Radon Regulation and Research in Europe -
Is It Relevant for the Asian-pacific Region?

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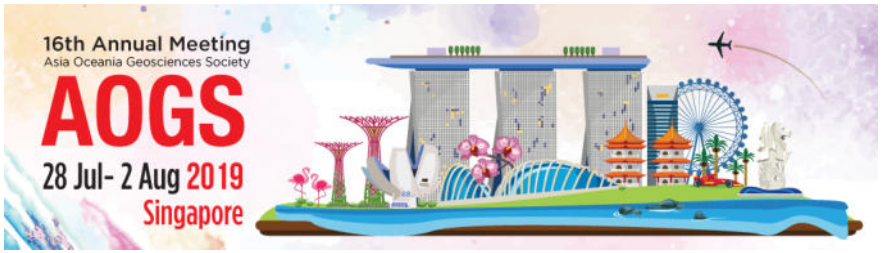


Content

- Radon basics
- Regulation
- Supporting research
- Radon mapping, European Atlas
- Rn policies in Asia-Oceania
- Rn topics in Asia-Oceania?
- a sort survey of applications

Europe…

Asia Oceania…

Tracer …

Motivation

- 2017 – 2020: Metro Radon project, a EU-funded international project about QA of the chain from metrological basics (primary standards, calibration) to aggregated quantities, such as radon priority areas, as items which allow reliable decisions in compliance with radon legislation.
- This includes investigation of what is being done in other regions of the world, and dissemination of results acquired during Metro Radon.

http://metroradon.eu/

Two faces of radon

- Radon – a health hazard
- Radon – a valuable tracer

➔ **important subject in research and regulation**

Radon physics and health – the basics

^{238}U (4.5Ga half life; crustal abundance 1.8 - 2.8 ppm)

^{226}Ra(1600a; α,γ; $\cong$ Ca $\rightarrow$ bones!)

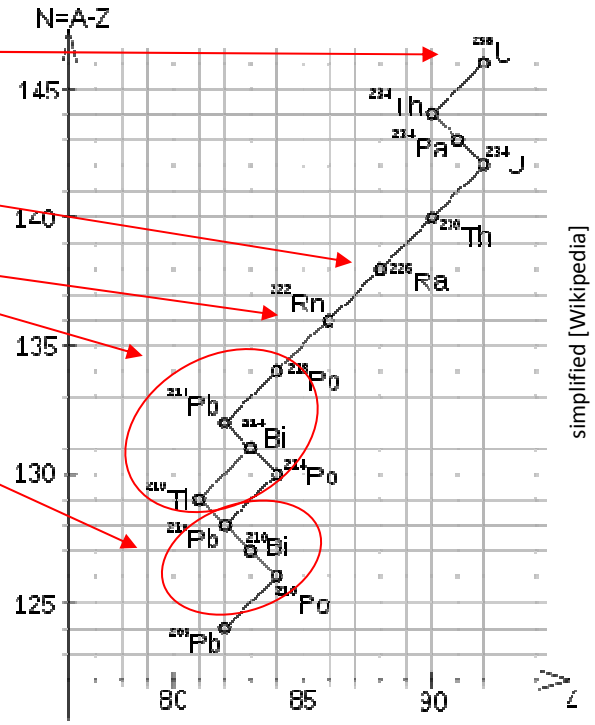
^{222}Rn (3.72d; α; noble gas)

short-lived progeny (µs - 30 min; α,β,γ; inhaled $\rightarrow$ lungs)

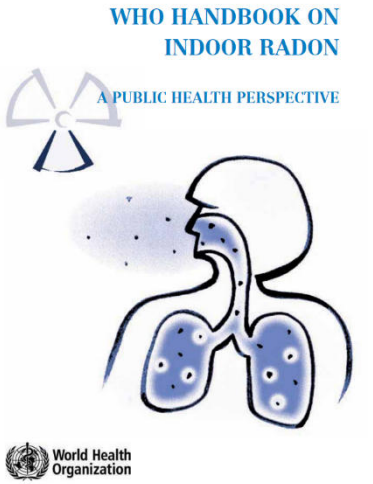
long-lived progeny (d – 22a; α,γ; ingestion)

High-energy α irradiate bronchial tissue $\rightarrow$ lung cancer

^{232}Th series similar: ^{220}Rn (55 sec, “thoron”)



simplified [Wikipedia]



www.who.int/ionizing_radiation/env/9789241547673/en/

Epidemiological studies (Darby et al. 2005, and others):

- Lung cancer fatality risk doubles about every 100 Bq/m³ indoor Rn;
- Apparently linear - no threshold relationship; there is no “safe level”
- Effect statistically proven from ca. 100 Bq/m³ upwards.

Indoor radon - essentials

Indoor radon – most important contribution to dose!
Second most important cause of lung cancer after smoking!
In Europe estimated about 62,000 lung cancer fatalities per year attributed to Rn.
In Asia & Oceania: about 128,000.
(Gaskin et al., Envir. Health Perspectives 125, 5 (2018); Eur. incl. RU, TR; Asia incl. Near + Middle East; many countries missing due to lack of Rn data; mostly very rough estimates due to sparse data.)

Sources of indoor Rn:

1. Geogenic Rn (most important in most cases)
2. Building materials
3. Tap water, natural gas

Concentrations of indoor Rn controlled by

Geogenic factors:

Geology, soil type, U concentration in topsoil, permeability, granulometry,…

Anthropogenic factors:

Construction type (tightness of structures in contact with the ground),
life or usage patterns (ventilation)

Very high local and temporal variability → makes prediction very difficult.

Legal background

EURATOM Basic Safety Standards (BSS)

Council Directive 2013/59/Euratom laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation

http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L:2014:013:TOC (OJ L, 17.01.2014)

RL: Reference level ≤ 300 Bq/m³ workplaces & dwellings (Art. 54,1 & 74,1)
RPA: "Member States shall identify areas where the radon concentration (as an annual average) in a significant number of buildings is expected to exceed the relevant national reference level." These areas are called Radon Priority Areas (RPA), to indicate priority in taking action. (Formerly also "Radon Prone Areas") (Art. 103,3)
Radon Action Plan:
In areas according Art.103,3: Buildings with public access and workplaces must be measured and if above RL, remediated. New buildings: particular Rn prevention. Strategy to reduce Rn in dwellings. (Art. 54, 74, annex XVIII)

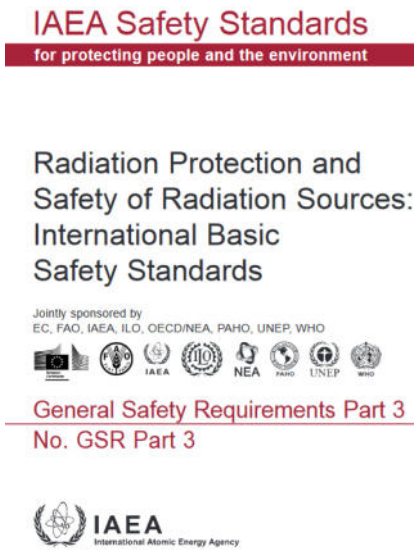
Must be transposed into national law by all EU Member States!

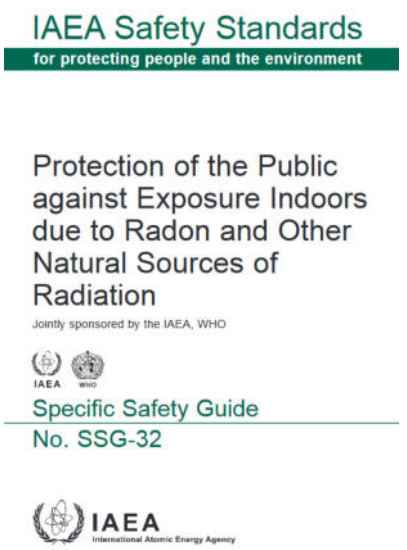
IAEA Basic Safety Standards

Very similar to EURATOM! - Recommendations to national competent authorities for Rn Action Plan

- Set RL ≤ 300 Bq/m³ (dwellings, schools etc) / 1000 (offices etc)
- Measurement programs, surveys, to identify dwellings and public buildings with Rn > RL, identify RPA
- "Priority principle": start where it is most important & effective
- Provide for QA
- Reduction strategy & verify efficiency
- Inform the public, increase awareness

https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1651Web-62473672.pdf ,
https://www-pub.iaea.org/MTCD/publications/PDF/Pub1578_web-57265295.pdf





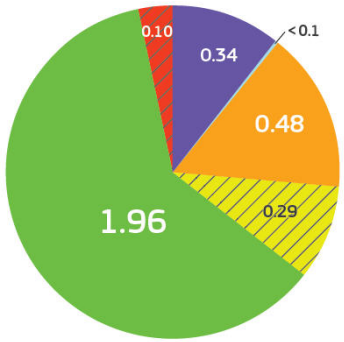
Radon mapping

Radon mapping basics

- Not technically easy because of high local variability of indoor or geogenic radon concentration
- Complex structure of predictors:
  - geogenic factors: geology, U concentration in the ground, soil characteristic, hydrology etc.;
  - anthropogenic factors: building type, human behaviour
- Methods:
  - Aggregation into geographical units (grid cells, municipalities, etc.)
  - Geostatistics (kriging family, sequential simulation)
  - Machine learning (MARS, SVM, ANN, random forest,… powerful for high-dim. multivariate situations)

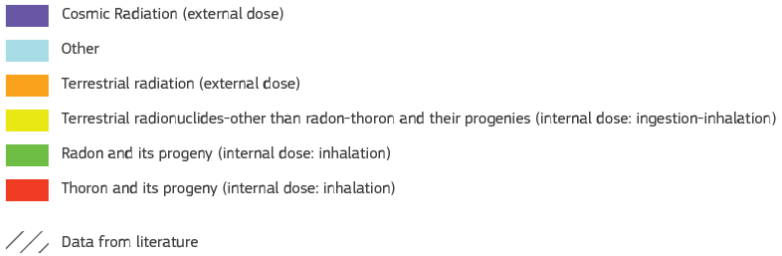
European Atlas of Natural Radiation

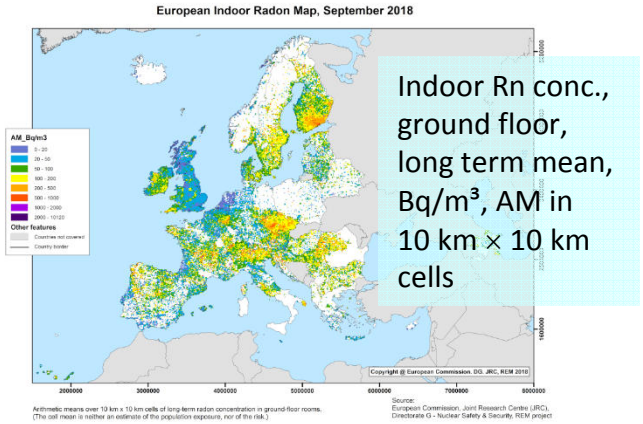
- A long-term project of the Joint Research Centre of the European Commission (2005 -)
- Compile data on natural radiation from Europe
- Methodological harmonization, mapping, scientific evaluation, incentive for new research
- Support of BSS implementation
- <u>Maps, so far:</u>
  - Indoor radon (based on ca. 1.1 mill. data);
  - U, Th, K in soil and rock;
  - Cosmic radiation;
  - Ambient dose rate
- Web version:
  https://remon.jrc.ec.europa.eu/About/Atlas-of-Natural-Radiation
  printed version under production



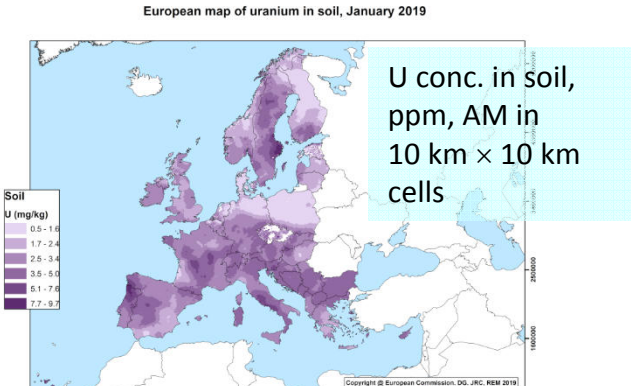
Total: 3.2 mSv/yr

Dose budget, natural radiation sources; valid for Europe

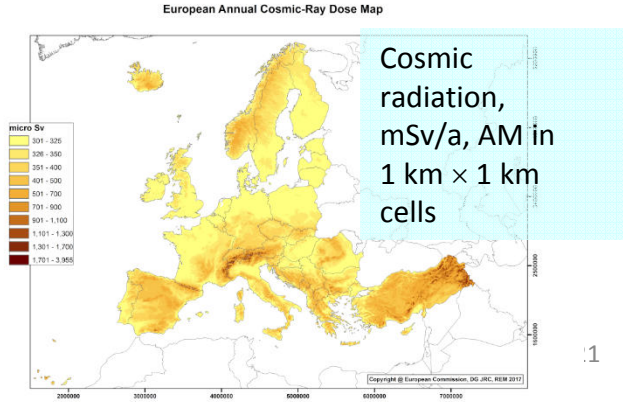




Indoor Rn conc., ground floor, long term mean, Bq/m³, AM in 10 km × 10 km cells



U conc. in soil, ppm, AM in 10 km × 10 km cells



Cosmic radiation, mSv/a, AM in 1 km × 1 km cells

Supporting research activities / 1

Metro Radon

- Devoted to QA aspects in the chain from correct calibration and measurement to estimation of highly aggregated quantities such as radon priority areas;
- Decisions about action in compliance with BSS must be reliable, because of possibly high economical and political cost implied.
- Topics:
  - Primary standards
  - Calibration at low exposure
  - Influence of thoron
  - Retrospective Rn measurement
  - Intercomparisons and mapping exercises
  - Definition, estimation and uncertainty of radon priority areas
  - Relations between geogenic and indoor radon
  - Radon extremes
  - Geogenic radon hazard index
  - Methodological harmonization
- Funded by EU Horizon 2020 programme

Metro RADON

http://metroradon.eu/

Supporting research activities / 2

LIFE RESPIRE

- Objective: demonstrate in 4 significant areas, with different Geogenic Radon Potential in Italy and Belgium, a cost-effective and eco-friendly solution for Radon real-time measurement and remediation to keep indoor Radon levels below 100 Bq/m³.
- Construction of a Radon remediation system composed of sensors, an Air Quality Balancer and an external additional fan-system (eolian and/or electric) when additional ventilation is required.
- http://www.liferespire.it/ Funded by EU LIFE programme

RESPIRE

Big Buildings

- "Big" buildings have often particular physical characteristics concerning Rn infiltration and dispersion. Public, educational and cultural institutions, offices, manufacturing often in "big" buildings; but also high-rise residential buildings. In EU: all subject to Rn regulation.
- Questions:
  - Classification of Big Buildings;
  - Rn behaviour in such buildings;
  - Specific Rn measurement protocols, to comply with regulation
- www.ribibui.org/ Self-funded by project partners.

European Radon Association ERA

- Platform for everything Radon!
- Promote public awareness on radon!
- Cooperation with AARST (USA) and CARST (Canada), open to everybody!
- http://radoneurope.org/ Funded by membership.

ERA
European Radon Association

Rn programs and policies, Asia/Oceania

- Evidently, Rn mitigation implies assessment of the situation by performing Rn surveys. Also geological / geochemical reasoning can give hints. Some countries in Asia / Oceania are already advanced in this respect, others less so.
- Radon policy requires Rn legislation including Action Plans to the extent necessary
  → IAEA
  - Rn Action Plan: www.iaea.org/sites/default/files/18/03/final-radon.pdf
  - Various IAEA publications about Rn (slide 6)

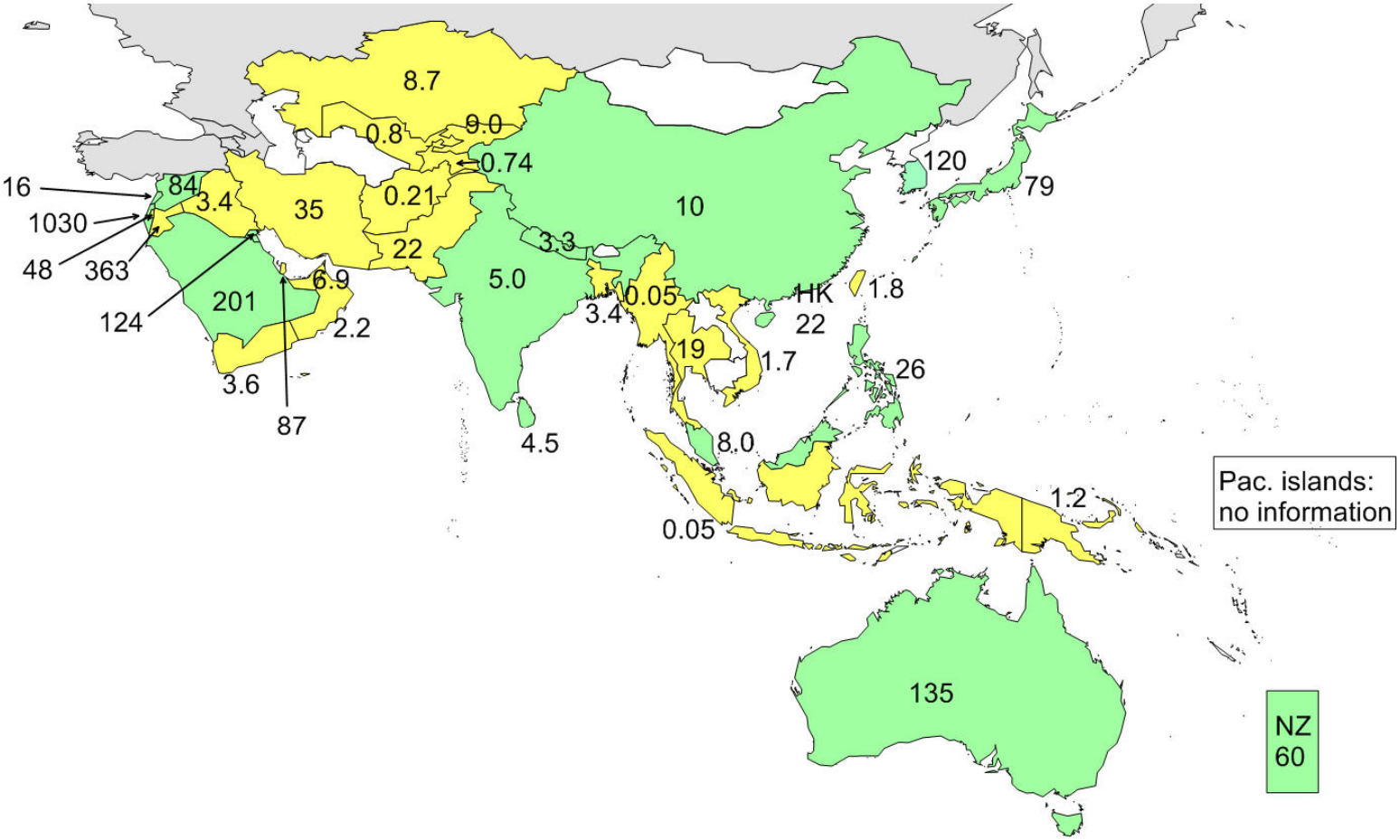
country	
S Korea	"Indoor Air Quality Control etc. Act", RL = 148 Bq/m³
Australia	In 1990, National Health and Medical Research Council recommended Action Level 200 Bq/m³
China	"Requirements for control of indoor radon and its progeny", 2015: RL (existing buildings) = 300 Bq/m³, for new buildings: target level 100.
other countries	no regulation to our knowledge

Apparently no meta-survey available!

Radon surveys, Asia/Oceania

- Map of sampling density, measurement locations per 1 mill. population;
  Data from international scientific literature by Google search; probably incomplete!
- green: national survey; yellow: regional or local surveys; white: no information
- grey: Russia, Turkey, Armenia, Georgia, Azerbaijan: commonly counted with Europe

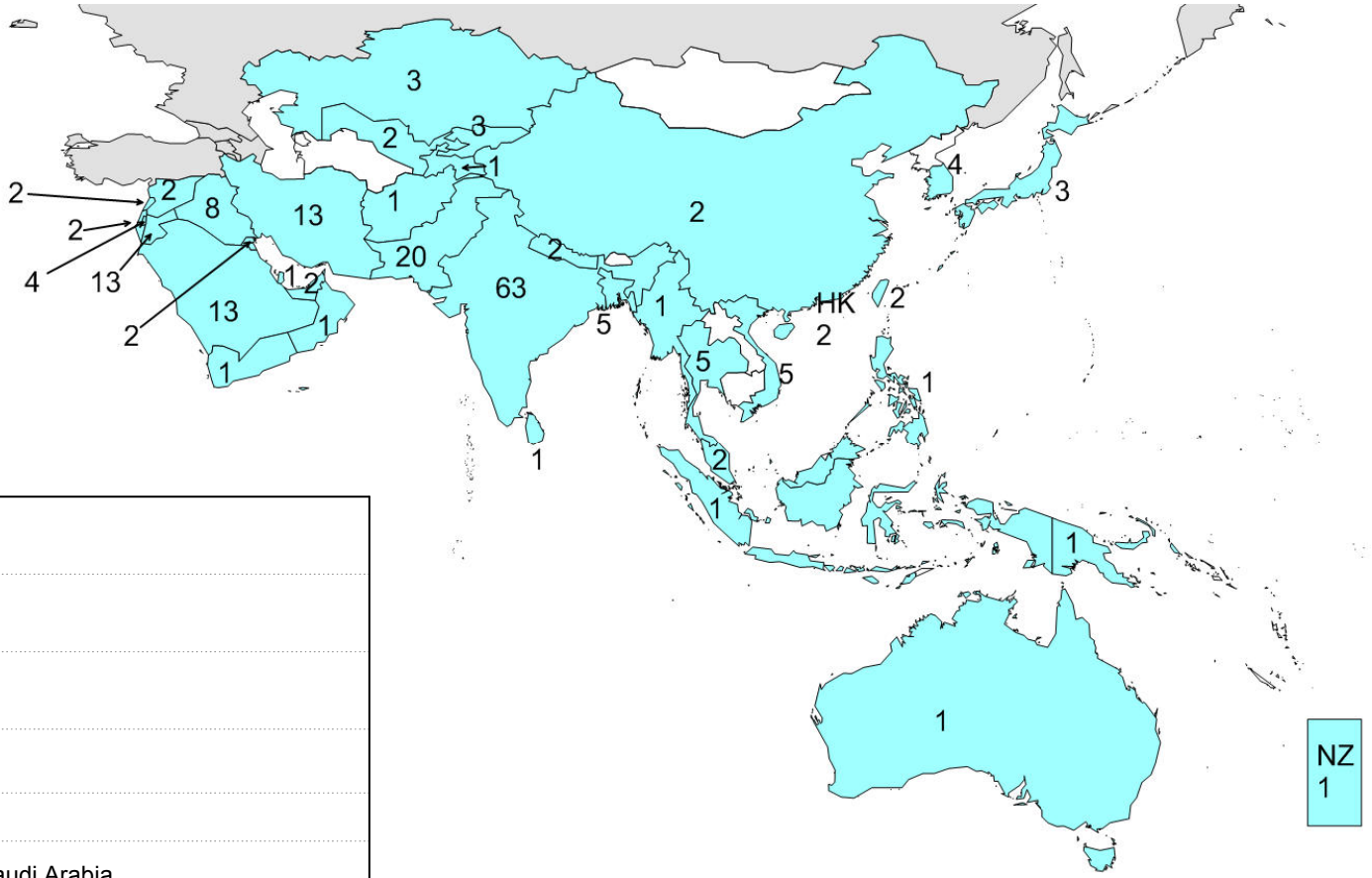
Europe, map participants: 2125

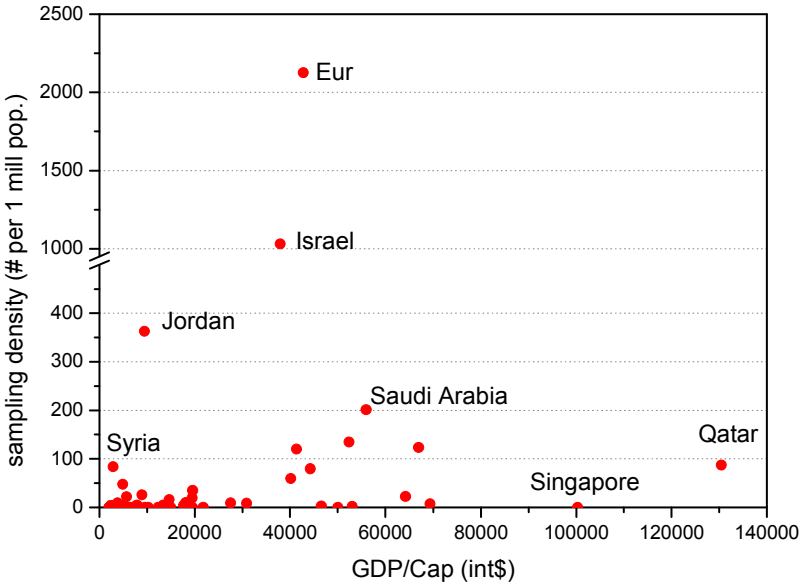


No data found:
Bahrain
Brunei
Bhutan
Cambodia
Laos
Maldives
Mongolia
North Korea
Pacific island nations
Singapore
Timor Leste
Turkmenistan

Surveys (2)

Numbers of references evaluated





Economic explanation of the diversity in sampling densities?
Not convincing!

Asia / Oceania – possible Rn topics

- high-rise buildings: Rn characteristics little known. Some findings indicate possible Rn accumulation in high floors due to stack effect
- building styles:
  - traditional house without basement and without sealing against ground: exposed to geogenic Rn;
  - warm climate: no heat insulation required → high air exchange → low Rn; BUT:
- role of air conditioning: can reduce but also enhance Rn, if building is insulated, windows closed – little known!
- geogenic control: acid magmatic rocks, organic-bearing sediments
- tectonic control: close to fault lines ground permeability increased → enhanced Rn migration
- Clay as building material: Thoron problem (has been recognized in China and Vietnam)

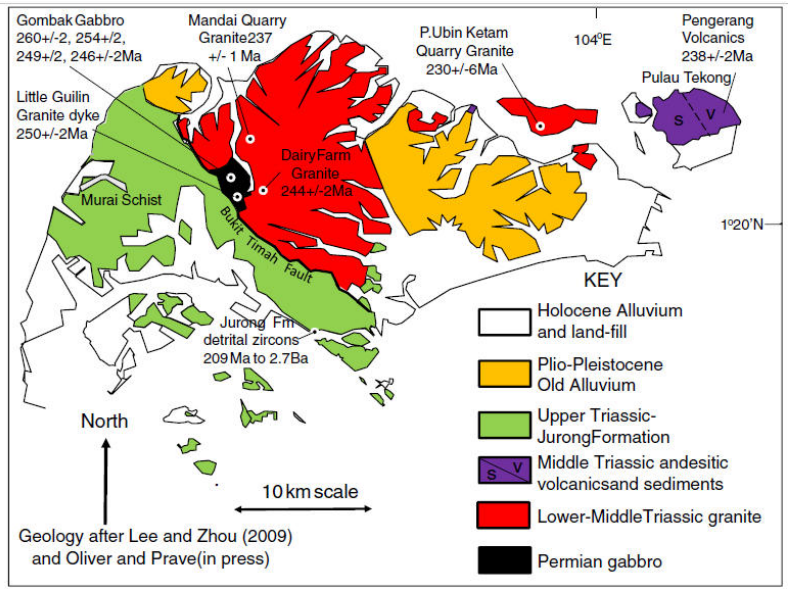


Fig. 2. Geology map of Singapore showing sample localities and results of zircon U–Pb age dating. Map modified from Lee and Zhou, 2009.

"Bukit Timah Granite" – granite, granodiorite

Simplified geological map of Singapore
[Oliver et al., Gondwana Res. 26 (2014)]

Rn as tracer - physics

- What is a tracer?
  A substance, whose purpose is to track, indicate or elucidate a process; not modifying the process which it is supposed to track, therefore usually in small quantity or concentration.
- Radon, as noble gas, does not interact chemically;
- With 3.7 days half life, it can be carried a distance before decaying;
- Soluble in liquids: moderately in water, highly in certain organic solvents;
- Radon (^{222}Rn, from ^{238}U series) and Thoron (^{220}Rn, ^{232}Th series) investigated together carry additional information;
- Rn progeny (short and long-lived) themselves carry useful information;
- Rn is easy to measure!
- Spatial (geographical, vertical) and temporal surveys (time series) being performed: mainly soil, water
- *Plenty of literature! – mainly from China, Taiwan, Japan, India, Australia*

Tectonic and seismic studies

- Soil Rn levels can indicate the presence of hidden active faults;
- Rn soil and water dynamic can indicate seismic and volcanic activity and may ultimately serve as seismic and volcanic predictor;
- Concentration ratios Tn/Rn, Rn/CO_2, Rn/He etc. can yield additional geophysical and geochemical information.
- Highly relevant e.g. in Indonesia, China, Taiwan, Japan, PNG, India,…
- An active research field! Analysis technically complicated, so far not conclusive. (See my presentation on Rn & seismic on Friday 11-12:30, same room)

Resource exploration

- Enhanced Rn flux on the surface may indicate buried U rich rock or other minerals;
- Depletion may indicate presence of organic fluids (petrol)

Atmospheric and climatic studies

- Rn ground exhalation, Rn flux: used to model long-range air transport in climatic studies
- changes in CO_2 and CH_4 exhalation due to melting of permafrost
- Atmospheric studies: Rn used to investigate planetary boundary and atm. mixing layers, atmospheric “rivers” (“Rn storms”), monsoon air circulation,...

Hydrology

- Ground water origin and movement, karst studies, infiltration and mixing with rain water
- Water mixing in the ocean
- Sedimentation and erosion rates (mainly with progeny ^{210}Pb, 22 y HL, used as “geo-chronometer”)

Environmental pollution studies

- Atmospheric transport: possible indicator for origin of air-borne pollutants
- Different solubility in water and organic solvents is used for monitoring subsurface organic pollution by NAPL (non-aqueous phase liquid).

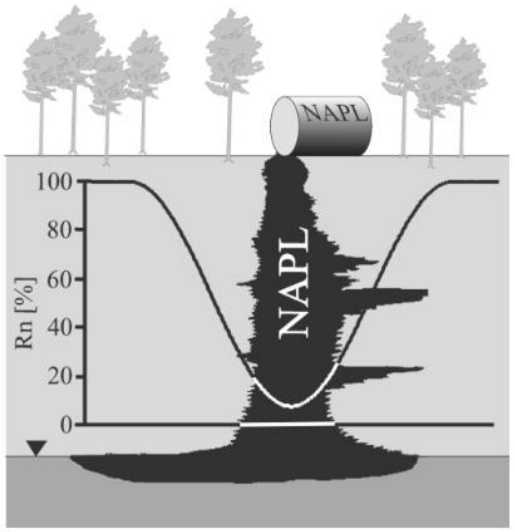


Fig. 1. Schematic sketch of the principle of the local reduction of the soil gas radon concentration in the vicinity of the contaminated soil volume.

[Schubert et al. (2012)]

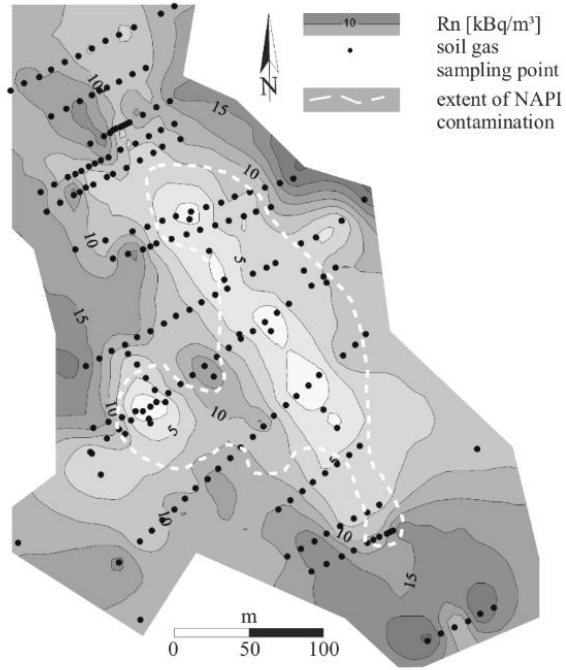


Fig. 2. Anomalous low radon concentrations of the soil gas in the close vicinity of a NAPL-contaminated soil volume.

Conclusions

Europe:

- natural conditions → Rn hazard maybe more pronounced
- Due to EU and BSS unified and compulsory Rn policy
- QA standards high, mapping quite advanced
- Rn policy efficient? – future will tell!
- Seismic research: Italy, Turkey most affected

Asia – Oceania:

- Believed that some regions have little problem due to climate and low-Rn ground
- Seems that every country has its own approach
- QA differently high developed
- Seismic research: India, Taiwan, China, Japan, etc.

Relevance of European experience

- Legislation unified in EU, high QA standards; also non-EU participate
- Coordinated evaluation (partly), intense scientific cooperation, importantly through EU projects (some open to non-EU)

Thank you!

Bundesamt für Strahlenschutz
German Federal Office
for Radiation Protection

European Commission

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Metro RADON