The widespread presence of fallout radionuclides in cryoconite: an anthropogenic legacy and emerging issue

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Background:
- Fallout radionuclides (FRNs), a product of nuclear accidents and weapons testing, are known environmental contaminants. Emerging research is revealing that FRNs and other contaminants are being stored within and released from glaciers following deposition onto the snow/ice surface years or decades before present.
- As glaciers retreat there is thus a risk of secondary release of high concentrations of contaminants into the proglacial environment through melting and down-wasting of the ice.
- To investigate whether FRNs are concentrated to potentially harmful levels through their interaction with cryoconite, and the extent to which this is a global issue, we developed a collaborative database to share data and improve understanding of contaminant storage and release from glacier catchments.

The database includes sites across the Arctic (Sweden, Iceland, Greenland and Svalbard), the European Alps, the Georgian Caucasus, British Columbia, and Antarctica, spanning mountain glaciers, ice caps, and ice sheet settings, and a range of climatological regimes.

Key findings:
- FRNs are widespread in cryoconite across the global cryosphere.
- The levels of FRNs found at most sites are orders of magnitude higher than those detected in other environments, with some of the highest levels ever recorded outside of nuclear accident exclusion zones.
- Exceptionally high activity levels are found in both natural (Pb-210) and artificial (Cs-137, Am-241) FRNs, well above those found in moraine sediment control sites and in materials known to be strongly influenced by atmospheric deposition (e.g. lichen and moss).
- The interaction of FRNs with snow, meltwater and particularly cryoconite can result in much higher concentrations than historical deposition in the environment, which could result in secondary contamination events under future glacier melt and retreat.

Methods:
- Cryoconite was collected in the field through grab sampling or pipetting/filtering. The number of samples from each site ranges from 1 up to 23 dependent upon individual study research design.
- All samples were analysed for the presence of FRNs using gamma spectroscopy, which quantifies radionuclides through analysis of the gamma-ray energy spectrum produced in a gamma-ray spectrometer.

Impacts:
- Multiple sources of anthropogenic and natural contamination threaten glacial environments, including atmospheric pollutants, helicopter and snowmobile emissions, fuel spills, borehole drilling, and exposure of heavy metals by glacier erosion.
- Given the widespread occurrence of high activity concentrations of FRNs in glacier catchments, the impacts on downstream water and environmental quality, including uptake of FRNs into flora and fauna, should be a focus of future research efforts.
- An interdisciplinary approach should be taken to evaluate the environmental and socio-economic impact of legacy contaminant release within glacier-fed catchments.
- Cryoconite could play a role in bio-remediation of legacy and future radioactive contamination, as has previously been assessed for hyper-accumulation of FRNs and heavy metals seen in fungi, but a much-improved understanding of the uptake of FRNs in cryoconite, including interaction with organics and inorganics, is required.