What is the objective of radon abatement policy?

Revisiting the concept of radon priority areas

Bundesamt
für Strahlenschutz

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Motivation

- BSS of IAEA and EURATOM require developing Rn Action Plans to reduce Rn exposure.
- Key tools are reference levels (RL) and Rn priority areas (RPA)

QUESTIONS:

- Which is the underlying objective of Rn policy?
- Do the RL and RPA concepts serve the objective?
- Reversely: Which objective do they serve?

“abatement” = prevention, mitigation, remediation, validation
+ inclusion of and communication to stakeholders

Structure
(more or less)

- Objectives of radioprotection in general and of Rn abatement policy in particular
- Risk, hazard, detriment
- What does BSS article 103/3 mean?
- What is the effect of Rn policy based on RPA and RL?
- Real-world example
- From hazard mapping to risk mapping
- Possible consequence for regulation and political action ?????

Radioprotection objectives in general and concerning radon in particular

IAEA fundamental safety principles [1]:

- *Principle 6: Limitation of risks to individuals: Measures for controlling radiation risks must ensure that no individual bears an unacceptable risk of harm.*
- *Principle 7: Protection of present and future generations. People and the environment, present and future, must be protected against radiation risks.*
- *Principle 10: Protective actions to* ***reduce*** *existing or unregulated radiation risks.*

EU-BSS:

- Annex XVIII, (13): *Long-term goals in terms of* ***reducing lung cancer*** *risk attributable to radon exposure (…)*
- Otherwise, the EU-BSS does not explicitly address radioprotection objectives! Only speaks about "controlling" exposure etc.

[1] IAEA Safety Standards Series No. SF-1; www-pub.iaea.org/MTCD/publications/PDF/Pub1273_web.pdf

"reducing risk"

- Individual risk? (→ Rn exposure of a person)
- Collective risk? (→ number of people affected)

<u>Objectives of radiation protection</u>

Twofold!

1. Protect individuals from high exposure, to reduce individual risk … also if few persons are concerned.
2. Avoid high exposure to the collective, because the detriment to society is proportional to collective exposure (assuming LNT).

But for Rn: which risk can be avoided at all?

- IRC < outdoor conc. (2 – 20 Bq/m^3): impossible
- IRC < 100 Bq/m^3 - reasonable given the costs?
  This implies the discussion of how to weigh health vs. costs.

risk and detriment

- The “detriment” due to Rn exposure, inflicted to society, is the number of lung cancer fatalities.
- This number is proportional to the collective exposure, if LNT is assumed.
- BSS speaks about objective = reducing risk by Rn. If it means reducing detriment, in the sense of the 2nd objective ⇒ reduce collective exposure

BSS Article 103/3:

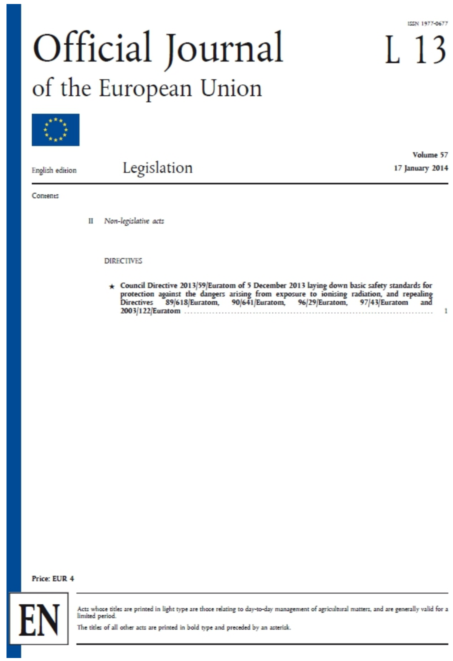
Member States shall identify areas where the radon concentration (as an annual average) in a significant number of buildings is expected to exceed the relevant national reference level.

Annex XVIII

List of items to be considered in preparing the national action plan to address long-term risks from radon exposures as referred to in Articles 54, 74 and 103:

(2) Approach, data and criteria used for the delineation of areas or for the definition of other parameters that can be used as specific indicators of situations with potentially high exposure to radon.

(6) Strategy for reducing radon exposure in dwellings and for giving priority to addressing the situations identified under point 2.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Contents

II *Non-legislative acts*

DIRECTIVES

★ **Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom** 1

Price: EUR 4

EN

Acts whose titles are printed in light type are those relating to day-to-day management of agricultural matters, and are generally valid for a limited period.

The titles of all other acts are printed in bold type and preceded by an asterisk.

“significant number”

- From the beginning (2013) there were discussions about the meaning of this apparently cryptic formulation.
- Perhaps it was put like this on purpose to allow flexible interpretation?
- Mostly it has been interpreted as
  - “significant fraction” of buildings in an area > RL
  - “mean over buildings” in an area > RL

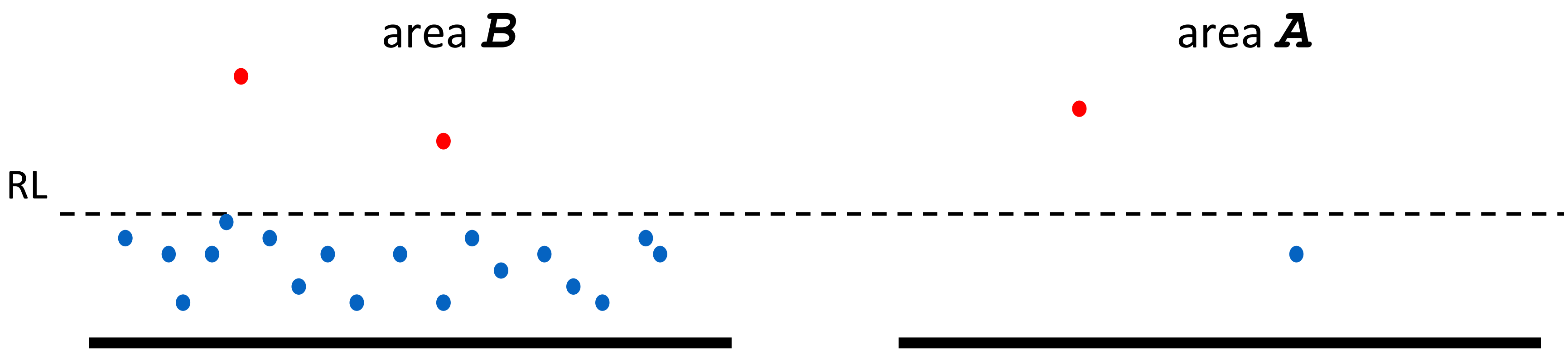
compatible with BSS objective?

- Conventional interpretation assigns an area a value (mean IRC, probability to exceed a RL) or RPA status (Y/N or several classes) according to its predictors (i.e., IRC or surrogates);
- but irrespective the number of buildings or persons affected.
- This seems partly opposed to the objective of BSS, if one assumes that it is subject to general radioprotection objectives, among which is reduction of the detriment = number of lung cancer cases.

Problem:

- A sparsely populated area ***A*** (low number of houses) can be RPA, because of high mean IRC or high fraction of houses exceeding RL.
- Still, collective exposure and hence risk related to Rn is low.

- On the other hand, a densely populated area ***B*** (many houses) can be non-RPA, because of low mean IRC or low fraction of houses exceeding RL.
- Still, collective exposure in ***B*** can be higher than in ***A***.



prob(IRC>RL)=2/20=0.1
$\Rightarrow$ RPA status <u>low</u>

also mean(IRC) in ***B*** < mean(IRC) in ***A***.

but:
collective risk ~ exposure ~ Σ IRC = <u>high</u>

prob(IRC>RL)=1/2=0.5
$\Rightarrow$ RPA status <u>high</u>

but:
collective risk = <u>low</u>

According to the conventional interpretation of Art. 103/3 and Annex XVIII (6), one would concentrate Rn policy on area ***A***, but not on ***B***, although the collective risk due to Rn is higher in ***B***.

Reference level

- The RL and conventional RPA concept apply to individual exposure
- There is no equivalent of the RL for collective exposure

Open question, therefore:

- Propose a measure of “priorityness” of action to applied for areas with low individual but high collective risk -- in analogy to the RPA status, which decides about the priorityness given to action in an area, considering the high rate of individual risk.
- Perhaps $\Sigma IRC/km^2$? or $\Sigma(IRC\text{-threshold})/km^2$?, where threshold = value which is considered inevitable or unreasonable to be of concern, such as 50 or 25 Bq/m^3, or the national mean or median? (Outdoor: 2-20)

What is risk? (1)

Simple statistical definition:

- Probability that a certain detriment (Z) occurs in a region in some time period:
- $R_{stat} := \text{prob}(Z \in U_z \mid x \in U_x, t \in U_t)$
- Z = detriment, U_z = detriment in a neighbourhood of Z=z, occurring in a certain spatio-temporal interval $U_x \times U_t$.
- For example,
  Z=earthquake, $U_z=[z,\infty)$, U_x=a country, U_t=[today, today + 1 year): The probability that an earthquake of magnitude greater than z occurs in a country, within the next year.
- This definition may not be satisfying for a physical understanding of a risk.

The discussion about "what is risk" has popped up recently at the Ricomet meeting.

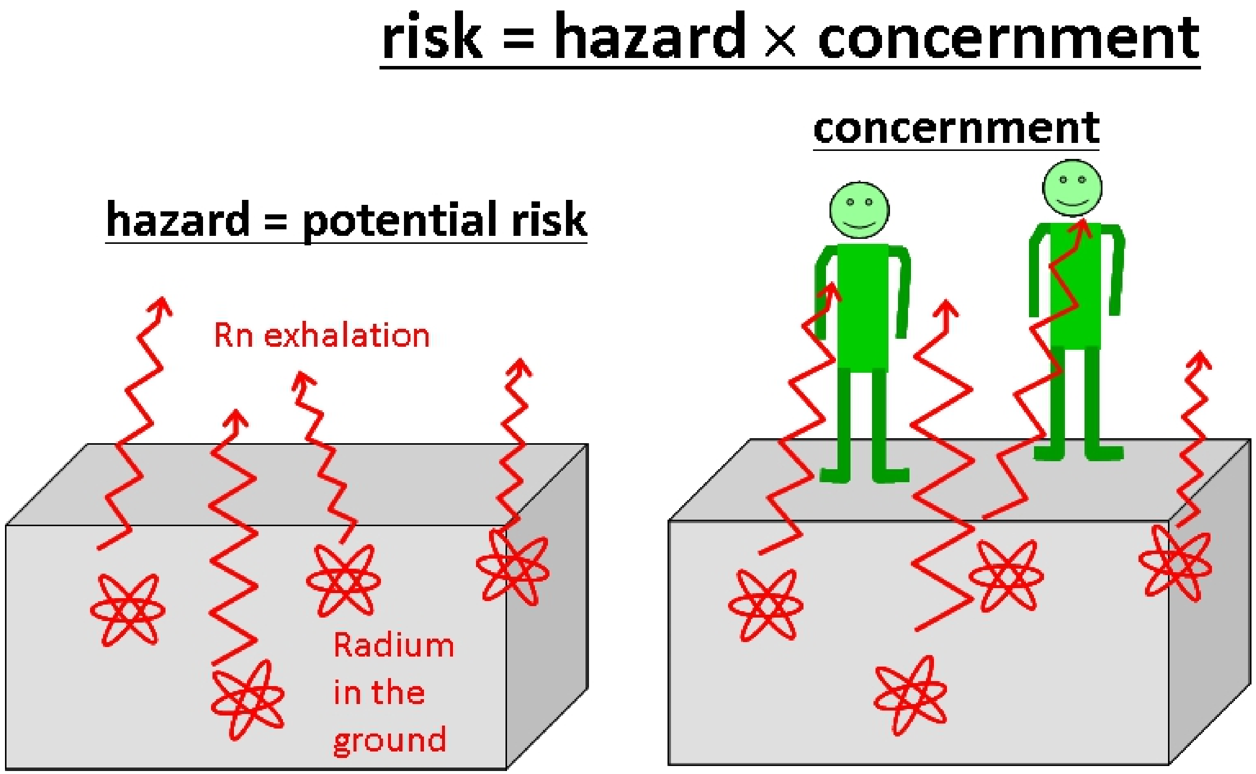
Risk (2)

Physical risk definitions

- Very common:
  - weighted detriment: $\mathbf{R_{phys} := z \times prob(Z=z)}$
  - Problem: becomes undefined for $z \to \infty$, $prob \to 0$, which are in practice often the most relevant cases.
- Common for low-probability large detriments:
  - $\mathbf{Z_{max}}$ = maximal consequence of a very rare event.
  - This notion motivated the "stress tests" for NPPs in the EU, initiated by the EC after the Fukushima accident. Such events are nearly incalculably improbable, but should nevertheless be considered and define a kind of upper boundary risk.
  - Problem: this way, every theoretical detriment can be regarded as nearly infinitely "dangerous".

Risk (3): Hazard and risk, 1

- **Hazard** exists also if nobody is affected or concerned;
- It becomes a **risk**, (= a certain probability of damage), if there is somebody who can be harmed. If there is nobody, evidently there is no risk, even if a physical cause exists.
  (Or in general, any being or thing whose damage should be avoided.)



The RPA concept, as conventionally understood, addresses hazard, not risk!

Risk (4): Hazard and risk, 2

		Rn risk:
Risk =	(at a location, at a time)	Lung cancer rate
Hazard $\times$	Probability of ***occurrence*** or size of a potentially harmful phenomenon	GRP
Vulnerability $\times$	Conditions (environmental, social, economic,…) which determine the ***susceptibility*** of the good which can be harmed (people, community, infrastructure, material assets,…)	Building type, living habits, social factors
Exposure	***Presence*** of this good	number of people, pop. density

- In the previous scheme, "concernment" $\approx$ vulnerability $\times$ exposure
- '$\times$' linkage, not necessarily multiplication
- R = f(hazard, vuln, exp) may also be a logistic-type function

Conventional RPA notion compatible with radioprotection objective?

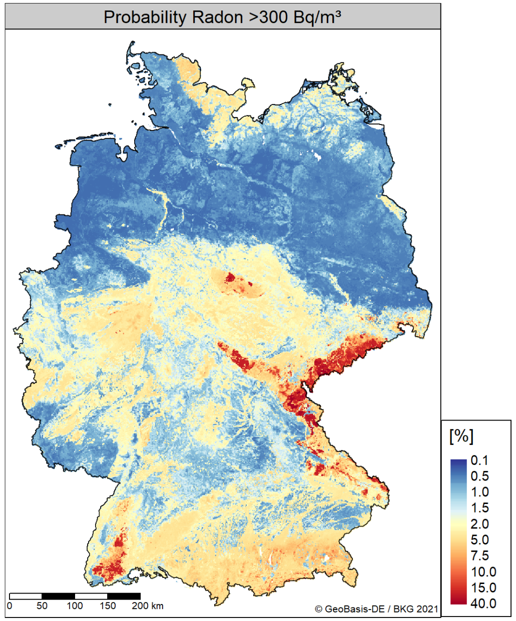
- The conventional RPA concept, which assigns RPA status to an area (municipality or other), in fact assigns a hazard type indicator to the area (because it does not consider exposure ~ number of persons), but **not** a risk indicator (which would have to include exposure).
- The conventional strategy, i.e. concentrating on area ***A*** (high RPA status, therefore high individual risk, but low number of cases, therefore low collective risk), is not efficient, if the objective is reducing the detriment measured as number of lung cancer fatalities.

A real-world example

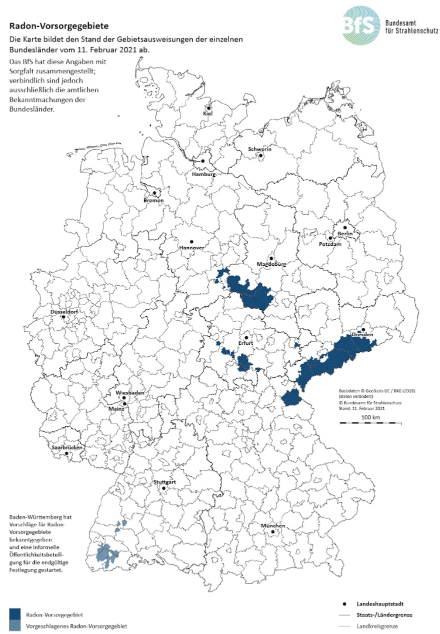
- Calculations from Germany, which motivated these thoughts.
- RPA abstractly defined as areas (municipalities or districts), in which prob(IRC>RL=300 Bq/m^3)>10%.
- The geographical distribution of the probability has been estimated by statistical means (not to be discussed here).
- How the local probability p(x) is transposed into the RPA status of a municipality, is up to the Federal States; it is not necessarily the mean of p(x) over $x \in$ area.

  (This is because by German constitution, while the radioprotection law is on federal level, its implementation is with the Federal States.)
- Prevention also outside RPA: for all new buildings basic Rn isolation required.

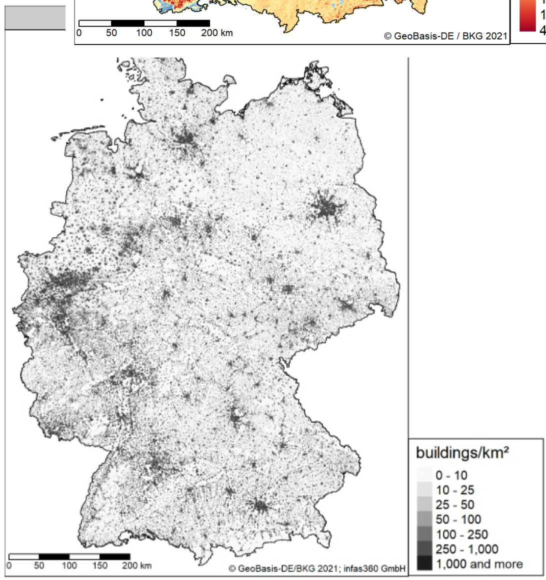
Estimated prob(IRC>300)



“official” RPA defined by the Federal States:



Density of residential buildings:



Estimated number of buildings with IRC>300 <u>within</u> RPA, defined as areas p(IRC>300)>10%, i.e. not the official ones: ~27.000

Estimated number of buildings with IRC>300 <u>outside</u> RPA: ~345.000

Estimated annual number of lung cancer fatalities due to Rn inside / outside RPA: ?/? (Σ 1900 assumed)

Number attributable to houses with IRC>300 inside / outside RPA: 7/88

approximate numbers!

Calculations in: Petermann & Bossew: On the effectiveness of radon priority areas – a critical evaluation. Subm. JER

Result:

1. Most buildings which have IRC>300, are outside defined RPAs;
2. Number of lung cancer fatalities attributable to buildings >300 is small; even smaller the number of those in buildings within RPAs.

<u>Reasons:</u>

a) High geographical variability of IRC (and GRP);

b) RPA do not honour number of persons affected, i.e. population density.

$\Rightarrow$ Efficiency of conventional RPA / RL concept is questionable.

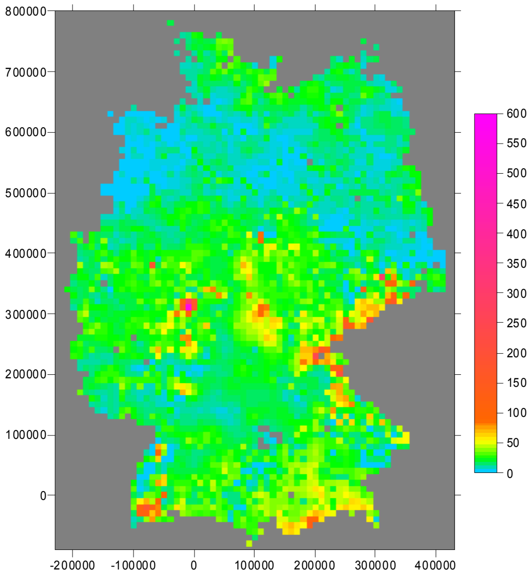
Although: Probability to find a high-Rn building is higher in RPA than outside. Hazard based radon policy can be efficient for reducing risk of individuals exposed to very high concentrations in regions with a geogenic predisposition.

$\Rightarrow$ How could a risk-focused approach look like?

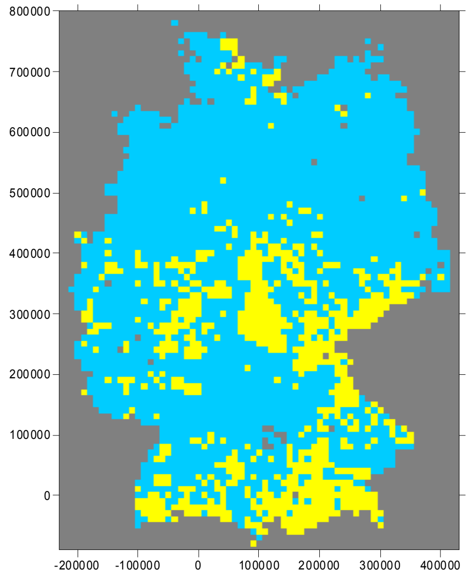
hazard // risk maps

hazard

GRPNez



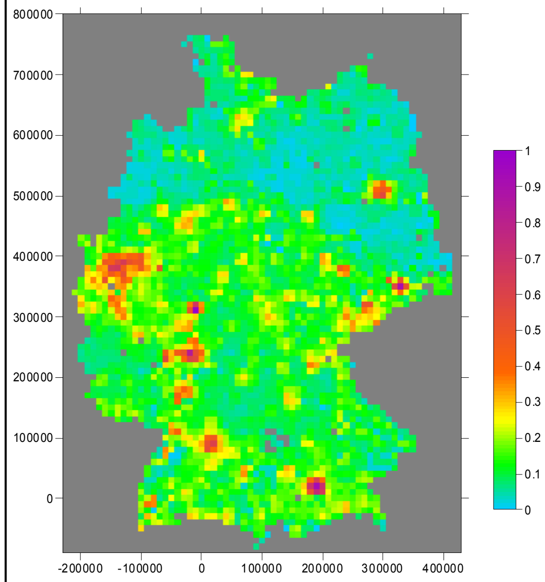
RPA status



RPA: prob(IRC>300)>10% $\leftrightarrow$ GRP=27.5

risk

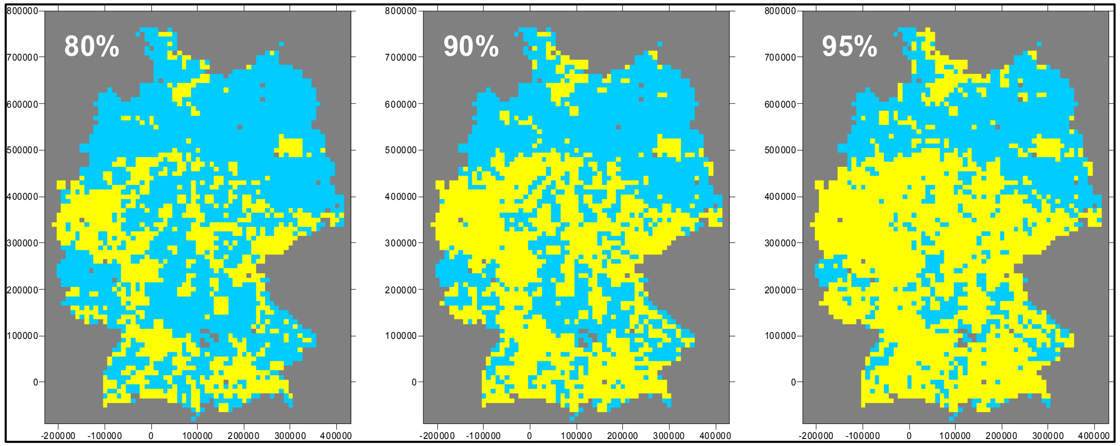
coll. expos. (sqrt) scaled [0,1]



risk $\propto$ GRP $\times$ pop.dens.

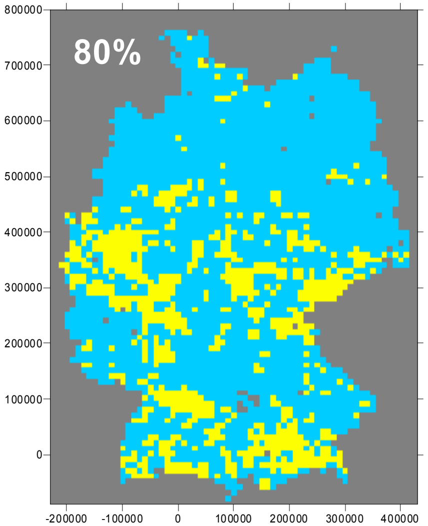
Zones which represent different percentages of the total detriment (coll. exposure)

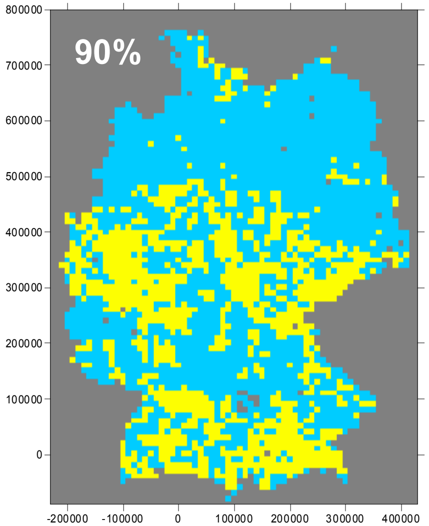
cumulated starting from the cell with the highest coll. dose; the total areas are the smallest possible related to a given percentage.

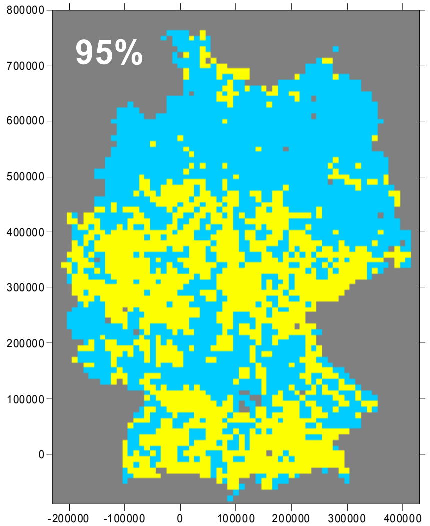


Cells with "trivial" mean IRC not considered

yellow = area in which given percentage of collective exposure is located



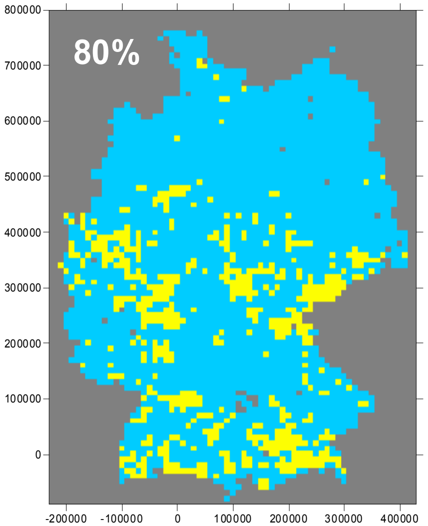


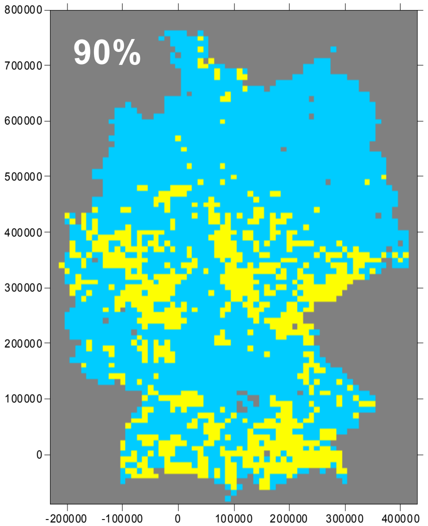


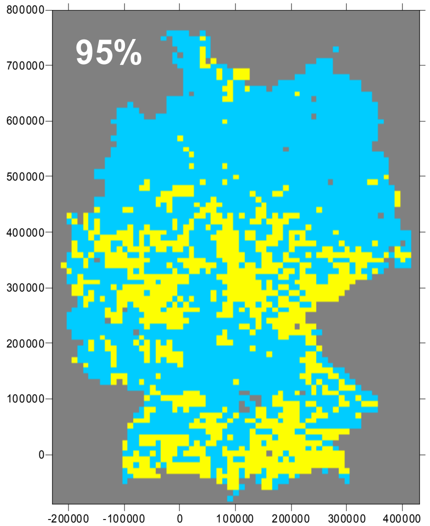
"triviality thresholds"

GRP=15

$\leftrightarrow \langle IRC \rangle \approx 25$,
prob(IRC>100)≈2.9%
prob(IRC>300)≈0.13%





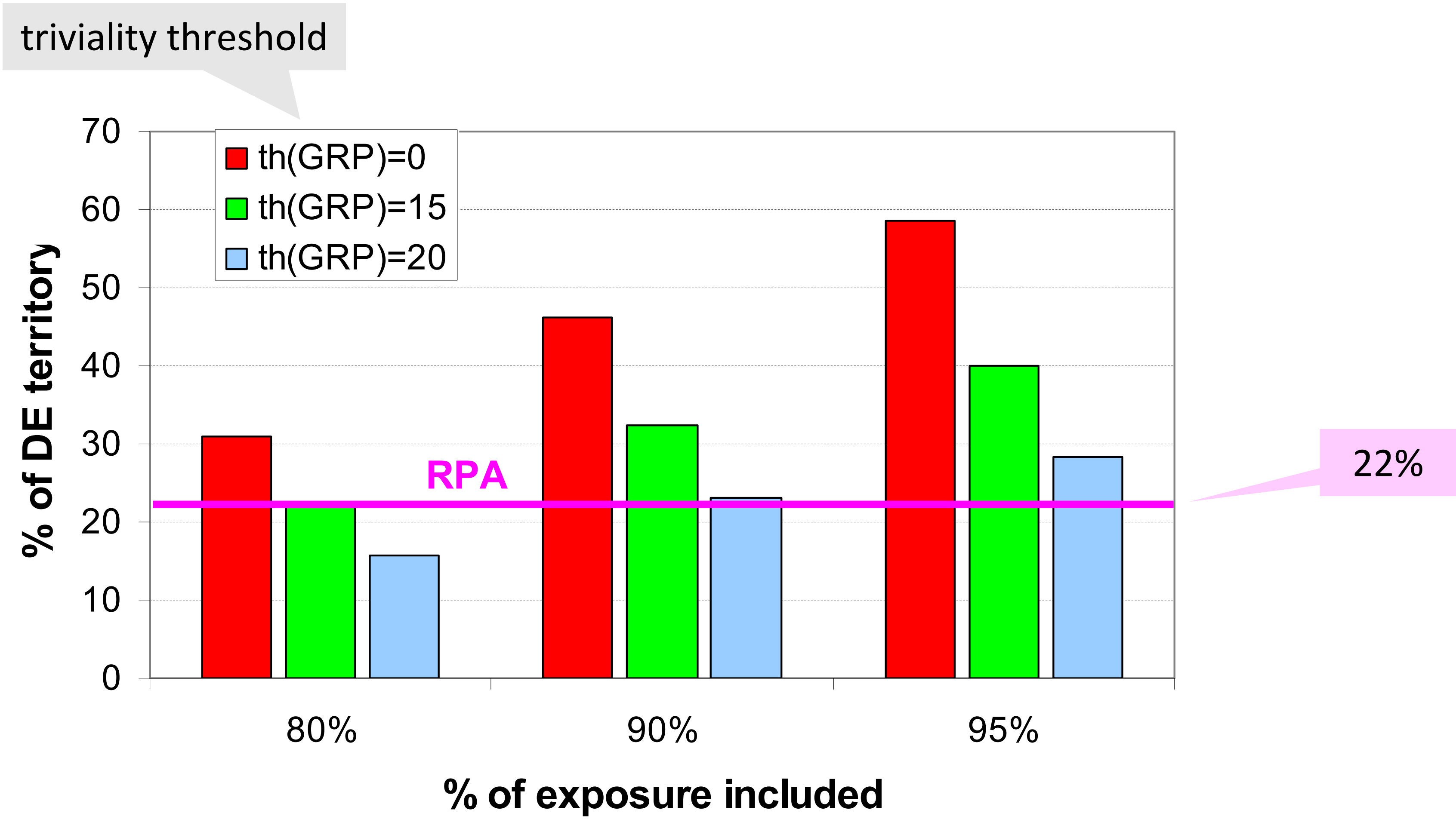


GRP=20

$\leftrightarrow \langle IRC \rangle \approx 50$,
prob(IRC>100)≈12%
prob(IRC>300)≈1%

GRP and $\langle IRC \rangle$:
means per
10 km × 10 km cells

fraction of DE territory affected



Tentative conclusions

- Rn abatement action should depend on the objective of Rn abatement. (sounds trivial…)
- If the objective = reduction of detriment = number of lung cancer cases or fatalities ~ collective Rn exposure:
  RPA / RL concept little efficient!
- Why sticking to a concept which is not only inefficient, but also expensive (economically and politically)?
- Options:
  - Modify, refine the concept, introduce new and/or additional RPA criteria;
  - Abandon the current concept, find new one.

To-do

- So far we did Rn hazard mapping
- Move from hazard to risk mapping!
- how?
  a) dense **representative** indoor Rn survey
  b) IRC map (= hazard+vulnerability) + demographic model (e.g. AT, shown by Valeria yesterday, Javi's European IRC map [2])
  c) GRP (=hazard) map + vulnerability model + demographic model (shown here; vulnerability factor neglected)
- all: + risk model (e.g. Darby)
- would need analogues to RPA and RL, risk classification criteria!

[2] Elio J. et al. 2019: The first version of the Pan-European Indoor Radon Map. Nat. Hazards Earth Syst. Sci., 19, 2451–2464, 2019 https://doi.org/10.5194/nhess-19-2451-2019

More troubles

Risk budget

- Risk was understood here as the one caused by Rn exposure leading to possible detriment;
- But Rn abatement policy also generates risks: costs money!
- More generally: how to include stakeholder interests into a "risk budget"? How to assign relative weights to the interests?

Thank you!