

Informal measurements of natural radiation at various geomagnetic latitudes during a trip to the Antarctic Peninsula

Measurements of radiation dose rates using low-cost radiation detectors: In January, 2025 I traveled to islands in the South Atlantic and Southern Oceans as well as to the Antarctic Peninsula. Using low-cost radiation detectors, I made measurements of radiation dose rates in the air from NYC to Ushuaia Argentina, at sea, and in shore locations (both snow-covered and bare rock and soil). As expected, radiation dose rates were elevated during the flights and were very low at sea and on land covered with snow and ice. Spectra showed a gamma peak at 511 keV during the flight, likely due to high-energy cosmic rays penetrating into the upper atmosphere. Surprisingly (to me), sea-level spectra at sea at high latitudes (about 60° S and higher) also showed a gamma peak at 511 keV (possibly from cosmic rays penetrating more deeply into the atmosphere in these locations) as well as a clear peak from ⁴⁰K dissolved in the seawater.

About where the journey led

In January, 2025 I had the opportunity to travel to Antarctica on vacation. Knowing that I would be flying a considerable distance and would then be at sea at high southern latitudes I decided to bring radiation detectors with me to

collect spectra, measure and map radiation dose rates, and measure neutron count rates as I traveled.

Due to the nature of the trip the majority of the radiation measured was cosmic radiation; because of the shielding effect of water and snow/ice, radiation

from geologic materials was only present when I was on or near bare rock or soil.

Most tourist travel to Antarctica departs from South America, from Ushuaia Argentina or Punta Arenas Chile; travel to the ports of embarkation is usually by air from Santiago Chile or Buenos Aires Argentina. My travel and the types of radiation to which I was exposed are summarized in Table 1.

Cosmic radiation

Geologic sources of radiation

During shore excursions and while in Ushuaia before and after the cruise I was exposed to radiation from geologic sources. This consisted primarily of gamma radiation from ⁴⁰K, U, Th, and decay series nuclides that include alpha-, beta-, and gamma-emitters. Light-colored igneous rocks contain high concentrations of feldspar and silica minerals and are referred to as felsic rocks while dark igneous rocks contain high concentrations of magnesium (Mg) and iron (Fe) and are called mafic rocks.

Highest concentrations in felsic rocks

Date(s)	To/From	Distance (km)	Source(s) of radiation	Altitude (typical)
Jan 1–2	NYC – Buenos Aires	8,526	Cosmic	13,000 m
Jan 3	Buenos Aires – Ushuaia	2,374	Cosmic	10,000 m
Jan 4–5	Ushuaia	0	Cosmic, geologic	20 m
Jan 6	Ushuaia – Falkland Islands	772	Cosmic	Sea level
Jan 7–9	Falkland Islands	0	Cosmic, geologic	10 m
Jan 10–11	Falkland Islands – S. Georgia Island	1,483	Cosmic	Sea level
Jan 12–16	S. Georgia Island	745	Cosmic, geologic	Sea level – 50 m
Jan 17–18	S. Georgia Island – Antarctica	1,711	Cosmic	Sea level
Jan 19–22	Antarctic Peninsula	483	Cosmic, geologic	Sea level – 50 m
Jan 23–24	Antarctic Peninsula – Ushuaia	1,285	Cosmic	Sea level
Jan 25	Ushuaia	0	Cosmic, geologic	Sea level – 20 m
Jan 26–27	Ushuaia-Buenos Aires-NYC	10,900	Cosmic	13,000 m

Table 1: Travel itinerary and the types of radiation

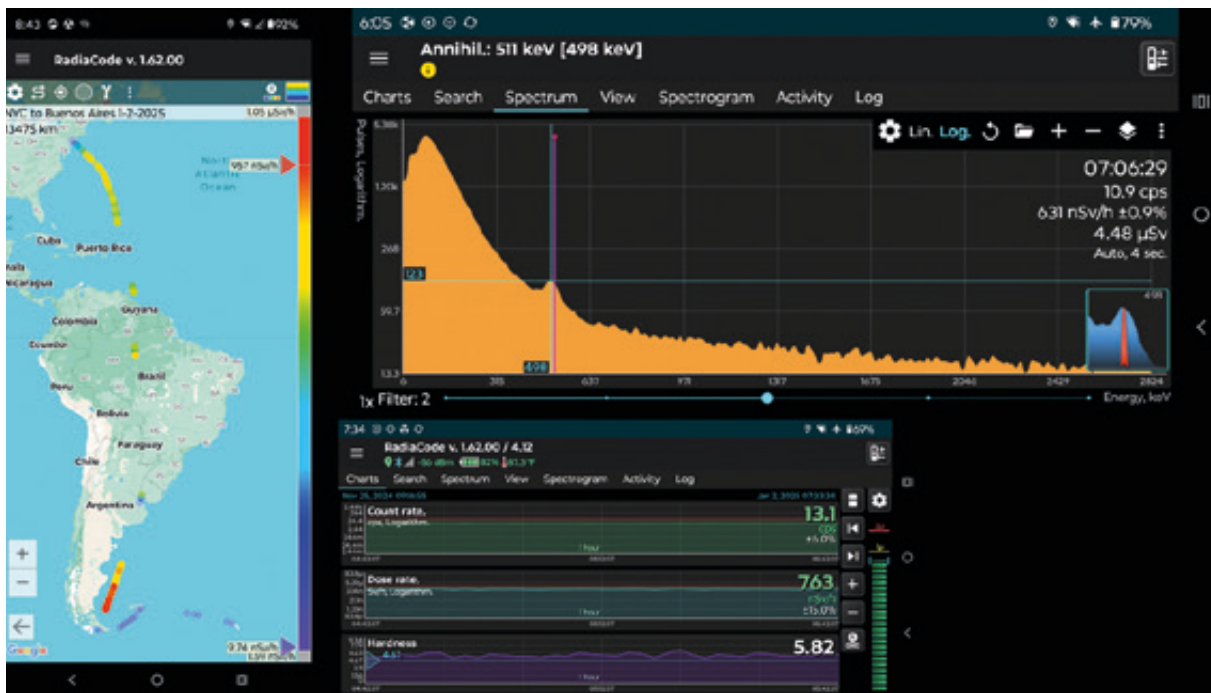


Fig. 1: Map of in-flight radiation dose rates from NYC to Ushuaia Argentina and at-sea radiation levels in the South Atlantic Ocean; an airborne gamma spectrum showing a clear annihilation peak; and a plot of radiation parameters, also at 10 km altitude.

Owing to the geochemistry of uranium, thorium, and potassium, radionuclides are present in the highest concentrations in felsic rocks such as granites and andesites, and in dark (organic-rich) sedimentary rocks such as coal and black shales. Mafic rocks such as basalts and dacites and light-colored sedimentary rocks tend to have lower levels of radioactivity.

In the areas visited:

- The rocks in the vicinity of Ushuaia are largely sedimentary rocks derived from both felsic and mafic rocks from the surrounding mountains.
- The Falkland Islands are comprised of largely sedimentary rocks (sandstone, mudstone, quartzite) and unconsolidated sediments derived from felsic sources.
- South Georgia Island has a more interesting history: It was most likely detached from the South American continent and moved approximately 1,700 km eastward; thus, South Georgia Island is a remote piece of the continental crust,

**Annual radiation exposures
on contact with igneous rocks at the present time**

are about

- 0.75 mGy (corresponding to about 85.6 nGy h⁻¹) for felsic rocks,
- 0.27 mGy (30.8 nGy h⁻¹) for mafic rocks, and
- 0.66 mGy (75.3 nGy h⁻¹) for the average continental crust (*Karam and Leslie* 1999) [2].

Whatever radiation is emitted is attenuated by water, including ice and snow.

containing mostly felsic and sedimentary with minor amounts of mafic rocks.

- Rocks of the Antarctic Peninsula tend to be more mafic, but do include some minor felsic components.

Cosmic sources of radiation

Cosmic rays fall into 2 primary categories:

- **Solar cosmic rays** are mostly protons, electrons, and alpha particles with energies of 10 keV or less, emitted from the sun as the solar wind.

- **Galactic cosmic rays**, that include high-energy particles with masses of up to 80 atomic mass units and higher and energies as high as 10¹⁵ MeV (although most are in the MeV-GeV range) comes from outside the solar system.

Charged particles interact with the Earth's magnetic field, which tends to deflect them towards the poles, where they can penetrate more deeply into the atmosphere where, among other things, they produce the

Aurora australis in the Southern Hemisphere

Instrument	Detector	Measurement(s)	Specifications
Mirion AccuRad	CsI(Tl)	Gamma dose rate	https://accurad.mirion.com/
Kromek D5M	CLLBC (Cs ₂ LiLa(Br,Cl) ₆ Ce)	Gamma dose rate, neutron count rate, gamma nuclide ID	https://www.kromek.com/product/d5-riid/
SafeCast bGeigieZen	GM ("Pancake")	Gamma count rate, gamma dose rate	https://bgeigiezen.safecast.jp/features/
GQ GMC-320S	GM	Gamma dose rate	https://www.gqelectronicsllc.com/comersus/store/comersus_viewItem.asp?idProduct=5792
RadiaCode 103	CsI(Tl)	Gamma dose rate, gamma nuclide ID	https://www.radiacode.com/

Table 2: Instrument summary

aurora borealis in the Northern Hemisphere and the aurora australis in the Southern Hemisphere.

When charged particles interact with atoms in the atmosphere they undergo interactions that produce muons, pions, neutrinos, gamma rays, neutrons, and other debris, as well as Cherenkov radiation, causing a cascade of secondary and tertiary radiation known as a cosmic ray air shower. In general, cosmic radiation increases in intensity at higher elevations and at higher geographic latitude.

Potassium-40

In addition to the other primary radiation sources there is also exposure to ⁴⁰K in biological materials (including the bodies of passengers and crew) as well as ⁴⁰K in the seawater.

Equipment for the measurements

I collected gamma count rate and dose rate information as well as gamma spectroscopy and neutron count rate using the instruments noted in Table 2.

None of the instruments were calibrated.

None of the instruments used were calibrated, nor were they designed to provide accurate dose rates across a wide range of gamma energies. For this reason I checked each instrument against a calibrated Ludlum 9DP pressurized ionization chamber at 2 distances from a variety of NIST-traceable gamma sources, with results that are summarized in Table 3.

Because of the asymmetry of the bGeigieZen, owing to its construction and the asymmetry of the "pancake" GM tube, the comparison was made in 2 configurations, with the top and the

bottom of the instrument facing the source. As you can see, measurements made through the instruments' bottom were more accurate than those made through the top.

Please note

that the instruments were not adjusted, nor was this intended to provide conversion or correction factors to any of the instruments; the purpose of this was to give a general feel for the accuracy of the instruments.

Based on this comparison I decided to use the D5M primarily to check neutron count rate. Due to problems connecting the Mirion AccuRad or the GQ GMC-320S to the exact operating system on my Android phone I was unable to use my phone's GPS to map radiation dose rates with these instruments.

Feel for the accuracy of the instruments

Nuclide	activity (μCi)	energy (keV)	reading (μR/hr))						
			Ludlum 9DP	Mirion AccuRad	Kromek D3M	GQ GMC-320S	Radia-Code 103	SafeCast bGeigieZen (top/bottom)	
²⁴¹ Am	500	60	19	12	9	24	21	0	23
¹³³ Ba	200	356, 81	58	40	25	55	65	40	59
¹⁵² Eu	232	121, 1,408, 964, 1,112, 1,085	185	130	63	155	173	130	220
¹³⁷ Cs	4,500	662	1,800	770	890	900	2,000	860	1,360
⁶⁰ Co	1,000	1,170, 1,330	1,220	840	670	2,300	1,500	970	1,250
background			12	9	11	11	14	19	19

Table 3: Instrument comparison measurements

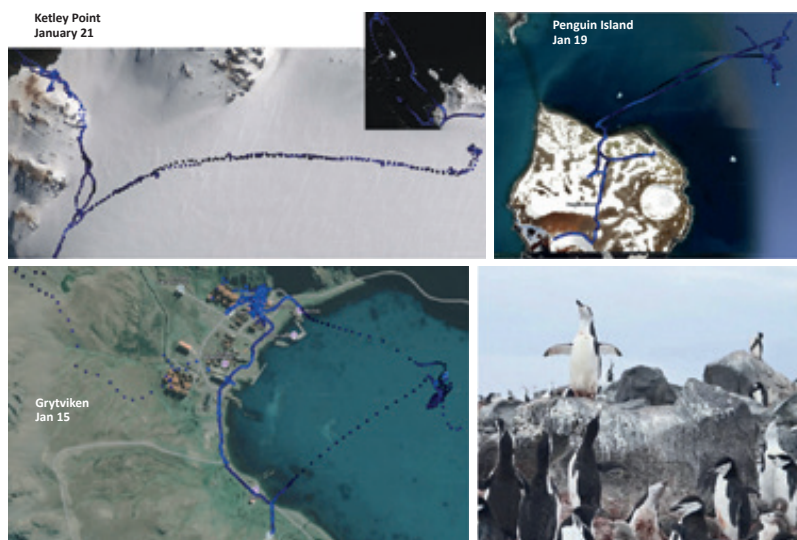


Fig. 2: Radiation dose rate maps from Antarctica and South Georgia Island. Note the lighter colors ashore or near rocks (indicating higher dose rates) and lower levels over ice, snow, and water. The lower photo shows a block of mafic rock on Penguin Island, partially obscured by penguins.

I was, however, able to collect and map data from the RadiaCode 103 and the bGeigieZen instruments and these became my primary instruments on this trip.

Measurements

The Kromek D3M, SafeCast bGeigieZen, and RadiaCode 103 were first turned on when the airplane was taxiing at JFK International Airport. During the flight they remained active until my taxi arrived at my hotel in Buenos Aires. Instruments were turned on again the next day prior to takeoff and remained on until reaching my hotel in Ushuaia.

With a few exceptions when batteries were fully discharged, instruments were left on continuously from around 1,700 on Monday January 6 until about 1,200 on January 27 when I returned to my home in New York City. Although initially I did not routinely bring detectors with me during shore and boat excursions (“zodiac cruises”), by the midway point I took the bGeigieZen and/or RadiaCode 103 with me at all times when ashore or on a small boat on the water.

GPS coordinates were provided from the phone to which instruments were connected or, in the case of the bGeigieZen, by an onboard GPS receiver. However, the instruments did not provide a full map when the GPS signal was lost due to being at high latitudes or loss of GPS or satellite internet signal due to shielding by the structure of the ship or the airplane fuselage. Thus, there are gaps in the maps during “sea days” while transiting between land masses (e. g. between Tierra del Fuego and the Falkland Islands) as well as during the flights between NYC and Buenos Aires (on the return flight I realized that I could get more reliable GPS signals from a window seat with the instrument close to the window rather than in a backpack in the overhead storage space).

Measurements were saved in data files on my phone for the RadiaCode or on an SD memory card on the bGeigieZen. Data were uploaded to the SafeCast (<https://safecast.org/>) and Cosmic On Air (<https://cosmic-on-air.org/>) citizen science websites.

Dose rate

Unsurprisingly, radiation dose rates fell upon leaving the ground until an

altitude of about 3,000 m and then increased with increasing altitude, reflecting first the increasing distance from radionuclides in the ground below and then the reduction in atmospheric shielding. Radiation dose rates were lower when at sea, reflecting the shielding effect of the water in reducing radiation exposure from geologic materials as well as the maximum shielding from the atmosphere; when ashore on ice and snow radiation dose rates were similarly low, although when on shallow snow or thin ice and near to large rock outcroppings radiation levels were relatively higher. Dose rates are summarized in Table 4.

Reduction in atmospheric shielding

Phase of travel	Range of dose rates
Sea level – NYC and Ushuaia	50 to 100 nGy/hr
En route – 13,000 m	80 to 170 nGy/hr
Sea level – at sea and on ice	10 to 30 nGy/hr
Sea level – on rock or soil	20 to 50 nGy/hr

Table 4: Radiation dose rates during different phases of travel

Spectrum

As expected, spectra while airborne showed only 1 distinct gamma peak; the 511 keV peak from electron/positron annihilation. Other than that there were no recognizable gamma peaks with spectrum integration times of up to 5 hours.

Unexpectedly, the 511 keV peak was also present at sea level during the sea transit from South Georgia Island to the Antarctic Peninsula. A literature search showed that this was noted by (among others) *Jovan Puzovic* and *Juan*

Spectrum integration times of up to 5 hours

Instruments were left on continuously

Notes on data upload

After collection, data, including radiation readings and GPS coordinates, were uploaded to the CosmicOnAir (<https://cosmic-on-air.org/>) and/or SafeCast (<https://safecast.org/>) websites, where they were mapped and made available to the rest of the world for review if desired. Both sites make data upload fairly easy for supported instruments.

Anicin (2002) [3], who attributed it to interactions between cosmic radiation and Al, Fe, Sn, and Pb.

Onboard ship the most likely target atoms were Al and Fe. This may be related to the "ship effect" (*Estanislav Aguayo* et al, 2013) [1] in which spallation of atoms due to cosmic rays produces excess neutrons in the vicinity of large metal objects such as ships. A colleague (*Goldhagen*, private communication) suggested that the annihilation peak might have been visible at sea due to the very low background radiation levels at sea. It's also possible that, at high geomagnetic latitudes, a greater number of charged particles are able to penetrate to low altitudes where cosmic ray air showers can produce electron-positron pairs that give rise to the annihilation radiation.

Cosmic ray air showers

"Hardness"

Related to spectra is the concept of "hardness" – the average energy of the gamma spectrum. While the RadiaCode company does not publicize their formula for calculating "hardness," it does appear as though the spectrum shifts to higher energies at higher elevation, which is to be expected since there is less atmosphere to scatter incoming and secondary radiations to lower energies.

Summary and conclusions

The radiation measurements were largely as expected with my instru-

ments showing higher radiation levels at high altitudes and lower radiation levels at sea and on ice, even at high geomagnetic latitudes. Gamma spectra were also largely unsurprising, showing a "harder" gamma spectrum at altitude than at sea level and no discernable gamma peaks from geologic emitters such as ^{40}K , or series nuclides from ^{235}U , ^{238}U , or ^{232}Th either in

the air, at sea, or on ice and snow more than a few meters deep. The presence of a gamma peak at 511 keV at commercial aircraft altitude was due to charged particles penetrating into the atmosphere to near the level of the airplane. The same peak seen at sea level was more surprising to me, although this, too, has been reported in the literature and seems due to the "Ship Effect" or to charged particles penetrating more deeply into the atmosphere at high geomagnetic latitudes. When at sea a peak at 1,460 keV was also noted and is most likely due to potassium in seawater.

Most surprising to me was that relatively inexpensive instruments provided readings that compared favorably to those of "professional-grade" instruments. In addition, these inexpensive detectors, often marketed to amateurs and enthusiasts, can provide access to online logging or mapping software maintained by international citizen science projects.

P. Andrew Karam □

Spectra were unsurprising

Citizen science projects

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