Geogenic Radon Potential
Short overview

Report of EURAMET 16ENV10 MetroRadon

László Szűcs, Zsófia Nagyné Szilágyi, Ádám Nagy
Dr. Péter Nagy, Renáta Botos, Ferenc Árva, Norbert Szabó, Károly Rózsa, Dénes Párkányi

Short overview on the geogenic radon potential and radon mapping in Europe

Introduction

Radon is a radioactive noble gas, originating from the soil's uranium and thorium content. Radon is considered responsible for more than half the average natural radiation dose for humans and one of the major causes of lung cancer. The health concerns of radon made regulatory control necessary and many countries implemented some measures for handling exposure to radon. The usual regulatory approach is specifying dose limits, an amount of radiation dose that is acceptable, these would be translated to reference levels, meaning permissible activity concentrations in various media (set in a way not to reach the dose limits). These reference levels then would be compared to the measured activity concentrations and if those concentrations exceed the reference levels the appropriate measures set in the national regulations would have to be implemented. Developments in the dose conversion calculations further raised the importance of radon (the conversion factors were approximately tripled from the previously used ICRP 65). The European Union has included exposure to radon in the 2014 Basic Safety Standards, which requires the Member States to introduce reference levels for indoor radon concentrations not exceeding (as an annual average) 200 Bq m^{-3} for new dwellings and new buildings with public access, 300 Bq m^{-3} for existing dwellings, and 300 Bq m^{-3} for existing buildings with public access, allowing for low occupancy time a maximum of 1000 Bq m^{-3}. Since regulating radon concentrations requires a large number of measurements some method is necessary to optimize the allocation of the limited resources available for each country. The indoor radon concentration and the exposure from radon are dependent on many factors, but an assumption can be made that geology is a major control on the variation of indoor radon. This radon potential can be described by many different ways.

Geogenic radon potential concepts

The EU BSS describes radon-prone areas as a geographic area or administrative region where surveys indicate that the percentage of dwellings expected to exceed national reference levels is significantly higher than in other parts of the country. This is a good concept for national regulations, however it can't be used across borders, it is highly dependent on national regulations and and gives only a sense of risk related to the average concentration of said country, as high or as low it may be.

One of the often (used methods assessing the geogenic radon potential is the continuous variable originally proposed by Neznal.

$$GRP = \frac{c_\infty}{-log_{10}(k) - 10}$$

, where *GRP* is the geogenic radon potential, c_∞ is the equilibrium soil gas radon activity concentration at a definite depth (0.8–1 m) (kBq m^{-3}) and *k* is the soil gas permeability (m^2). Based on research conducted in the Czech Republic, three categories of GRP were set: low (GRP < 10), medium (10 < GRP < 35) and high (35 < GRP) In practice there are some variations on providing the values for *c* and *k*.

If *C* and *k values* are not available, then the radon potential is usually estimated from proxies. Such proxies are the standardised indoor radon concentration (measured in defined standard conditions such as ground floor rooms, presence of a basement, etc. to 'factorise out' anthropogenic factors) The standardised indoor radon concentration is correlated to the GRP, with inaccuracies caused by remaining unaccounted for or poorly assessed factors. Other quantities such as equivalent uranium (eU) or dose rate have similarly describable relations to the GRP, however these relations can be locally different, according to the regional predominance of some factors. The controlling factors have to be taken into account when using substitutes for the soil radon in the formula.

A different way of defining radon potential is based on multivariate cross-tabulation. This method results in an index with a categorical-ordinal quantity, the results are given in classes such as (I, II, III, IV) or (low, medium, high). Classes are assigned based on scores either assigned to a combination of input quantities or calculated as the sum of points delegated to the input quantities. The second type allows for the consideration of multiple factors. Available quantities are soil radon, permeability, standardised indoor concentration, equivalent uranium concentration or other geochemical quantities, external terrestrial gamma dose rate, geological categories, quantities related to tectonics, and the presence of ‘special features’ like mines, caves, water bodies and other extraordinary conditions, which are coded binary (yes, no).

For compiling maps, similarly to the definition, several options exist. First the definition of the target variable has to be decided upon. Then said variable has to be matched to spatial units (area), which will serve as the basis of the map. These spatial units can take various shapes and forms such as administrative or geological units or a grid cells. Geographical units might be a practical choice for the radon potential, and if desired those units can be decompiled into a grid system. The spatial units are then assigned a value derived from the measured target variables inside (arithmetic mean, geometric mean, median, etc.). If insufficient data is available for the mean calculation to be representative of the area that technique shouldn’t be used. Various estimation or interpolation techniques (local regression methods, disjunctive kriging, Bayesian inference or extensive Monte Carlo simulations) can be implemented during the construction of such maps, but it should be kept in mind that the interpolated concentration is only an estimate, not the actual radon concentration, even though it can be useful for the visualisation of the data and in defining areas with higher risk probability. The different spatial units offer different advantages and disadvantages. Administrative boundaries make administrative action easier, but disregard the relation between the radon potential and the geology and soil properties. Grids makes mapping independent from other variables, but ignores variation within the grid cells. Geological boundaries are much more closely related to the radon potential but still there can be variations in the radon potential inside the geological units. In case of sufficient data density maps can be made by displaying each point of data, without interpolation for the areas between the data points, which would still give an instinctive grasp of the overall situation.

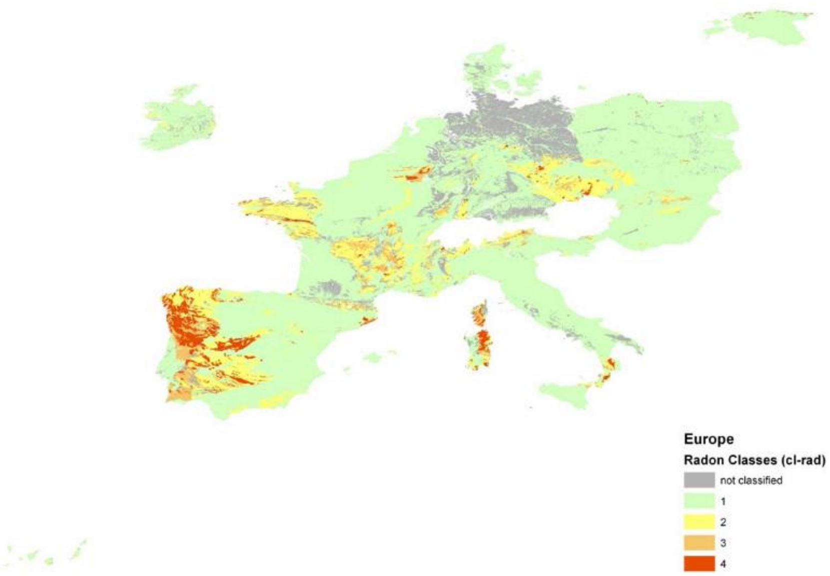
Relationship between various parameters used in the estimation of geogenic radon potential

In case of the multivariate cross-tabulation values can be assigned to the various parameters or qualitative categories can be set up. For example, in case of a study on Bourgogne a five step qualitative scale was used to define radon source potential based on lithology and uranium content, while for the geogenic radon potential map they narrowed down the number of categories to three and included the various artefacts such as mines and hot springs into the analysis.

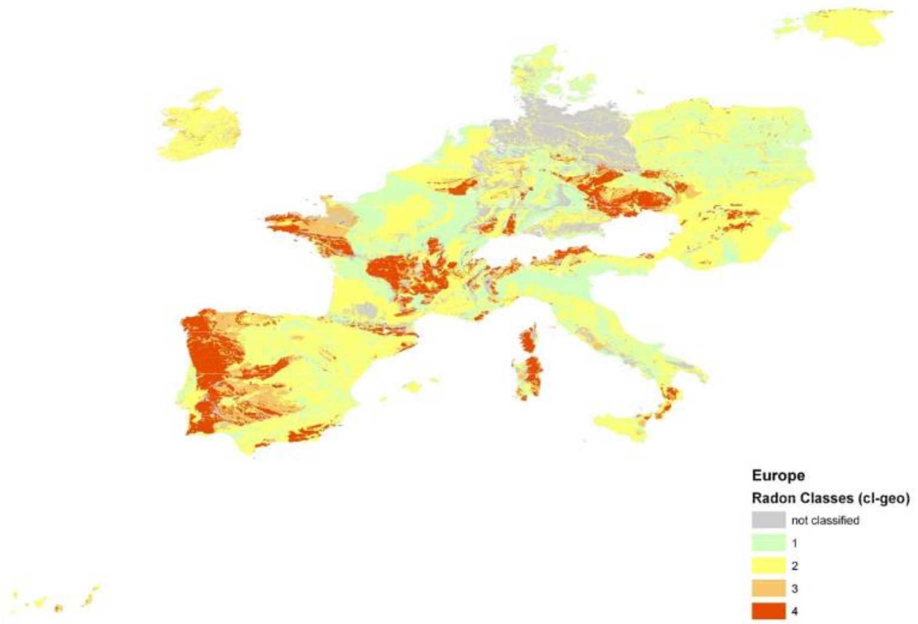
In case of the geogenic radon potential formula reliant on soil gas and soil permeability measurements there are some methods correlating various other parameters if the input is not directly available. There are many different mathematical methods for establishing the correlation between two or more parameters (soil gas radon, indoor radon, soil radium content, external gamma dose rate, etc.), however usually there are problems of the correlations being location specific, the results cannot be directly used in other areas, analogues and approximations can be used, however there is a chance of over or underestimating the actual concentrations, so they have to be validated before use.

Spatial distribution of radon in Europe

The Joint Research Centre of the European Commission made some efforts for compiling a map for the Geogenic Radon Potential, however that project is still ongoing and has many issues to be solved before completion. The latest available map is a trial version of the European Geogenic Radon Map was based on German geotypes. This has some problems due to countries that are not part of the same geological database and the issues of geology classification (types missing, different classification systems used, difficult classification, incomplete data, etc.).



Trial version of the European Geogenic Radon Map (EGRM) with „radiological” radon classes (Gruber et al. 2012)



Trial version of the European Geogenic Radon Map (EGRM) with „geological” radon classes (Gruber et al. 2012)

While the EGRM presents a unified picture of the collected data the trial version was calibrated using German geotypes, so for other countries analogies were used. For the improvement of the map an iterative approach is necessary, with feedback from the experts of other countries. The EGRM has to be supplemented by data on the geotypes not present in Germany, while in other countries the geological analogies have to be confirmed and validated.

Distribution of radon measurement methods and measurement devices in Europe

The following table shows the methods used in national surveys of radon and some scientific endeavours in the various European countries. Unfortunately, the list is limited by the number of processed resources, many countries own equipment not covered by the reference material. Germany, France, Hungary and many other countries not only own active and passive devices, but have production and calibration capabilities as well.

Country	Track detector	Scintillation based equipment with Lucas cells	Active devices	Electret	Charcoal	Gamma-spectrometry
Albania	x	x				
Armenia			x			
Austria	x		x	x	x	
Azerbaijan						x
Belarus	x		x			
Belgium	x				x	
Bosnia and Herzegovina	x		x			
Bulgaria	x		x	x		
Croatia	x		x			
Cyprus						
Czech Republic	x	x				
Denmark	x					
Estonia	x		x			x
Finland	x	x				
France	x	x				
Georgia	x	x	x	x		
Germany	x	x			x	
Greece	x		x	x		
Hungary	x		x			
Iceland	x					
Ireland	x					
Italy	x	x				x
Kazakhstan	x		x			

Country	Track detector	Scintillation based equipment with Lucas cells	Active devices	Electret	Charcoal	Gamma-spectrometry
Kosovo	x		x			
Latvia			x	x		
Liechtenstein						
Lithuania			x	x		
Luxembourg	x	x				
Macedonia	x					
Malta	x		x			
Moldova			x			
Monaco			x			
Montenegro			x			
Netherlands	x					x
Norway	x					
Poland	x	x	x		x	
Portugal	x		x			
Romania	x	x			x	
Russia	x		x			
Serbia	x		x		x	
Slovakia	x	x			x	
Slovenia	x		x			
Spain	x	x			x	x
Sweden	x		x		x	
Switzerland	x			x		
Turkey	x		x			
Ukraine	x					
United Kingdom	x	x				x