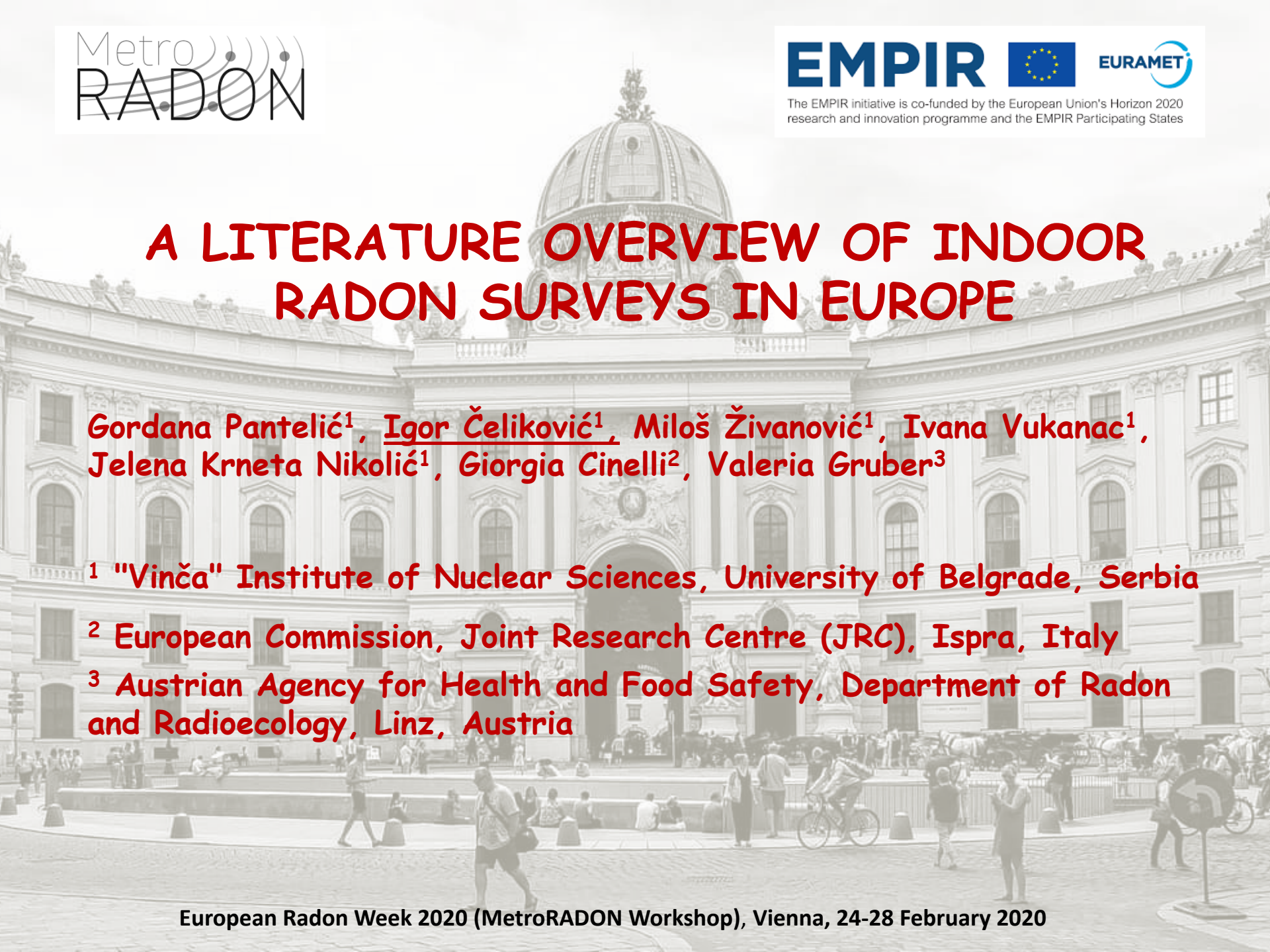

A LITERATURE OVERVIEW OF INDOOR RADON SURVEYS IN EUROPE

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Framework of literature overview on Rn surveys

- **An excerpt from the WP3:**
  - i) to collect and analyse meta-information from radon surveys and existing radon databases in European countries,
  - ii) to evaluate if the data and methodologies are comparable
  - iii) to identify how they could be harmonised in the event of methodical inconsistency.

- **Task 3.1 Overview and analysis of indoor radon surveys in Europe**

Literature overview (among others):
should serve as an input to derive methodologies to

- **harmonise data and**
- **reduce inconsistencies in the results**

Brief history:

- back to XVI century and Paracelsius…
- discovery of Rn…

- 1956 first measurements of Rn in dwellings in Sweeden (Hulquist)
- 1964 Indoor Rn survey around Kalna Uranium mine, Serbia (Hajdukovic)

- many surveys in the 70's and the 80's (small and national)

Some national:

- UK (Wrixon et al. 1988), Ireland (McLaughlin and Wasiolek 1988), Italy (Bochicchio et al. 1993), Finland (Castrkn 1993), Sweden (Swedjemark et al. 1993)

McLaughlin

- …

- 2006: Epidemiologic studies (Darby, et al., Krewski et al. Lubin et al.)
- 2009: WHO Handbook of Indoor Radon,
- Council Directive 2013/59/Euratom

  Basic Safety Standards (Article 103) oblige EU member states to:
  - establish a radon action plan
  - inform public about their radon
  - identify Radon Priority Areas (RPA)

We are we now?

- Radon activities and radon surveys therefore were started or repeated in several countries in the last years and are still on-going and maybe will be also increased in the next years.

- For non-EU-member states also IAEA BSS require radon surveys and IAEA guidelines how to perform radon surveys exist (IAEA, 2011).

- IAEA Technical Cooperation Project:
  Establishing Enhanced Approaches to the Control of Public Exposure to Radon

All ingredients are here, but is it really that easy!?

WP3 started already 15 years ago (and more)

- European Atlas of Natural Radiation *De Cort et al, 2011 ... Cinelli et al, 2019*
  - collect, validate and report information on radioactivity levels in the environment
- A first overview of indoor radon surveys in Europe *(Dubois 2005)*
  - data reveal heterogeneity of survey strategies, measurement techniques, measurement duration…
- European map of indoor radon levels using a 10 km x 10 km grid cells *(Dubois et al., 2010)*

- JRC report based on literature review of indoor radon surveys in Europe *(Pantelic et al., 2018) doi:10.2760/977726*

- Qualitative overview of radon surveys with a special attention to the qualitative description of surveys, representativeness and QA/QC *(Pantelic et al., 2019) doi:10.1016/j.jenvrad.2019.04.010*

Literature

Country
Paper
Area
Survey goal
Sampling strategy
Sampling procedure
Measurement technic
Evaluation of single
Survey period
Time of year
Single measurement
Number and type of
Evaluation
Interpretation of resu
Quality assurance
Thoron measurement
Comment/link

38 Serbia

In Serbia there were several local and regional surveys of indoor radon concentrations. Some of those researches were conducted by individual efforts to identify regions with high indoor radon. Perennial survey in several regions of Serbia (former Yugoslavia, former Serbia and Montenegro) starting 1997 had a specific goal to estimated population exposure to natural radioactivity based on geochemical and integrative pattern research approach. This was the first identification and assessment of high areas of natural radiation in Serbia which provides insight into its regional characteristics, the interpretation of the results in terms of geological aspects, building types and human habits, the first introduction and field applicability of both (surface and volume trap) retro techniques in Serbia and assessment of doses and risks to the population in investigated high natural radiation rural communities. Several differently designed chambers for the CR-39 and polycarbonate detectors were used such as: SSI/NRPB detectors, the CR-39 detectors enclosed in small cylindrical (5 cm height, 3 cm diameter) diffusion chamber, passive discriminative Cr-39 Radopot and Raduet detectors, passive discriminative polycarbonate UFO detectors. Exposure periods were generally of about 3 months covering one season. Annual averages were obtained using either results of all the seasonal measurements, if available, or results of some periods corrected with seasonal factors. Annual averages were obtained using either results of all the seasonal measurements, if available, or results of some periods corrected with seasonal factors. In these surveys, indoor radon concentration of rural communities of Serbia and some part of Balkans were investigated. Obtained data followed lognormal distribution, strongly depending on the type of underlying rock and average radon levels range between 45 Bq/m³ for limestone in Montenegro and 1560 Bq/m³ for travertine in Niška Banja (Žunić, 2009 investigated in details by Žunić and colla Gornja Stubla an area with high radon a indoor radon concentrations in dwellings, Serbia were investigated as well (Žunić, 2

In Vojvodina, the northern province of S by using charcoal canisters. In total 220 maximal radon concentration of 503 Bq/m 28.5 Bq/m³ (Forkapić, 2007).

The first large survey in Serbia, was co December 2002- March 2003. In total performed with 1 measurement per dwell considered typical and thus the most rep A lognormal distribution was obtained wit

Table 38.1. Descriptive statistics of the indoo period December 2002 - March 2003.

Number of measurements	Measurements			
	Mean	Standard deviation	Geo. Mean	Stan of
968	144	120	104.2	2.3

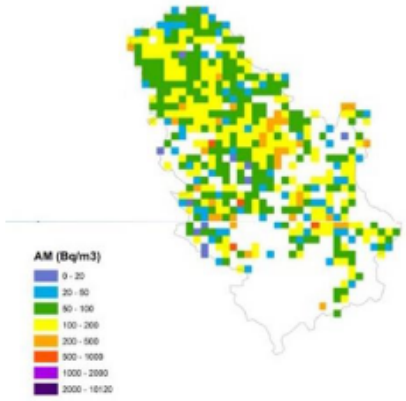
Source: Forkapic, 2007.

A radon map of Vojvodina, from the same

Figure 38.1. Radon map of Vojvodina. Numbers given along the names of municipalities indicate geometric mean radon concentration in Bq/m³.

Source: Forkapić, 2007.

Figure 38.2. Indoor radon map of Republic of Serbia, January 2017.



*Source:*IAEA SRB/9/006 , 2018.

14, with the first step of preparing, and erbia, planned and conducted to be done as conducted in 2015 and 2016 using CR- through the national project: SRB/9/003 egislative System. During the realization asurements several institutes involved in Protection and Nuclear Safety Agency basic information leaflet on radon to rpose of the measurement, internet site, to high survey efficiency (about 88 %), detectors have been distributed during tments for six months (till April 2016). nt to an authorized laboratory (Landauer on concentrations varied in a wide range: nent radon concentration was below 200 higher than 400 Bq/m³ and 0.3 % higher was 105 Bq/m³ (*IAEA SRB/9/006, 2018*). exposed for 1 year, and thus seasonal ver the 10 km x 10 km, and from March ndoor Radon Map. Indoor radon map of

References

Žunić, Z.S. et al.,(2009) Identification and assessment of elevated exposure to natural radiation in Balkan region (Serbia), Radioprotection 44(5): 919–925 (and reference therein).

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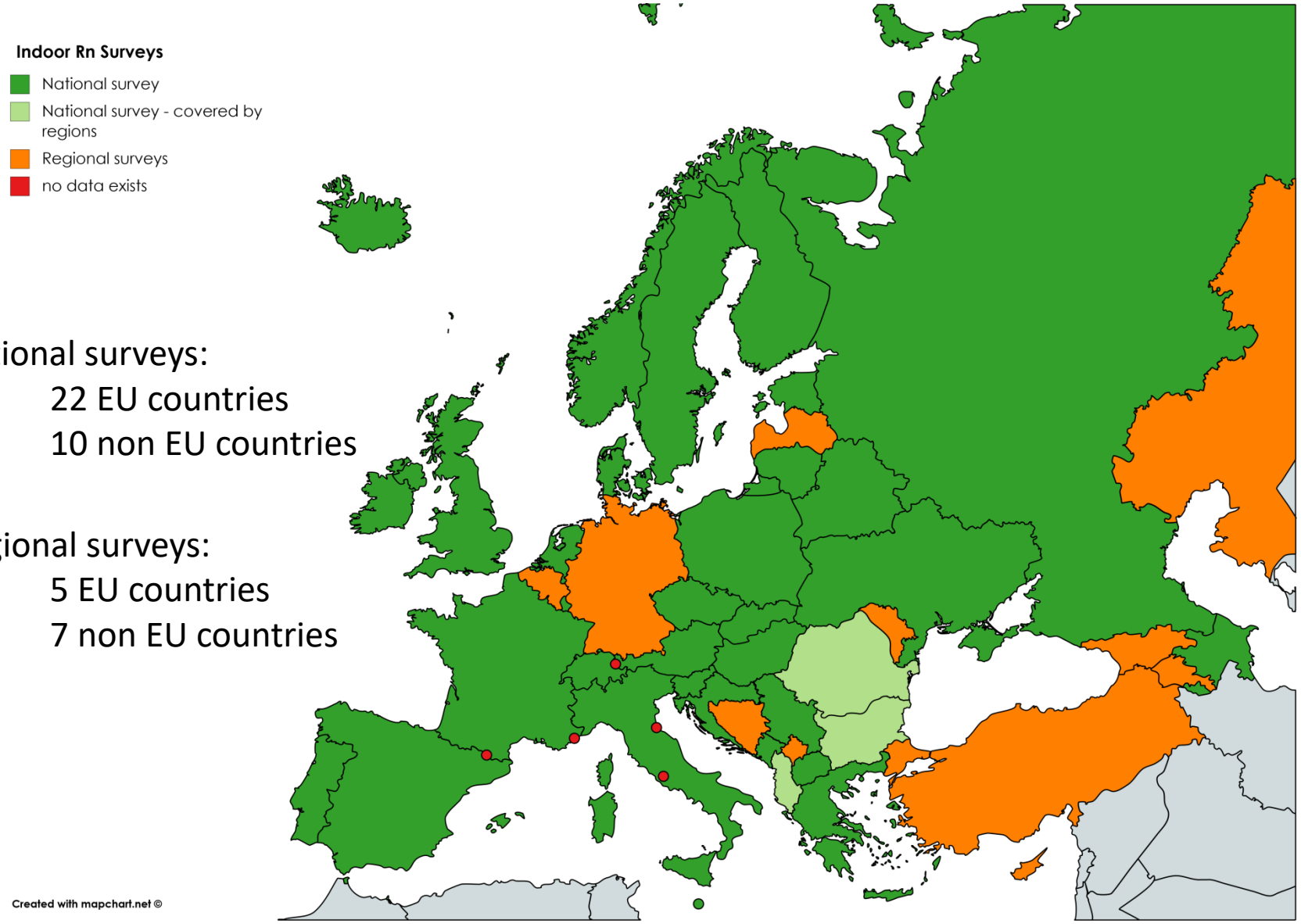
Forkapić, S. et al., (2007) Indoor Radon In Rural Dwellings Of The South-Pannonian Region, Radiat. Prot. Dosim., 123, 378–383.

Udovičić V. et al., (2016) First steps towards national radon action plan in Serbia, Nukleonika, 61(3): 361-365.

IAEA SRB/9/006 (2018) Upgrading National Capabilities and Infrastructure for the Systematic Approach to the Control of Public Exposure to Radon, presentation on meeting in Belgrade, Serbian Radiation Protection and Nuclear Safety Agency, 22 February 2018.

Overview of radon surveys:



National surveys:

22 EU countries

10 non EU countries

Regional surveys:

5 EU countries

7 non EU countries

Survey design and representativeness

- numerous factors influencing indoor radon
- not feasible to measure radon in all dwellings

Necessary to carefully design survey – representative distribution of radon in dwellings

- truly representative survey – rather difficult
  - complete list of dwellings – seldom available

- each step prone to numerous biases:
  - type of sampling: (use of volunteers – oversampling in RPA)
  - choice of measurement technique
  - duration of measurement and seasonal corrections…

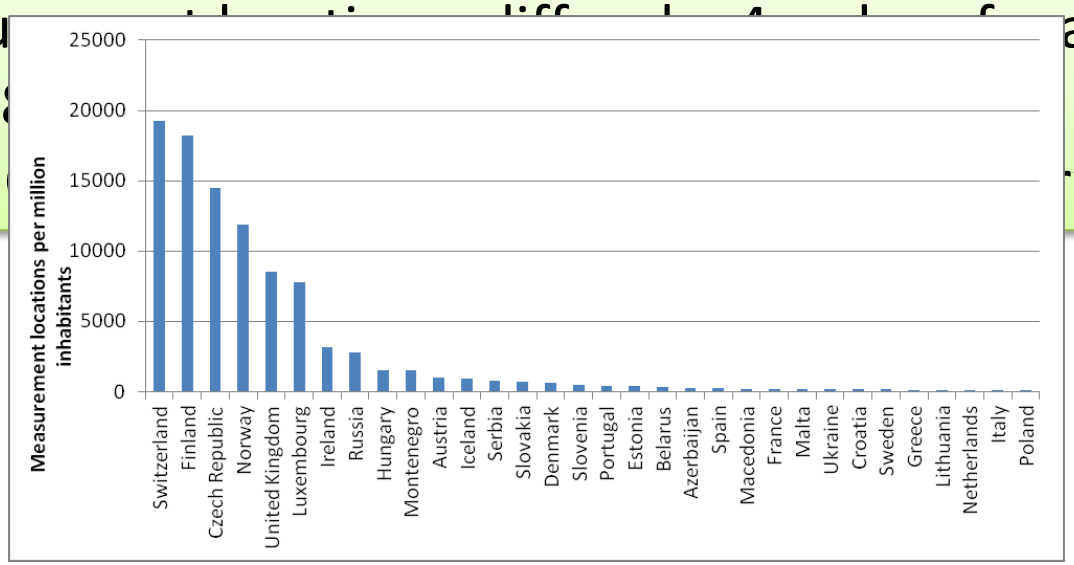
Niška Banja RPA *(Z. Zunic et al.)*
seasonal factor: 2.7 (year/3m summer)
range: 1.1 – 6.0

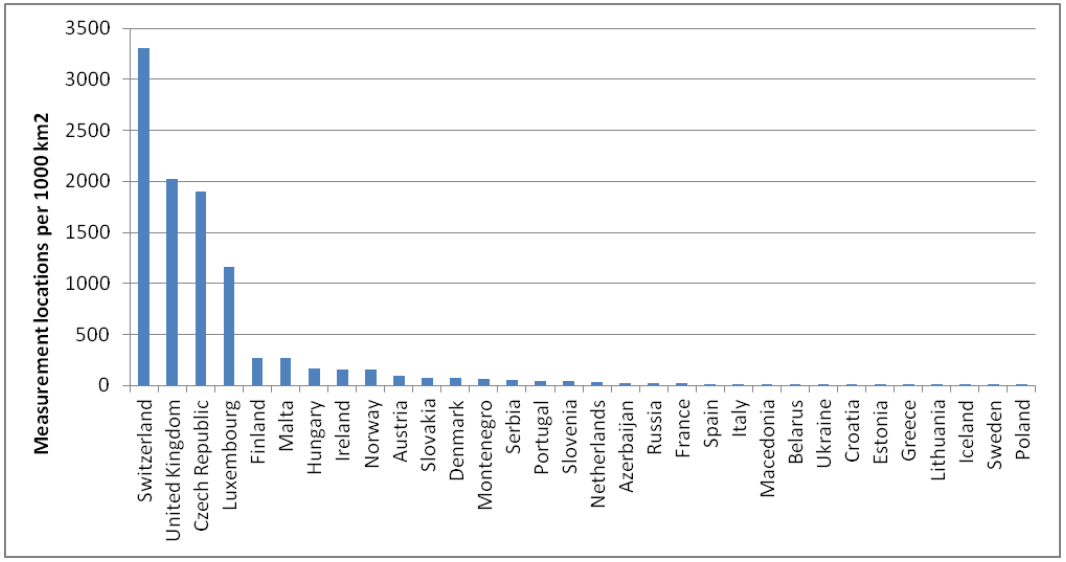
Serbian National Rn Survey (Udovicic et al.)
seasonal factor: 0.8 (year/6m heating)
range: 0.5 – 1.4

IAEA Report, 2013 – Review of methodology and measurement techniques

Survey design: density of deployed detectors

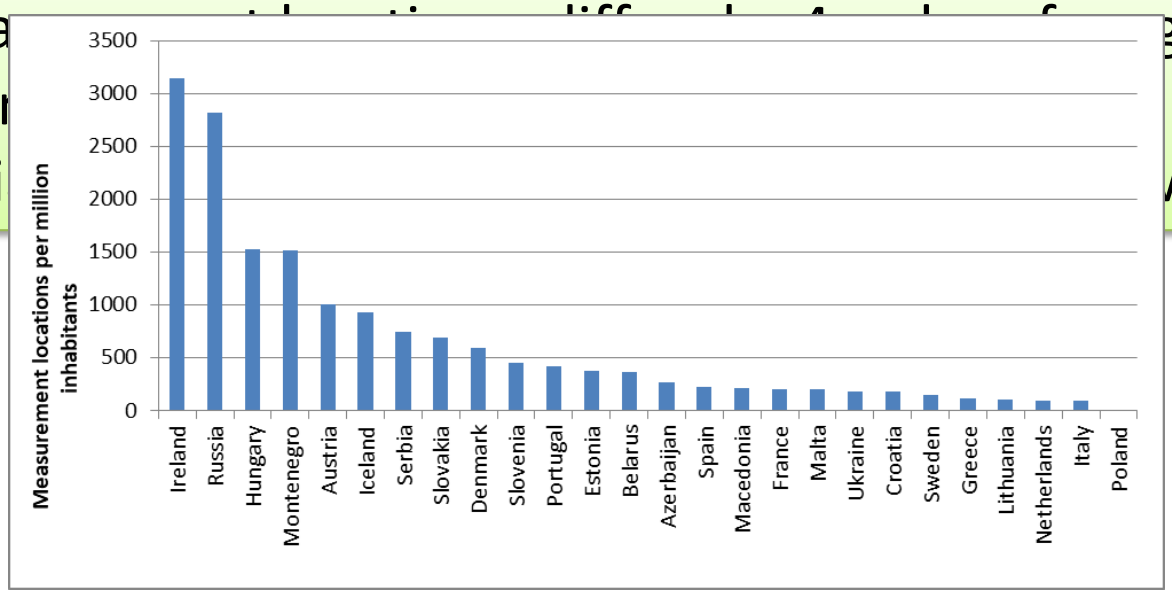
- no. of measu… …agnitudes
- ranges from 8…
- U.K., Russia, …rway > 50000

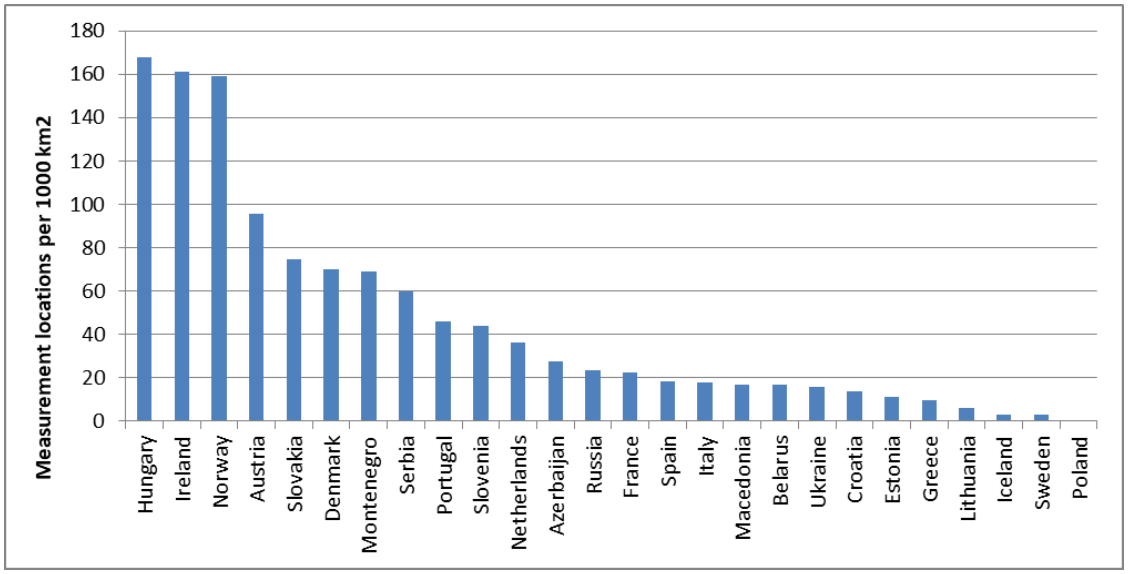




Survey design: density of deployed detectors

- no. of mea… …gnitudes
- ranges fro…
- U.K., Russi… …way > 50000





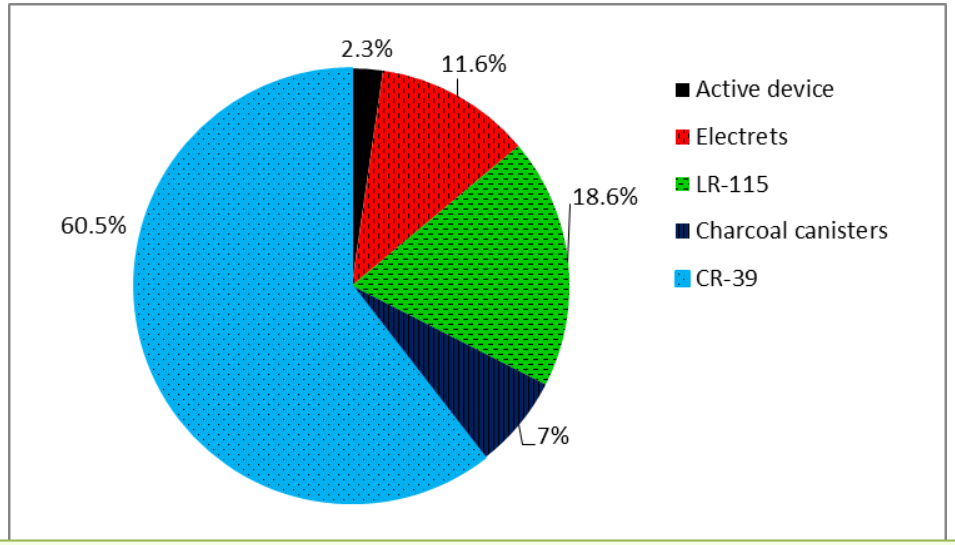
Sampling strategy

- Sampling strategy:
  - based on administrative units
  - grid cells: 10x10 km2, 5x5km2, 1x1km2, 0.5x0.5km2
  - geological regions
  - density correlated with population density or RPA regions
  - combination of several requirements
  - 10 km x 10 km grid - more prevalent in recent surveys

- Measurement locations:
  - dwellings (great majority)
  - schools, kindergartens
  - industrial buildings and workspaces (as a part of the survey)
  - swimming pools… (as a part of the survey)

Measurement techniques

- Types of detectors



- Measurement time:
  - covering wide range of time: 48h; a few: days, weeks, months, half/whole year
  - different seasons: heating season, no particularly indicated season…

- Applied corrections:
  - seasonal: heating season over whole year;
    weekly variations and corresponding variation
    no corrections at all
  - corrections based on wind speed and outdoor temperature

Data analysis

- In only few surveys only arithmetic and geometric mean was used

- Descriptive statistics (used in all other surveys)

- Test for lognormality (large majority of surveys)

- Additional analysis:
  - Correlation with different geological regions
  - Identification of outliers
  - Declustering of oversampled region…
  - Mapping

Representativeness

- Detailed analysis of survey representativeness is generally missing
- In few surveys authors only state that survey was representative
- In 1 survey: construction expert was consulted for selection of representative house for each grid cell
- Only in 2 surveys: data were compared with national Census
- In one survey: could results from Rn in schools be representative for general population
- In few surveys: declustering of oversampled area to achieve regional representativeness
- In 1 survey : Representativeness reached by following 4 criteria: surface, population, high radon potential, and lithostratigraphic criterion with random sampling

QA/QC

- Important to avoid mistakes
- Reduce and estimate uncertainties

In many papers QA/QC of radon measurements is described, but proper description of QA/QC in radon surveys is missing

- Reported quality assurance and quality control of radon and/or radon decay products measurements:
  - Periodical calibration (or accreditation ISO 17025): 34 %
  - Intercalibration and intercomparison: 30 %
  - Comparison of the results from different detector systems: 11 %
  - Duplicate detectors: 9 %
  - More than 2 QA/QC procedures: 20 %
  - None: 36 %

Thoron and thoron measurements

- Different sensitivity to Tn - true especially for older types
  - **Kfk(Germany,1981): 0.78**
  - **RadTrak(USA,1991): 0.68**
  - **NRPB/SSI: 0.05**
- Tn could cause overestimation of Rn concentration
- >70% of surveys Tn is not mentioned
- In only a few surveys:
  - Contribution to doses due to Tn
  - Tn measurement in regions with high ^{232}Th

- Thoron is mainly measured in regional surveys
- Large effort of thoron mapping in rural regions of Balkans (Zunic et al)
- Identified regions in which Tn contribution could not be neglected

Conclusions:

- Design of surveys are quite diverse and not comparable (in general);
- Often some crucial information regarding Rn survey is missing;

- Almost all measurement methods were included, however large majority by passive detectors

- Descriptive statistics and test for lognormality common for surveys
- Additional analysis not comparable

- In only a few papers authors have paid attention on representativeness
- Necessary to test to what extent the representativeness of survey was reached
- Necessary to identify the sources of biases (to help making appropriate corrections)

Thank you for your attention