Radioactivity measurement in glacier and Polar ice-caps: An overview

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Abstract. Glacier is an extended mass of ice formed by snow falling and accumulating over the years and moving very slowly either by descending from high mountains, as in valley glaciers or by moving out of accumulation centers, as in glaciers on the continent. Glaciers are a significant source of potable water and plant irrigation, any contamination of this significant source in glaciers due to radionuclides may affect freshwater supplies and livelihoods. It is well known that exposure to ionizing radiation could lead to health hazards and harm to the environment. Therefore, awareness of the distribution and concentrations of natural and artificial radionuclides in the glacier region is crucial, and that is why it provides and clarifies helpful information about radionuclide pollution in the environment. This evaluation gives insights into the overview of the radioactivity of natural and artificial radionuclides in the glacier region (Arctic and Antarctica). These information are crucial for predicting the effects of radionuclide distribution and transport in ecosystems, and can also be an indication of the effects of external human activities in the cold regions.

1. Introduction
The Arctic is located in the northern part of the Earth and covers an area of 14.5 million Km² [1]. Antarctica covers the region around 14 million Km² and 98% of the region is covered by ice, making Antarctica one of the most significant locations on earth [2]. In Polar Regions, the winter precipitation falls as snow [3]. This leads to the existence of radionuclides in the atmosphere caused by snow and accumulated on the earth [4-5]. Therefore, People have been continually exposed to ionizing radiation throughout their lives [6-8] emerging inside and outside the earth. The primary natural source of ionizing radiation is the content of radionuclides in rocks and soil [9-10]. The assessment of radiation vulnerability from natural radioactive materials (NORM) has been concentrated over the past 20 years [11], which has led to comprehensive studies showing the primary sources of NORM emerging from 238U, 232Th and their descendants and 40K [12]. 60 nGyh⁻¹ from global average of natural gamma dose rate come from the contribution of 40K, 232Th, 226Ra elements in the proportion:13.8 %, 14 %, 55.8% respectively [13].

Anthropogenic radionuclides for example, 137Cs and Pu 239-240 isotopes [14] have circulated around the world since the 1950s [15], in addition, environmental contamination with artificial radionuclides is mostly caused by atomic weapons testing and nuclear power plant accidents; such as, thenuclear power plant accidentin Fukushima Daiichi that released 137Cs into the atmosphere, and later deposition
resulting in the radioactive pollution of a greater extent across eastern Japan [16]. The Chernobyl accident in April 1986 resulted in radionuclide pollution in a wide region of Europe and the former Soviet Union. For instance in Ukraine, the amount of contamination rose to 1Ci / km² from artificial $^{137}$Cs to an area equal to about 260,000 km² [17]. The fallout from Airborne radionuclides is attached to atmospheres or particles such as wind-borne dust and later deposited as airborne residues in sheets of glacier surfaces. The mass sedimentation rates have been less steady with the passage of time, but at last during the summer, the rate of radionuclide sedimentation has increased on some glaciers [18]. Anthropogenic radionuclides resulting from atmospheric nuclear tests which were conducted in the time period between 1953 and 1980 after transport in the atmosphere and stratosphere were deposited in Antarctica, creating distinctive reference levels in the snow from radioactivity [19]. According to A. Tieber et al.(2009), EdytaŁokas et al.(2016), and T. Willflinge et al (2018), glacier has the highest concentrations of natural and artificial radionuclides causing additional sources of contamination which may appear in the future resulting in the increased melting of the glacier due to increase of air temperatures and global climate changes [20-21]. Meltwater from the glacier on elevated hills of significant necessities for the local population and downstream residents, ecosystems, and economy, because glacier and snowmelt are very sensitive to global warming [22], and plays a major role in water supply, storage and regional regulation [23] [21]. Glacier melting water can be an important and vital element of the annual river flow; it can also influence the hydrology of the region, which has significantly impacted the ecosystems on downstream by sediment Suspended transported, which affects water quality and so life is affected [24]. However, ongoing global warming induced by increasing the global temperature [25], has resulted in significant losses and decreased glacier mass and ice-caps which after melting can be brought into rivers by runoff of melting water and causes the large amounts of contamination by transporting radionuclides to downstream ecosystems [26-27].

2. Summary of the results

2.1. The concentration of radionuclides in the Arctic area

The reviewed studies of this paper show that the measurement of radioactivity by different groups of researchers in Arctic glaciers are summarized in the table below. A. Tieber et al. (2009) found that in the anthropogenic of radionuclides accumulation in cryoconite on Alpine glaciers, the activity concentration of $^{137}$Cs vary between 1.7 ± 0.2 kBqkg$^{-1}$ and 140.0 ± 1.0 kBqkg$^{-1}$, and activity concentrations of $^{239,240}$Pu was found to have a wide range of 1.6 ± 0.2 Bqkg$^{-1}$ to 197.8 ± 7.7 Bqkg$^{-1}$ [28].

P. Cámara-Mor et al. (2010) found in the study of the artificial radionuclides in Arctic Ocean sea ice, he said that the maximum value of $^{137}$Cs was detected to be equal to 4001.5±77.6 Bq kg$^{-1}$ in sediments samples in an iceberg, and the activity concentration of the $^{239,240}$Pu has a significant changeability from 0.018 to 31.8 Bqkg$^{-1}$[14]. E. Łokas et al. (2014) measured the soil profiles in the dry tundra to assess the anthropogenic radionuclides and transported the soils to the high arctic site of the adjacent proglacial area in glaciers part of Svalbard, then reported that, the specific activity of the fallout radionuclides in two profiles from the proglacial arranged between the undetectable levels of inventories radionuclides to the high levels was (30,900 ± 940, 47 ± 6, 886 ± 80 and 296 ± 19 Bq/m² of $^{137}$Cs, $^{238}$Pu, $^{239,240}$Pu, and $^{241}$Am, respectively) [29]. EdytaŁokas et al. (2016) performed a survey on the accumulation of radionuclides in atmospheric holes of cryoconites on an Arctic glacier in Hans Glacier in SW Spitsbergen, which they discovered that the activity levels of $^{137}$Cs in the Hans region vary in the range between the highest values of 678.0 ± 91.0 Bqkg$^{-1}$ to the minimum values of 89.0 ± 44.0 Bqkg$^{-1}$. And for $^{239,240}$Pu, the maximum is 16.62 ±1.21 Bqkg$^{-1}$, while the minimum value is 1.65 ± 0.16 Bqkg$^{-1}$, and the maximum activity concentration value for $^{210}$Pb is 4557 ±225 Bqkg$^{-1}$, and minimum value 939.0±153.0 Bqkg$^{-1}$ [20]. Agata Zaborska (2017) studied the sources of $^{137}$Cs in Arctic fjord (Hornsund, Svalbard), reported inventories of $^{137}$Cs ranging from 13.0 to 444.0 Bqm$^{-2}$, and the mean of $^{137}$Cs flux was calculated from the range of 2.7 to 44.1 Bqm$^{-2}$yr$^{-1}$[30].
Inventories of anthropogenic radionuclides ($^{137}\text{Cs}$, $^{238}\text{Pu}$, $^{239,240}\text{Pu}$, $^{241}\text{Am}$) for the proglacial soils samples studied by Edyta Łokas et al (2017) in south-western part of the island of Spitsbergen to measure airborne radionuclides in the proglacial environment as indicators of sources and transfers of soil material used by (HPGe detector gamma spectrometry) ($^{40}\text{K}$, $^{232}\text{Th}$, $^{226}\text{Ra}$, $^{210}\text{Pb}$, $^{137}\text{Cs}$), and alpha spectrometry analysis ($^{238}\text{Pu}$, $^{239,240}\text{Pu}$), a peak activity level of $^{137}\text{Cs}$ was found to be 3300.0±100.0 Bq kg$^{-1}$, and minimum activity concentration 2.0 ±1.0 Bq kg$^{-1}$, and activity concentration of $^{239,240}\text{Pu}$ varies between maximum 20.4±1.7 Bq kg$^{-1}$ and minimum concentration 0.05±0.05 Bq kg$^{-1}$, and for $^{226}\text{Ra}$ is 44.0±8.0 Bq kg$^{-1}$[31].

| Study area | Type of samples | Concentration of Radionuclides | Technique used | References |
|------------|-----------------|-------------------------------|----------------|------------|
| Alpine glacier | Cryoconites | $^{137}\text{Cs}$ Range between 1.7 to 140 K Bq /Kg $^{239,240}\text{Pu}$ Range between 1.6 to 197 Bq /Kg | Gamma spectrometry (HPGe Detector) Liquid scintillation counting(LSC) | [28] |
| Arctic Ocean | sea-ice sediments | $^{137}\text{Cs}$ Range between 1.8 to 4x10$^3$ Bq/Kg $^{239,240}\text{Pu}$ Range between 0.018 to 31.8 Bq /Kg | Gamma spectrometry using Ge detector Magnetic-sector inductively coupled plasma mass spectrometer(MS-ICPMS) | [14] |
| High Arctic site (north-western part of the Wedel Jarlsberg Land(Svalbard)) | soils | $^{137}\text{Cs}$ Range between U.D to 30.9 K Bq/m$^2$ $^{223,229}\text{Pu}$ Range between U.D to 0.88 K Bq /m$^2$ | Gamma spectrometry (HPGe Detector) Alpha spectrometric | [29] |
| Arctic fjord(Hornsud, Svalbard) | sediment cores collected | $^{137}\text{Cs}$ Range between 0.3 to 1.9 K Bq /m$^2$ | Gamma spectrometry (HPGe Detector) | [30] |
| Salzburg in the Central Eastern Alps | Cryoconites | $^{137}\text{Cs}$ Range between 357 to 223x10$^3$ Bq/Kg $^{239,240}\text{Pu}$ Range between B.D to 153 Bq /Kg | Gamma spectrometry (HPGe Detector) Alpha spectrometric | [18] |

T. Wilflinge et al. (2018) reported The activity concentration of $^{210}\text{Pb}$ varies between 1590 and 5750 Bq kg$^{-1}$ with average of maximum value 57500 ± 2300 Bq kg$^{-1}$ and minimum value 1589.8±76.1 Bq kg$^{-1}$, and an artificial $^{239,240}\text{Pu}$ from below limit of detection to maximum value 153.3±11.4 Bq kg$^{-1}$, and artificial $^{137}\text{Cs}$ was found to have the highest radionuclide concentrations with maximum value of 223.15±71.4 KBqkg$^{-1}$, and minimum value of 0.357±0.043.3 KBqkg$^{-1}$[18]. Henning Dahlgaard et al. (2004), found in Greenland the source of $^{137}\text{Cs}$ and $^{239,240}\text{Pu}$ in terrestrial and fresh water environments is mainly global fallout and a small contribution of $^{137}\text{Cs}$ from Chernobyl accident [32].

2.2. The concentration of radionuclides in the Antarctica area

M.Pourchet et al. (2003) found in snow and ice samples over Antarctica the inventory of $^{137}\text{Cs}$ in therrange; between 18 to 220 Bq m$^{-2}$ and for $^{241}\text{Pu}$ (estimates based on $^{241}\text{Am}$ measurements) vary between non-measurement to 80 Bq m$^{-2}$, ice cores and snow samples collected from the Russian
Miry to Vostok), Australian (Casey to Vostok), Italian (Talos Dome to Dome Concordia) and French (Dumont d’Urville to Dome C) on Antarctic continent, mainly in the 90–180°E sector [19]. Christian J. Sanders et al. (2010) reported that the concentration of radionuclides varies between 18.92 to 23.38, 78.71 to 186.26 and 1.62 to 11.17 Bq kg\(^{-1}\), for \(^{226}\)Ra, \(^{210}\)Pb, and \(^{137}\)Cs, respectively near the Brazilian Antarctic Station in the coastal region of Martel Inlet at Admiralty Bay, by collecting sediment core of 25 cm [33]. Paulo A. Lima et al. (2013) studied the mobility of \(^{137}\)Cs in the environment in five sediment profiles collected from Admiralty Bay, Antarctica, and found the inventory of \(^{137}\)Cs equivalent to 20.23 ± 8.94 Bq m\(^{-2}\) [15].

3. Discussion

Most of the data reported by some research groups around the world are on the measurement of concentration of radioactivity in soil, water, sediment, and plant in non-glacial fields. Very few study data are about the study of concentration radioactivity in the glacier and ice-caps region. In this paper, we select \(^{137}\)Cs and \(^{239,240}\)Pu radioisotopes representative of artificial radionuclides to study their distribution in the Arctic and Antarctica regions. The presence of artificial radioisotopes: \(^{137}\)Cs and \(^{239,240}\)Pu, in the atmosphere due to nuclear tests over the past 50 years [34], as well as the release of nuclear weapons and deposited in the earth after an exchange in the upper atmosphere and stratosphere [35] in the phase of cryoconite growth [36-38].

Gamma spectroscopy (NaI (Tl) and HPGe detector) was used to investigate the radioactivity in natural radionuclides (\(^{226}\)Ra, \(^{232}\)Th) and artificial radionuclides (\(^{137}\)Cs) in cryoconites samples. Alpha spectroscopy techniques and Magnetic-Sector Inductively Coupled Plasma Mass Spectrometer (MS-ICPMS) has also been used to estimate artificial radionuclide concentrations of \(^{239,240}\)Pu. By reviewing the outcomes of other studies, their different findings showed that, the activity concentrations of artificial radionuclides indicate an extremely wide range, from the detection limit to very high levels and the concentration of radioactivity measured in different parts of the glacier and ice-caps area around the world shows the relatively high value of \(^{137}\)Cs in arctic area due to tendency of arctic sea ice stage in cold arctic water thus relatively and less movement than sea ice in non-arctic area that moving more freely and it is located in a land mass surrounded by an ocean resulting in higher drift speeds of the radionuclides [18].

The highest value of concentration of anthropogenic \(^{137}\)Cs and \(^{239,240}\)Pu was found in cryoconites samples because cryoconites are one of the good storage sources of radionuclides, after being deposited from airborne. Here, there is no dilution by biological substances or soil matrix, making the radionuclides appear at high rates in cryoconites samples as it is shown in Table 1. so, the concentration of artificial radionuclides in cryoconites is the highest in comparison with other environments [39]. However, the maximum concentration radioactivity value of anthropogenic \(^{137}\)Cs in the Arctic glacier area was reported to be 223.15 KBq kg\(^{-1}\), in the Central Eastern Alps in Salzburg because this region was one of the most polluted areas outside the former Soviet Union due to an incident of Chernoby [40], and minimum value for \(^{137}\)Cs is 89.0 Bq kg\(^{-1}\), in Artic glacier of southern part of Spitsbergen (Wedel Jarsberg Land). The maximum value of \(^{239,240}\)Pu was reported to be 197.8 Bq kg\(^{-1}\) in Alpine glacier this value is often high due to nuclear testing which is conducted on 180 above ground nuclear tests in 1961-62 were carried out over the Arctic, particularly on October 1961 tested the most powerful nuclear weapon by the Soviet Union [41]. The minimum value of \(^{239,240}\)Pu was reported in the Arctic Ocean is equal to 0.018 Bq kg\(^{-1}\).

The research recorded for glaciers demonstrates that the concentration of radionuclides in the Arctic is higher than the concentration of these radionuclides in Antarctica. All previous studies discussed the measurement of anthropogenic and natural radioactive concentrations in glacier areas, but didn't touch the study of the effect of these concentrations on the surrounding environmental results of the glacier melts specifically in the Arctic region, which is warming up three times quicker than in other parts of the world [42], despite the importance of the aquatic systems in polar cold areas, which are considered to be one of the most severely affected systems by radionuclide pollution, usually introduced by weathering factors and human activities, as shown in Figure (1) [43].
For many years, this phenomenon was neglected by researchers, therefore greater efforts are needed to study the effects of glacier and snow melting flow on transport of radionuclides through meltwater and after that by the surface water flow through the river [44], which may be working on changing of the radiological map in the rivers in downstream, seas and ocean [15] due to airborne radionuclides in the fallout are attached to aerosol and later deposited as Aeolian (airborne) sediments on surfaces of glaciers in cryoconite. It is also known that water is one of the major sources of migrations and transfer of radionuclide in the environment and exposure the population to radiation; hence, it is the basic indicator of radiological contamination in the atmosphere [45].

![Transport of fallout radionuclide to the river](image)

Figure 1. Transport of fallout radionuclide to the river [44].

4. Conclusion and future study
In conclusion, the current review show that the above studies have been carried out in the arctic and non-arctic regions, which were characterized by a high density of snowfall and resulted in the accumulation of the radionuclides through atmospheric washing. So we find out that, the concentration of radionuclides in the Arctic region is higher than that of the Antarctica regions due to the fact that Arctic sea ice remains comparatively less moving in cold Arctic waters than sea ice in Antarctica waters, which move more freely in a land mass encircled by oceans, leading in greater drift speeds of radionuclides.

In our future research, we will investigate the concentrations and migration of natural and anthropogenic radionuclides in the river basin environment in China, which are characterized by seasonal snowfall, and will also compare the outcomes with world information in order to obtain appropriate information to assess the present distribution of these radionuclides.

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