# Radionuclide contaminants as a potential threat to ecosystems from melting Alpine glaciers in high-mountain environments

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Recent studies have reported rapid mass loss of mountain glaciers in response to climate warming, particularly in the Alps, where small glaciers are especially vulnerable to these processes, experiencing significant retreat and shrinkage. Consequently, glaciers are considered as secondary sources of pollutants, including fallout radionuclides ($^{137}$Cs, $^{210}$Pb, $^{238}$Pu, $^{239+240}$Pu, $^{241}$Am), which are transported over long distances through the atmosphere and then deposited with wet and dry precipitation. These radionuclides can originate from nuclear weapons testing and local or regional incidents.
This study focuses on a representative case - the Dosdè Glacier, a small glacier (0.59 km$^2$ in 2016) in the Italian Alps. For this purpose, cryoconite (dark sediment on the glaciers) samples were collected during field expeditions conducted in August 2023, along with proglacial sediments and mosses growing near the glacier front. These additional materials were used to assess the potential transfer of anthropogenic radionuclides in the surrounding habitats. The samples were analysed using alpha and gamma spectrometry, and atomic ratios were determined with the Agilent 8900 triple quadrupole ICP-MS.
The results strongly demonstrate cryoconite's unique ability to accumulate radionuclides, as evidenced by the mean activity concentrations measured at 2,960 Bq/kg for $^{137}$Cs, 8,160 Bq/kg for $^{210}$Pb, 1.34 Bq/kg for $^{238}$Pu, 35.3 Bq/kg for $^{239+240}$Pu, and 24.0 Bq/kg for $^{241}$Am. The activity concentrations of these radionuclides in cryoconite were by magnitude higher than those found in forefield sediments and plants. The activity ($^{238}$Pu/$^{239+240}$Pu) and atomic ($^{240}$Pu/$^{239}$Pu) ratios were determined to identify potential sources of contamination. The reference activity and atomic ratios for global fallout are 0.0249 ± 0.0057 (Perkins and Thomas, 1980; decay corrected to 2023) and 0.180 ± 0.014 (Kelley et al., 1999), respectively. The activity ratios of $^{238}$Pu/$^{239+240}$Pu (0.0390 ± 0.0067) and the atomic ratio of $^{240}$Pu/$^{239}$Pu (0.1608 ± 0.0042) in cryoconite samples suggest that the plutonium pollution at the Dosdè Glacier could mostly originate from global fallout (with a contribution from the re-entry of the SNAP-9A satellite). However, the study also showed possible inputs, such as the redistribution of anthropogenic radionuclides with ash particles and gases in the lower atmosphere and/or low-yielded nuclear detonations (e.g., from Semipalatinsk, Algeria, and Nevada test sites).
Our findings highlight the need for ongoing research into the release of environmental contaminants from glaciers, especially smaller ones like the Dosdè Glacier, which are expected to disappear within decades, releasing radionuclides contained in cryoconites into the surrounding environment when the glaciers begin to recede.

This study was financed by the NCN (Poland) grant no. 2022/45/N/NZ8/01179

**References:**

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