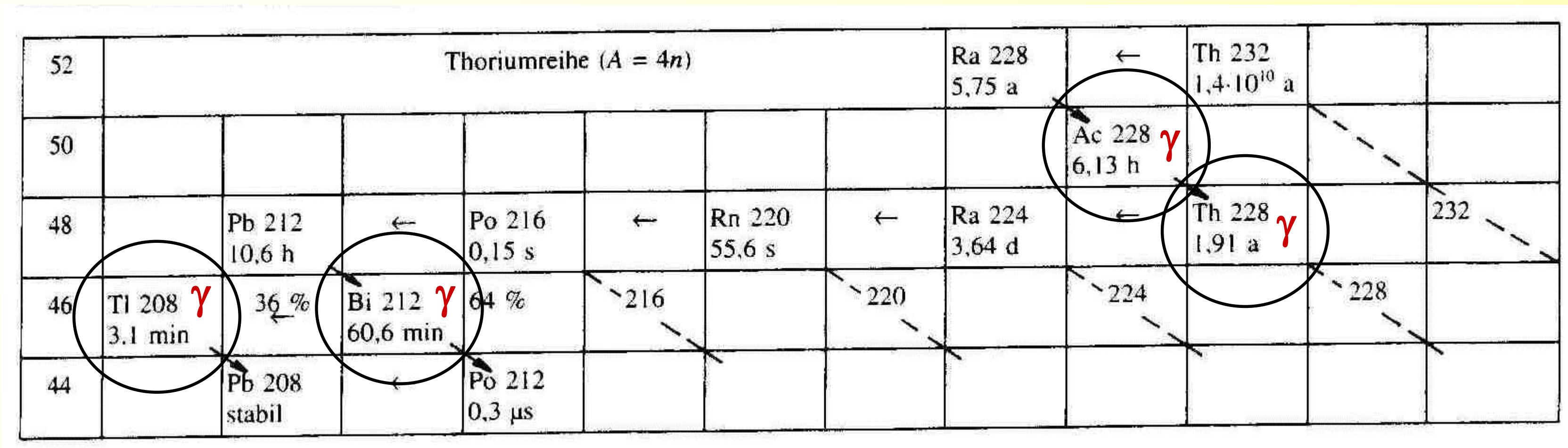
- Low-level gamma-ray spectrometry



$$\text{if } a_{Ra\text{-}226} \approx a_{Rn-222} \Rightarrow a_{Ra\text{-}226} = \frac{a_{Pb-214} + a_{Bi-214}}{2}$$

Th-232 decay chain

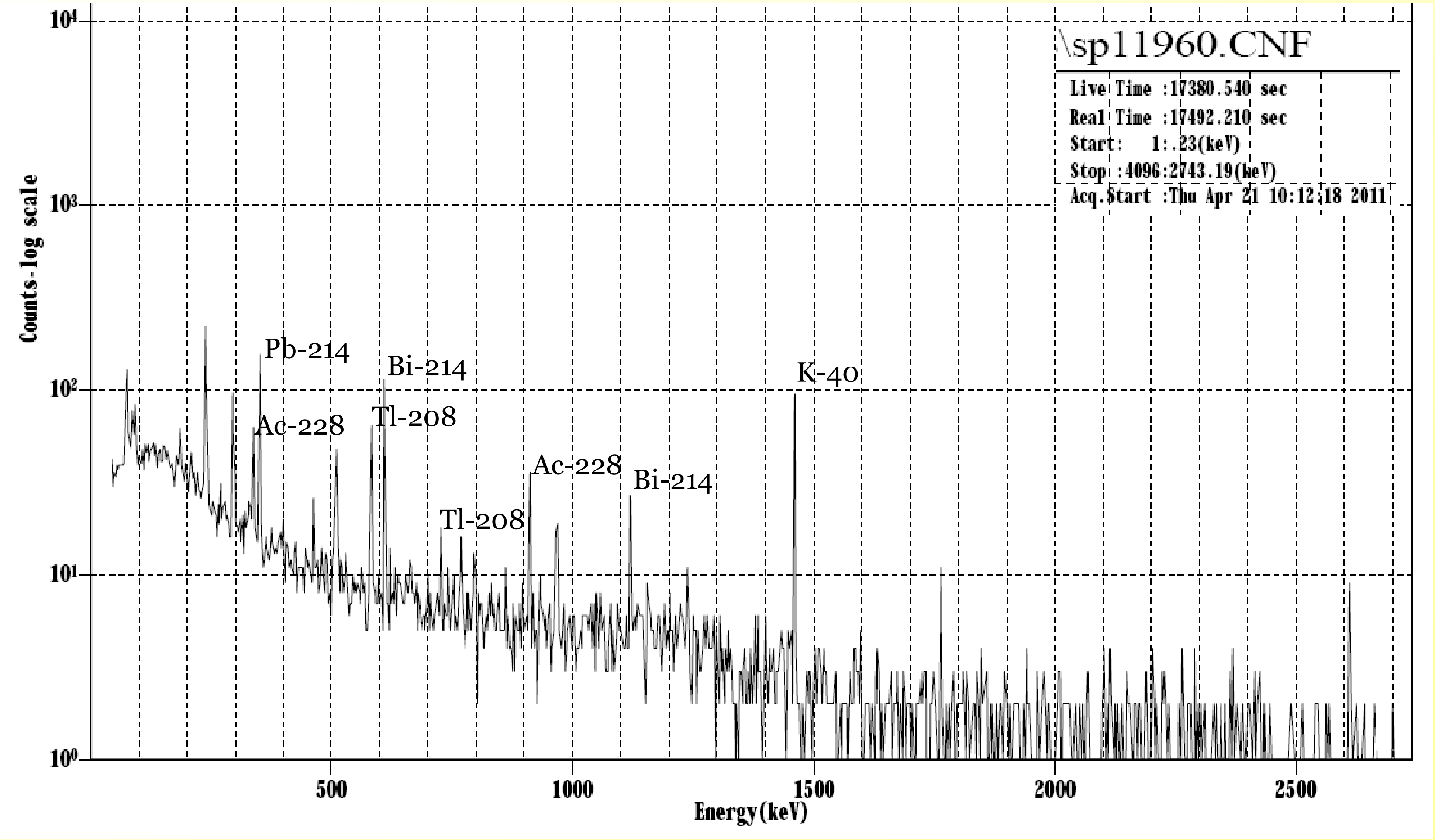
- Low-level gamma-ray spectrometry



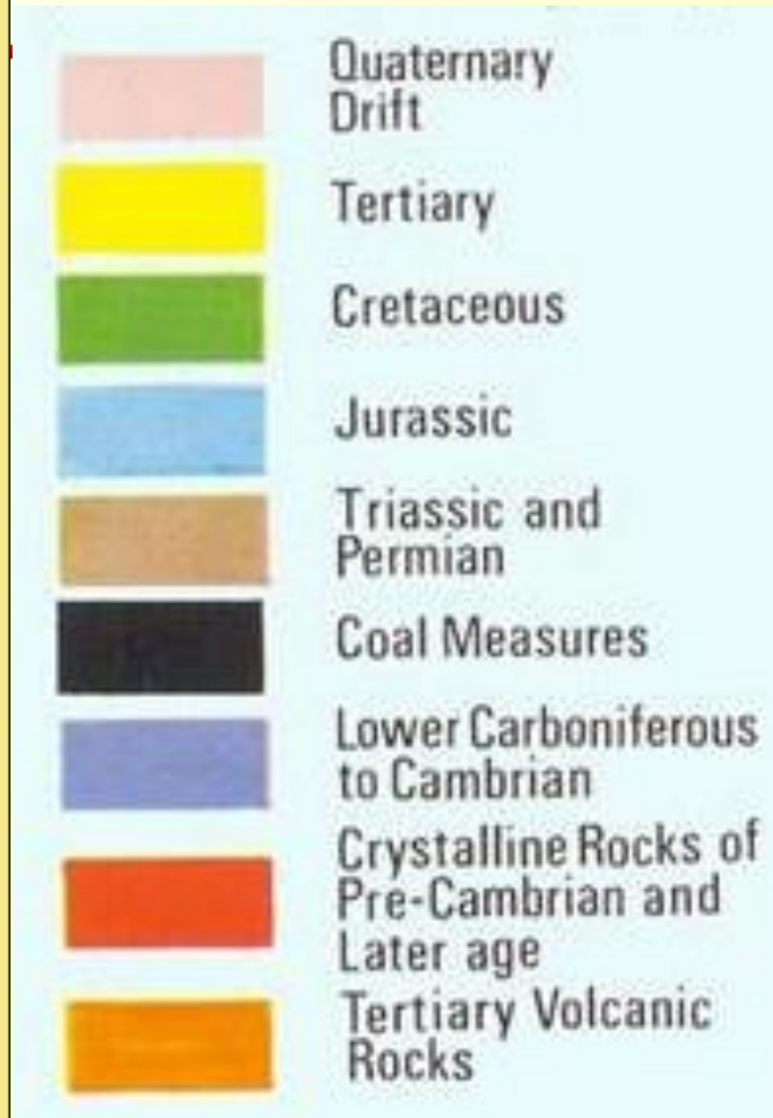
$$\text{if}\ \ a_{Ra\text{-}228} \approx a_{Th\text{-}228} \Rightarrow \quad a_{Th\text{-}232} = \frac{a_{Ra\text{-}228} + a_{Th\text{-}228}}{2} \quad \textit{with} \quad a_{Ra\text{-}228} = a_{Ac\text{-}228}$$

Low-level gamma-ray spectrometry

building material sample




Geological Map of Western Europe
(Modified after Kirkaldy, 1967)
Quaternary Drift
Tertiary
Cretaceous
Jurassic
Triassic and Permian
Coal Measures
Lower Carboniferous to Cambrian
Crystalline Rocks of Pre-Cambrian and Later age
Tertiary Volcanic Rocks
FAEROES (Igneous)
SHETLANDS
ORKNEYS
HEBRIDES
HIGHLANDS
MIDLAND VALLEY
Southern Uplands
Lake District
Pennines
NORTH SEA
ANTRIM
CENTRAL PLAIN
Carboniferous
Cork
WALES
Salop
Jurassic
East ANGLIA
LONDON Basin
CORNUBIA
HANTS Basin
Weald
CHANNEL ISLANDS
ATLANTIC OCEAN
NORWAY
SWEDEN
GULF OF BOTHNIA
Oslo
Stockholm
GOTTLAND
ESTHONIA
BALTIC SEA
DENMARK
Copenhagen
ZUIDER ZEE
HOLLAND
Osnabruck
Hanover
NORTH GERMAN PLAIN
RUHR
BELGIUM
ARDENNES
RHENISH SCHIEFER-GEBIRGE
HESSE
HARZ
BOHEMIAN MASSIF
CARPATHIANS
BRITTANY
PARIS BASIN
Cretac. & Tertiary
VOSGES
RHINE VALLEY
BLACK FOREST
FRANCONIAN JURA
MOLASSE BASIN
EASTERN ALPS
HUNGARY
BAY OF BISCAY
AQUITAINE BASIN
MASSIF CENTRAL
CAUSSE
JURA Mountains
WESTERN ALPS
RHONE VALLEY
CANTABRIAN MTS
PYRENEES
MESETA
APENNINES
ADRIATIC
DINARIC ALPS
GREECE
CORSICA
SARDINIA
BALEARICS
MEDITERRANEAN SEA
SICILY
Ian West, 2001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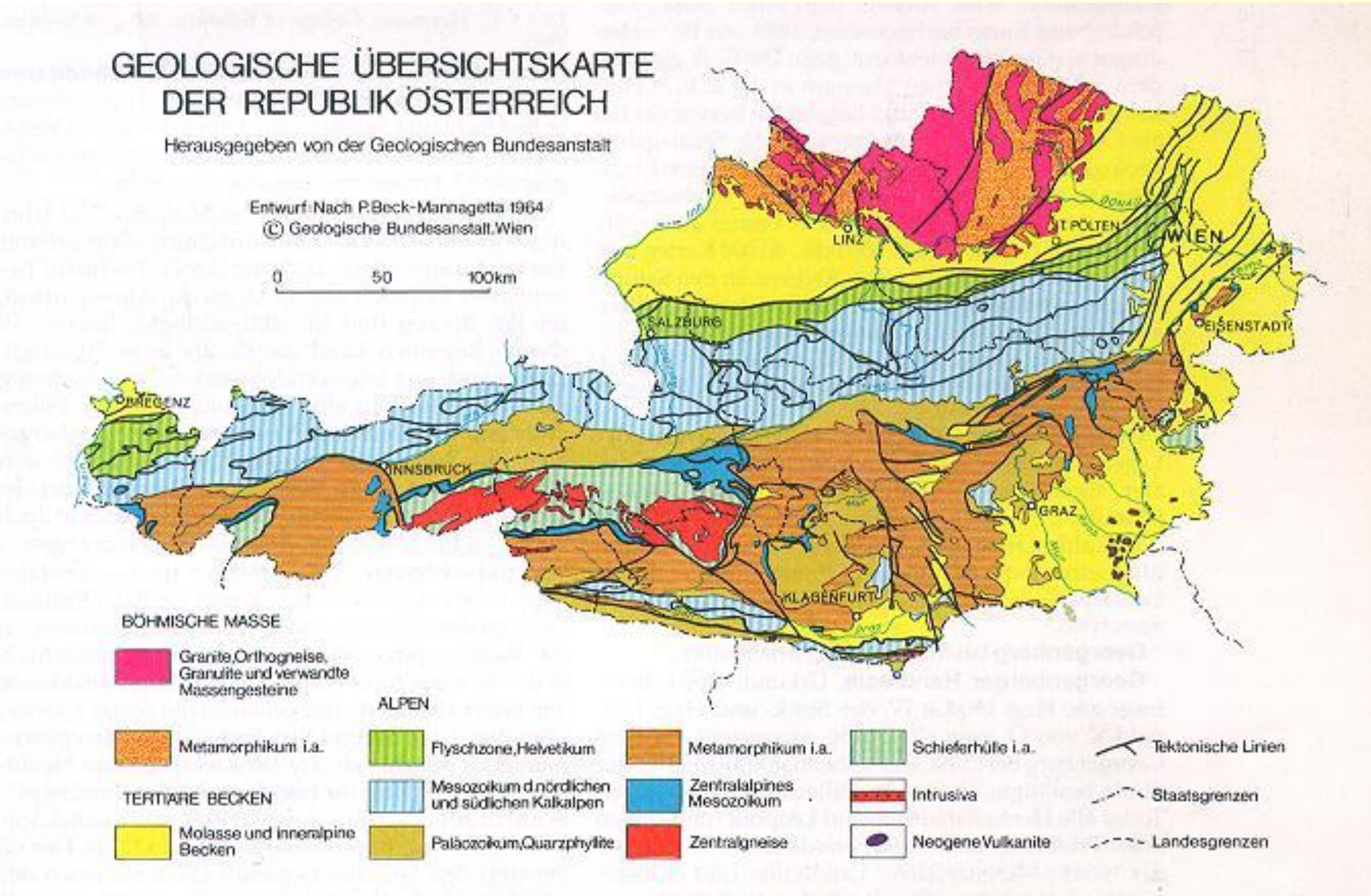
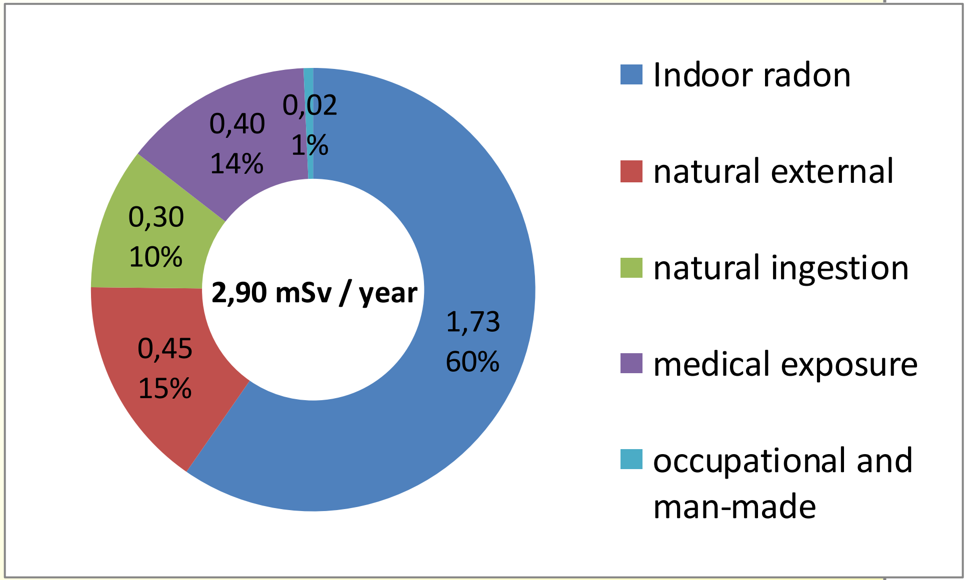

GEOLOGISCHE ÜBERSICHTSKARTE
DER REPUBLIK ÖSTERREICH
Herausgegeben von der Geologischen Bundesanstalt
Entwurf: Nach P.Beck-Mannagetta 1964
© Geologische Bundesanstalt, Wien
0 50 100km
LINZ
ST.PÖLTEN
WIEN
SALZBURG
EISENSTADT
BREGENZ
INNSBRUCK
GRAZ
KLAGENFURT
BÖHMISCHE MASSE
Granite, Orthogneise, Granulite und verwandte Massengesteine
Metamorphikum i.a.
TERTIÄRE BECKEN
Molasse und inneralpine Becken
ALPEN
Flyschzone, Helvetikum
Mesozoikum d.nördlichen und südlichen Kalkalpen
Paläozoikum, Quarzphyllite
Metamorphikum i.a.
Zentralalpines Mesozoikum
Zentralgneise
Schieferhülle i.a.
Intrusiva
Neogene Vulkanite
Tektonische Linien
Staatsgrenzen
Landesgrenzen

Activity concentrations of stone samples

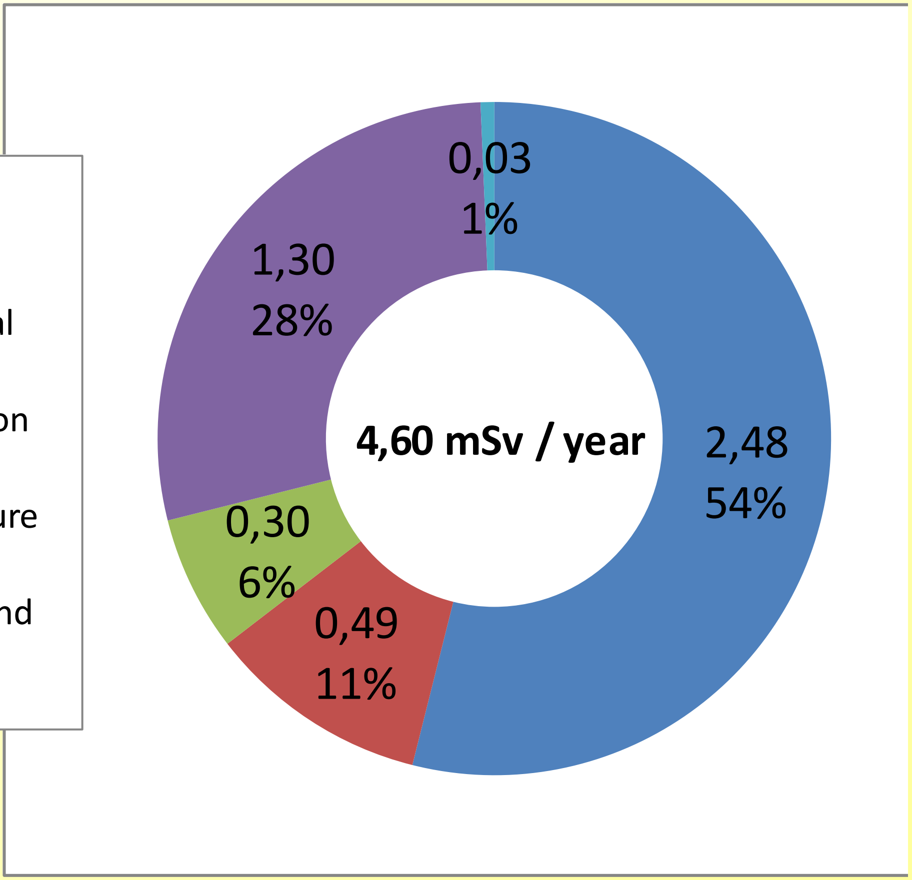
	a (Bq/kg)		
	K-40	Th-232	Ra-226
Granit	1000	80	60
Diorit	700	30	20
Basalt	250	10	10
Durit	150	25	0,4
Kalkstein	90	7	30
Sandstein	350	10	20
Tonschiefer	700	50	40

Average annual exposure (2010)

worldwide



Austria



Dose model EC RP 112 (1999)

Activity concentrations K-40, Ra-226, Th-232

➔ effective dose E

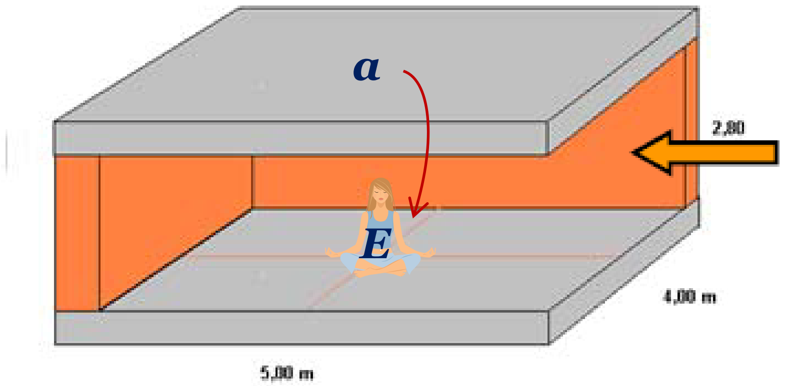
Modell room:

12,0 x 7,0 x 2,80 m

2350 kg/m³ (concrete)

d = 0,20 m

- **Analytical**
- **Numerical**
- **Monte Carlo**



Practice in Europe

- 4 EU countries: CZ, FIN, POL, AT / but not harmonised

- **Czech Republic**

Draft regulation No 2005-452-CZ:

- Ra-226 < 150 Bq/kg

Regulations of the State Office for Nuclear Safety No 307/2002:

- EC RP 112 (1999) *Index* < 0,5 ⇔ *E* < 0,3 mSv /year

$$I = \frac{a_{Ra-226}}{300 \cdot Bq \cdot kg^{-1}} + \frac{a_{Th-232}}{200 \cdot Bq \cdot kg^{-1}} + \frac{a_{K-40}}{3000 \cdot Bq \cdot kg^{-1}}$$

Practice in Europe

- **Finland**

Technical guide 12.2 STUK (2010):

- EC RP 112 (1999) *Index* < 1
- Specific evaluation possible

- **Poland**
- EC RP 112 (1999) *Index* < 1
- Ra-226 < 200 Bq/kg

limit tolerance: + 20%

Practice in Europe

- **Austria** $I < 1 \Leftrightarrow E_{excess} < 1$ mSv / year

Austrian NORM Ordinance BGBl II 2/2008:

$$I = \frac{a_{Ra-226} - 40 \cdot Bq \cdot kg^{-1}}{40 \cdot Bq \cdot kg^{-1}} + \frac{a_{Th-232} - 25 \cdot Bq \cdot kg^{-1}}{240 \cdot Bq \cdot kg^{-1}} + \frac{a_{K-40} - 370 \cdot Bq \cdot kg^{-1}}{4000 \cdot Bq \cdot kg^{-1}}$$

Austrian Standard ÖNORM S5200 (2009):

$$I = \frac{a_{Ra-226}}{880 \cdot Bq \cdot kg^{-1}} \left(1 + 0{,}07 \cdot \varepsilon \cdot \rho \cdot d\right) + \frac{a_{Th-232}}{530 \cdot Bq \cdot kg^{-1}} + \frac{a_{K-40}}{8800 \cdot Bq \cdot kg^{-1}} \quad (2)$$

ε ... radon emanation factor, ρ ... building material density, d ... thickness

→ EC BSS proposal 2011

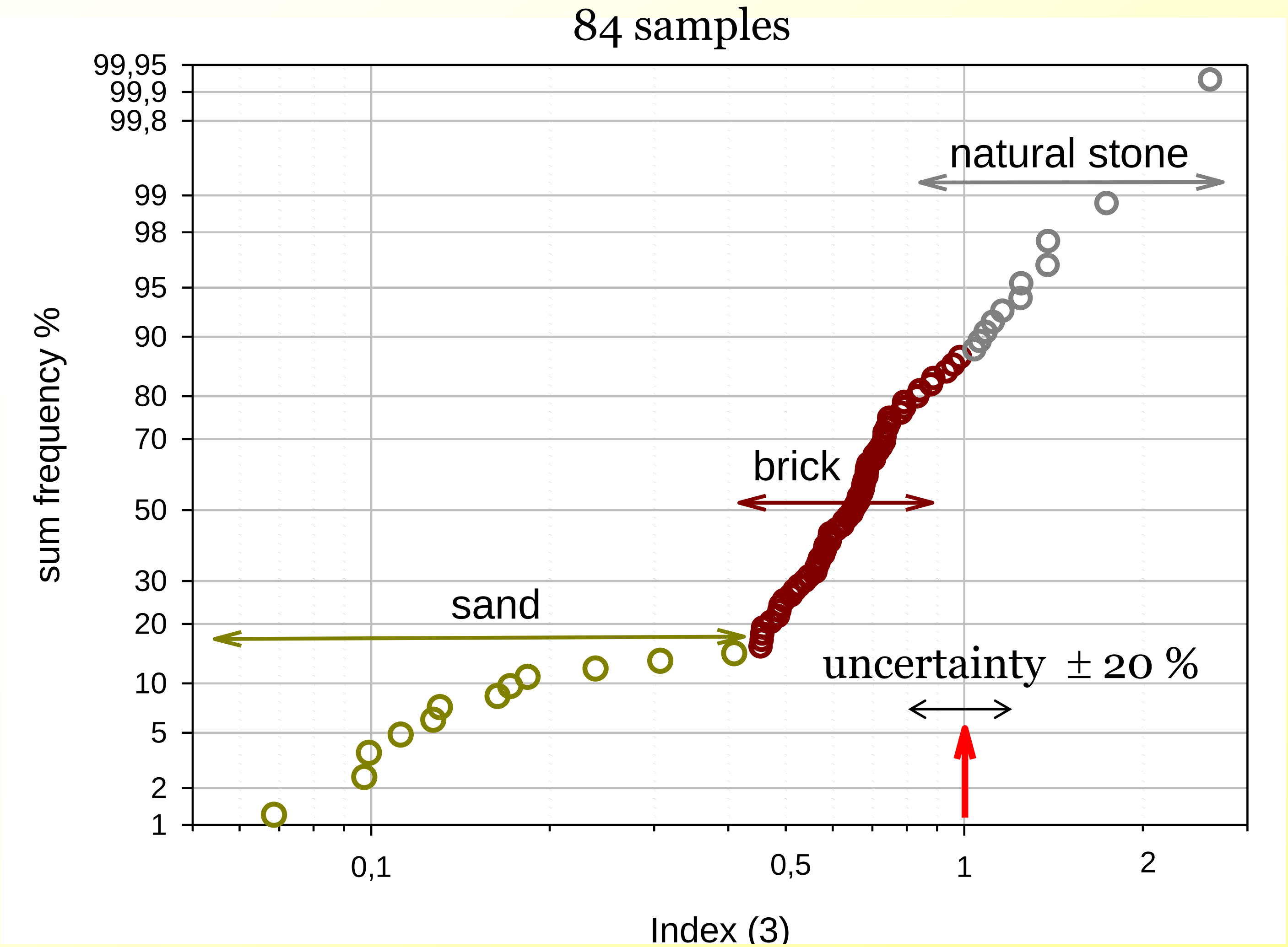
- Article 75 (2) / Annex VII ← EC RP 112 (1999)

$$I = \frac{a_{Ra-226}}{300 \cdot Bq \cdot kg^{-1}} + \frac{a_{Th-232}}{200 \cdot Bq \cdot kg^{-1}} + \frac{a_{K-40}}{3000 \cdot Bq \cdot kg^{-1}} \qquad (3)$$

	Category (corresponding default dose)	
Use	A (≤ 1 mSv)	B (> 1 mSv)
{1} materials used in bulk amounts	I ≤ 1	I > 1
{2} superficial and other materials with restricted use	I ≤ 6	I > 6

- Allocation of materials into A or B and into {1} or {2} → national building codes
- Where appropriate, actual doses for comparison with the reference level should be assessed using more elaborate models, which may also take into account the background outdoor external exposure from local prevailing activity concentrations in the undisturbed earth's crust.

EC BSS proposal 2011 formula index (3)



Improvement: application parameter

$$I = \left(\frac{a_{Ra-226}}{300 \cdot Bq \cdot kg^{-1}} + \frac{a_{Th-232}}{200 \cdot Bq \cdot kg^{-1}} + \frac{a_{K-40}}{3000 \cdot Bq \cdot kg^{-1}} \right) \frac{d \cdot \rho}{470 \cdot kg \cdot m^{-2}} \quad (4)$$

d .... thickness of the wall, superficial or other material in m

ρ .... gross dry density of the material in kg/m³

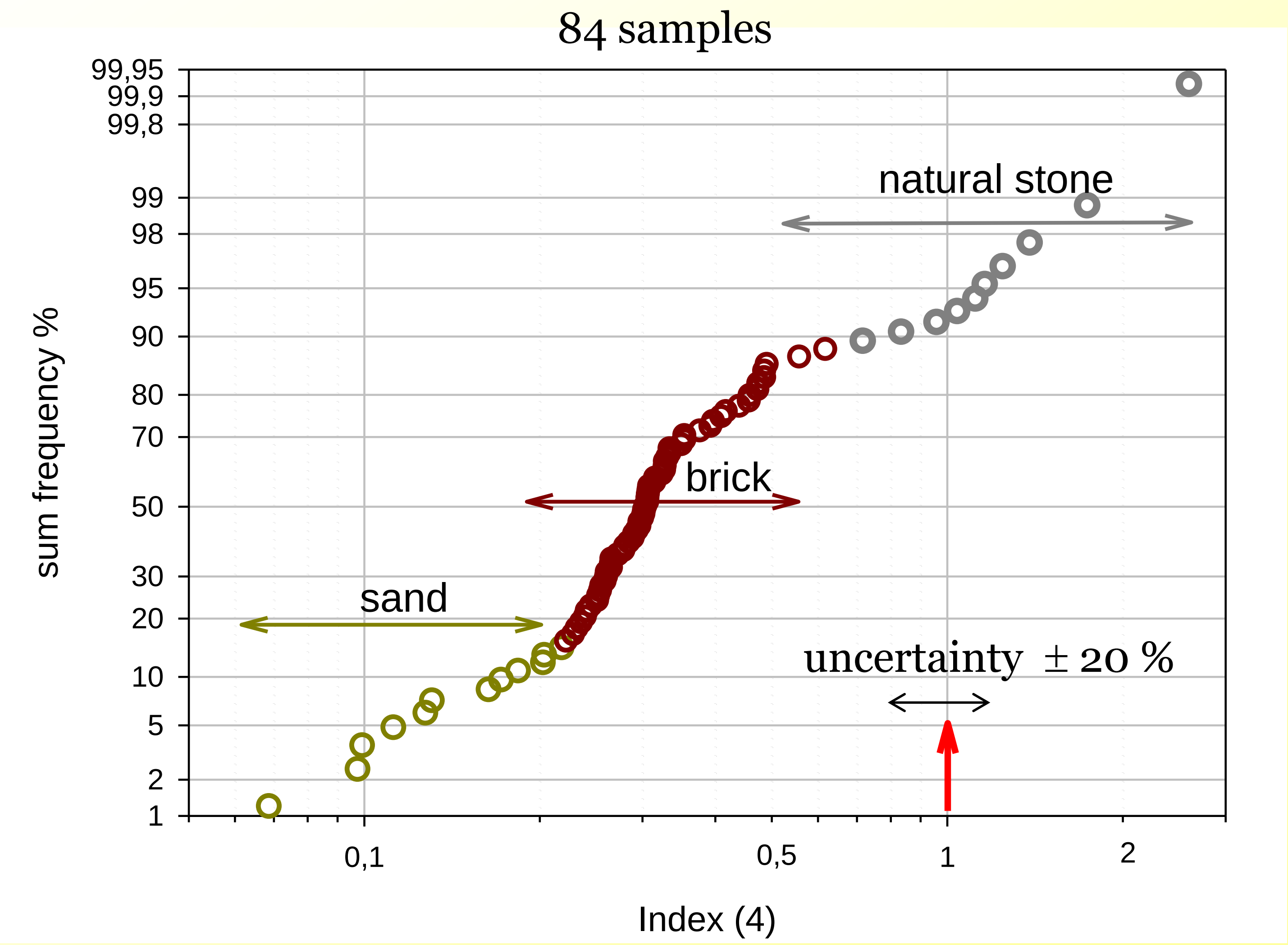
470 kg/m² is the weight per unit area of the model room in EC RP 112 (1999)

e.g. bricks: d = 0,3 m, ρ = 700 kg/m³ → **$d \cdot \rho$ = 210 kg/m²**

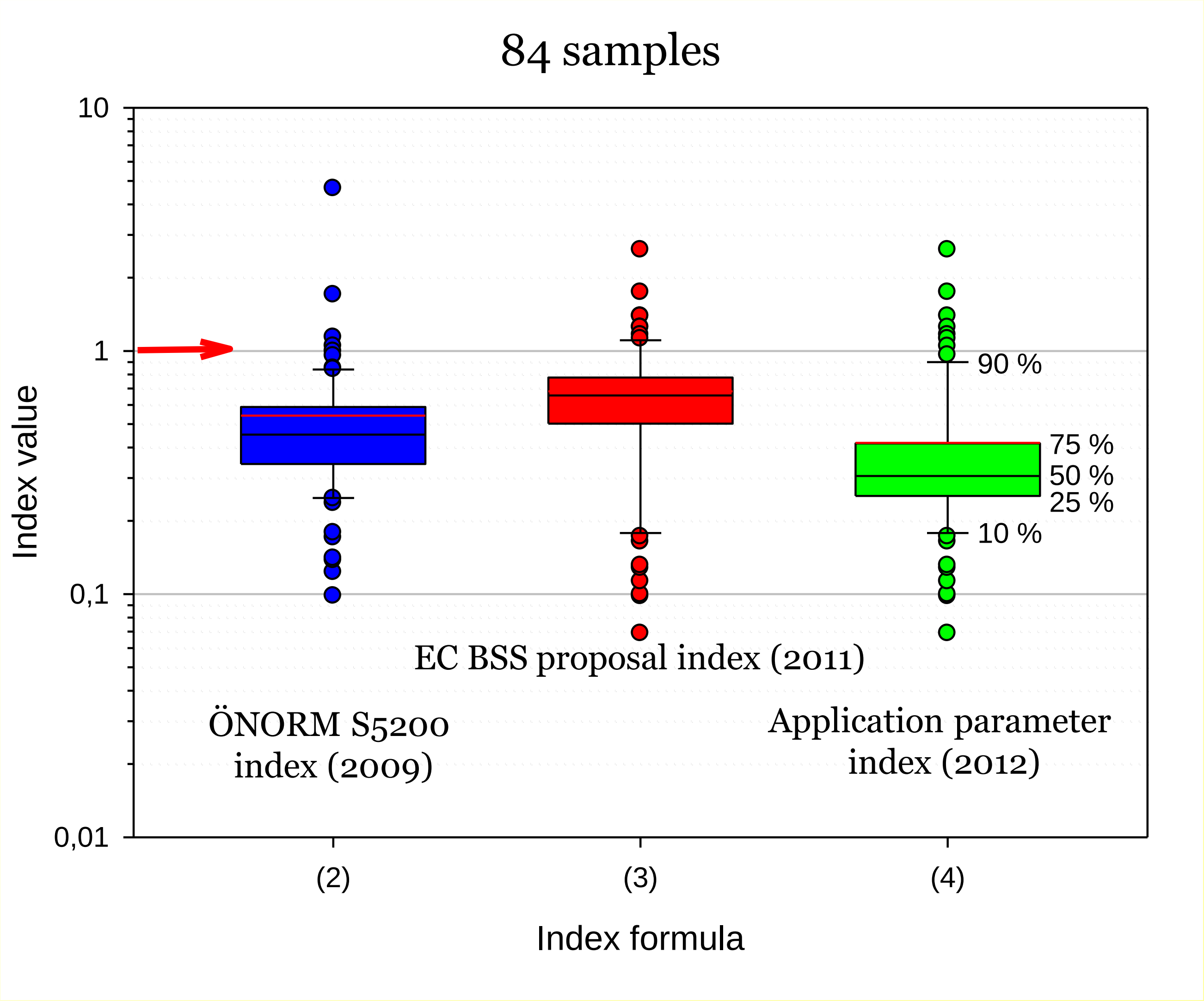
Building material examples

Sample code	Activity concentration Bq/kg			Index I (formula)		
	^{40}K	^{226}Ra	^{232}Th	(2)	(3)	(4)
2-R	631	24	41	0,31	0,50	0,22
4-R	661	33	51	0,39	0,59	0,26
9-R	547	56	62	0,51	0,68	0,30
6-R	569	64	66	0,53	0,73	0,33
1-Z	667	30	38	0,33	0,51	0,23
3-Z	755	43	46	0,46	0,63	0,28
8-Z	571	54	64	0,50	0,69	0,31
10-Z	754	85	62	0,69	0,84	0,38
5-Z	505	47	61	0,41	0,63	0,28
7-Z	437	35	56	0,38	0,54	0,24
67-S	417	14	25	0,24	0,31	0,31
11-Z	890	46	60	0,42	0,75	0,34
68-S	0	6	19	0,14	0,11	0,11
69-S	9	4	11	0,12	0,07	0,07
13-Z	632	42	43	0,36	0,57	0,25

Application parameters formula index (4)



Three evaluation formula index



CEN TC 351/WG3

- European Standardisation Institute CEN Technical Committee 351 'Construction Products - Assessment of release of dangerous substances' Working Group 3 'Radiation from construction products'
- Start: 2011 Februar → proposed end: 2013
- Task TG 31 'Gamma radiation measurement of building material
- Task TG 32 Dose modelling ($a \rightarrow E$)
  - FJ Maringer (AT), M Markkanen (FIN), ML Perrin (F), D Rosen (D), M Taylor (UK), P Vuorinen (FIN) and G De With (NL)

TG 3.2: Questions to be answered

- ‘Typical’ level for outdoor exposure
  reference limit for exposure due to building material’s radioactivity is defined as the “excess to typical outdoor exposure”; outdoor exposure rates vary locally
- Geometry of the standard room used in the dose model
- Indoor occupancy time
- Shielding effect of building materials for cosmic radiation
- Assumptions on other materials in the building than the examined
- Factor for converting the ambient dose equivalent in air to the effective dose

Conclusions

- ALA**R**A for indoor exposure from natural radionuclides in building materials
- Legislative setup of effective dose limits only but not activity concentration limits
- Harmonised dose modelling: from effective dose to activity concentration limits including general building material application parameters
- Establishment of a harmonised standard for indoor exposure

  ➔ *in Europe: EU BSS & CEN TC 351/WG3 → 2013*

Thank you for your attention!

University of Natural Resources and Live Science Vienna