

Assessment of the Population-Weighted Radon Exposure from Geographically Based Data in Austria

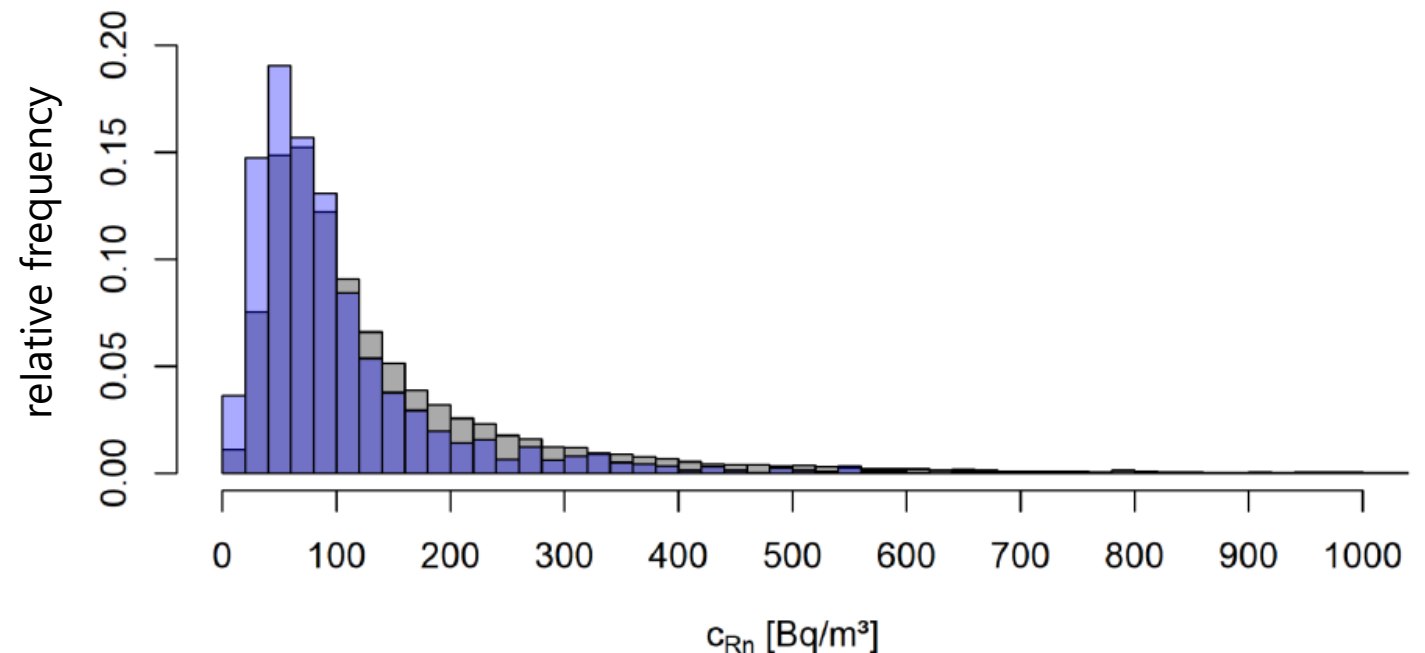
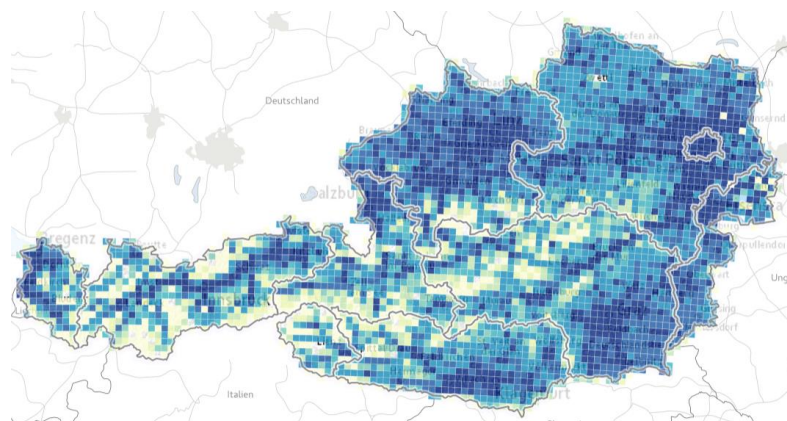
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Content

Radon Exposure

- Overview
- Radon – Survey and Modeling
- Population weighted radon exposure



How much?

Radon Exposure



- What is the radon exposure of the public?

Purposes

Radon Exposure



- What is the radon exposure of the public?
- For communication and comparison
- For decisions if there is a radon health risk in a country; and if yes, to what extend?
- for implementation of national radon policy (national reference level (RL), estimate number of homes above RL and cost of corrective actions, estimate the cost of the national radon programme, etc.)
- for evaluating the impact of a national radon policy

Contributors

Radon Exposure



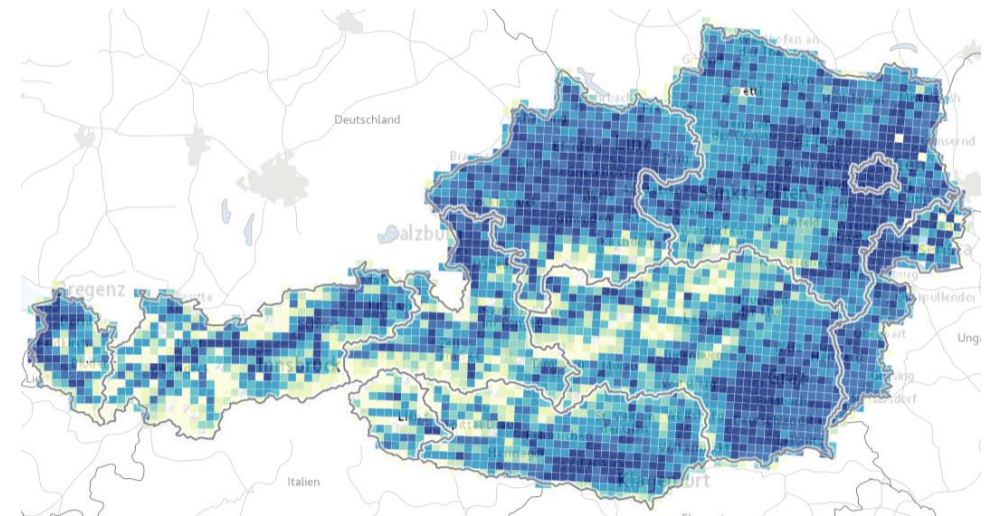
- What is the radon exposure of the public?

- Indoor radon concentrations in
 - Homes
 - Workplaces
 - Public buildings
- Outdoor radon concentrations

How to generate?

Radon Exposure

- What is the radon exposure of the public?
- Using existing measurements from an extensive Radon Survey for producing a radon map.
- Additional information of population density and housing stock



Two types of radon surveys

Population-weighted vs. Geographically-based



- To estimate the average exposure
 - is there a radon health risk in a country; if yes, to what extend?
 - for implementation of national radon policy (national reference level (RL), estimate number of homes above RL and cost of corrective actions, estimate the cost of the national radon programme, etc.)
 - for evaluating the impact of a national radon policy
- **population-weighted survey** by measuring indoor radon levels in randomly selected homes
- To identify radon priority areas (radon map)
 - to give priority to high radon areas in terms of risk communication, measurements, mitigation, preventive measures because resources are limited
 - more extensive survey
- **geographically-based survey** where homes are selected to obtain a minimum density of measurements per area unit chosen - e.g. a grid square, an administrative unit

Design of the new Austrian indoor radon survey

ÖNRAP 2 (2013 – 2019)



Gruber Valeria et al

The new Austrian indoor radon survey (ÖNRAP 2, 2013–2019): Design, implementation, results
Journal of Environmental Radioactivity,
Volume 233, July 2021;
<https://doi.org/10.1016/j.jenvrad.2021.106618>

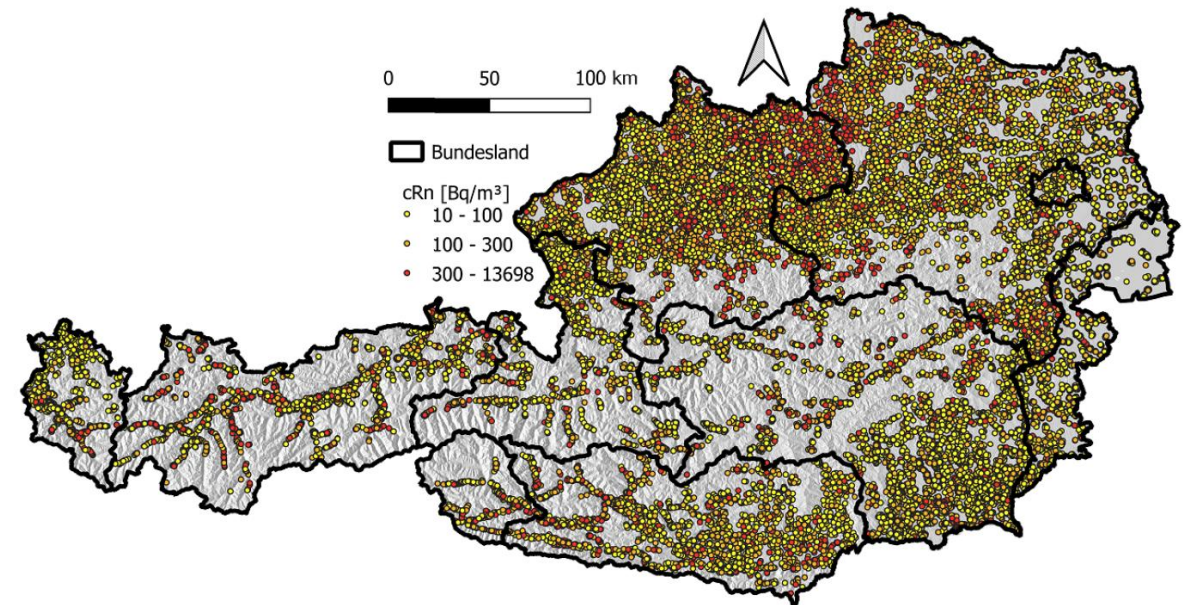
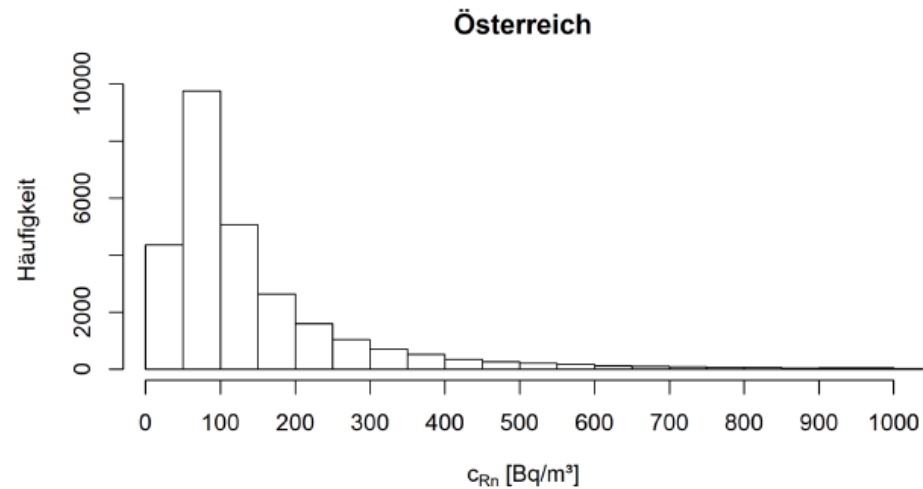
- Purpose: Reliable delineation of radon priority areas
- **Geographically-based survey**
 - All populated areas should be uniformly covered with measurements -> 1-3 dwellings per 2x2 km grid cell (depending on heterogeneity of geology)
- One single measurement method:
 - Track etch detectors
 - 6 months (half winter, half summer time)
 - 2 rooms (preferably ground floor or lowest inhabited floor)



Results of the new Austrian indoor radon survey

Overview

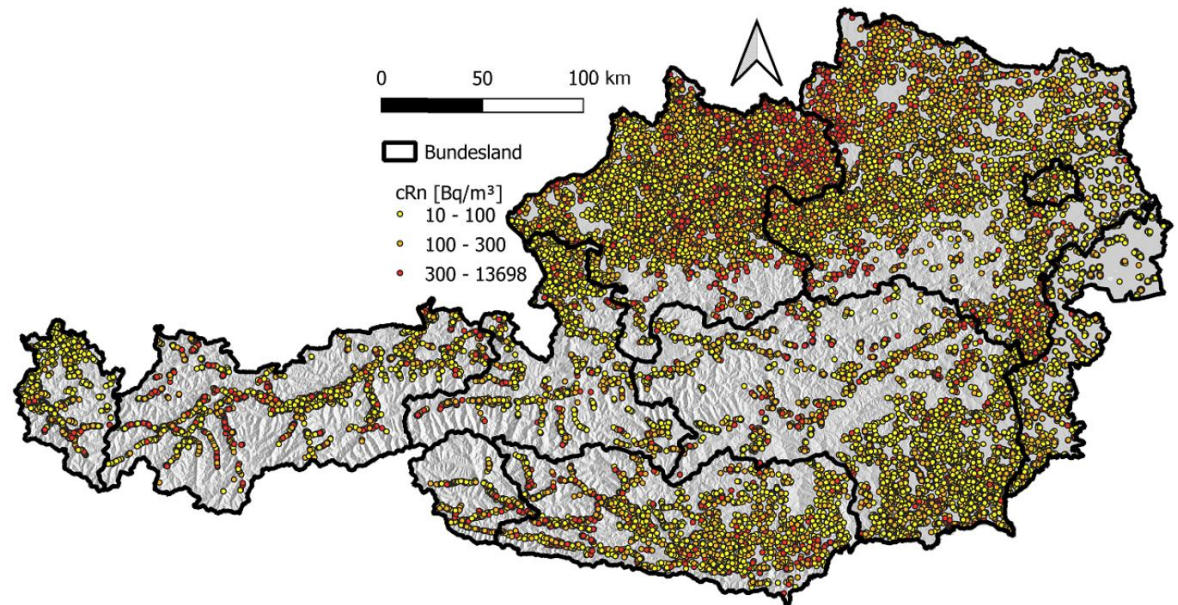
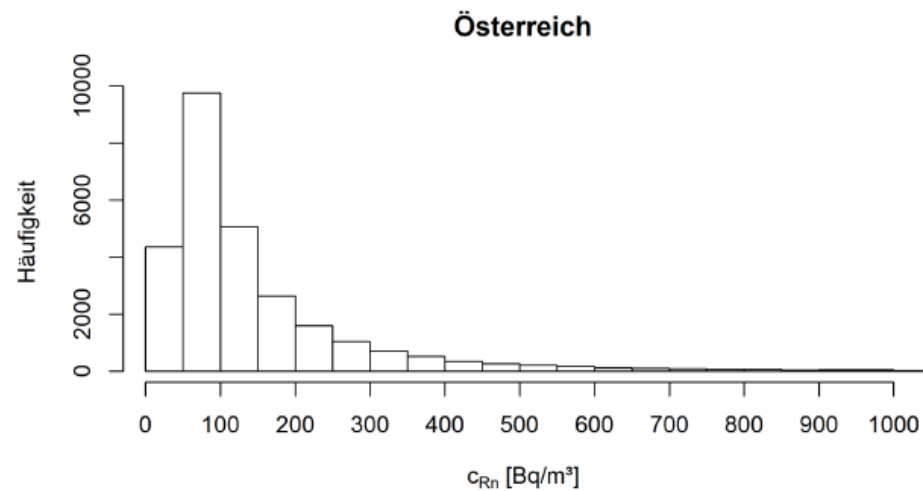
- **~ 50.000 Measurements (~27.000 homes)**
- **Geographical representative**
- **Six month measurement time**
- **2 most occupied rooms, preferred ground floor**
- **Building characteristics**



Results of the new Austrian indoor radon survey

Overview

n measurements	n buildings	AM [Bq/m ³]	Median [Bq/m ³]	> 100 Bq/m ³	> 300 Bq/m ³	> 1000 Bq/m ³
46.339	27.630	166	99	49 %	12 %	1 %



From the survey to the radon map

Modelling

Geostatistical Modelling → Generalised Additive Mixed Model (GAMM)

- Modelling the results of the Indoor Radon Concentration (IRC) in dependency of explaining factors:
 - Building characteristics & living habits
 - Geology
 - Spatial correlation
- Log-norm distribution assumed
- To evaluate influence of variables (building characteristics) → stepwise forward selection with *5-fold cross validation*

$$\log(IRC_{ij}) = \underbrace{\beta_0}_{\text{Intercept (Rn background level)}} + \underbrace{\beta_1 Z_{ij} + \dots + \beta_m Z_{ij}}_{\text{Fixed effects according to the relevant parameters (building characteristics)}} + \underbrace{s(x_j, y_j)}_{\text{Smoothing function (thin plate regression splines), spatial intercept}} + \underbrace{U_j}_{\text{Random effect (dwelling)}} + \underbrace{\varepsilon_{ij}}_{\text{rest variation}}$$

Advantages of the modelling approach:

- Characterisation of areas with no or small number of measurements possible
- Takes into account
 - geology
 - building factors – reflecting geogenic radon potential
 - spatial correlations – more homogenic classification possible

+ allows assessment of population-weighted exposure !!!

Alber Oliver et al 2023
Modeling and predicting mean indoor radon concentrations in Austria by generalized additive mixed models

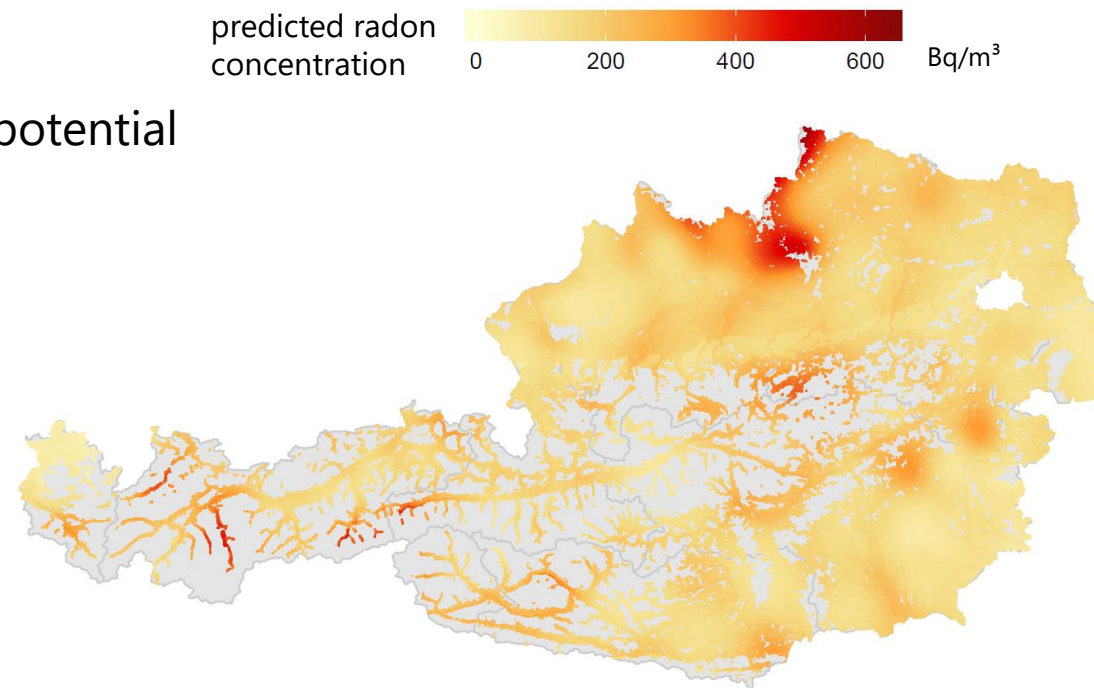
From the survey to the radon map

Folie evt. streichen



Prediction of radon concentration in a reference house

- Prediction of radon concentration (IRC) for reference house on 250 x 250 m grid (radon potential of the grid cell)
- Definition of reference house has strong impact
- Reference house – representative for requirements for workplaces and for cost-efficient newly built houses
- Estimate of geogenic radon potential



Variable	Characteristic
earth-boundness	no
year of construction	after 2000
floor	0
basement	no
stone walls	no
concrete walls	no
usage of building	single family house
number of adults	2
low-energy house	no
windows	tight
foundation	full
thermal retrofitted	no
geological unit	assigned by coordinates

The new Austrian Radon map

Delineation of Radon areas




– Radon protection areas

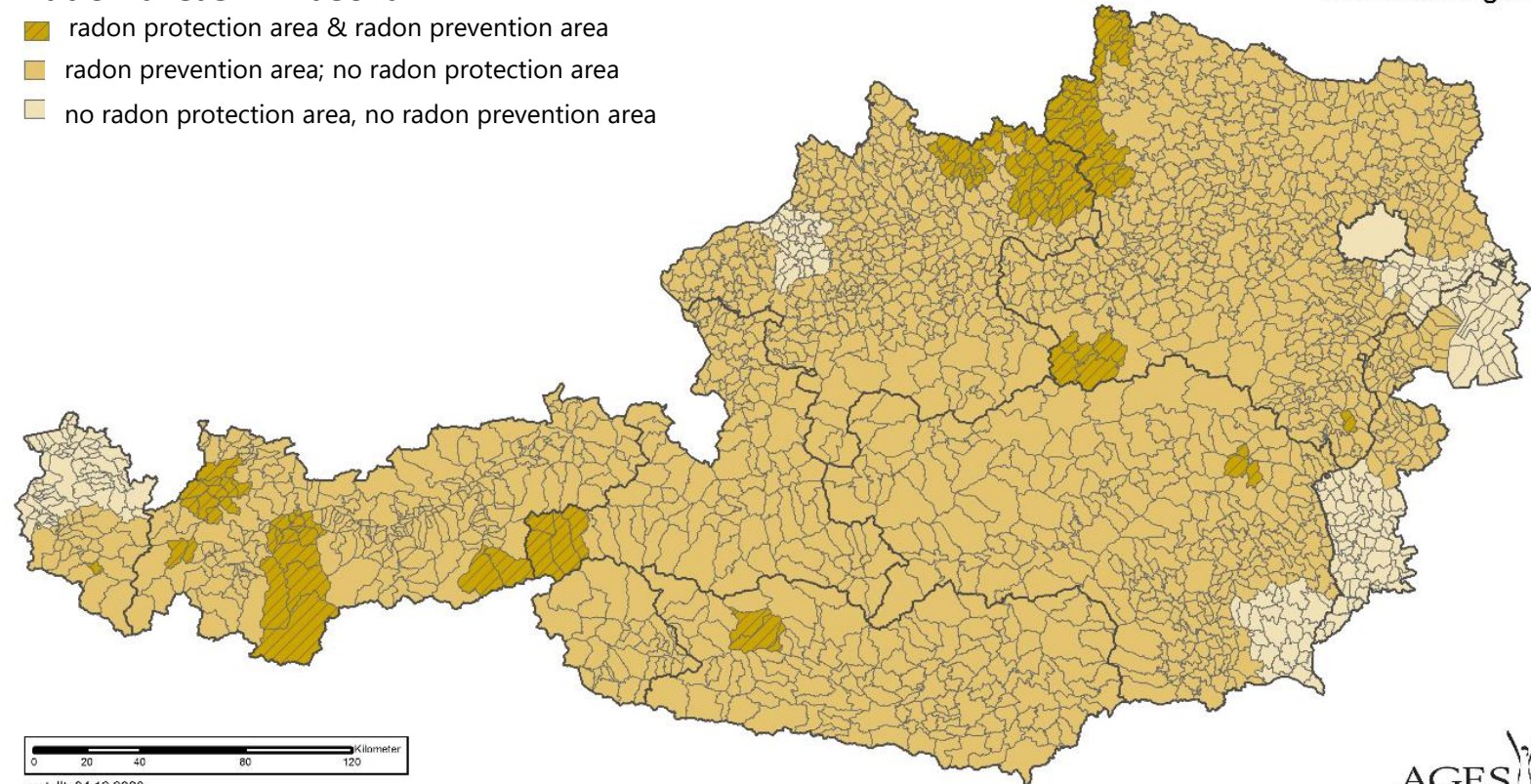
- Predicted radon potential of municipality is above 300 Bq/m³
- Measurements in workplaces (groundfloor & basement) mandatory

– Radon prevention areas

- Predicted radon potential of district is above 150 Bq/m³
- Preventive measures for new buildings mandatory

Radon areas in Austria

-  radon protection area & radon prevention area
-  radon prevention area; no radon protection area
-  no radon protection area, no radon prevention area



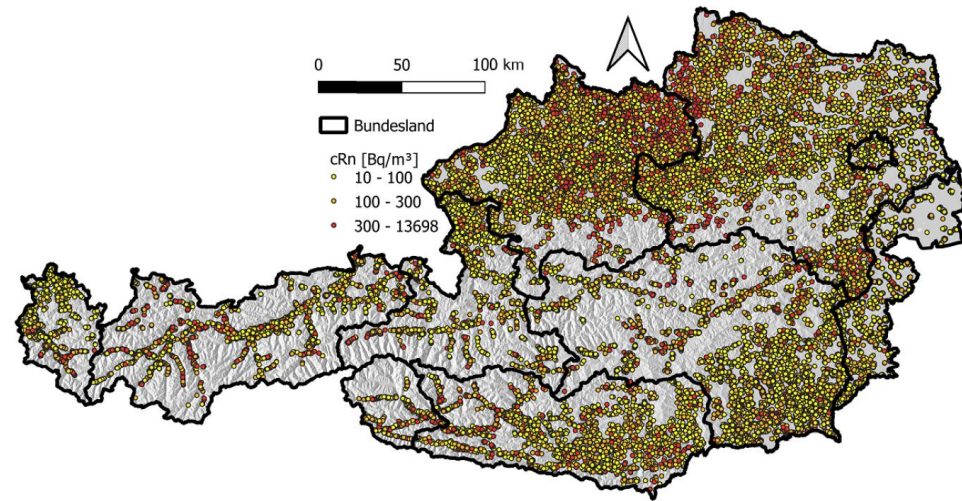
www.radon.gv.at



erstellt: 04.12.2020
Quelle: Österreichische Fachstelle für Radon; Gemeindegrenzen: BEV 2020

Radon exposure of the population

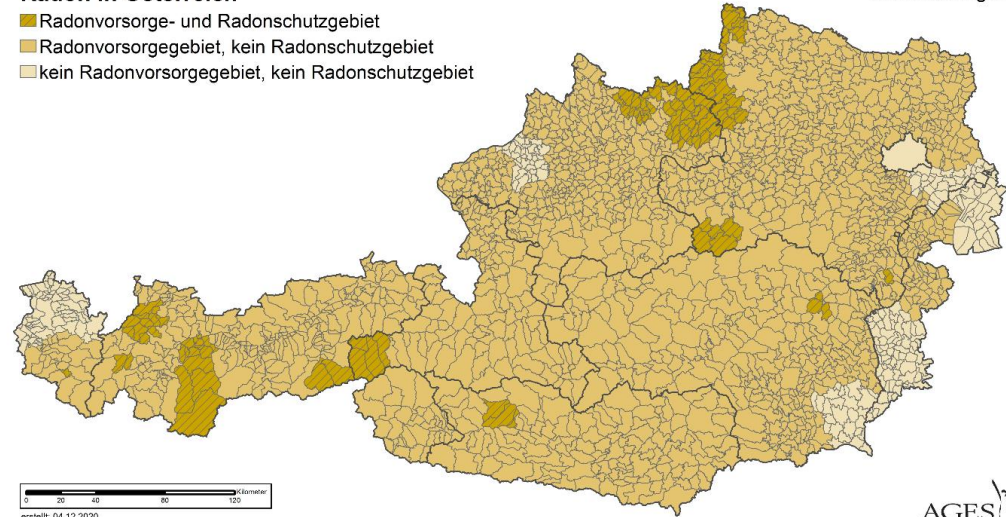
Population-representative distribution of radon indoors



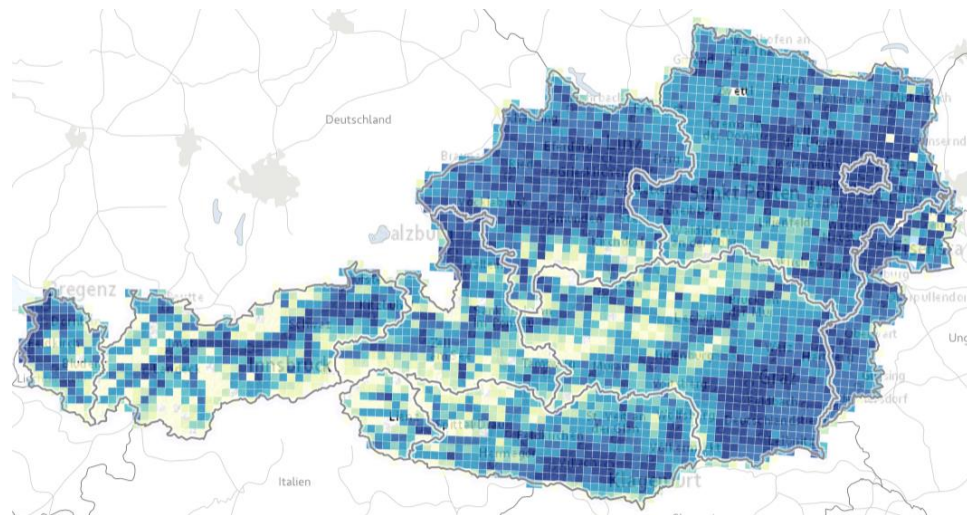
Radon in Österreich

www.radon.gv.at

- Radonvorsorge- und Radonschutzgebiet
- Radonvorsorgegebiet, kein Radonschutzgebiet
- kein Radonvorsorgegebiet, kein Radonschutzgebiet

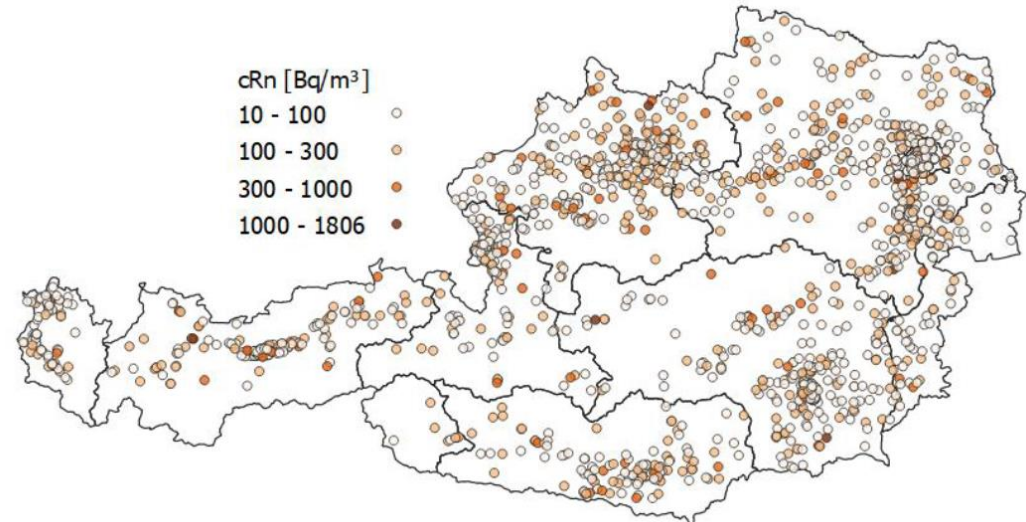


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cRn [Bq/m³]

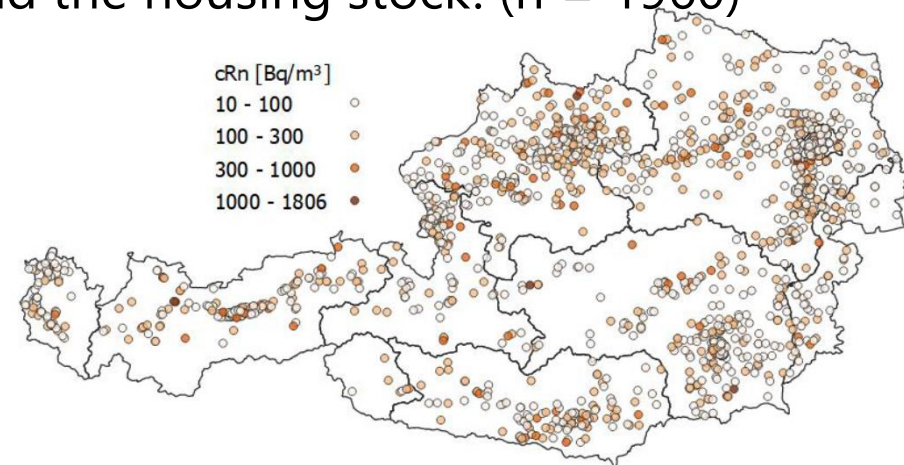
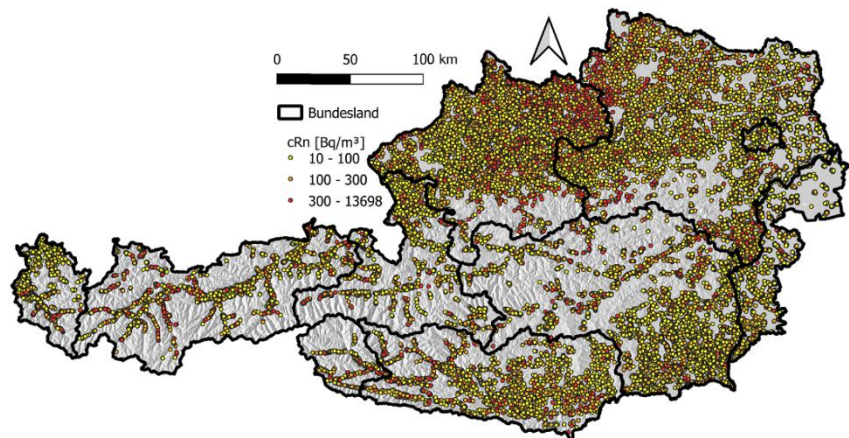
- 10 - 100
- 100 - 300
- 300 - 1000
- 1000 - 1806



Rn-concentration

Population-representative selection

- Collected data is geographically – representative:
 - **Undersampling of dense populated areas (e.g. cities)**
 - **Overesampling of rural areas**
- Generate population-representative Radon data:
 - Additional data needed: population density and housing stock
 - Estimate mean of the population-representative Rn-concentration via model
 - Draw a population-representative sample out of the whole data set with respect to the estimated mean, the population density and the housing stock. (n = 1960)



Radon exposure of the population

Population-representative distribution of radon indoors



Input data from survey as given above:

- radon concentrations in households
- characteristics of measured rooms and buildings (year of construction, floor, basement)
- location of dwelling
- Geology

-> need geographical distribution of households (from Statistics Austria on 10x10 km² grid) and their building characteristics (from ÖNRAP 1) - **year of construction, floor, basement**

-> apply geo-statistical model GAMM

-> calculate for every grid the radon level for all occurring different types of households

-> weighting according to number of households per type and number of households

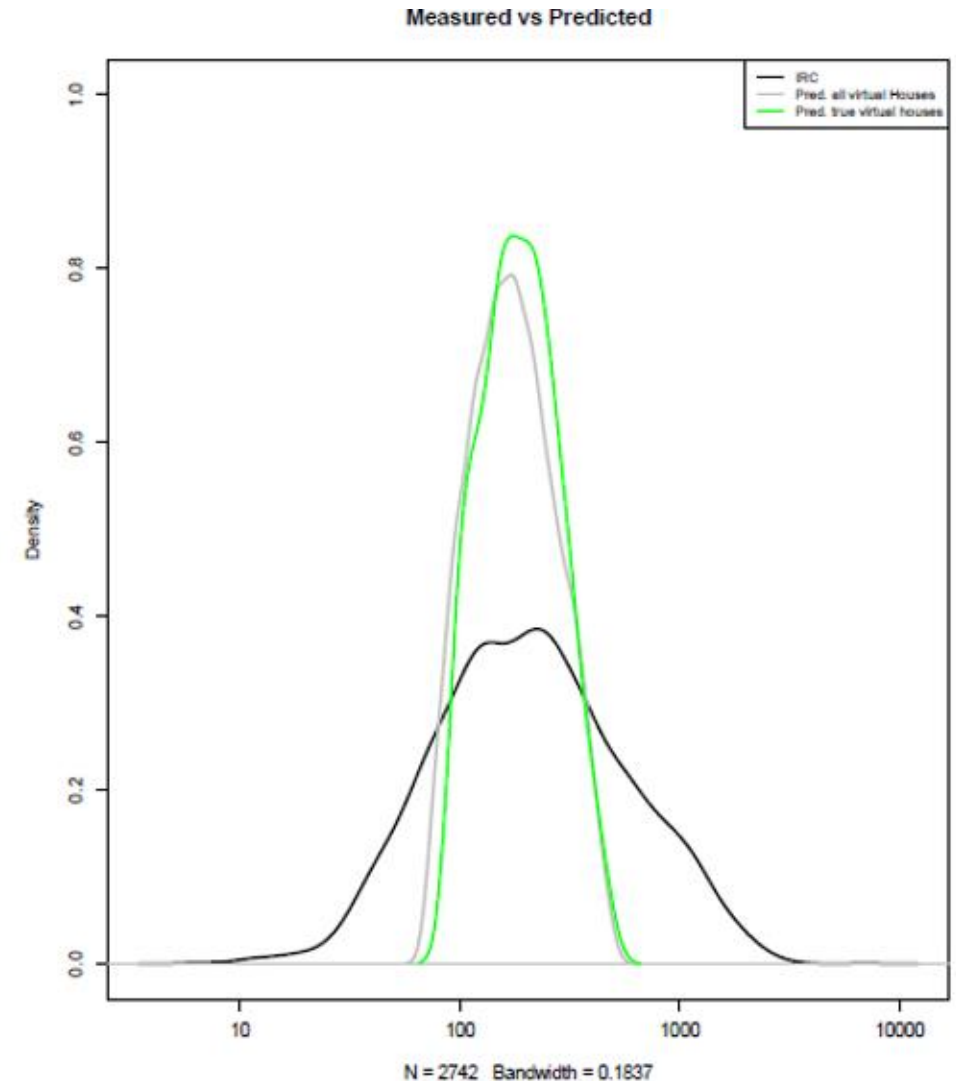
-> drawing / random sampling of to get representative distribution

Drawing sample?

Population-representative distribution of radon indoors

- Target of model is mean radon concentration
- The tails of the distribution modelled poor
- Consequence: Statements like households $> 300 \text{ Bq/m}^3$ are not valid

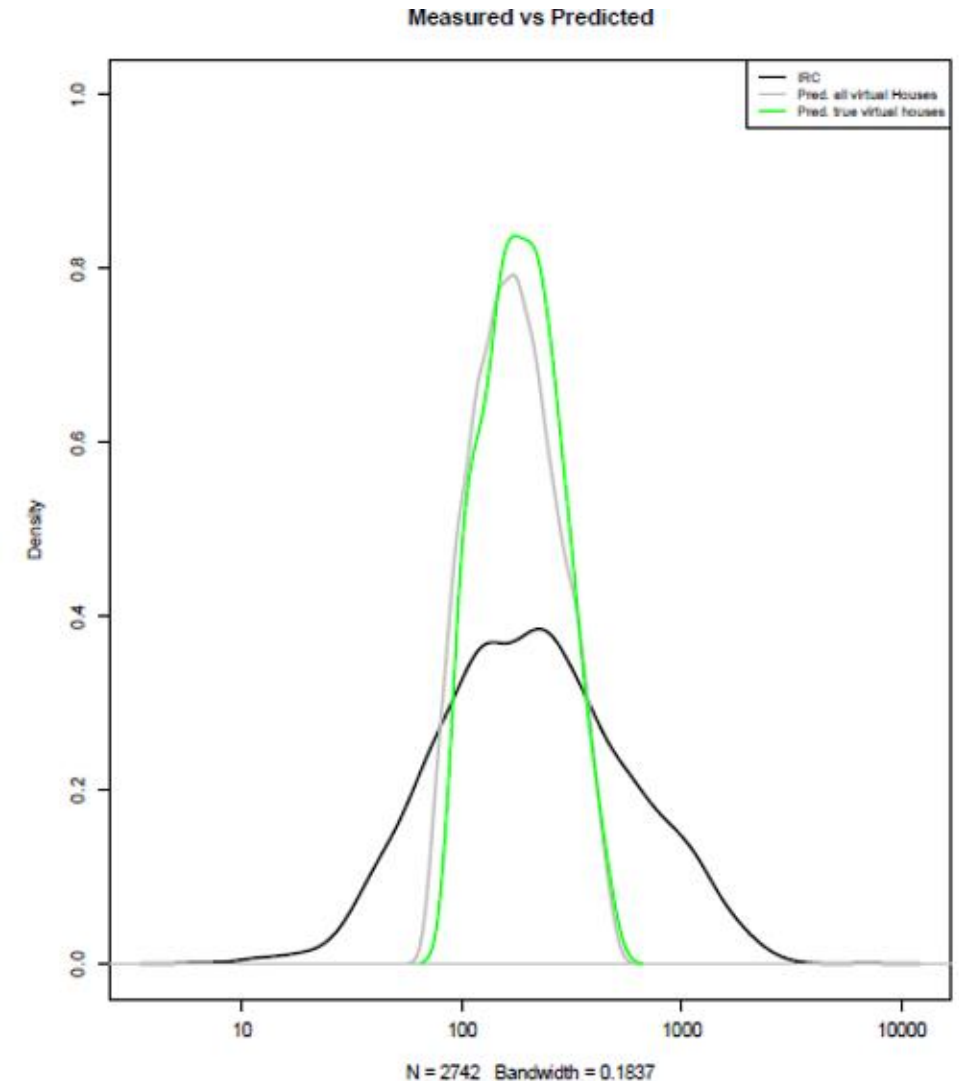
Drawing a representative sample



Drawing sample!

Population-representative distribution of radon indoors

- Goal: Tails of distribution
- Random weighed sampling
- For each federal state
- 500 repetitions
- ~0.05 % of population
- No putting back
- Ground truth: Averages of model



Geographically/Population

Results and findings radon survey

— Raw data – geographically representative:

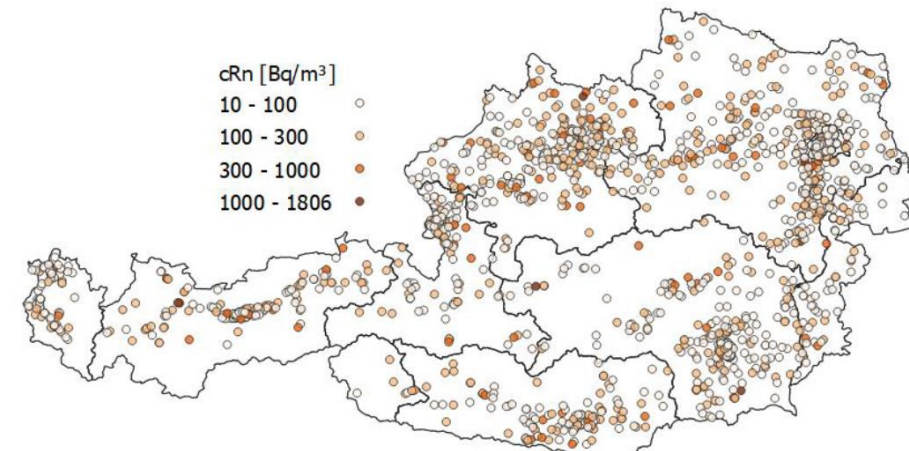
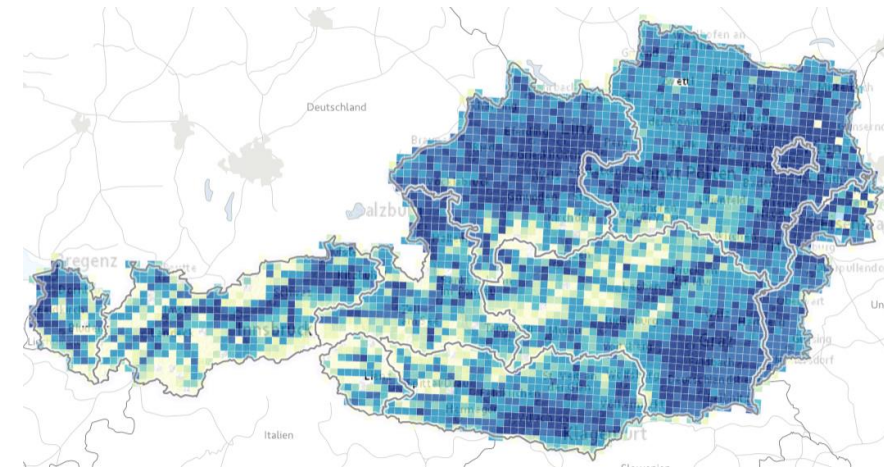
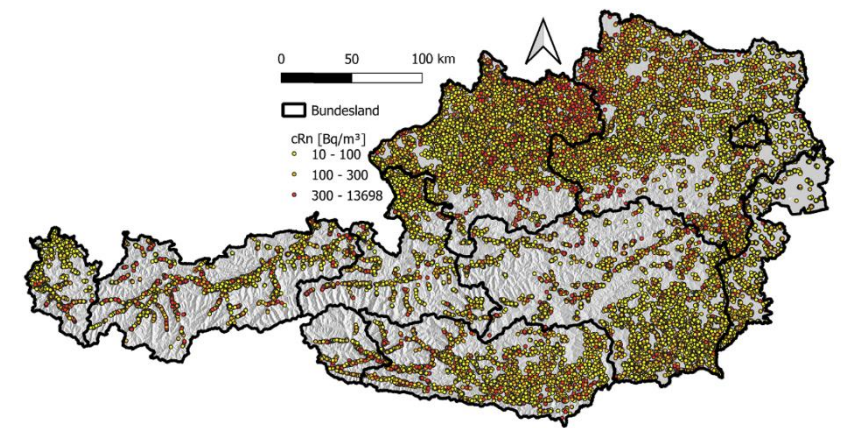
n (meas.)	n (dwell.)	AM [Bq/m ³]	Med [Bq/m ³]	> 100 Bq/m ³	> 300 Bq/m ³	> 1000 Bq/m ³
46.339	27.630	166	99	49 %	12 %	1 %

— Considering population density and buildingstock → population representative:

n (meas.)	n (dwell.)	AM [Bq/m ³]	Med [Bq/m ³]	> 100 Bq/m ³	> 300 Bq/m ³	> 1000 Bq/m ³
3912	1960	112	77	34 %	6 %	<< 1 %

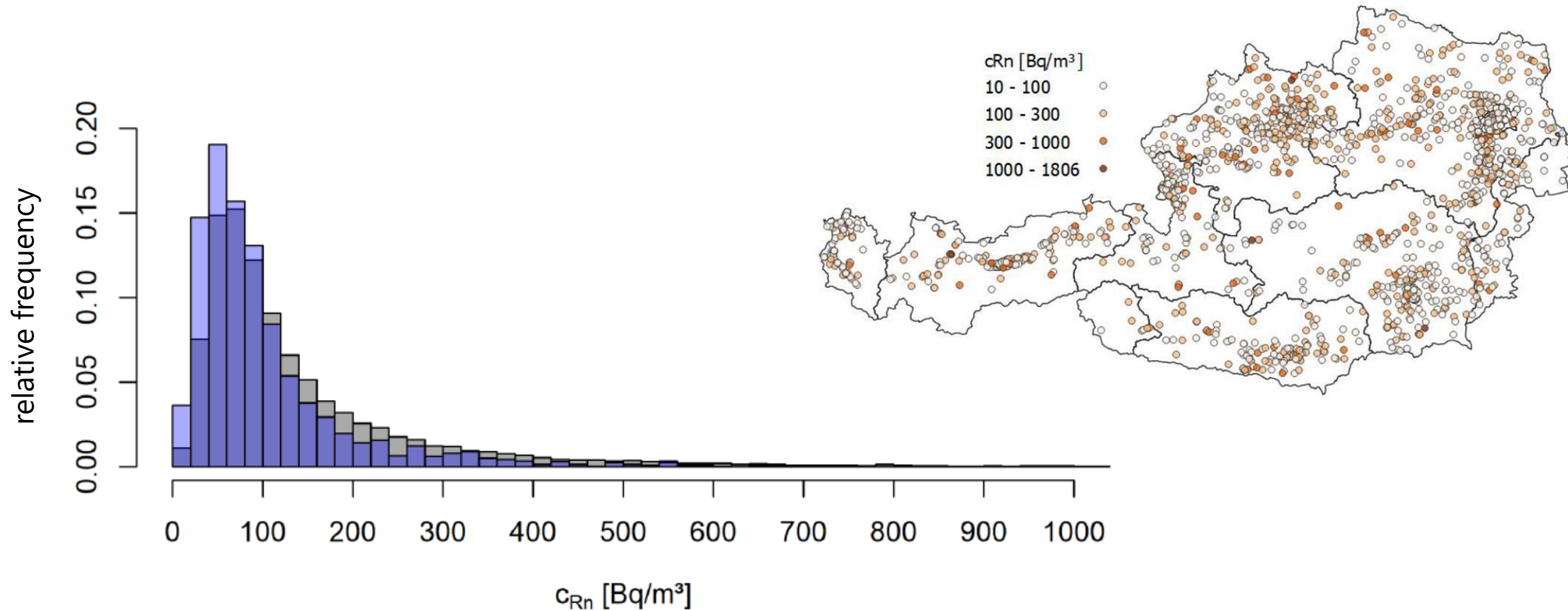
lower than from raw data because measurements in rural areas and predominantly at ground floor level

~ 230,000 households
~ 500,000 people



Exposure

Population-representative radon distribution



- light blue: population-representative distribution
- gray: distribution of measured radon concentrations
- dark blue: overlap of distributions

Dose

From exposure to dose

- mean radon concentration (AM)
- dose conversion factor from UNSCEAR 2019
- equilibrium factor of 0.4
- indoor occupancy of 7500 h/a
- assumption of similar radon levels at workplaces
- dose from radon outdoors negligible

∅ radon dose = 3 mSv/a

with

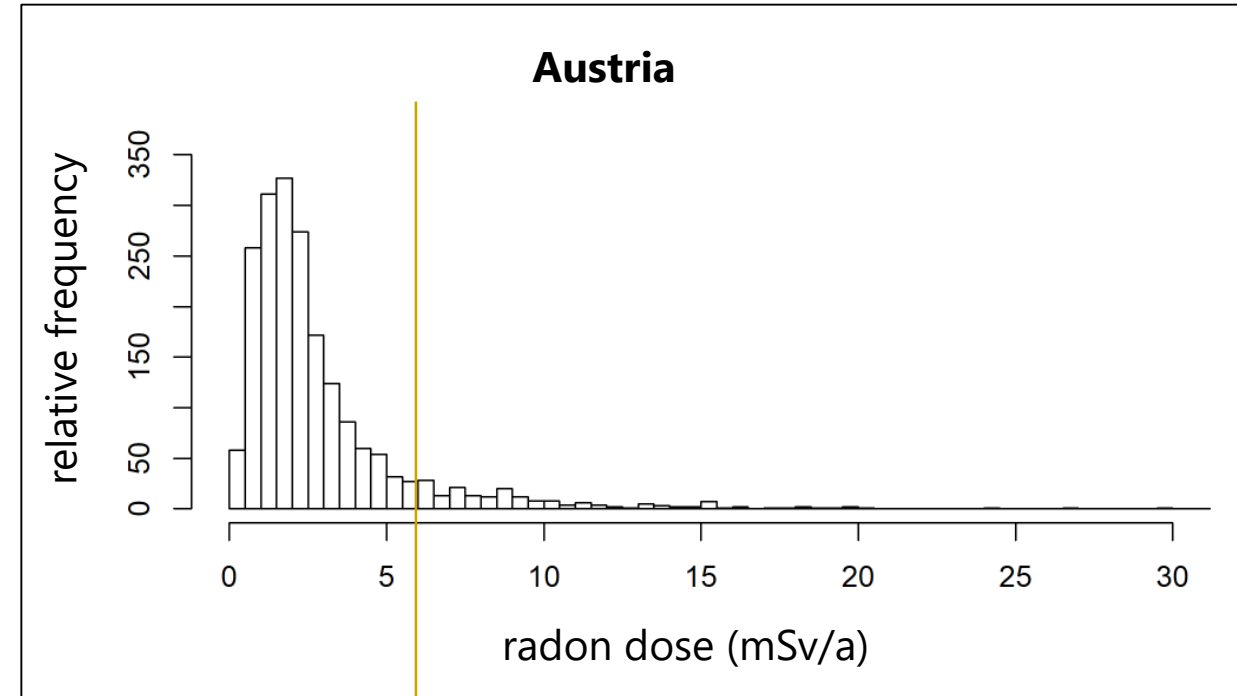
AM = 112 Bq/m³

DCF = 9 nSv/(h·Bq/m³)
(UNSCEAR 2019)

F = 0.4

t = 7500 h/a (from ÖNRAP 1)

∅ radon dose (ICRP137) = 5.6 mSv/a



~ 10 % > 6 mSv/a

Determination of Dose from Radon

Limitations | Improvements



- not strictly population-representative but household-representative (measured radon concentrations reflect household but not an individual person)
- assumption of same radon levels at workplace than in dwellings
- re-assessment of occupancy (7500 h)
- more measurements / data from highly populated areas (cities)
- dose conversion factor from UNSCEAR – or ICRP?

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