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Unprecedented Radioactive Pollution in Spitsbergen Air during the 21st Century

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1. INTRODUCTION

Advances in nuclear science during the 20th century have led to the systematic production of a novel form of environmental contamination on a global scale. Introduced radionuclides, categorised as artificial, technogenic, man-made or anthropogenic, were previously non-existent or present in ultra-trace quantities across the Earth system. Despite the ongoing presence of the nuclear era, it should be noted that significant changes have occurred in terms of scope, objectives, and main directions over time. The initial focus on military applications has evolved significantly since then, with the development of nuclear power plants, nuclear medicine and the handling of radioactive materials in the nuclear industry being the main drivers of this change. It is clear that the ongoing revolution has brought a plethora of benefits. However, the parallel identification of new radionuclide emissions and transportation over long distances from the epicentre, with the potential to increase natural background radiation levels, has raised public awareness of the necessity to monitor and control the radiological situation routinely. These measures are required not only for critical groups, objects or areas but also to review the exposures of the population and surrounding areas. Monitoring radioactivity levels in the air is of particular importance, given that inhalation represents a significant exposure pathway.

In certain regions, there have been no air monitoring programmes dedicated to anthropogenic actinides since 2000. This is particularly evident for atmospheric radioactivity in the Arctic, where data on the level, isotopic signature or temporal variation of $^{238, 239, 240}$Pu and ^{241}Am

are lacking over the 21st century. Research in this domain is still of particular interest and importance for several reasons. The artificial actinides have become a key tool in investigations of atmospheric circulations or natural "feeder" mechanisms through which previously deposited contaminants are transferred back to the air. Furthermore, research has identified $^{238, 239, 240}$Pu and ^{241}Am as the most radiotoxic elements that may be directly inhaled via aerosols or accumulated in plants and animals. It should also be noted that these radionuclides have relatively long half-lives ($^{238, 239, 240}$Pu: $T_{1/2}$ = 87.7 y, 24100 y, 6560 y, respectively, ^{241}Am: $T_{1/2}$ = 432.6 y), indicating that such pollution remains in the environment for a significant duration. In the context of potential terrorist attacks involving "dirty bombs", undeclared nuclear activity or any intentional or unintentional releases from nuclear installations, there is an imperative for the development of novel monitoring strategies. It is vital that the world's national and international nuclear safety monitoring networks incorporate routine measurements of pure beta and alpha emitters in the atmosphere.

The research project outlined in this study aimed to address the limitations in database capabilities and to enhance the understanding of the relevant processes for artificial actinides suspended in the ground-level air layers of Hornsund, SW Spitsbergen, during the years 2007–2021.

2. RESULT DESCRIPTION

While the overall levels of ^{238}Pu and $^{239+240}$Pu were consistent with recent observations from various locations, ^{241}Am levels were found to be remarkably high, with a maximum of 354 nBq/m^3 recorded in the first quarter of 2019 (Cwanek et al.2025). Further analysis of the isotopic ratios revealed a frequent enrichment of ^{238}Pu over $^{239+240}$Pu. This was inconsistent with previously documented releases. Additionally, there were single incidents of ^{237}Np in 2013, 2014, and 2018, all of which were unexpected.

A multivariate analysis incorporating data on ^{7}Be, ^{210}Pb, ^{137}Cs activity concentrations and a wide range of meteorological factors was applied to explain the behaviour of artificial actinides in the lower atmosphere. Spearman's correlation coefficients were used to establish explicit links between $^{239+240}$Pu seasonal trends and natural processes. These processes included local resuspension throughout the year and horizontal tropospheric transport of haze layers from remote areas in the first quarter. It is worth noting that analogous mechanisms were found to regulate a specific percentage of ^{238}Pu, but to a lesser extent. The maximum activity concentrations of 6.61 nBq/m^3 for ^{238}Pu and 15.51 nBq/m^3 for $^{239+240}$Pu recorded in Hornsund during the 3rd quarter of 2015 (Cwanek et al.2025), registered simultaneously at middle latitudes, could be related to random events, such as fly ash particles remobilised by wildfires of 2015 occurring, for instance, in proximity to the Chernobyl zone.

It was determined that the majority of the significantly elevated levels of ^{241}Am, ^{238}Pu, and ^{237}Np were not environmentally induced. The average annual doses associated with the exposure to the investigated alpha emitters were negligible, being about a million times smaller than the typical background radiation doses of 2.4 mSv per year. Therefore, the contamination detected did not pose a radiological threat to the Arctic environment. However, the ^{241}Am, ^{238}Pu, and ^{237}Np signals were of concern, as the circumstances of their occurrence could indicate man-made emissions, which would have been completely unnoticed by the regular monitoring of gamma emitters in Hornsund air. Trajectory simulations performed for the 1st quarter of 2019 showed the most prominent transport pathways from northern Asia and Europe via the island of Novaya Zemlya (Cwanek et al.2025). Nuclear aerosols were carried at low levels in the troposphere (below 100 metres), resulting in weak dilution and intense deposition. It should be noted that there have been no reports of radioactive discharges of man-made actinides into the

atmosphere in recent decades. However, a ^{241}Am incident was identified exclusively in the urban air of central Poland during a few weeks in 2021, possibly generated by the combustion of isotopic smoke detectors. The research underlined the importance of incorporating alpha emitters into routine measurements within radiation situation control programmes.

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