Occupational radiation doses of United Kingdom high altitude mountain guides as a result of cosmic ray exposures.

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Abstract

UK based mountain guides lead multiple expeditions throughout the course of a year. They will receive radiation doses from cosmic rays during air travel and their time spent at elevated altitudes in the mountains of the world. These radiation doses are received as part of their employment.

This paper illustrates that UK based high altitude mountain guides can potentially receive greater than 1 milliSv per year of cosmic radiation dose in excess of what they would have received at ground level. These individuals are "occupationally exposed" to cosmic radiation as a result of their profession.

The European Community Basic Safety Standards Directive 96/29/EURATOM does not apply to exposure to cosmic radiation prevailing at ground level. The highest "ground level" that a UK mountain guide may be working at is 8848m. The maximum flying altitude of some internal flights in the UK is 7925m. 96/29/EURATOM does apply to cosmic radiations being received by aircrews therefore there is an anomaly in radiation protection where the cosmic radiation exposures of aircrew operating for short durations at altitudes lower than mountain guides operating at high altitudes for prolonged times have to be taken into account. UK based high altitude mountain guides are undergoing planned occupational exposures to cosmic radiation whilst still on the ground.

Consideration should be given by the legislative authorities to include the control and assessment of cosmic radiation exposures of professionals likely to receive greater than 1 milliSv per year of cosmic radiation in excess of what would have been received in their home country at ground level.

In their next set of recommendations, the ICRP should consider whether the occupational cosmic radiation exposure of high altitude mountain guides should be included as a specialised group for whom some control and assessment of cosmic radiation exposures may be justified.

KEYWORDS: Radiation dose, cosmic ray, high altitude, mountain guide, seven summits.

1. Introduction

The United Kingdom (UK) has a mountaineering and exploration tradition. UK citizens routinely travel overseas to various extreme environments and nowadays their activities are often facilitated by specialised expedition logistics companies. These companies routinely provide a UK based professional mountain guide to lead expeditions to the Earth's extremes. These UK based mountain guides will often lead multiple expeditions throughout the course of a year. They will receive radiation doses from ultraviolet radiation (UVR) and cosmic rays during air travel and their time spent at elevated altitudes in the mountains of the world. These radiation doses are received as part of their employment.

Studies have shown that mountain guides receive considerable UVR doses [1] due to altitude related increase of UVR [2] and reflection from snow and ice covered surfaces. Their daily UVR doses will depend on the latitude in which they are working, the time of day and the meteorological conditions prevailing at the time [3]. Exposure to solar ultraviolet radiation is an occupation health and safety issue [4] for mountain guides and controls are often put in place to mitigate exposures such as use of sunscreen, use of suitable goggles or glasses, and the wearing of clothing to minimise the exposure of skin.

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In Publication 60 [5], the ICRP suggested the inclusion of exposure to elevated levels of natural radiation as occupational exposure. It is known that air crew can receive considerable cosmic radiation doses during the course of their employment [6] and legislation exists for the control of their radiation doses [7, 8]. Passengers on aircraft, including frequent flyers, are not included in this legislation at present. The ICRP currently maintains the view that it is not necessary to treat the exposure of frequent flyer passengers as occupationally exposed for the purpose of control [9, 10].

Mountain guides are a special group of frequent flyers who not only routinely travel long haul routes but upon arrival at their destination spend significant amounts of time at elevated altitudes. This paper estimates the potential magnitude of cosmic radiation doses for a hypothetical UK based high altitude mountain guide assisting a client to ascend all of the seven summits [11] in a year. Modelling of this hypothetical scenario helps determine whether significant cosmic radiation doses are being received by this group of workers and whether controls should be considered in future legislation for this group of employees.

2. Cosmic radiation

Cosmic radiation can be divided into various types and there are three important sources of cosmic radiation when considering human doses: galactic cosmic radiation (GCR), solar cosmic radiation (SCR) and radiation from the Earth's (van Allen) radiation belts [12]. In the case of mountain guides it is only the contribution from galactic and solar cosmic radiations that need to be taken into account.

Cosmic radiation comes from the outside the Earth and consists of different types of highly charged particles such as protons, helium nuclei, some other heavier nuclei and electrons. The Earth is continually exposed to cosmic radiation and it enters the Earth's atmosphere from all directions. When these high energy particles enter the Earth's lower atmosphere they generate secondary particle showers [13].

Galactic cosmic ray fluence varies with solar activity, being lower when the solar activity is higher [12]. Solar activity varies on average with a 11 year periodicity [14]. GCR particles have to penetrate the Earth's magnetic field and as a result of this influence the number of particles penetrating close to the poles is higher than near the equator [12].

Solar cosmic radiation (SCR) originates from solar flares when the particles, mostly protons, are directed towards the Earth. Solar flares occur more frequently at the period of maximum solar activity. Due to SCR having lower energy than GCR the influence of the Earth's magnetic field is much more important to SCR penetration through the Earth's atmosphere, hence there are more SCR particles penetrating close to the poles than near the equator [12].

UK mountain guides will be exposed to both GCR and SCR during the delivery of their work and the precise doses received will vary depending on the latitude and altitude worked in, as well as the solar cycle.

The European Community Basic Safety Standards Directive 96/29/EURATOM [7] does not apply to exposure to cosmic radiation prevailing at ground level. The highest altitude in the United Kingdom is 1344 m (4,409'). The highest "ground level" that a UK mountain guide may be working at, when overseas and not in an aircraft is 8848m (29,028') [11].

The maximum flying altitude of the BAe Jetstream 41 aircraft, which services numerous internal flights in the UK, is 7925m (26,000') and its typical cruising altitude is 6700m (22,000'). 96/29/EURATOM [7] does apply to cosmic radiations being received by aircrews therefore there is an anomaly in radiation protection where the cosmic radiation exposures of aircrew operating for short durations at altitudes lower than mountain guides operating at high altitudes for prolonged times have to be taken into account. UK based high altitude mountain guides are essentially undergoing planned occupational exposures to cosmic radiation whilst still on the ground.

3. Seven summits

The term “seven summits” [11] refers to the highest mountain on each of the Earth’s seven continental plates. There are two principal variations on what constitutes the seven summits as there is some debate on the definition [15] of the continents therefore most mountaineers aspiring to ascend the seven summits actually do eight summits. Various mountain guides have ascended all of the seven summits and some have made multiple ascents of them.

The hypothetical UK based high altitude mountain guide scenario being used in this paper is an ascent of each of the seven summits in the space of a calendar year (with an ascent of the harder Carstensz Pyramid rather than Australia’s Kosciuszko). In 2007 the UK based company Adventure Peaks, using one UK based high altitude mountain guide, successfully took a client up these seven summits in a new world record time of 156 days [16]. The seven summits are Aconcagua, Carstensz Pyramid, Elbrus, Mount Everest (also known as Sagamartha or Chomolungma), Denali (also known as Mount McKinley), Kilimanjaro and Mount Vinson.

By taking clients to do the seven summits, UK based high altitude mountain guides will receive a greater cosmic radiation exposure through the delivery of their work than they would have received by doing guiding work in the much lower altitude mountains of the UK.

Mountain guides are a special group of frequent flyers who not only routinely travel long haul routes but upon arrival at their destination spend significant amounts of time at elevated altitudes. The following sections estimate the potential magnitude of cosmic radiation doses for a UK based high altitude mountain guide assisting a client to ascend each of the seven summits. For the purposes of these estimates it is assumed that the guide is based in Glasgow, Scotland.

For the purposes of consistency, all cosmic radiation exposures estimated were performed using the “Federal Aviation Administration Office of Aerospace Medicine Galactic Radiation Received in Flight” calculator [17]. All cosmic radiation dose rate estimates are based on an average value for the 2011 calendar year.

For all country internal flights it is assumed that it takes 30 minutes to get up to cruising altitude and that the internal flight cruised at 34,000’ for a period of time prior to taking 30 minutes to gradually descend and touchdown. For all long haul flights it is assumed that it takes 30 minutes to get up to a cruising altitude of 34,000’ where the plane will remain for half of the cruise time, then the remainder of the cruise time will be spent at an altitude of 40,000’ prior to taking 30 minutes to gradually descend and touchdown. For all internal flights on small aircraft a cruising height of 20,000’ is assumed. For the purposes of this paper it is assumed that the mountain guides are not travelling on any aircraft which are also carrying any class 7 dangerous goods (radioactive materials) such as radiopharmaceuticals for medical diagnosis and treatment.

For estimates of cosmic radiation dose rates whilst at ground level, reference [17] was used to determine a dose rate per hour for a flight at the elevation of interest between two airports of the same latitude as the mountain of interest. For the purposes of generating data for this paper it is assumed that the cosmic radiation dose rates at the same latitudes north and south of the equator are equivalent. Using this approach the data in table 1 has been generated, for use in the subsequent sections, to determine the potential cosmic doses received by UK high altitude mountain guides whilst at various altitudes. Appendix A provides the supporting information for the results presented in the following sections.

Table 1: Cosmic radiation dose rates (in microSv/hr) at different altitudes on the seven summits

Elevation (in feet)	Elevation (in m)	Glasgow, UK (Sea level)	Aconcagua (6960m)	Carstensz Pyramid (4884m)	Elbrus (5642m)	Everest (8848m)	Denali (6194m)	Kilimanjaro (5895m)	Mount Vinson (4897m)
0	0	0.05	0.04	0.03	0.04	0.03	0.05	0.03	0.05
3000	914	0.06	0.05	0.04	0.06	0.04	0.06	0.04	0.06
6000	1829	-	0.08	0.07	0.09	0.07	0.10	0.07	0.10
9000	2743	-	0.12	0.11	0.15	0.11	0.18	0.11	0.18
12000	3658	-	0.20	0.17	0.25	0.18	0.31	0.17	0.31
13500	4115	-	0.26	0.22	0.32	0.23	0.41	0.22	0.41
15000	4572	-	0.33	0.27	0.40	0.29	0.53	0.27	0.53
16500	5029	-	0.41	0.34	0.51	0.37	0.68	0.34	0.68
18000	5486	-	0.51	-	0.65	0.46	0.88	0.43	-
19000	5791	-	0.59	-	0.75	0.52	1.03	0.49	-
20000	6096	-	0.68	-	-	0.60	1.19	0.56	-
21000	6401	-	0.77	-	-	0.68	1.39	-	-
22000	6706	-	0.88	-	-	0.77	-	-	-
23000	7010	-	0.99	-	-	0.87	-	-	-
24000	7315	-	-	-	-	0.98	-	-	-
25000	7620	-	-	-	-	1.09	-	-	-
26000	7925	-	-	-	-	1.21	-	-	-
27000	8230	-	-	-	-	1.34	-	-	-
28000	8534	-	-	-	-	1.47	-	-	-
29000	8839	-	-	-	-	1.62	-	-	-

3.1 Aconcagua, Argentina

The highest point in South America is Aconcagua in the Andes mountain chain. Its elevation is 6,960m (22,834’). To ascend Aconcagua is typically a 24 day expedition including travel from and back to the UK. It is estimated that this will involve approximately 34 hours flying with an associated estimated cosmic radiation exposure of 99.2 microSv. The cosmic radiation dose estimate calculated for an ascent of Aconcagua, based on the itinerary given by the UK guiding company Adventure Peaks [18] and the assumptions stated above, is 160.8 microSv. This gives a total cosmic radiation dose of 0.260 milliSv. If the UK based guide had spent these 24 days guiding in the UK, spending 50% of the time at sea level and the other 50% at 3000’ then a dose of 0.032 milliSv would have been received. Therefore the typical occupational exposure for a UK high altitude mountain guide to lead an expedition to Aconcagua is estimated to be 0.228 milliSv.

3.2 Carstensz Pyramid, Papua

The highest point on the Oceania/Australia continent is Carstensz Pyramid in Papua. Its elevation is 4,884m (16,024’). To ascend Carstensz Pyramid is typically a 22 day expedition including travel from and back to the UK. It is estimated that this will involve approximately 49 hours flying with an associated estimated cosmic radiation exposure of 125.2 microSv. The cosmic radiation dose estimate calculated for an ascent of Carstensz Pyramid, based on the itinerary given by the UK guiding company Adventure Peaks [18] and the assumptions stated above, is 68.6 microSv. This gives a total cosmic radiation dose of 0.194 milliSv. If the UK based guide had spent these 22 days guiding in the UK, spending 50% of the time at sea level and the other 50% at 3000’ then a dose of 0.029 milliSv would have been received. Therefore the typical occupational exposure for a UK high altitude mountain guide to lead an expedition to Carstensz Pyramid is estimated to be 0.165 milliSv.

3.3 Elbrus, Europe

The highest point on the European continent is Mount Elbrus in the Caucasus mountains. Its elevation is 5,642m (18,510’). To ascend Mount Elbrus is typically a 14 day expedition including travel from and back to the UK. It is estimated that this will involve approximately 14.5 hours flying with an associated estimated cosmic radiation exposure of 59.7 microSv. The cosmic radiation dose estimate calculated for an ascent of Elbrus, based on the itinerary given by the UK guiding company Adventure Peaks [18] and the assumptions stated above, is 64.6 microSv. This gives a total cosmic radiation dose of 0.124 milliSv. If the UK based guide had spent these 14 days guiding in the UK, spending 50% of the time at sea level and the other 50% at 3000’ then a dose of 0.018 milliSv would have been received. Therefore the typical occupational exposure for a UK high altitude mountain guide to lead an expedition to Elbrus is estimated to be 0.106 milliSv.

3.4 Mount Everest, Asia

The highest point on the Asian continent is Mount Everest. Its elevation is 8,848m (29,028’). To ascend Mount Everest is typically a 72 day expedition including travel from and back to the UK. It is estimated that this will involve approximately 25.5 hours flying with an associated estimated cosmic radiation exposure of 85.4 microSv. The cosmic radiation dose estimate calculated for an ascent of Everest, based on the itinerary given by the UK guiding company Adventure Peaks [18] and the assumptions stated above, is 1011.9 microSv. This gives a total cosmic radiation dose of 1.097 milliSv. If the UK based guide had spent these 72 days guiding in the UK, spending 50% of the time at sea level and the other 50% at 3000’ then a dose of 0.095 milliSv would have been received. Therefore the typical occupational exposure for a UK high altitude mountain guide to lead an expedition to Everest is estimated to be 1.002 milliSv. This one mountain represents a significant radiation exposure to high altitude mountain guides.

3.5 Denali (Mount McKinley), North America

The highest point on the North American continent is Denali. Its elevation is 6,194m (20,320’). To ascend Denali is typically a 25 day expedition including travel from and back to the UK. It is estimated that this will involve approximately 32.5 hours flying with an associated estimated cosmic radiation exposure of 189.7 microSv. The cosmic radiation dose estimate calculated for an ascent of Denali, based on the itinerary given by the UK guiding company Adventure Peaks [18] and the assumptions stated above, is 207.9 microSv. This gives a total cosmic radiation dose of 0.398 milliSv. If the UK based guide had spent these 25 days guiding in the UK, spending 50% of the time at sea level and the other 50% at 3000’ then a dose of 0.033 milliSv would have been received. Therefore the typical occupational exposure for a UK high altitude mountain guide to lead an expedition to Denali is estimated to be 0.365 milliSv.

3.6 Kilimanjaro, Africa

The highest point on the African continent is Kilimanjaro. Its elevation is 5,895m (19,340’). To ascend Kilimanjaro is typically a 13 day expedition including travel from and back to the UK. It is estimated that this will involve approximately 20.5 hours flying with an associated estimated cosmic radiation exposure of 59.4 microSv. The cosmic radiation dose estimate calculated for an ascent of Kilimanjaro, based on the itinerary given by the UK guiding company Adventure Peaks [18] and the assumptions stated above, is 36.8 microSv. This gives a total cosmic radiation dose of 0.096 milliSv. If the UK based guide had spent these 13 days guiding in the UK, spending 50% of the time at sea level and the other 50% at 3000’ then a dose of 0.017 milliSv would have been received. Therefore the typical occupational exposure for a UK high altitude mountain guide to lead an expedition to Kilimanjaro is estimated to be 0.079 milliSv.

3.7 Mount Vinson, Antarctica

The highest point on the Antarctica continent is Mount Vinson. Its elevation is 4,897m (16,023’). To ascend Mount Vinson is typically a 19 day expedition including travel from and back to the UK. It is estimated that this will involve approximately 48.75 hours flying with an associated estimated cosmic radiation exposure of 170.8 microSv. The cosmic radiation dose estimate calculated for an ascent of Vinson, based on the itinerary given by the UK guiding company Adventure Peaks [18] and the assumptions stated above, is 69.4 microSv. This gives a total cosmic radiation dose of 0.240 milliSv. If the UK based guide had spent these 19 days guiding in the UK, spending 50% of the time at sea level and the other 50% at 3000’ then a dose of 0.025 milliSv would have been received. Therefore the typical occupational exposure for a UK high altitude mountain guide to lead an expedition to Vinson is estimated to be 0.215 milliSv.

4. Discussion

The hypothetical scenario presented in section 3, and supported by Appendix A, illustrates the cosmic radiation doses that an UK high altitude mountain guide could receive whilst taking clients up each of the seven summits in the same calendar year. Table 2 summarises the cosmic radiation exposures associated with this work and the estimated dose if the mountain guide had remained in the UK to work for the duration of these expeditions. Figures 1 and 2 illustrate the estimated expedition cosmic radiation dose distribution graphically for each of the seven summits.

Table 2: Summary of cosmic radiation dose exposure information

Mountain guided	**Cosmic radiation received on expedition (microSv)**	**Cosmic radiation received during flights (microSv)**	**Total Cosmic radiation dose received for expedition (microSv)**	**Cosmic radiation received for same time period in UK (microSv)**	**Occupational exposure received from leading these expeditions (milliSv)**
Aconcagua	160.8	99.2	260	31.7	0.228
Carstensz Pyramid	68.6	125.2	193.8	29.0	0.165
Elbrus	64.6	59.7	124.3	18.5	0.106
Everest	1011.9	85.4	1097.3	95.0	1.002
Denali	207.9	189.7	397.6	33.0	0.365
Kilimanjaro	36.8	59.4	96.2	17.2	0.079
Mount Vinson	69.4	170.8	240.2	25.1	0.215
Totals	**1620**	**789.4**	**2409.4**	**249.5**	**2.160**

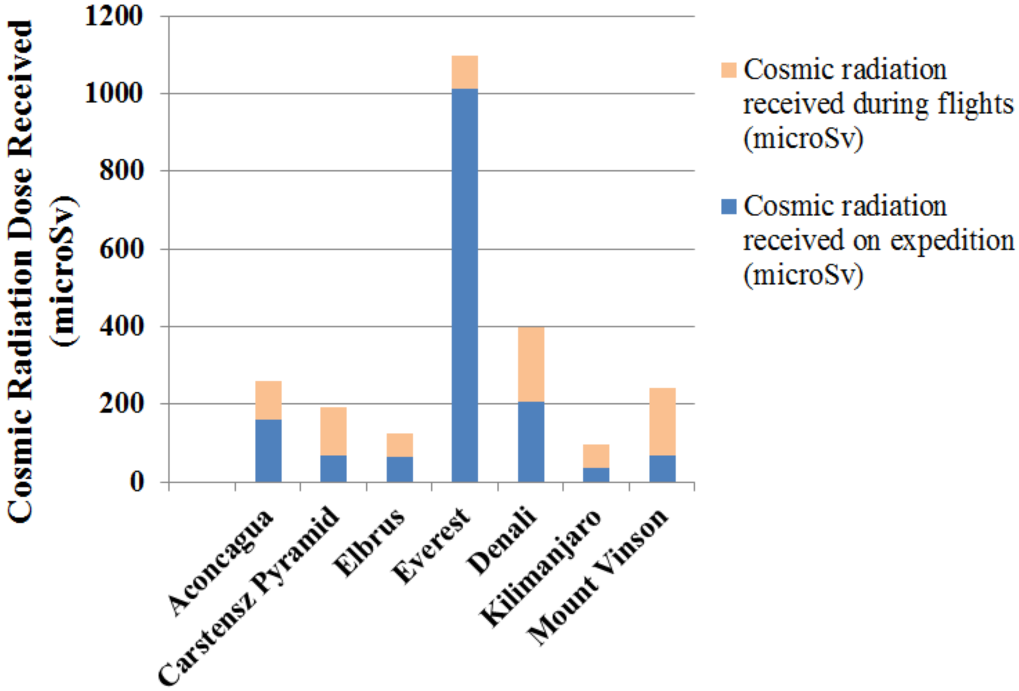

Figure 1: Estimated cosmic radiation doses received by UK high altitude mountain guide when taking clients up each of the seven summits. Data based on cosmic radiation average for 2011.

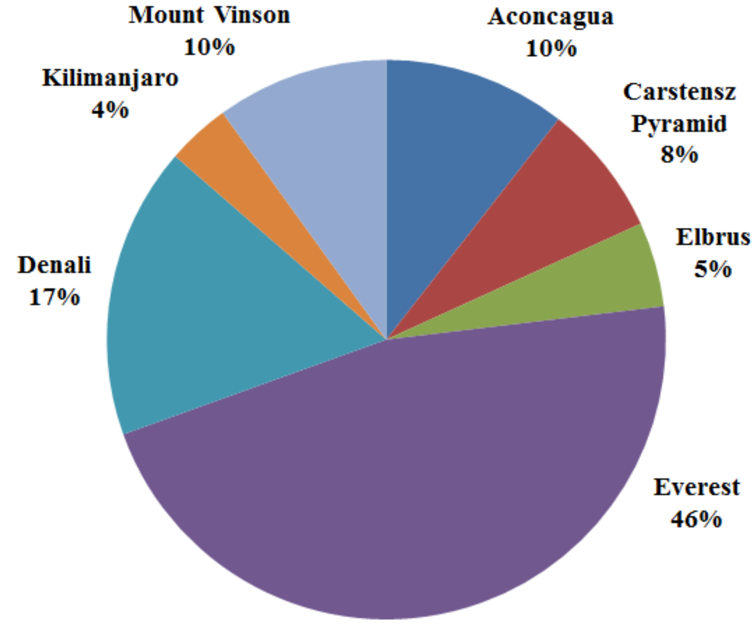

Figure 2: Contribution of individual expeditions to the UK based guide's estimated occupational exposure of 2.16 milliSievert for the hypothetical situation modelled in Figure 1.

UK based high altitude mountain guides do receive occupational radiation dose from cosmic radiation both at ground level and during transit whilst in aircraft. To guide one client up all of the seven summits takes approximately 189 days, involves approximately 225 hours of flying and results in over 2 milliSv of occupational radiation dose of which over two thirds of the dose is received whilst at ground level overseas. An ascent of Mount Everest gives greater than 1 milliSv of dose at ground level and as such is a significant radiation dose [19], if the UK Ionising Radiations Regulations 1999 were to be applied to this existing exposure situation.

Due to meterological conditions it is highly unlikely that any mountain guides would attempt to lead clients up more than two or three 8000 metre peaks in a calendar year. It is conceivable, although very unlikely, for a UK based high altitude mountain guide to make two rounds of the seven summits in a calendar year therefore it is likely that the occupational cosmic radiation exposure of UK mountain guides may be bounded at the region of 4 milliSv per annum. However it should be noted that their occupational cosmic radiation exposures could be higher depending on the solar cycle and cosmic radiation levels at the time and location of their work.

As some UK high altitude mountain guides can receive greater than 1 milliSv per year from cosmic radiation, after UK cosmic radiation doses have been subtracted, these personnel must therefore be officially considered “occupationally exposed to radiation”. Reference [20] states that “Although air couriers and other exceptionally frequent flyers are not mentioned in Article 42” of reference [7], “it is recommended that employers of such individuals should make arrangements for determining doses similar to those made by airlines for their staff.”

In the United Kingdom, the Air Navigation Order 2000 [8] requires protection of air crew from cosmic radiation as part of the implementation of Article 42 [7]. This requires the assessment of the exposure to cosmic radiation when in flight of those air crew who are liable to be subject to cosmic radiation in excess of 1 milliSv per year. It also requires that assessment of cosmic radiation exposure be taken into account when organising work schedules and inform the workers concerned of the health risks their work involves, etc.

UK high altitude mountain guides are aware of a wide range of highly significant hazards in their work environments (such as extreme cold, frostbite, avalanches, hypoxia, pulmonary oedema, cerebral oedema, rock fall, and ultraviolet radiation) but are perhaps not fully aware of their increased exposure to cosmic radiation.

Consideration should be given by the legislative authorities to include the control and assessment of cosmic radiation exposures of professionals likely to receive greater than 1 milliSv per year of cosmic radiation in excess of what would have been received in their home country at ground level.

5. Conclusions

High altitude mountain guides from the United Kingdom can potentially receive greater than 1 milliSv per year of cosmic radiation dose in excess to what they would have received at UK ground level. These individuals are occupationally exposed to cosmic radiation as a result of their profession.

Consideration should be given by the legislative authorities to include the control and assessment of cosmic radiation exposures of professionals likely to receive greater than 1 milliSv per year of cosmic radiation in excess of what would have been received in their home country at ground level.

In their next set of recommendations, the ICRP should consider whether the occupational cosmic radiation exposure of high altitude mountain guides should be included as a specialised group for whom some control and assessment of cosmic radiation exposures may be justified.

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Appendix A – Data sets used to formulate cosmic radiation dose estimates of UK based high altitude mountain guides.

Table A1: Cosmic radiation dose estimate during flights for an ascent of Aconcagua

Flight	**Duration of flight**	**Estimated dose (microSv)**
Glasgow to London	1 hour 30 minutes	4.2
London to Buenos Aires	13 hours 40 minutes	42.3
Buenos Aires to Mendoza	1 hour 50 minutes	3.1
Mendoza to Buenos Aires	1 hour 50 minutes	3.1
Buenos Aires to London	13 hours 40 minutes	42.3
London to Glasgow	1 hour 30 minutes	4.2
Totals:	34 hours	99.2

Table A2: Cosmic radiation dose estimate whilst on the ground during an Aconcagua expedition

Day	Description	Approximate Altitude (m)	Estimated time at altitude (hours)	Dose rate estimate (microSv/hr)	Dose estimate (microSv)
1-2	International flights	0 760	12 19	0.05 0.05	0.60 0.95
3	Stay in Mendoza	760	24	0.05	1.20
4	Travel to Puente del Inca	760 2720	10 14	0.05 0.12	0.50 1.68
5	Trek to Pampa de Lenas	2720 2867	8 16	0.12 0.13	0.96 2.08
6	Trek to Casa de Piedra	2867 3245	8 16	0.13 0.16	1.04 2.56
7	Trek to Plaza Argentinas	3245 3700 4203	8 8 8	0.16 0.20 0.26	1.28 1.60 2.08
8	Rest day	4203	24	0.26	6.24
9	Load carry to camp 1 at 5000m and return	4203 4600	16 8	0.26 0.33	4.16 2.64
10	Load carry to camp 1 at 5000m and return	4203 4600	16 8	0.26 0.33	4.16 2.64
11	Move to camp 1	4203 4600 5000	8 8 8	0.26 0.33 0.41	2.08 2.64 3.28
12	Rest day	5000	24	0.41	9.84
13	Load carry to camp 2 at 5840m and return	5000 5400	16 8	0.41 0.51	6.56 4.08
14	Move to camp 2	5000 5400 5840	8 8 8	0.41 0.51 0.59	3.28 4.08 4.72
15	Rest day	5840	24	0.59	14.16
16-18	Summit day attempts (summit 6960m)	5840 6400 6960	57 14 1	0.59 0.77 0.99	33.63 10.78 0.99
19	Return to Plaza Argentinas	5840 5000 4203	8 6 10	0.59 0.41 0.26	4.72 2.46 2.60
20	Rest day	4203	24	0.26	6.24
21	Trek to Pampa de Lenas	4203 3500 2867	8 6 10	0.26 0.19 0.13	2.08 1.14 1.30

22	Trek out and return to Mendoza	2867 2720 760	8 6 10	0.13 0.12 0.05	1.04 0.72 0.50
23-24	Return international flights	760 0	12 19	0.05 0.05	0.60 0.95
				Total cosmic dose whilst at ground level:	160.80

Table A3: Cosmic radiation dose estimate during flights for an ascent of Carstensz Pyramid

Flight	**Duration of flight**	**Estimated dose (microSv)**
Glasgow to Manchester	1 hour 5 minutes	1.9
Manchester to Abu Dhabi	7 hours 10 minutes	27.2
Abu Dhabi to Jakarta	8 hours 30 minutes	18.7
Jakarta to Bali	1 hour 45 minutes	2.3
Bali to Timika	4 hours 35 minutes	8.5
Timika to Ilaga	1 hour	0.6
Ilaga to Timika	1 hour	0.6
Timika to Sulawesi	4 hours 5 minutes	7.2
Sulawesi to Jakarta	2 hours 15 minutes	3.4
Jakarta to Abu Dhabi	8 hours 30 minutes	18.7
Abu Dhabi to Manchester	8 hours 5 minutes	34.2
Manchester to Glasgow	1 hour 5 minutes	1.9
Totals:	49 hours 5 minutes	125.2

Table A4: Cosmic radiation dose estimate whilst on the ground during a Carstensz Pyramid expedition

Day	Description	Approximate Altitude (m)	Estimated time at altitude (hours)	Dose rate estimate (microSv/hr)	Dose estimate (microSv)
1-2	International flights to Jakarta	0 0	7.25 14	0.05 0.03	0.4 0.4
3	Flights from Jakarta to Ilaga in Papua	0 2280	8 8.75	0.03 0.08	0.2 0.7
4	Trek from Ilaga to Pinapa	2280 2400	8 16	0.08 0.09	0.6 1.4
5	Trek from Pinapa to Camp 1	2400 3280	12 12	0.09 0.14	1.1 1.7
6	Camp 1 to Camp 2	3280 3600 3760	8 8 8	0.14 0.17 0.18	1.1 1.4 1.4
7	Camp 2 to Camp 3	3760 3800	8 16	0.18 0.18	1.4 2.9
8	Camp 3 to Camp 4	3800	24	0.18	4.3
9	Camp 4 to Camp 5	3800	24	0.18	4.3
10	Camp 5 to Camp 6	3800	24	0.18	4.3
11	Camp 6 to Carstensz Base Camp	3800 4100 4280	8 8 8	0.18 0.22 0.23	1.4 1.8 1.8
12	Ascent of Carstensz Pyramid	4280 4600 4884	15 8 1	0.23 0.27 0.34	3.5 2.2 0.3
13	Rest day	4280	24	0.23	5.5
14	Return to Camp 6	4280 4100 3800	8 8 8	0.23 0.22 0.18	1.8 1.8 1.4
15	Return to Camp 4	3800	24	0.18	4.3

16	Return to Camp 2	3800	24	0.18	4.3
17	Return to Camp 1	3800 3600 3280	8 8 8	0.18 0.17 0.14	1.4 1.4 1.1
18	Return to Ilaga	3280 2700 2280	8 8 8	0.14 0.11 0.08	1.1 0.9 0.6
19	Rest day	2280	24	0.08	1.9
20	Fly Ilaga to Jakarta	2280 0	8 8.67	0.08 0.03	0.6 0.3
21-22	Return international flights	0 0	16 16.33	0.03 0.05	0.5 0.8
				Total cosmic dose whilst at ground level:	68.6

Table A5: Cosmic radiation dose estimate during flights for an ascent of Elbrus

Flight	**Duration of flight**	**Estimated dose (microSv)**
Glasgow to Amsterdam	1 hour 45 minutes	5.5
Amsterdam to Moscow	3 hours 10 minutes	16.4
Moscow to Mineralnye Vodi	2 hours 10 minutes	6.6
Mineralnye Vodi to Moscow	2 hours 10 minutes	6.6
Moscow to Amsterdam	3 hours 35 minutes	19.1
Amsterdam to Glasgow	1 hour 45 minutes	5.5
Totals:	14 hours 35 minutes	59.7

Table A6: Cosmic radiation dose estimate whilst on the ground during an Elbrus expedition

Day	Description	Approximate Altitude (m)	Estimated time at altitude (hours)	Dose rate estimate (microSv/hr)	Dose estimate (microSv)
1	International flights to Moscow	0 200	8.5 8.5	0.05 0.04	0.4 0.3
2	Fly to Mineralnye Vodi and travel to Upper Baskan Valley	200 1250 2130	8 4 10	0.04 0.07 0.11	0.3 0.3 1.1
3	Acclimatisation walk	2130 2700 2130	8 8 8	0.11 0.15 0.11	0.9 1.2 0.9
4	Load carry to camp below VCSPS pass	2130 2700 2130	8 8 8	0.11 0.15 0.11	0.9 1.2 0.9
5	Move up to camp below VCSPS pass	2130 2700 3200	8 8 8	0.11 0.15 0.20	0.9 1.2 1.6
6	Ascent of Andirchi (3800m) via VCSPS pass	3200 3500 3800	15 8 1	0.20 0.23 0.26	3.0 1.8 0.3
7	Ascent of Krumrichi (4200m) via VCSPS pass then back to valley	3200 3700 4200 2130	8 8 1 7	0.20 0.25 0.33 0.11	1.6 2.0 0.3 0.8
8	Ascend to the Barrels (3800m) and walk to Prijutt hut (4200m). Overnight at the Barrels.	2130 3800 4000 4200 3800	8 2 4 1 9	0.11 0.26 0.30 0.33 0.26	0.9 0.5 1.2 0.3 2.3

9	Ascend to Pastukov Rocks (4850m) and stay at Prijutt hut (4200m)	3800 4400 4850 4200	8 7 1 8	0.26 0.37 0.46 0.33	2.1 2.6 0.5 2.6
10	Rest day	4200	24	0.33	7.9
11	Potential summit day	4200 4900 5642 4200	6 13 1 4	0.33 0.46 0.71 0.33	2.0 6.0 0.7 1.3
12	Rest day (or summit day)	4200	24	0.33	7.9
13	Return journey to Moscow	4200 3000 2130 1250 200	6 2 2 4 6	0.33 0.17 0.11 0.07 0.04	2.0 0.3 0.2 0.3 0.2
14	Return international flights	200 0	8 10.67	0.04 0.05	0.3 0.5
				Total cosmic dose whilst at ground level:	64.6

Table A7: Cosmic radiation dose estimate during flights for an ascent of Everest

Flight	**Duration of flight**	**Estimated dose (microSv)**
Glasgow to Dubai	7 hours 20 minutes	29.6
Dubai to Delhi	3 hours 5 minutes	6.5
Delhi to Kathmandu	1 hour 40 minutes	2.3
Kathmandu to Delhi	1 hour 40 minutes	2.3
Delhi to Dubai	3 hours 45 minutes	8.3
Dubai to Glasgow	8 hours	36.4
Totals:	25 hours 30 minutes	85.4

Table A8: Cosmic radiation dose estimate whilst on the ground during an Everest expedition

Day	Description	Approximate Altitude (m)	Estimated time at altitude (hours)	Dose rate estimate (microSv/hr)	Dose estimate (microSv)
1-2	International flights to Kathmandu	0 240 1400	16 4 16	0.05 0.03 0.05	0.8 0.1 0.8
3-4	Final preparations, enter Tibet and overnight in Zangmu	1400 1750 2350	24 8 16	0.05 0.07 0.09	1.2 0.6 1.4
5	Drive to Nylam (4000m)	2350 4000	10 14	0.09 0.21	0.9 2.9
6-7	Acclimatisation walks up to 4800m	4000 4400 4800	34 12 2	0.21 0.26 0.33	7.1 3.1 0.7
8	Drive to Tingri (4600m)	4000 4600	10 14	0.21 0.29	2.1 4.1
9-10	Acclimatisation walks up to 5200m	4600 4900 5200	34 12 2	0.29 0.35 0.41	9.9 4.2 0.8
11	Drive to Everest Base Camp (north side)	4600 5200	10 14	0.29 0.41	2.9 5.7
12-16	Everest Base Camp – acclimatisation walks up to 6000m	5200 5600 6000	75 40 5	0.41 0.49 0.57	30.8 19.6 2.9

17	Walk to intermediate camp (5700m)	5200 5450 5700	8 8 8	0.41 0.46 0.51	3.3 3.7 4.1
18	Walk to Advanced Base camp (6400m)	5700 6100 6400	8 8 8	0.51 0.60 0.68	4.1 4.8 5.4
19-20	Rest days	6400	48	0.68	32.6
21	Ascend to north col (7010m) and return	6400 6700 7010	10 12 2	0.68 0.77 0.87	6.8 9.2 1.7
22	Rest day	6400	24	0.68	16.3
23	Ascend to north col and spend night there	6400 6700 7010	8 8 8	0.68 0.77 0.87	5.4 6.2 7.0
24	Descend to Advanced Base Camp	7010 6700 6400	8 4 12	0.87 0.77 0.68	7.0 3.1 8.2
25-26	Rest days	6400	48	0.68	32.6
27	Ascend to north col and stay there	6400 6700 7010	8 8 8	0.68 0.77 0.87	5.4 6.2 7.0
28-29	Rest days	7010	48	0.87	41.8
30	Ascend to Camp 2a (7500m) and descend to north col	7010 7300 7500	10 12 2	0.87 0.98 1.06	8.7 11.8 2.1
31	Rest day	7010	24	0.87	20.9
32	Ascend to Camp 2a and spend night there	7010 7300 7500	8 8 8	0.87 0.98 1.06	7.0 7.8 8.5
33	Ascend to Camp 2b (7800m) and return to Camp 2a	7500 7650 7800	14 8 2	1.06 1.09 1.17	14.8 8.7 2.3
34	Rest day	7500	24	1.06	25.4
35	Ascend to Camp 2b and spend night there	7500 7650 7800	8 8 8	1.06 1.09 1.17	8.5 8.7 9.4
36	Descend to north col	7800 7400 7010	8 8 8	1.17 1.02 0.87	9.4 8.2 7.0
37	Descend to Advanced Base Camp	7010 6700 6400	8 4 12	0.87 0.77 0.68	7.0 3.1 8.2
38	Descend to Base Camp	6400 5800 5200	8 8 8	0.68 0.52 0.41	5.4 4.2 3.3
39-43	Rest days	5200	120	0.41	49.2
44	Re-ascend to Advanced Base camp	5200 5800 6400	8 8 8	0.41 0.52 0.68	3.3 4.2 5.4
45-46	Rest days	6400	48	0.68	32.6
47	Re-ascend to North Col and stay there	6400 6700 7010	8 8 8	0.68 0.77 0.87	5.4 6.2 7.0
48	Ascend to Camp 2a and spend night there	7010 7300	8 8	0.87 0.98	7.0 7.8

		7500	8	1.06	8.5
49	Ascend to Camp 2b and spend night there	7500 7650 7800	8 8 8	1.06 1.09 1.17	8.5 8.7 9.4
50	Ascend to Camp 3 (8200m)	7800 8000 8200	8 8 8	1.17 1.25 1.34	9.4 10.0 10.7
51	Ascend to Everest summit and return to Camp 3	8200 8500 8848	7 16 1	1.34 1.47 1.62	9.4 23.5 1.6
52	Descend to north col	8200 7600 7010	6 6 12	1.34 1.09 0.87	8.0 6.5 10.4
53	Descend to Advanced Base camp	7010 6700 6400	8 4 12	0.87 0.77 0.68	7.0 3.1 8.2
54-63	Contingency / weather days spent at Advanced Base Camp during expedition	6400	240	0.68	163.2
64	Clear Advanced Base Camp	6400	24	0.68	16.3
65	Descend to Base Camp	6400 5800 5200	8 8 8	0.68 0.52 0.41	5.4 4.2 3.3
66	Clear Base Camp	5200	24	0.41	9.8
67	Drive to Nylam (4000m)	5200 4000	10 14	0.41 0.21	4.1 2.9
68	Drive to Kathmandu	4000 2700 1400	8 8 8	0.21 0.11 0.05	1.7 0.9 0.4
69-70	Rest day in Kathmandu	1400	48	0.05	2.4
71-72	International flights from Kathmandu	1400 240 0	16 3 16	0.05 0.03 0.05	0.8 0.1 0.8
				Total cosmic dose whilst at ground level:	1011.9

Table A9: Cosmic radiation dose estimate during flights for an ascent of Denali

Flight	**Duration of flight**	**Estimated dose (microSv)**
Glasgow to Paris	1 hour 45 minutes	5.3
Paris to Seattle	10 hours 25 minutes	73.8
Seattle to Anchorage	3 hours 40 minutes	17.4
Talkeetna to Kahiltna glacier	45 minutes	0.9
Kahiltna glacier to Talkeetna	45 minutes	0.9
Anchorage to Seattle	3 hours 40 minutes	17.4
Seattle to Paris	9 hours 50 minutes	68.7
Paris to Glasgow	1 hour 45 minutes	5.3
Totals:	32 hours 35 minutes	189.7

Table A10: Cosmic radiation dose estimate whilst on the ground during a Denali expedition

Day	Description	Approximate Altitude (m)	Estimated time at altitude (hours)	Dose rate estimate (microSv/hr)	Dose estimate (microSv)
1	Travel to Anchorage	0	8.5	0.05	0.4
2	Equipment checks	0	24	0.05	1.2
3	Drive to Talkeetna and fly to Kahiltna Glacier (2134m)	0 110 2134	8 7 8	0.05 0.05 0.13	0.4 0.4 1.0
4	Load carry to Camp 1 and return to Kahiltna	2134 2368	12 12	0.13 0.14	1.6 1.7
5	Move up to Camp 1 (Base of Ski Hill)	2134 2368	8 16	0.13 0.14	1.0 2.2
6	Load carry to Camp 2 (Base of Motorcycle hill) and return to Camp 1	2368 2850 3353	15 8 1	0.14 0.19 0.28	2.1 1.5 0.3
7	Move up to Camp 2	2368 2850 3353	8 8 8	0.14 0.19 0.28	1.1 1.5 2.2
8	Rest day	3353	24	0.28	6.7
9	Laud haul around Windy Corner (4054m) and return to Camp 2	3353 3700 4054	15 8 1	0.28 0.31 0.40	4.2 2.5 0.4
10	Move up to Camp 3 at 4369m	3353 3850 4369	8 8 8	0.28 0.36 0.48	2.2 2.9 3.8
11	Active rest day to collect cache at 4054m	4369 4054	20 4	0.48 0.40	9.6 1.6
12	Load carry up head wall and cache at 4907m, return to Camp 3	4369 4600 4907	15 8 1	0.40 0.53 0.65	6.0 4.2 0.7
13	Rest day	4369	24	0.40	9.6
14	Move up to high camp at 5243m.	4369 4800 5243	8 8 8	0.40 0.59 0.78	3.2 4.7 6.2
15-16	Rest days at 5243m	5243	48	0.78	37.4
17	Summit attempt	5243 5700 6194	7 14 1	0.78 1.00 1.25	5.5 14.0 1.3
18-19	Contingency summit days at 5243m	5243	48	0.78	37.4
20	Descend to Camp 3	5243 4800 4369	8 8 8	0.78 0.59 0.40	6.2 4.7 3.2
21	Descend to Kahiltna Glacier	4369 3200 2134	8 8 8	0.40 0.25 0.13	3.2 2.0 1.0
22	Return to Anchorage	2134 110 0	8 7 8	0.13 0.05 0.05	1.0 0.4 0.4
23	Contingency day for weather	0	24	0.05	1.2
24-25	Return international flights	0	32.75	0.05	1.6
				Total cosmic dose whilst at ground level:	207.9

Table A11: Cosmic radiation dose estimate during flights for an ascent of Kilimanjaro

Flight	**Duration of flight**	**Estimated dose (microSv)**
Glasgow to Amsterdam	1 hour 45 minutes	5.5
Amsterdam to Kilimanjaro	8 hours 25 minutes	24.2
Kilimanjaro to Amsterdam	8 hours 35 minutes	24.2
Amsterdam to Glasgow	1 hour 45 minutes	5.5
Totals:	20 hours 30 minutes	59.4

Table A12: Cosmic radiation dose estimate whilst on the ground during a Kilimanjaro expedition

Day	Description	Approximate Altitude (m)	Estimated time at altitude (hours)	Dose rate estimate (microSv/hr)	Dose estimate (microSv)
1	International flights to Kilimanjaro airport and stay in Moshi	0 891	6 7.75	0.05 0.04	0.3 0.3
2	Commence acclimatisation ascent of Mount Meru	891 2000 2515	8 8 8	0.04 0.07 0.10	0.3 0.6 0.8
3	Miriakamba Hut to Saddle Hut (3570m)	2515 3100 3570	8 8 8	0.10 0.13 0.17	0.8 1.0 1.4
4	Saddle Hut to Socialist Peak (4566m) to Miriakamba Hut	3570 4566 2515	13 1 8	0.17 0.27 0.10	2.2 0.3 0.8
5	Miriakamba Hut to Moshi	2515 2000 891	8 8 8	0.10 0.07 0.04	0.8 0.6 0.3
6	Ascent of Kilimanjaro – Machame Gate to Machame Camp	891 2500 3000	8 8 8	0.04 0.10 0.12	0.3 0.8 1.0
7	Machame Camp to Shira Camp	3000 3400 3840	8 8 8	0.12 0.14 0.19	1.0 1.1 1.5
8	Shira Hut to Barranco Hut	3840 4200 4600 3950	8 7 1 8	0.19 0.23 0.27 0.20	1.5 1.6 0.3 1.6
9	Barranco Hut to Barafu Hut	3950 4250 4600	8 8 8	0.20 0.23 0.27	1.6 1.8 2.2
10	To summit of Kilimanjaro and out to Mweka Camp	4600 5250 5895 4600 3100	2 8 1 6 7	0.27 0.38 0.52 0.27 0.13	0.5 3.0 0.5 1.6 0.9
11	Mewka Camp to Moshi	3100 2000 891	8 8 8	0.13 0.07 0.04	1.0 0.6 0.3
12	Rest day	891	24	0.04	1.0
13	Return international flights	891 0	7.67 6	0.04 0.05	0.3 0.3
				Total cosmic dose whilst at ground level:	36.8

Table A13: Cosmic radiation dose estimate during flights for an ascent of Mount Vinson

Flight	**Duration of flight**	**Estimated dose (microSv)**
Glasgow to Paris	1 hour 45 minutes	5.3
Paris to Santiago	14 hours 15 minutes	43.8
Santiago to Punta Arenas	3 hours 30 minutes	12.8
Punta Arenas to Union Glacier	4 hours 30 minutes	23.0
Union Glacier to Vinson Base Camp	45 minutes	0.9
Vinson Base Camp to Union Glacier	45 minutes	0.9
Union Glacier to Punta Arenas	4 hours 30 minutes	23.0
Punta Arenas to Santiago	3 hours 30 minutes	12.8
Santiago to Paris	13 hours 30 minutes	43.0
Paris to Glasgow	1 hour 45 minutes	5.3
Totals:	48 hours 45 minutes	170.8

Table A14: Cosmic radiation dose estimate whilst on the ground during a Mount Vinson expedition

Day	Description	Approximate Altitude (m)	Estimated time at altitude (hours)	Dose rate estimate (microSv/hr)	Dose estimate (microSv)
1-2	International flights to Punta Arenas	0	28.5	0.05	1.4
3	Preparations & briefings in Punta Arenas	0	24	0.05	1.2
4	Flight to Union Glacier	0 750	9.5 10	0.05 0.06	0.5 0.6
5	Flight to Vinson Base Camp	750 2100	12 11.15	0.06 0.11	0.7 1.2
6	Ascent of acclimatisation peak (2800m)	2100 2450 2800	16 7 1	0.11 0.15 0.18	1.8 1.1 0.2
7	Load carry to turn in the glacier	2100 2350 2600	16 7 1	0.11 0.14 0.16	1.8 1.0 0.2
8	Move to Camp 1 at 2770m	2100 2450 2770	8 8 8	0.11 0.15 0.18	0.9 1.2 1.4
9	Load carry to High Camp	2770 3300 3773	14 9 1	0.18 0.26 0.33	2.5 2.3 0.3
10	Move up to High Camp	2770 3300 3773	8 8 8	0.18 0.26 0.33	1.4 2.1 2.6
11	Rest day at High Camp	3773	24	0.33	7.9
12	Mount Vinson summit attempt	3773 4350 4897	14 9 1	0.33 0.47 0.66	4.6 4.2 0.7
13-14	Contingency days for summit bid	3773	48	0.33	15.8
15	Return to Vinson base camp	3773 2900 2100	8 10 6	0.33 0.19 0.11	2.6 1.9 0.7
16	Fly to Union Glacier	2100 750	11.15 12	0.11 0.06	1.2 0.7

17	Fly to Punta Arenas	750 0	10 9.5	0.06 0.05	0.6 0.5
18-19	Return international flights	0	29.25	0.05	1.5
Total cosmic dose whilst at ground level:					69.4