Short Communication

RADON DOSES BASED ON ALPHA SPECTROMETRY

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Abstract

At the *railway station* in Postojna Cave and at the *lowest point* of the cave, repeated short-term monitoring in summer and in winter of air concentrations of radon (C_{Rn}) and radon decay products (C_{RnDP}), of the equilibrium factor (F) and unattached fraction of radon decay products (f_{un}), of barometric pressure (P), relative air humidity in the cave (RH) and air temperature outside (T_{out}) and in the cave (T_{in}) has been carried out, with the emphasis on f_{un}. Dose conversion factors (DCF), calculated from the f_{un} values (ranging from 0.09 to 0.65) exceed the ICRP-65 value of 5 mSv/WLM by a factor of 12-14 in summer and of 3.0-3.5 in winter.

Key words: radon decay products, unattached fraction, dose conversion factors

Introduction

Postojna Cave is the largest of the 12 show caves in Slovenia, and also one of the largest in the world, visited by about half a million tourists a year. An electric train takes visitors from the entrance to the railway station in the cave, from where they start a walking route which, in about 1.5 hours, brings them back to the railway station. Visits are scheduled for every full hour from 9 a. m. to 6 p. m. in spring, summer and autumn, and every second full hour from 10 a. m. to 4 p. m. in winter.

Because high air radon concentrations were found in the cave,[1-3] the Health Inspectorate at the Ministry of Health of Slovenia introduced regular radon monitoring in 1995. Radon is measured at the inner *railway station* and at the *lowest point*, somewhere in the middle of the walking route.[2-7] Etched track detectors[8] are exposed for 3 months all the year round, and radon exposure is calculated on the basis of the number of hours spent by a worker in the cave, as provided by the Cave management. Semi-annual and annual effective doses, obtained by using the ICRP-65 methodology, are reported to the Health Inspectorate, with the time to be spent by a person in the cave in the following half year limited accordingly.

Since the preliminary measurements of the unattached fraction of short-lived radon decay products in the cave, carried out by the Porstendörfer's group,[9] showed values from 0.056 to 0.16, the doses obtained with the ICRP-65 methodology might be underestimated. In order to check this point, in the period 1998-2001 we performed systematic monitoring of the concentration and the unattached fraction of short-lived radon decay products in air at the *railway station* and the *lowest point*. In this contribution, results of the monitoring are discussed, with emphasis on the temporal variation of the equilibrium factor, the concentration of short-lived radon decay products and their unattached fraction, and the dependence of these parameters on the barometric pressure, outdoor air temperature, relative air humidity in the cave and working regime of the cave.

Experimental

Measuring sites

The same measuring sites as for the regular radon monitoring programme were used, i.e., the *railway station* and the *lowest point*. Air temperature in the cave is almost constant all the year round, at between 13 and 15 °C, and relative air humidity is practically 100%. There is no forced ventilation in the cave and air is exchanged only through numerous cracks, corridors and shafts connecting the cave with the outdoor atmosphere.

Measuring techniques

Portable EQF3020 and EQF3020-2 devices (manufactured by SARAD, Dresden, Germany) have been used to measure concentrations of radon and radon short-lived decay products, equilibrium factor, unattached fraction of decay products, air temperature and relative air humidity.[10] The sampling and analysing frequency is once in two hours. The two Po isotopes are not distinguished by their alpha energies, but can be analysed using a quasi spectroscopy based on measuring the total alpha activity at three appropriately chosen time intervals.[11] The devices have been in operation for 10-15 days in summer and the same in winter from 1998 to 2002. The instruments were calibrated by the manufacturer on purchase, and have since then been regularly checked at the intercomparison experiments organized annually by the Nuclear Safety Administration at the Ministry of the Environment, Spatial Planning and Energy of Slovenia.[12] The hourly average values of the barometric pressure and the outdoor air temperature at the Postojna meteorological station were obtained from the Office of Meteorology of the Environmental Agency of the Republic of Slovenia.

Results and discussion

Temporal variations of the parameters under consideration

Results obtained at the *lowest point* are shown in Figure 1 and Figure 2 for summer and winter, respectively, of 1998. Average values of all parameters, i.e., concentrations of radon (C_{Rn}) and radon decay products (C_{RnDP}), equilibrium factor (F), unattached fraction of radon decay products (f_{un}), barometric pressure (P), relative air humidity in the cave (RH) and air temperature in the cave (T_{in}) and outdoors (T_{out}), during the whole period of measurement (denoted by t and called *total* average, e.g., C_{Rn}^{t}, C_{RnDP}^{t}, F^{t}, f_{un}^{t}, etc.) and also during working hours only (denoted by w, and called *working* average, e.g., C_{Rn}^{w}, C_{RnDP}^{w}, F^{w}, f_{un}^{w}, etc.) were calculated and are shown on the graphs. Standard deviations of the above averages, based on the experimental errors, are between 5 and 10%.

The patterns of temporal variation of parameters in summer differ substantially from those in winter. It is also clear that C_{Rn} and C_{RnDP} values are lower in winter (C_{Rn}^{t} = 1466 Bqm^{-3} and C_{RnDP}^{t} = 736 Bqm^{-3} in the period December 14-22, 1998, Figure 2) than in summer (C_{Rn}^{t} = 4089 Bqm^{-3} and C_{RnDP}^{t} = 1367 Bqm^{-3} in the period August 10-18, 1998, Figure 1). This is because of the so called *chimney effect*: in winter, the temperature outdoor is lower than in the cave, thus enhancing a natural draught of air from the cave through vertical channels into the outdoor atmosphere. In summer, the situation is reversed and the draught is minimal, if any. The opposite is true with F which is lower in summer (F^{t} = 0.34 in the period August 10-18, 1998) and higher in winter (F^{t} = 0.56 in the period December 14-22, 1998). The number of visitors is much higher in summer than in winter, thus causing a higher plate-out of *RnDP*, and thus, at the same T_{in} reducing F. In summer (Figure 1), daily decreases of C_{Rn} coincide with decreases in P. When the outdoor pressure, measured outdoors, starts to decrease, the cave system becomes overpressurized with respect to outdoors and starts to release radon-rich air, in accordance with the general effect of pressure fluctuations on radon exhalation.[13-15] In winter, this effect appears to be assisted by the *chimney effect*.

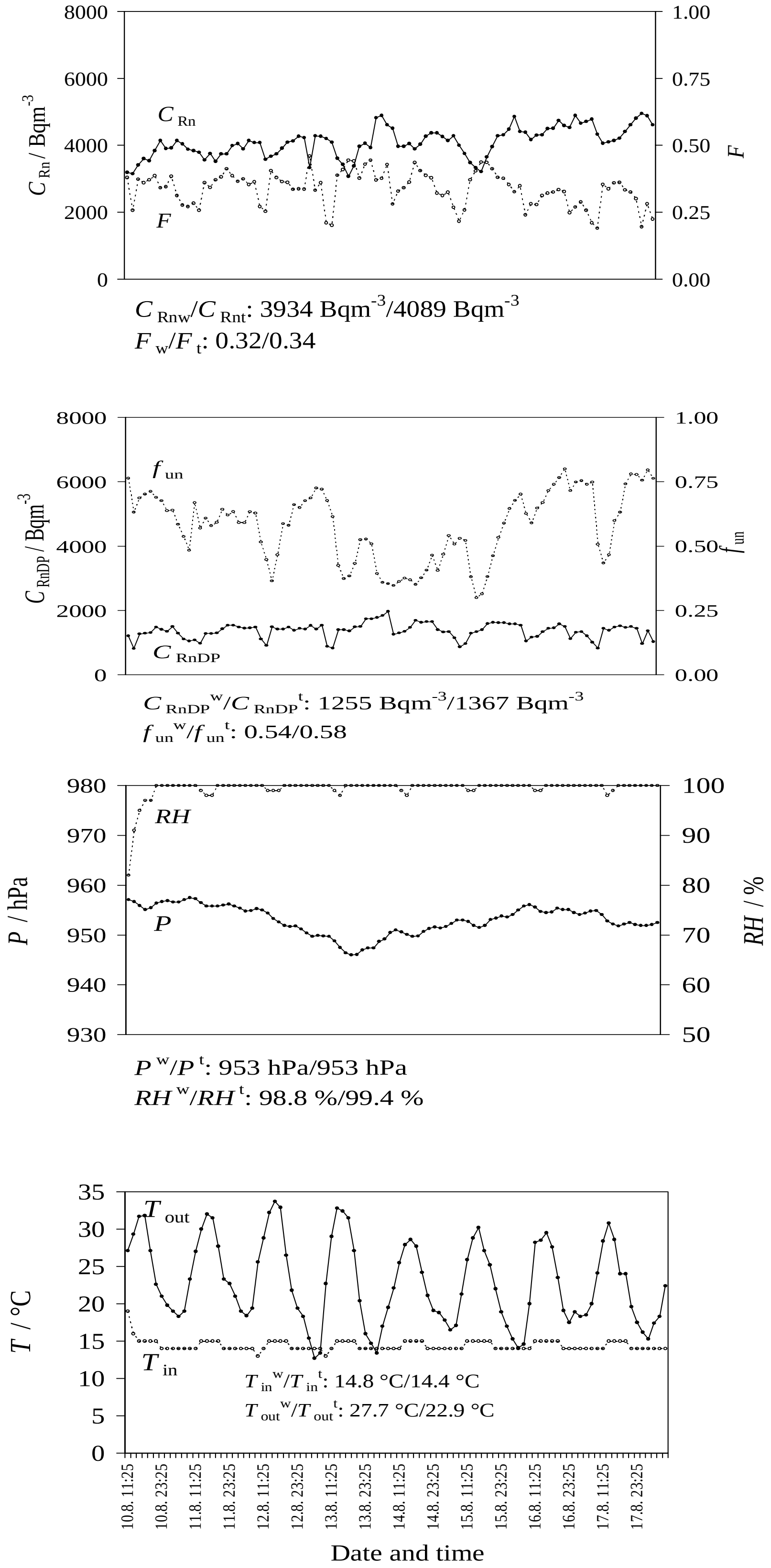

Figure 1. Time fluctuation of the measured parameters at the *lowest point*, August 1998 (see the text for definitions of parameters).

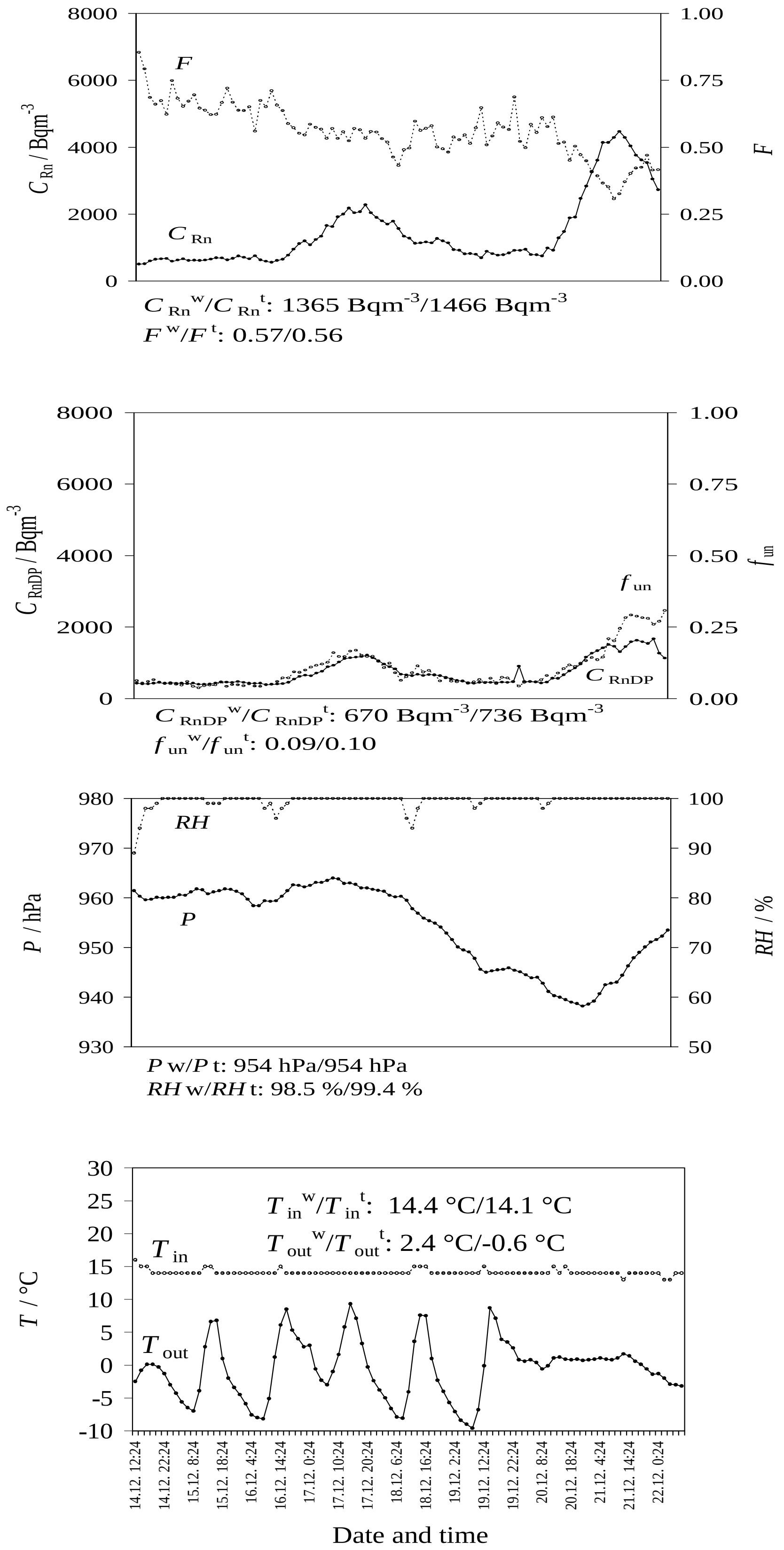

Figure 2. Time fluctuation of the measured parameters at the *lowest point*, December 1998 (see the text for definitions of parameters).

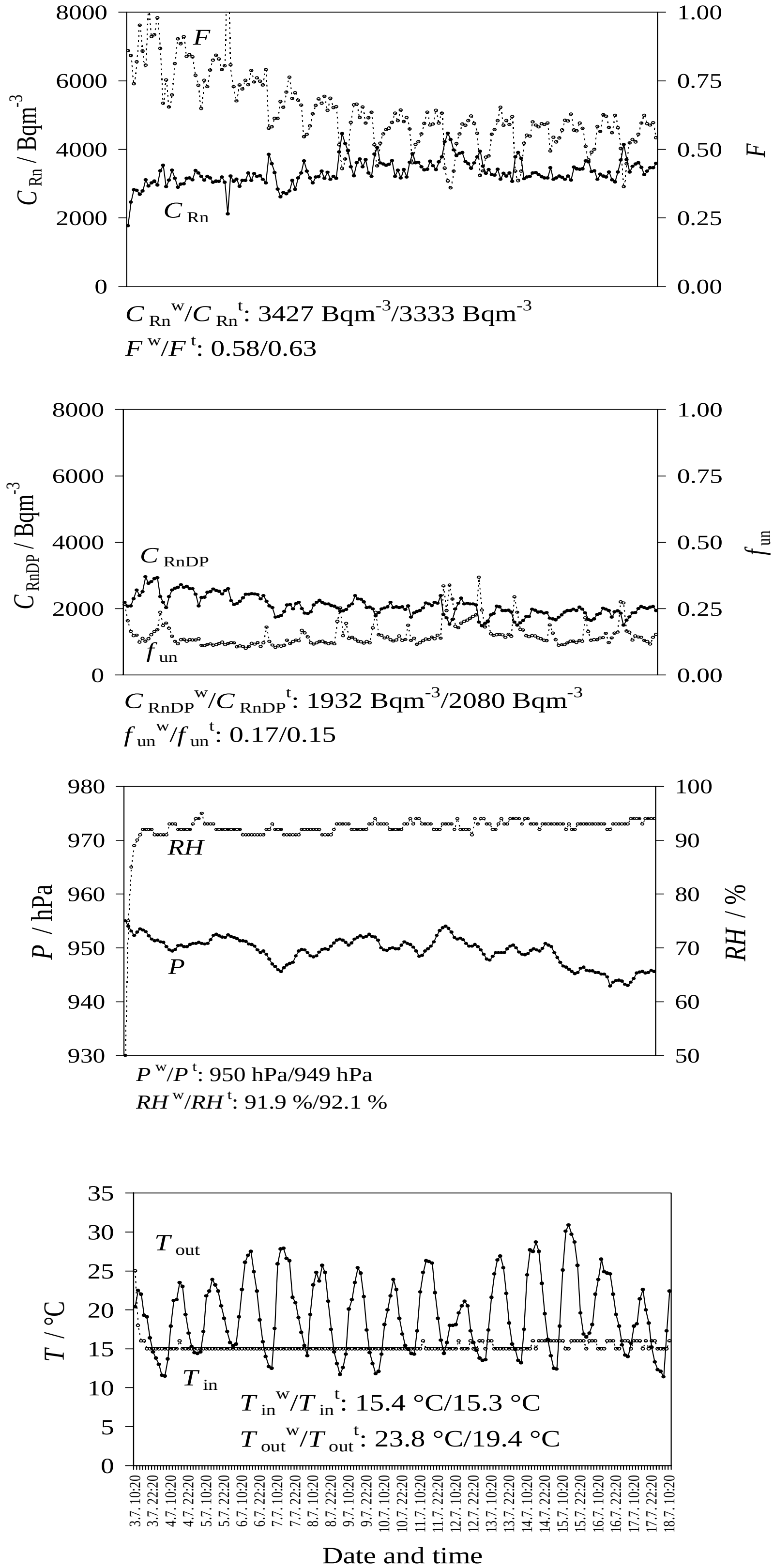

Figure 3. Time fluctuation of the measured parameters at the *railway station*, July 2001 (see the text for definitions of parameters).

While in summer, daily C_{Rn} increases/decreases are generally accompanied by F decreases/increases, the $C_{Rn} – F$ relationship in winter appears to be more complicated. Although higher F values are expected to be accompanied by lower f_{un} values,[16-18] this was observed in winter but not always in summer, when a minimum F value was often followed by a delayed maximum in f_{un}. Due to the *chimney effect* the air draught from the cave to the outdoor atmosphere is stronger in winter than in summer, thus the cave air is more stagnant and the f_{un} value lower in summer than in winter. The opposite was found, with much higher f_{un} values in summer (f_{un}^{t} = 0.58 in the period August 10-18, 1998) than in winter (f_{un}^{t} = 0.10 in the period December 14-22, 1998). The *chimney effect* appears to be obscured by the air mixing produced by the visitors' moving through narrow corridors. A low f_{un} value in stagnate air[19] during the night was rapidly increased on starting the visits in the morning, and started to decrease again in the afternoon. Fluctuations of f_{un} are much more pronounced in summer than in winter, most probably because of the much larger numbers of visitors in summer. There may, however, be more complex factors at work.

Figure 1 and Figure 3 compare the summer situation for the two measuring sites, the *lowest point* in the period August 10-18, 1998 and the *railway station* in the period July 3-18, 2001. C_{Rn} values are higher and F values lower at the *lowest point* than at the *railway station*, the C_{RnDP} values being similar at the two sites. f_{un} values are significantly lower at the *railway station*. This marked difference cannot be explained by a small difference in *RH* (92% at the *railway station* and 99% at the *lowest point*) at the same T_{in},[20,21] but is rather caused by higher aerosol concentartion[9,22] at the *railway station*, produced by train traffic and presence of a number of groups of tourist waiting for the train. While diurnal variation of f_{un} is pronounced at the *lowest point*, it is almost constant at the *railway station*. The *railway station* is situated in a large hall in which the microclimatic conditions affecting f_{un} are more constant than in the narrow corridors at the *lowest point*.

Dose conversion factors

The ICRP-65 methodology[23] for estimating doses due to radon and short-lived radon decay products is based on the results of epidemiological studies and recommends as dose conversion convention 4 mSv/WLM at home and 5 mSv/WLM at the workplace.

A refined dosimetric approach,[24] based on a new lung model,[25] has recently been proposed. The activity median aerodynamic diameter (AMAD) of the unattached short-lived radon decay products is taken as 0.8 nm, while that of the attached fraction, as 200 nm. Dose conversion factor (*DCF* in mSv/WLM) is expressed by:

$DCF_m = 101\times f_{un} + 6.7\times (1 - f_{un})$ for mouth breathing, and

$DCF_n = 23\times f_{un} + 6.2\times (1 - f_{un})$ for nasal breathing.

Table 1. Dose conversion factors (*DCF* in mSv/WLM) for mouth (m) and nasal (n) breathing calculated from the *working* average of the unattached fraction of radon short-lived decay products (f_{un}^{w}), measured in summer and winter at the *lowest point* in the Postojna Cave. Also *DCF* / 5 values are given.

season, year	f_{un}^{w}	DCF_m mSv/WLM	DCF_m / 5	DCF_n mSv/WLM	DCF_n / 5
winter, 1998	0.12	18.0	3.6	8.2	1.6
summer, 1998	0.54	57.6	11.5	15.3	3.1
winter, 1999	0.14	19.9	4.0	8.6	1.7
summer, 1999	0.61	64.2	12.8	16.5	3.3
summer, 2000	0.56	59.5	11.9	15.6	3.1
summer, 2001	0.68	70.8	14.2	17.6	3.5
summer, 2002	0.67	69.9	14.0	17.5	3.5

Using these equations, dose conversion factors were calculated from f_{un}^{w} for the periods under investigation, and are collected in Table 1 for the *lowest point*. They are also divided by 5 (ICRP-65) and the ratio is also given in the table. For mouth breathing *DCF* value at the *lowest point* is higher than the value recommended by ICRP-65 by a factor 11.5-14.2 in summer and 3.6-4.0 in winter. Although not shown in the table, this factor is 4.5 in summer at the *railway station*. On the other hand, for nasal breathing the *DCF* values presently in use are underestimated by a factor of 3.1-3.5 in summer and 1.6-1.7 in winter at the *lowest point*. For a selected "working profile" *DCF* value is a proper combination of the DCF_m and DCF_n values.

Conclusions

The fraction of unattached radon short-lived decay products in air of the Postojna Cave ranged from 0.09 to 0.68. It was higher at the *lowest point* of the tourist guided route than at the *railway station* and, at the *lowest point*, higher in summer than in winter. The calculated dose conversion factors are higher in summer than the value of

5 mSv/WLM presently in use by a factor of 11.5-14.2 for mouth breathing and 3.1-3.5 for nasal breathing. Systematic measurements covering longer periods are underway, with the aim of re-evaluating the annual effective doses of the cave employees. Elevated *DCF* values, and thus resulting elevated effective doses of the employees, signify their increased health risk toward lung cancer. This should be the further step of the study.

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Povzetek

V letih od 1998 do 2001 smo v zraku Postojnske jame na *najnižji točki* in na *železniški postaji* merili konentracijo radona (C_{Rn}) in radonovih kratkoživih razpadnih produktov (C_{RnDP}), ravnotežni faktor (F), delež nevezanih radonovih razpadnih produktov (f_{un}), zračni tlak (P), relativno vlažnost zraka v jami (RH) in temperaturo zraka v jami (T_{in}) ter zunaj (T_{out}). Poseben poudarek je bil na f_{un} in na njegovi odvisnosti od vremenskih razmer. Vrednosti f_{un} so bile v širokem razponu, od 0,09 do 0,68. Z uporabo novega dozimetrijskega modela smo na osnovi izmerjenih vrednosti f_{un} izračunali dozne pretvorbene faktorje in ugotovili, da so bili poleti za faktor 11,5-14,2 pozimi pa za faktor 3,1-3,5 višji od 5 mSv/WLM, to je vrednosti, ki jo priporoča metodologija ICRP-65.