PRELIMINARY LUNG CANCER RISK ASSESSMENT OF EXPOSURE TO RADON PROGENY FOR TRANSYLVANIA, ROMANIA

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RADON INHALATION AND LUNG CANCER RISK

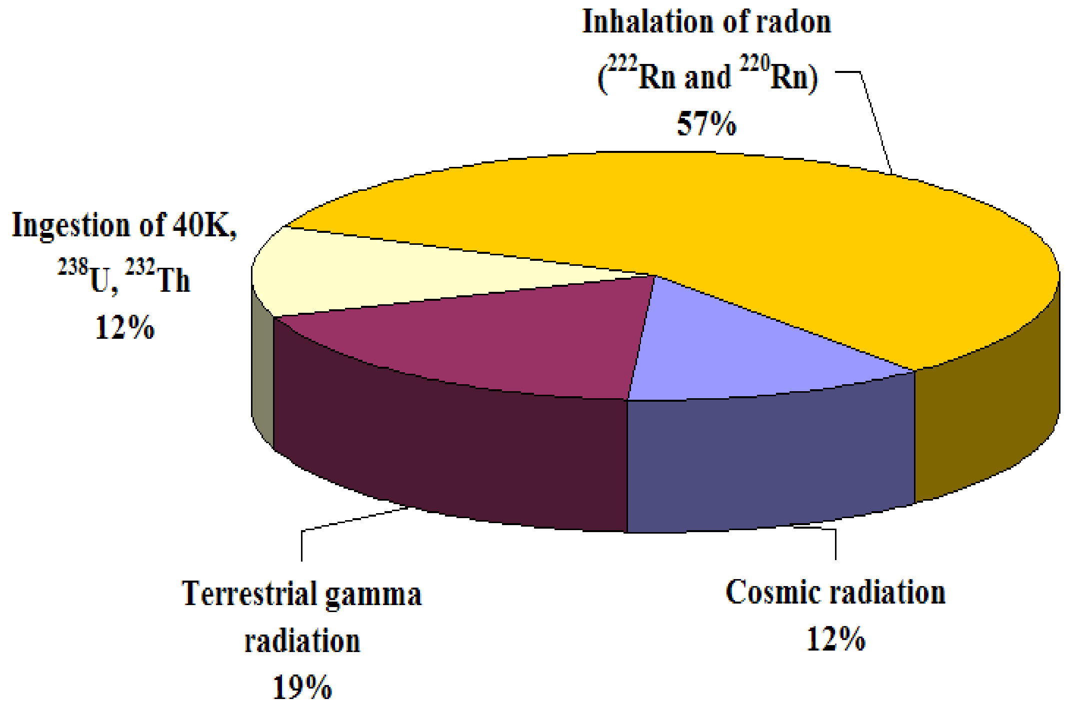

Fig. 1 ***Average annual dose from natural sources of radiation to the population of Romania (O. Iacob, 2000)***

LUNG CANCER AMONG OTHER CANCERS

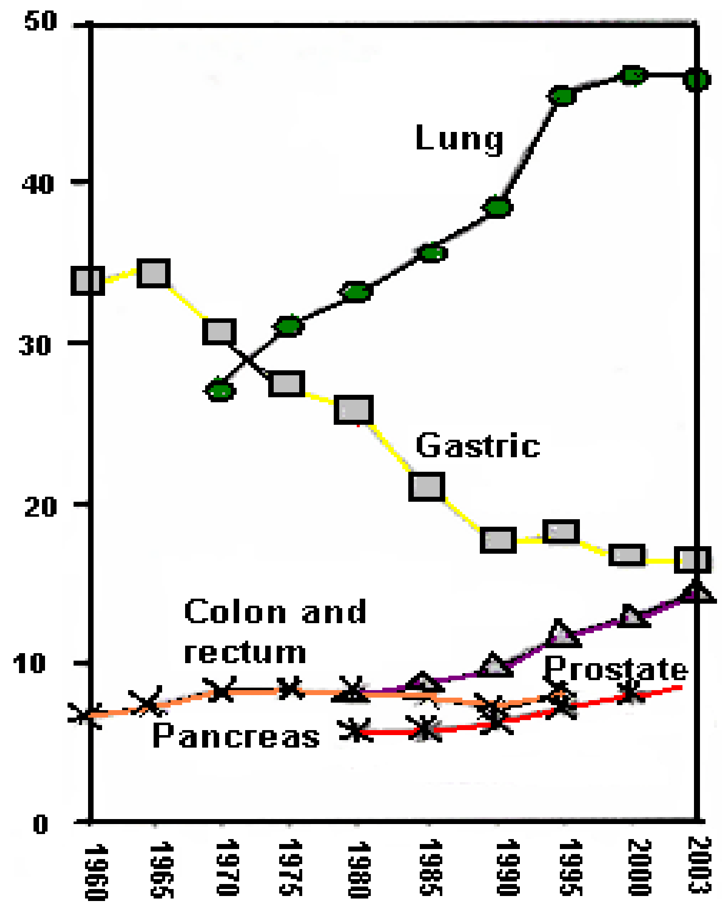

Fig. 2 ***Age-adjusted cancer death rates for males in Romania*** *(V. M. Nagy, 2007)*

OBJECTIVES OF THE PRESENT STUDY

- To assess lung cancer risk due to radon exposure for populations living in selected regions of Transylvania based on measured radon concentrations.
- To predict lung cancer risk in these areas by using a cancer model based on cellular radiation effects.
- To estimate the fraction of lung cancer cases in each region based on the total number of reported lung cancers cases in Romania and the number of people living in these regions.

REGIONS IN TRANSYLVANIA INVESTIGATED

The uranium mine from Stei causes a percentage of about 30% of subjects living in the neighboring dwellings be exposed at elevated radon levels > 200 Bq m^{-3}.

Fig. 3 ***Investigated areas in Romania***

MEASUREMENT OF RADON CONCENTRATIONS

Indoor radon concentrations were measured in **667 dwellings** of these areas, using **CR-39 track detectors**, **exposed** for a **minimum of 3 months**. The development process and the automatic reading of all detectors was performed with the **RadoSys-2000** equipment. The equilibrium factor was F≅0.4.

Area / county	Range of measured values	Mean Measured Rn concentrations [Bq/m3]*	Frequency [%]	Mean annual Rn concentration [Bq/m3]
Stei area	0-99	57	36	**232**
	100-199	139	34	
	200-399	268	17	
	400-599	471	4	
	600-799	694	3	
	800-1000	857	2	
	>1000	1550	4	
Cluj county	<25	20	10	**114**
	25-49	38	23	
	50-99	69	32	
	100-199	140	20	
	200-399	266	11	
	400-799	592	4	
Bistrita county	<25	16	15	**71**
	25-49	38	33	
	50-99	69	30	
	100-199	128	16	
	200-399	250	6	
Sibiu county	<25	21	18	**62**
	25-49	40	36	
	50-99	68	31	
	100-199	144	16	
Alba county	<50	38	11	**161**
	50-99	65	11	
	100-199	127	44	
	200-399	281	33	

Table 1. ***Measured radon concentrations in the investigated areas and mean annual radon concentrations***

AVERAGE RADON CONCENTRATIONS

The mean measured radon concentration values (*) were corrected for seasonal variations, with:

$$C = C_{summer} \cdot \frac{3}{2} \qquad\qquad C = C_{winter} \cdot \frac{3}{4}$$

(*C. Cosma et al., 2009*)

The weighted average annual Rn-222 concentrations were estimated, for each area/county:

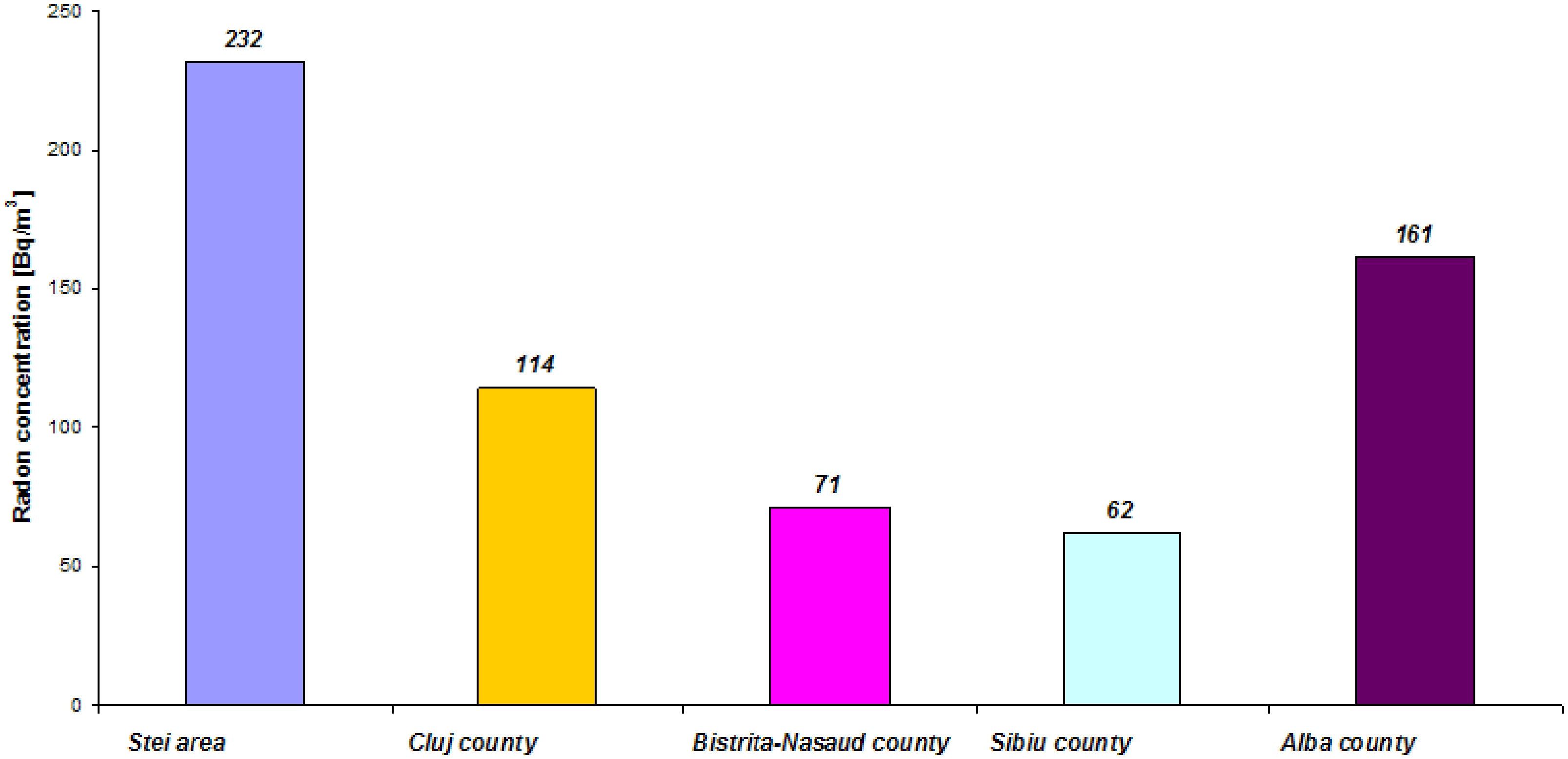

Fig. 4 ***Average annual Rn concentration [Bq/m³] for the investigated areas***

CONVERSION OF RADON CONCENTRATIONS

To establish a dose-effect relationship and hence to assess the lifetime lung cancer risks for the populations in the mentioned areas/counties, measured Rn-222 concentrations were converted into:

- **exposure**,

  1 WLM ≅ 230 Bq/m^3 (***ICRP 65, 1994***)

- **absorbed dose**,

  1 WLM = 5 mGy (***E. L. Alpen, 1998***)

FROM CELLULAR RADIATION EFFECTS TO LUNG CANCER RISK

Transformation frequencies for alpha particles:

- Experimental data: in-vitro transformation frequencies per surviving cell: TFS
- For in-vivo exposure we need transformation frequencies per exposed cell: TFE

$$TFE = TFS \exp(-\gamma D)$$

where γ represents the cell killing efficiency

Tissue response: TR

- From in-vitro transformation in single cells to in-vivo transformation in tissue (stem cell system):

- In-vitro to in-vivo: from λ_2 (1 day cycle time) to λ_1 (30 days cycle time)
- Single cell to stem cell system: Replacement of radiation-induced cell killing of neighboring cells by stimulated division of stem cells: from λ_1 (30 days cycle time) to λ_2 (1 day cycle time), where p denotes the probability that a stem cell is forced to divide if an epithelial cell is killed.

$$TR = [\lambda_1 + \lambda_2 \, p \, (1 - \exp(-\gamma D)] / \lambda_1$$

SINGLE AND MULTIPLE CELLULAR TRAVERSALS

- Epidemiological studies on lung cancer suggest that in cases of protracted exposures the crucial quantity for cellular radiation effects is the dose per cell cycle.
- While the number of cells hit increases with the tissue or organ dose, the average dose received by the traversed cells remains constant until multiple alpha particle hits start playing a greater role.
- This observation questions the applicability of average doses for alpha radiations at the cellular level, where radiobiological effects originate, at sufficiently low doses and thus **average dose (D) was replaced by the frequency of single and multiple alpha particle hits**.

For a given average number of cellular hits ($\overline{H}$) per cell cycle time during the total exposure period (T), equivalent to the average dose D, **the actual number of single and multiple hits (P_n)**, delivering an **average dose D_n** to a traversed nucleus of a basal or secretory cell during the lifetime of these cells, were selected from a Poisson distribution:

$$P_n = \frac{\overline{H}^n \cdot e^{-\overline{H}}}{n!} \qquad \overline{H} = N_h / N_0 \qquad N_h = D / \overline{D_c}$$

where N_h is the number of hits during exposure period T, N_0 is the number of cell cycles during exposure period T, $\overline{D_c}$ is the mean cellular dose per single hit.

LUNG CANCER RISK (TF-TR) MODEL

$$R(D) = C \cdot \sum_{i=1}^{n} TFS(D_n) \cdot \exp\left(-\gamma \cdot D_n\right) \cdot \left\{\lambda_1 + \lambda_2 \cdot p \cdot \left[1 - \exp\left(-\gamma \cdot D_n\right)\right]\right\} / \lambda_1 \cdot P_n$$

where:

- $\overline{D_c}$ = 0.33 Gy^{-1} for cells with a nuclear diameter of 9 µm and an LET of 130 keV/µm

- and C is a constant scaling factor relating the number of transformed cells at dose D to the occurrence of an observable bronchial tumor, derived from epidemiological studies.

COMPARISON BETWEEN EPIDEMIOLOGICAL DATA AND MODEL PREDICTIONS

For the comparison of model predictions with epidemiological data for indoor exposures, the data reported by S. Darby et al. (*2005*) were used.

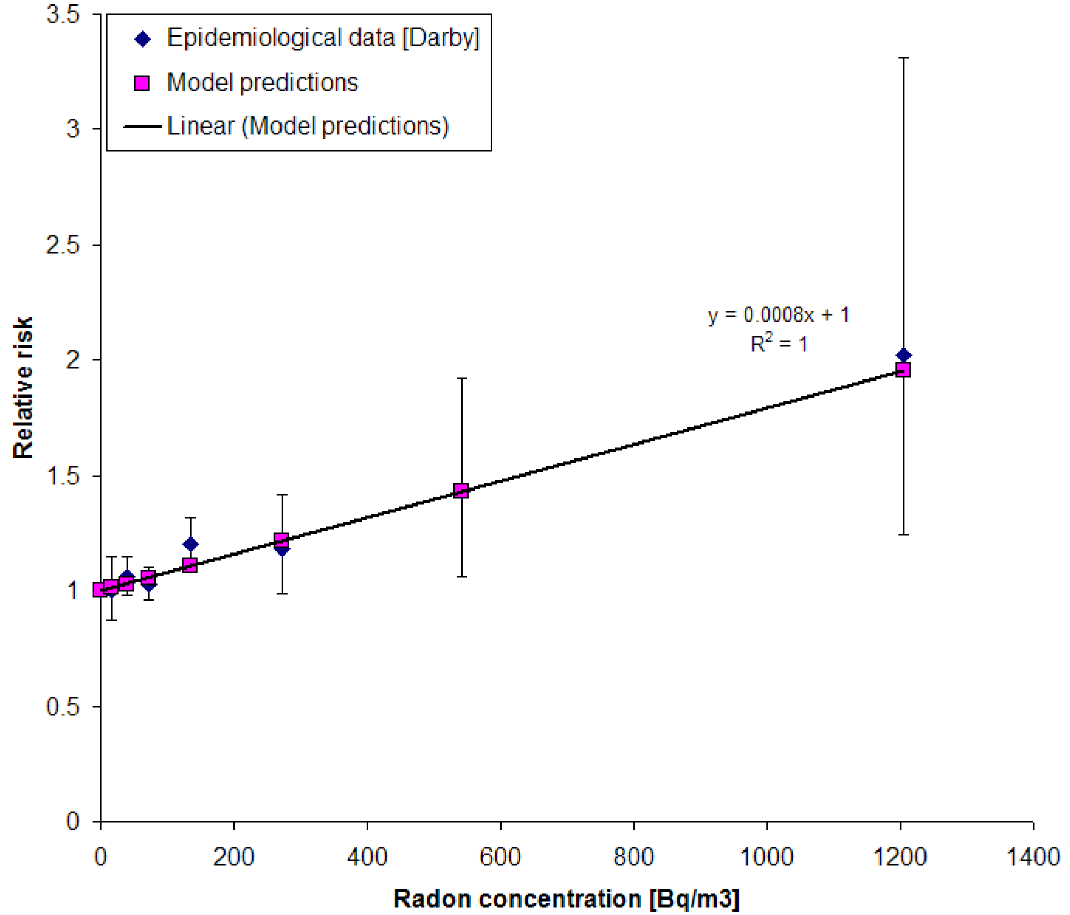

Fig. 5 ***Comparison between epidemiological data (2005) and model predictions***

RELATIVE RISK PREDICTIONS FOR THE INVESTIGATED AREAS

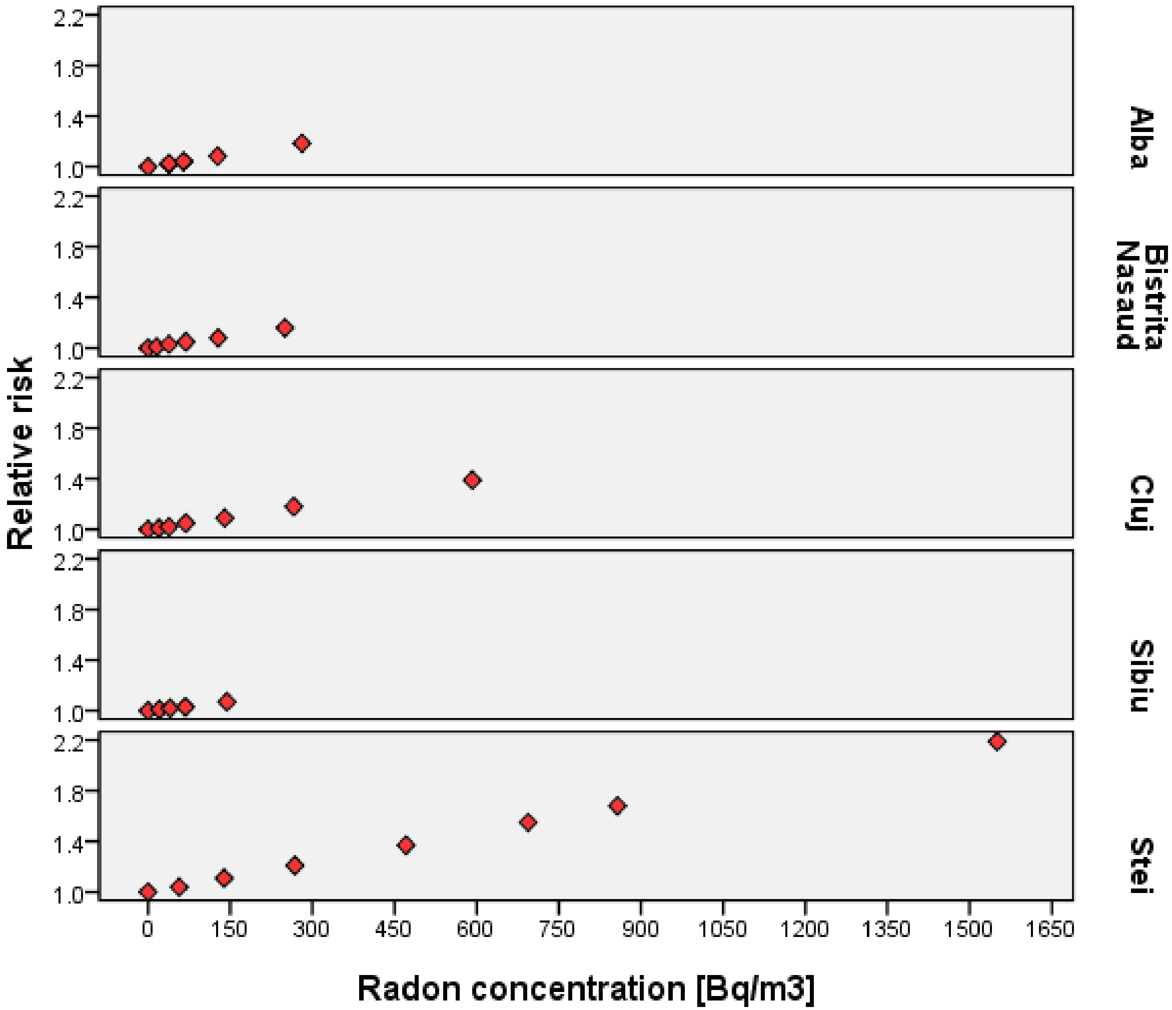

Fig. 6 ***Relative risk predictions for the investigated areas***

PREDICTION OF LUNG CANCER CASES

The number of total lung cancer deaths due to indoor exposure to Rn-222 ($N_{Rn,a}$) is:

$$N_{Rn,a} = \frac{(RR-1)}{RR} \cdot N_{T,a}$$

where $\frac{RR-1}{RR}$ is **the fraction of risk attributed to radon (FRA)**, *a* is the area where population is exposed, *RR* is the relative risk and $N_{T,a}$ is the total annual number of lung cancer deaths in the area a (equation adapted after ***O. Catelinois et al, and P. Pirard et al., BEH, 2007*)**.

The **National Institute of Statistics (INSSE)** Romania provided:

* the annual absolute numbers of lung cancer deaths,

* mortality rate for 100.000 people,

* the total population for the counties where Rn-222 concentrations were measured.

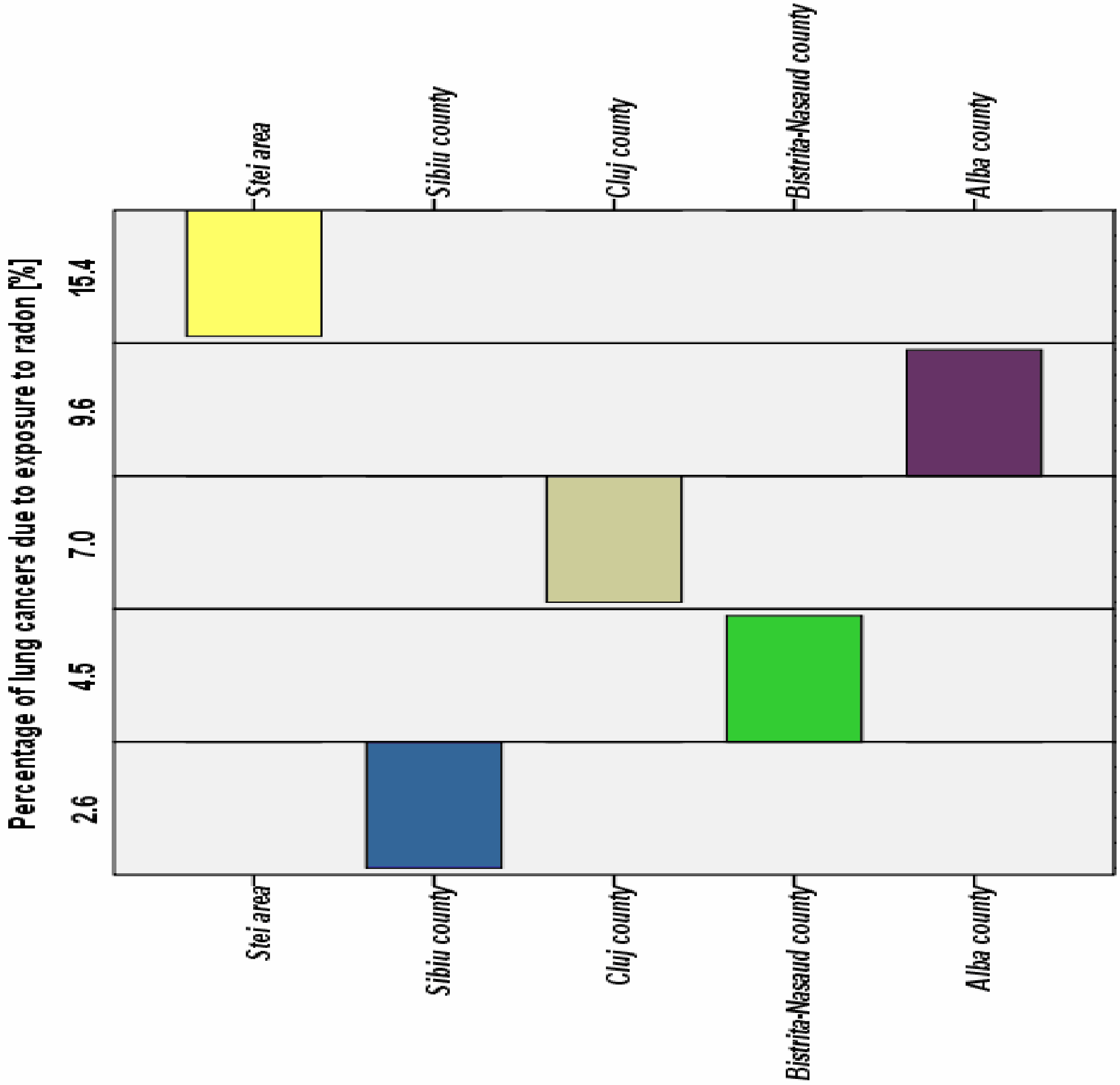

Fig. 7 ***Percentage of lung cancer deaths due to exposure to radon, for the investigated areas***

CONCLUSIONS

- The average annual radon concentrations for the investigated areas/counties were: 232, 114, 71, 62 and 161 Bq/m^3 for Stei area, Cluj, Bistrita-Nasaud, Sibiu, and Alba county, respectively.

- The relative risks calculated with the TF-TR model for the areas/counties where radon concentrations were measured are: 1.18 for Stei area, 1.08 for Cluj county, 1.05 for Bistrita-Nasaud county, 1.03 for Sibiu county and 1.11 for Alba county.

- The percentage of lung cancer deaths attributed to radon exposure are: 15.4 for Stei area, 7.0 for Cluj, 4.5 for Bistrita-Nasaud, 2.6 for Sibiu and 9.6 for Alba county.