Journal of Environmental Radioactivity 251-252 (2022) 106972

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

On a risk of inhalation exposure during visits in Chernobyl exclusion zone

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ARTICLE INFO

Keywords:
Chernobyl touristic visits
Radiation risk
Actinides
Inhalation doses

ABSTRACT

In recent years Chernobyl exclusion zone has become a very popular tourist destination. Many people visiting power plant, Pripyat city or surrounding villages use different types of personal dosimeters to control external exposure, however very small group of tourist have opportunity to control internal contamination of respiratory tract using dedicated, high sensitive whole body counters. In this study 11 anti-dust masks collected from CEZ visitors and filters from one military MP-5 mask were analyzed using alpha, beta and gamma spectrometry to determine doses from actinides and fission products which can be inhaled without proper protective equipment. Results showed, that average effective dose from inhalation of contaminated aerosol in case of single-day trip (avoided due to use of mask) was 1.3 μSv per person, which is much smaller than potential effective dose after exploration of highly contaminated areas like Jupiter complex, where combined dose from all measured nuclides collected on MP-5 mask filter was 1.4 mSv.

1. Introduction

The popularity of Chernobyl exclusion zone (CEZ) as a tourist destination is growing in recent years. This is one of example of the wider feature of the development of "dark" or "toxic" tourism, so the tendency of visiting locations, which are related to interest in death, sufferings or disasters (Yankovska and Hannam, 2014). The other examples categorized similar are for example Auschwitz, Hiroshima/Nagasaki, nuclear test sites or other nuclear disasters sites. The humans motivations standing behind choosing such destinations is rather complex, they are related with need to have deeper experience of civilization threats, it is reflective of the society in which we exist. …" Chernobyl possesses ritual to valorize penetrability, to allow temporary access to so-called dead-zone that is both illusionary and compensatory …" (Stone, 2013). The CEZ as tourist destination was recognized in mid 1990s with 900 visitors in 1995, whereas six years later this number was increased ten times. (Banaszkiewicz et al., 2017). Local maximum, reaching nearly 18 thousands, was in 2013. Then political instability in Ukraine diminished this number by factor of two in 2014, just to return to continuous grown in following years. In 2016 it was nearly 36 thousands and this number was doubled in two years period reaching above 124 thousands in 2019, so during the last year before COVID-19 pandemia. This peak was likely related to HBO miniseries on Chernobyl disaster (Statista Research Department, 2022) In 2020 the sanitary restrictions strongly reduced number of visitors back to 2016 level (36.5 thousands), but in next 2021 year, despite the pandemia, the number was exactly doubled reaching 73 thousands (Statista Research Department, 2022). Altogether (in recent almost 27 years) above half a million visitors saw CEZ. It seem to be quite a few as for "exclusion zone". Despite all complex motivation which might stand behind "dark tourism", for many people just the thrill of risk remains a main attraction of this trips, however the expected doses are considered truly low, so the real risk seems to be negligible. Only the external gamma dose rate is taken into consideration as dose source in typical risk assessment related to this social phenomenon. For example, the external dose rate for CEZ is reported to be within a range of from 0.14 to 7.55 μSv/h (Karlik and Downer, 2019). The incorporation of radioactive dust to lungs due to inhalation is considered usually as not important on basis of measurement done using outdoor aerosols collectors. Most visitors just goes along the standard route and limits the visit to few hours during one day. The more exposed could be guide person, who returns frequently to CEZ. However, the special visitors called sometimes themselves "stalkers" (after the name introduced by a novel by Strugacky brothers "Roadside Picnic", followed in a title of A. Tarkovsky movie), penetrates indoors and other places, even the places not expected to be visited, where radioactive dust could be easily re-suspended. Some people use filtration

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https://doi.org/10.1016/j.jenvrad.2022.106972
Received 24 February 2022; Received in revised form 10 July 2022; Accepted 19 July 2022
Available online 18 August 2022

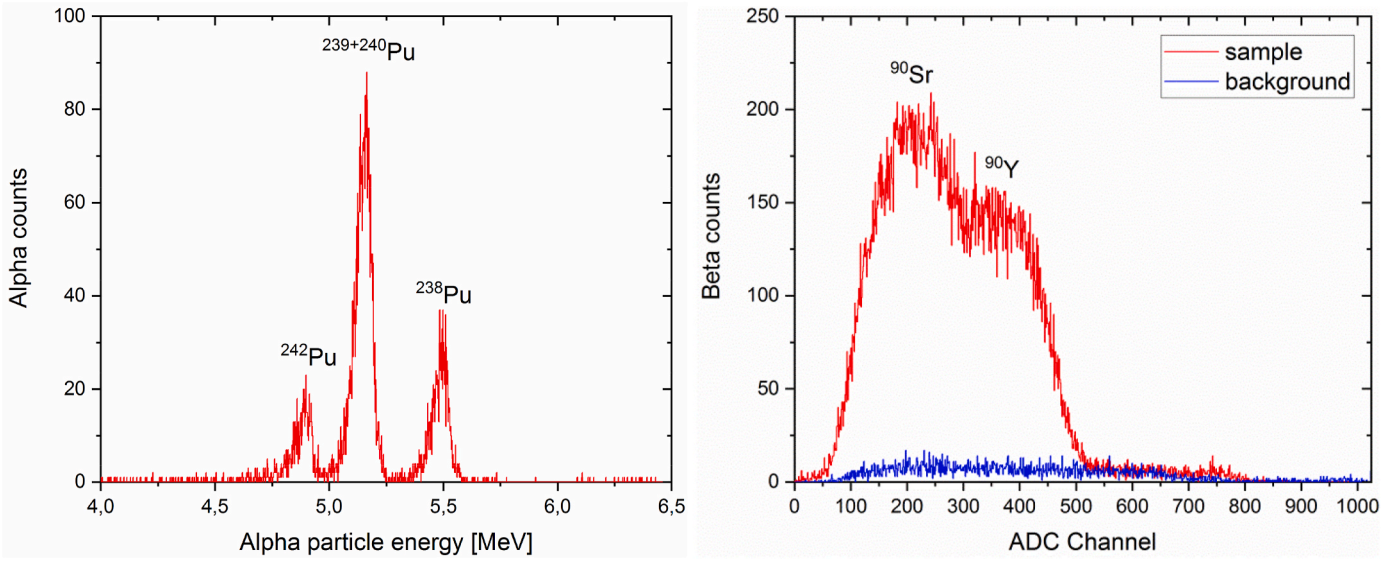

Fig. 1. Alpha spectrum of Pu fraction (left) and beta (liquid scintillation) spectrum of strontium fraction (right) separated from set of 11 masks used by visitors of Chernobyl zone in 2016.

masks in such places reducing risk of direct inhalation. They consider visit to CEZ as kind of extreme sport. They explore in CEZ places excluded for visitors, forbidden and remote from touristic places like for example the basement of Jupiter site or hospital in Pripyat, where contaminated clothes of firefighters were stored. The joy brings to be exposed to risk, and survive. Some makes movies from their „expeditions" and publish them in Web (You Tube, social media, private pages, etc.). The goal of present work was to show what could be a range for effective doses obtained by regular visitor as well as deeply penetrating CEZ "stalkers" due to possible exposure to radioactive dust containing actinides. The problem we show here will need much complex and complete further studies, which we hope will be undertaken.

2. Material and method

Eleven dust mask were obtained from tourists visiting Pripyat city by one day in July 2016. This set was enlarged by filter from an isolation mask (military MP-5 type) used by another tourist, who spent in Chernobyl zone in 2015 more than one day as a "stalker". This isolation mask was used only for 15 min in "Jupiter" site cellar where a lot of relatively easily resuspended, dark dust was present. As one can noticed from a documentary movie published in Net the dose rate above this dust container was >1 mSv/h (https://www.youtube.com/watch?v=N8oxisO4DoY).

All the samples were measured by high resolution gamma spectrometry (30% n-type HPGe detector, Ortec, USA) to determine activity of ^{137}Cs. After gamma-ray measurements masks were combusted at 600 °C. Ashes of 11 masks from 2016 were combined together to get a single averaged sample. The second sample was the filter from military isolation mask of a "stalker".

The analytical tracers: ^{242}Pu, ^{243}Am (both by NIST) and ^{85}Sr (IFJ PAN made) were added following by samples dissolution in concentrated nitric acid. Plutonium ($^{238,239+240}$Pu) and ^{90}Sr were separated from sample matrix using ion exchange chromatography with Dowex 1 × 8 (Sigma Aldrich) strongly basic ion-exchange resin, and Sr-Resin (Triskem) solid phase extraction resin, respectively using procedure described elsewhere (Mietelski et al., 2016.). The americium and curium fraction (containing ^{241}Am, ^{244}Cm) was separated by means of two subsequent co-precipitation (with calcium oxalates and with iron hydroxide) followed by column process on TEVA (Triskem) resin to remove traces of Th. Final separation of americium and curium from rare earth elements was done using methanol-acids solutions and Dowex-1x8 (IAEA, 1989). The alpha spectrometry sources were prepared by microcoprecipitation with NdF_3 (Sill, 1987). They were measured on Silena AlphaQuattro alpha spectrometer equipped with Canberrra P.I.P.S silicon detectors. For ^{90}Sr determination, sample was mixed with scintillating cocktail (Gold Star LT2 by Meridian) and measured on LSC spectrometer (Wallac 1414 Guardian) using standard, polyethylene LSC vials. In case of sample from 2015 the procedure was similar in all separation processes, however instead of leaching a full decomposition of ash using HF, HNO_3, HCl + H_3BO_3 was applied (Mietelski et al., 2016).

Table 1
Activity of radionuclides present in set of 11 masks used by visitors during a single day trip to CEZ in 2016. Used Dose Conversion Factors (DCF) are the highest values from those given in ICRP Publications 60 and 119 (conservative approach) (ICRP 1991; ICRP 2012).

Radionucide	Activity [Bq}	DCF	H [Sv]
Cs-137	1.86 ± 0.14	3.9E-8	7.2E-8
Sr-90	1.2 ± 0.1	2.8E-8	3.4E-8
Y-90	1.2 ± 0.1	2.7E-9	3.2E-9
Am-241	0.063 ± 0.007	9.6E-5	6.1E-6
Cm-243 + 244	0.006 ± 0.001	6.9E-5	4.1E-7
Pu-238	0.016 ± 0.002	1.1E-4	1.8E-6
Pu-239 + 240	0.047 ± 0.004	1.2E-4	5.7E-6
		SUM:	1.41E-5 (11 people)
		Mean	1.3 E−6

Estimation of effective doses was done on conservative approach based on ICRP publications Nos 60 and 119 (ICRP 1991; ICRP 2012) in this sense that highest values (regarding chemical form) of effective dose conversion factors given in those two reports were used. Such conservative approach seem to be proper because we do not goes into details of possible risk just we tried to estimate the level of avoided doses due to use of masks.

3. Results

Fig. 1 presents the examples of alpha spectrum and ^{90}Sr/^{90}Ybeta spectrum obtained from plutonium and strontium fractions (respectively) in course of radiochemical procedure of a set of 11 masks collected from visitors of Pripyat city (CEZ) in 2016. Obtained results expressed in Bq measured for set of 11 masks are presented in Table 1. The mass of ash was only 0.16 g.

Table 2
Activities present in a filter of isolation mask MP-5 after visit to the basement of:"Jupiter" factory in CEZ in 2015. Used Dose Conversion Factors (DCF) are the highest values from those given in ICRP Publications 60 and 119 (conservative approach) (ICRP 1991; ICRP 2012).

Radionucide	Activity [Bq}	DCF	H [Sv]
Cs-137	76.3 ± 0.6	3.9E-8	3.0E-6
Sr-90	47 ± 2	2.8E-8	1.3E-6
Y-90	47 ± 2	2.7E-9	1.3E-7
Am-241	8.6 ± 0.1	9.6E-5	8.2E-4
Cm-243 + 244	0.8 ± 0.2	6.9E-5	5.5E-5
Pu-238	0.96 ± 0.01	1.1E-4	1.1E-4
Pu-239 + 240	3.4 ± 0.02	1.2E-4	4.1E-4
Eu-154	0.44 ± 0.02	5.3E-8	2.3E-8
		SUM:	1.4E-3

The isotopic composition of plutonium indicates 100% content of Pu of Chernobyl accident release, if one applies the formulas given in our previous work (Mietelski and Wąs, 1995). The activity concentration of $^{239+240}$Pu in analyzed material of masks is nearly 300 Bq/kg for ash weight (with relative uncertainty below ~8%) what also is unusual high for a dust materials at remote from CEZ sites (Kierepko et al., 2016).

Our measurements showed, that during visiting Pripyat city or in general the CEZ, a tourist (if not protected by masks) can inhale radionuclides, which can be easily detected using typical low background radio analytical methods.

Taking into consideration, that our sample was formed from masks used by 11 people. The average avoided (by using masks) individual effective dose due to potentially inhaled long lived radionuclides would be equal to about 1.3 μSv. This was achieved during a singe day trip. For people working there as guides this could be a effective dose which should be increased by factor of even as high as perhaps 200 – as the number of days spent in CEZ during year.

The results obtained for the second case, so for a filter of isolating military mask during a short visit of a „stalker" in a basement of "Jupiter" factory, are presented in Table 2. The avoided effective dose (so the whole body life span dose which would be achieved if mask will be not used) would be as high as 1.4 mSv.

4. Conclusions

The activity of potentially inhaled aerosols (in fact avoided from inhalation due to using masks) seem to be much higher than it could be predicted by air monitoring system inside CEZ. This most likely comes from local scale resuspention of radioactive dust by visitors inside the buildings or in remote areas, not covered by monitoring or sampling stations. This confirms, that there is a real risk of inhalation actinides during trips to CEZ, however doses are relatively low in regular trip, when tourists do not explore area more intensively by themselves. It could be different for local workers, when they returns several times or even daily to zone. The use of protective masks in regular conditions is a reasonable choice to minimalize doses, which can also possibly originating from inhalation of micron-size fuel-type particles, containing both, fuel material and long-lived fission products. Due to COVID-19 pandemia, the habit of wearing masks became more common, what should help introducing such habits for CEZ visitors. The precautions undertaken by person like „stalker" (protective suit and mask, gloves) is the only choice for their activities,. Still it can be risky. However the remobilization of contamination (bringing it back to surface) is a risk not taken into account by such extreme visitors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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