Impact of cosmic-origin background radiation on human survival

Kateřina Podolská (1,2) and Jitka Rychtaříková (1)

(1) Department of Demography and Geodemography, Faculty of Science, Charles University, Prague, Czech Republic, (2) Institute of Atmospheric Physics CAS, Prague, Czech Republic
kapo@ufa.cas.cz, rychta@natur.cuni.cz

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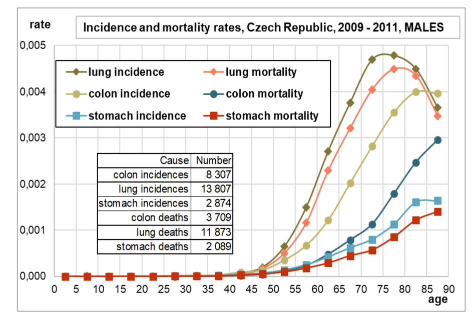
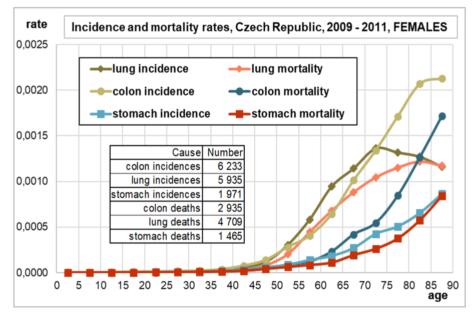
Abstract

We evaluate lifetime attributable risks induced by increasing concentration of cosmic radiation and cosmogenic radionuclides during periods of low solar activity in the specific conditions in the Czech Republic. The concentration of cosmic radiation and cosmogenic radionuclides reaches the highest values during the solar minima when their penetrability into the Earth magnetosphere is enforced. The computed estimate of lifetime attributable risks from solid neoplasms (colon, lung, and stomach) induced by natural background dose is higher for the period of the low activity solar cycle No. 24 than for the previous period of forced solar activity of the solar cycles No.19 – No. 23. We estimated lifetime attributable risks induced by annual natural background dose by sex for the Czech Republic and USA.
In addition, three different scenarios based on dose radiation level were explored. The cosmogenic radionuclides in our environment may thus play a greater role than in the last decades.

Data and regional delineation

Registration of deaths by cause of death is very stable in the Czech Republic (population 10 million) in long-term. In 2012, according to the Eurostat data Healthy Life Years (HLY) reached the values 62.3 years of life expectancy at birth for men and 64.1 years of 81.2 years of life expectancy at birth for women. With the increase in life expectancy is increasing incidence of neurodegenerative diseases occurring in the elderly.
The data were provided by Czech Statistical Office. Whole observed period belongs to time of validity of ICD-10. For detailed analysis were chosen causes of death of the chapter II. Neoplasms (C00–C77, C80) of ICD-10.



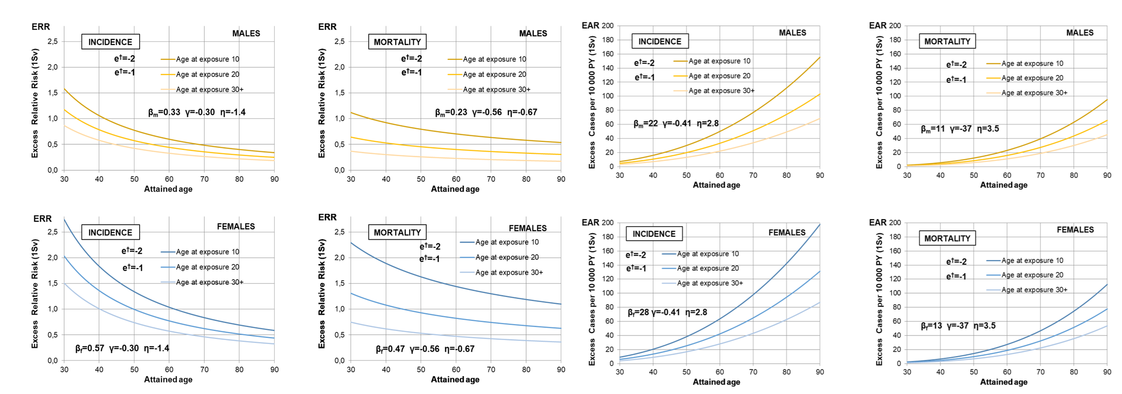


Age-specific incidence and mortality rates of three cancer sites for males, Czech Republic

Cancer risk estimate for low doses

Age-time patterns in radiation-associated risks for solid cancer incidence and mortality

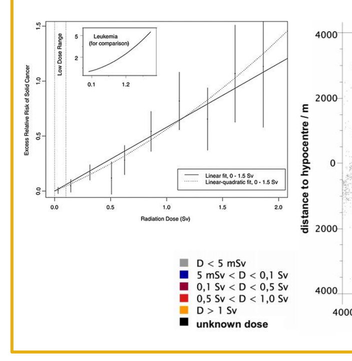
The quantifications of the relationship between radiation exposure and the resulting potential risk of carcinogenesis or cancer mortality in the Czech Republic. We present estimates of the lifetime attributable risks of incidence and of mortality for three solid tumor cancer sites (colon, lung and stomach), based on a combination of the Excess Relative Risk (ERR) and the Excess Absolute Risk (EAR) models. This analysis was performed separately for men and women exposed to radiation at age 10 and age 30. Finally, the possible effects of increased radiation impacting the lifetime attributable risks were computed for three different levels of radiation (2.71; 2.85; 3.3 in mSv).

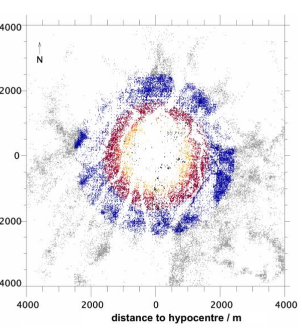


Age-time patterns in radiation-associated risks (d=1 Sv) for solid cancer incidence and mortality excluding thyroid and nonmelanoma skin cancers based on the ERR and EAR model

Life Span Study (LSS)

The most important source of epidemiological data is the Life Span Study (LSS) of the Japanese atomic bomb survivors from Hiroshima and Nagasaki, who received an acute dose of ionising radiation.
The models are based on a follow-up study of the LSS cohort (the initial number of subjects was 86 572, 48% of whom were alive on 1 January 1998; Preston, 2003) and include the number of incidences of site-specific cancers in the period 1958–1998 (number of cases: colon 1,165; lung 1,344; stomach 3,602) and the number of deaths in the period 1950–1997 (colon 478; lung 1,264; stomach 2,867). Models are provided for estimating risk as a function of age at exposure, age at risk, sex, and cancer site focusing on the risk from low-LET radiation.





The β_s*ERR(e,a) or the β_s*EAR(e,a) are respectively the *ERR* and the *EAR* per unit of dose expressed in Sievert with *e* as age at exposure.
Generalised models of Poisson rates were fitted in order to obtain dose-dependent excess absolute risk (*EAR*) .

ERR or $EAR = \beta_s * d * e^{(\gamma * e\dagger)} * (a/60)^{\wedge}\eta$ or ERR or $EAR = \beta_s * d * e^{[\gamma * e\dagger + \eta * \ln(a/60)]}$

$\lambda(s,a,b,d) = \lambda(s,a,b) * [1+\beta_s * ERR(e,a) * d]$

$\lambda(s,a,b,d) = \lambda(s,a,b) + \beta_s * EAR(e,a) * d$

where $\lambda(s,a,b)$ denotes the background rate at zero dose and depends on sex (s), attained age (a), and birth cohort (b).

Lifetime attributable risk $LAR(e,d) = \sum M(d,e,a) * S(a)/S(e)$
where the summation is from $a=e+L$ to ω (upper age), where a denotes attained age (years), and L is the risk-free latent period (L=5 for solid cancers)

For cancer incidence, $M(d,e,a)$ is calculated using either:

$M(d,e,a) = EAR(d,e,a)$ when using EAR model

$M(d,e,a) = ERR(d,e,a) * \lambda_i(a)$ when using ERR model

For cancer mortality, $M(d,e,a)$ is calculated using either:

$M(d,e,a) = EAR(d,e,a) * \lambda_m(a) / \lambda_i(a)$ when using EAR model

$M(d,e,a) = ERR(d,e,a) * \lambda_m(a)$ when using ERR model

where $\lambda_m(a)$ is the Czech baseline cancer mortality rate at age a, by sex (cause, units of age, period 2009–2011).

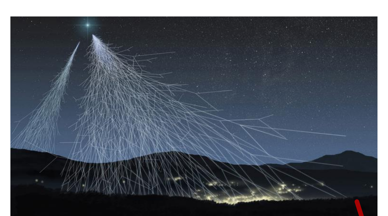
Cancer site	ERR models				EAR models			
	β_m	β_f	γ	η	β_m	β_f	γ	η
Colon (C18)	0,63	0,43	-0,30	-1,40	3,20	1,60	-0,41	2,80
Lung (C34)	0,32	1,40	-0,30	-1,40	2,30	3,40	-0,41	5,20
Stomach (C16)	0,21	0,48	-0,30	-1,40	4,90	4,90	-0,41	2,80

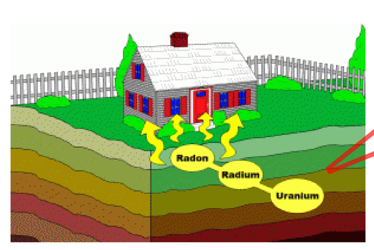
Source: BEIR VII report, p. 272; parameters for 100 000 patient-years and dose=100 mSv.

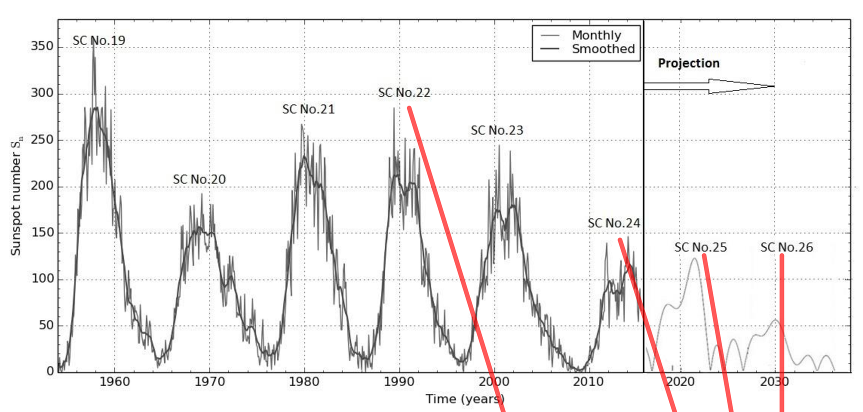
Introduction

Cosmic-origin background radiation has an impact on the health of human populations. The highest values of this radiation are observed during the solar minima because the penetrability of the Earth's magnetosphere is greatest at that time. It is consequently expected to have an impact on human health in the Czech Republic during the long solar minimum in 2020–2040.
The average effective dose of cosmic radiation on the territory of the Czech Republic was 0.35 mSv in the past; however, during the solar mimima it can rise to as much as 0.41 mSv (Table 1).
Four components of natural background radiation are presented: cosmic radiation, ingestion (both of which change with solar activity), inhalation, and terrestrial radiation (which is not affected by solar activity) - see Table 1. The total annual dose of natural background radiation was then used to model different scenarios of the potential increase in the lifetime cancer risk.
Deposit ^{14}C was estimate from modulation potential of the Earth's electromagnetic field 300 – 1500 MV in modern maxima, 100 MV in Maunder minima, for SC No. 25 and No. 26 changes in solar modulation can also lead to a factor of 2–3 variability on the global ^{14}C production rate.

Components of natural background radiation







Origin	Dose [mSv]	Dose in long-term solar minimum [mSv]
Cosmic radiation (H'_{co})	0.35	0.41
Ingestion (^{40}K, ^{210}Po, ^{210}Pb, ^{14}C) (H_{ig})	0.30	0.38
Inhalation (^{222}Rn, ^{220}Ra) (H_{ih})	1.25	1.25
Terrestrial radiation (H_{tr})	0.81	0.81
Total annual dose from natural background (H)	*2,71*	*2,85*

Table 1 Source: Data SÚRO, 2001, 2014

Conclusions

Lifetime attributable risk for people exposed to LET at age 10 and 30 in the Czech Republic

Lifetime Attributable Risk of Solid Cancer Incidence when age at exposure is 10 in 2009-2011

Cancer site	MALES				FEMALES			
	LAR based on EAR	LAR based on ERR	Combined and adjusted by DDREF	*USA 2009-2011*	LAR based on EAR	LAR based on ERR	Combined and adjusted by DDREF	*USA 2009-2011*
Colon (C18)	287	434	**256**	***277***	178	209	**133**	***162***
Lung (C34)	255	360	**189**	***210***	378	536	**280**	***463***
Stomach (C16)	439	50	**64**	***46***	439	58	**71**	***58***

Lifetime Attributable Risk of Solid Cancer Mortality when age at exposure is 10 in 2009-2011

Cancer site	MALES				FEMALES			
	LAR based on EAR	LAR based on ERR	Combined and adjusted by DDREF	*USA 2009-2011*	LAR based on EAR	LAR based on ERR	Combined and adjusted by DDREF	*USA 2009-2011*
Colon (C18)	117	188	**109**	***100***	77	91	**57**	***54***
Lung (C34)	225	308	**165**	***164***	309	408	**224**	***334***
Stomach (C16)	312	36	**46**	***22***	309	41	**50**	***29***

Note: Number of cases per 100 000 persons exposed to a single dose of 100 mSv. All results in the table refer to the Czech Republic, only the column named USA 2009–2011 shows the LAR values for the USA.

Lifetime Attributable Risk of Solid Cancer Incidence when age at exposure is 30 in 2009-2011

Cancer site	MALES				FEMALES			
	LAR based on EAR	LAR based on ERR	Combined and adjusted by DDREF	*USA 2009-2011*	LAR based on EAR	LAR based on ERR	Combined and adjusted by DDREF	*USA 2009-2011*
Colon (C18)	125	238	**131**	***142***	77	112	**67**	***82***
Lung (C34)	114	199	**90**	***101***	168	295	**132**	***219***
Stomach (C16)	191	28	**33**	***24***	191	32	**36**	***29***

Lifetime Attributable Risk of Solid Cancer Mortality when age at exposure is 30 in 2009-2011

Cancer site	MALES				FEMALES			
	LAR based on EAR	LAR based on ERR	Combined and adjusted by DDREF	*USA 2009-2011*	LAR based on EAR	LAR based on ERR	Combined and adjusted by DDREF	*USA 2009-2011*
Colon (C18)	52	104	**56**	***52***	34	50	**30**	***28***
Lung (C34)	100	171	**78**	***78***	137	226	**106**	***158***
Stomach (C16)	136	20	**24**	***11***	135	22	**26**	***15***

Note: Number of cases per 100 000 persons exposed to a single dose of 100 mSv. All results in the table refer to the
Czech Republic, only the column named USA 2009-2011 shows the LAR values for USA.

Lifetime attributable risk of cancer for three scenarios of radiation doses when age at exposure is 10 resp. 30

Dose mSv	2,71	2,85	3,30	2,71	2,85	3,30
Estimate of LAR incidence when age at exposure is 10						
Cancer site	**MALES**			**FEMALES**		
Colon (C18)	6,93	7,28	8,43	3,60	3,79	4,39
Lung (C34)	5,11	5,38	6,23	7,58	7,97	9,23
Stomach (C16)	1,73	1,82	2,11	1,93	2,03	2,35
Estimate of LAR mortality when age at exposure is 10						
Cancer site	**MALES**			**FEMALES**		
Colon (C18)	2,95	3,10	3,59	1,56	1,64	1,90
Lung (C34)	4,47	4,70	5,44	6,06	6,38	7,38
Stomach (C16)	1,24	1,31	1,52	1,36	1,43	1,66

Number of cases per 100 000 persons exposed to doses in mSv;

Dose mSv	2,71	2,85	3,3	2,71	2,85	3,3
Estimate of LAR incidence when age at exposure is 30						
Cancer site	**MALES**			**FEMALES**		
Colon (C18)	3,54	3,72	4,31	1,81	1,91	2,21
Lung (C34)	2,43	2,55	2,96	3,59	3,78	4,37
Stomach (C16)	0,89	0,94	1,08	0,98	1,03	1,19
Estimate of LAR mortality when age at exposure is 30						
Cancer site	**MALES**			**FEMALES**		
Colon (C18)	1,53	1,61	1,86	0,80	0,84	0,97
Lung (C34)	2,13	2,23	2,59	2,88	3,03	3,51
Stomach (C16)	0,64	0,67	0,78	0,69	0,73	0,84

Number of cases per 100 000 persons exposed to doses in mSv;

The increasing concentration of cosmic radiation and cosmogenic radionuclides during periods of low solar activity for the specific conditions in the Czech Republic augments the lifetime attributable incidence or death risks of solid cancers (colon, lung and stomach) for males and females. The adverse conditions are present when the cosmic radiation increases by about 16% during periods of very low solar activity. The estimated lifetime risks induced by the annual dose of natural background radiation are and will be significantly higher for the near future (years 2008–2040) during solar cycles Nos. 24 – 26, which will experience lower solar activity than in previous periods. While medical sources of radiation are much higher than natural background radiation, they are only applied to a part of any given population. In contrast, doses of natural background radiation affect the entire population without exception, and in the long term. In particular, the estimate of the annual dose of radiation from medical sources for the Czech Republic is around 0.3 mSv per year. Moreover, this value was reported in 1996, when modern diagnostic techniques, such as CT multidetectors etc., were still not widely available. At the same time, the US reported its dose from medical sources of radiation to be 5 mSv per year (Cohen, 2012). In comparison, the typical dose received during a transatlantic flight (Europe – North America) from galactic cosmic rays is 0.05 mSv (FGR, 1994). It can be significantly amplified by a solar energetic particle event. Enhancements of up to a factor of 10 have been estimated in cases of maximum exposure to an event. Nevertheless, the upcoming long period of solar minimum predicted for the years 2020–2040 will mean that cosmogenic radionuclides in our environment will play a much greater role in human health than previously.

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