Body concentration of caesium-137 in patients from Western Isles of Scotland

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Abstract

Objectives—**To compare caesium-137 concentrations in patients from the Western Isles Health Board, Glasgow area, and other parts of the Scottish mainland, and to investigate the source of ^{137}Cs in patients from the Western Isles.**

Design—**Study of hypertensive patients having electrolyte concentrations measured, including ^{137}Cs. Interview by questionnaire of island subjects about intake of foods likely to contain radiocaesium and the source of these foods. Measurement of ^{137}Cs and ^{134}Cs in food, urine, and vegetation.**

Setting—**Scottish mainland and Western Isles, 1979-86. All measurements before Chernobyl nuclear accident.**

Patients—**413 consecutive patients referred to the blood pressure unit for investigation of hypertension. 60 from the Western Isles, including 44 from North Uist; 32 from North Uist participated in the dietary analysis.**

Main outcome measures—**Concentration of radiocaesium in the body, urine, food, and vegetation. Islanders' consumption of local produce.**

Results—**Patients from the Western Isles had five times higher body concentrations of ^{137}Cs (median 2·54 (interquartile range 1·25-3·73)) Bq/gK) than did patients from around Glasgow (0·47 (0·26-0·66) Bq/gK) and other parts of the Scottish mainland (0·42 (0·24-0·71) Bq/gK). Islanders often consumed local milk and mutton, but ate local fish rarely. ^{137}Cs and ^{134}Cs were present in coastal (21·6 Bq/kg ^{137}Cs, 0·25 Bq/kg ^{134}Cs) and moorland (135·9, 0·65 Bq/kg) grasses and in islanders' urine (2·01, 0·013 Bq/l). Lower concentrations (0·336, 0·004 Bq/l), were found in the urine of Glasgow controls ($p<0·001$ for both isotopes).**

Conclusions—**Islanders have excess body ^{137}Cs concentrations, most of which probably comes from local milk and lamb. The radioactivity is not above the recommended safety limit. The presence of ^{134}Cs suggests that nuclear reprocessing is the source of some of the radiocaesium.**

Introduction

Whole body concentrations of caesium-137 are closely related to dietary intake of the isotope,[1] which has a physical half life of 30 years but a biological half life of only 110 days in man.[2] It is distributed widely throughout the body and is excreted mainly in urine.[2] Before the explosion of the Chernobyl nuclear reactor, ^{137}Cs in humans came mainly from fallout from nuclear weapons testing.[1] In 1981 Williams *et al* reported high concentrations of body ^{137}Cs in five patients from the Western Isles and suggested that fish contaminated with radiocaesium from the Sellafield nuclear fuel reprocessing plant was the main source.[3] Their conclusion was contested.[4]

We measured ^{137}Cs concentrations in Scottish patients and examined their diet to confirm the existence of higher body ^{137}Cs concentrations in island patients and to determine the source of the excess. Preliminary accounts of this work have been published.[5,6]

Subjects and methods

We studied 413 consecutive patients attending the blood pressure unit in Glasgow during 1979-86, all of whom had ^{137}Cs body concentrations measured at the Scottish Universities Research and Reactor Centre, East Kilbride. There were 243 men (mean age 45 years, range 18-72) and 170 women (46, 20-79). Most patients (218) lived in the Glasgow area, 101 in other parts of mainland Scotland, 25 in England, seven in Ireland, and two overseas. Sixty patients were from the Western Isles: 44 from North Uist, seven from Lewis, five from South Uist, and one each from Barra, Skye, Raasay, and Mull.

Most patients from Glasgow and all patients from the Western Isles were referred directly by their general practitioners for investigation of uncomplicated essential hypertension. The large number from North Uist reflects an interest of one of the authors (JAJM) in cardiovascular disease. Patients from other parts of the United Kingdom and overseas tended to have more complex disease and had been referred by hospital doctors.

MEASUREMENT OF BODY ^{137}CS CONCENTRATIONS

Patients underwent whole body composition analysis, primarily to assess their total body content of sodium and potassium.[7,8] As ^{137}Cs and potassium-40 are both gamma emitters ^{137}Cs concentration was determined when measuring ^{40}K and before the activation analysis needed to measure sodium. Radiocaesium concentrations are expressed in relation to potassium concentration. The whole body counter consisted of two large sodium iodide detectors mounted within a lead shield, and the method of measuring ^{137}Cs activity has been described.[9,10] Permission to undertake the body composition study was obtained from Western Infirmary ethics committee and from the Administration of Radioactive Substances Advisory Committee. All measurements were made before the Chernobyl accident in 1986.

DIETARY ASSESSMENT OF ISLANDERS

We obtained dietary histories in May 1984 from the 32 patients from North Uist—all those who had been investigated in Glasgow up until that time. Islanders completed a questionnaire on their intake of milk, meat, fish, and other foods and were asked whether their food was produced locally or imported and how often each item was consumed. Demographic details were also recorded.

^{137}CS AND ^{134} CS CONCENTRATIONS IN FOOD, URINE, AND ENVIRONMENT

Samples of the urine of islanders together with island milk, lamb, fish, vegetables, seaweed, herbage, and tidal sediments were collected and screened by rapid high sensitivity gamma ray counting to determine ^{137}Cs concentrations. The results were compared with those

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from similar products bought in the Glasgow area and with published reports of ^{137}Cs concentrations in foods from other parts of Britain.[11,12] We then examined selected samples with high ^{137}Cs concentrations by high resolution gamma ray spectrometry using both germanium-lithium and pure germanium detectors (E G and G Ortec) to obtain ^{137}Cs and ^{134}Cs values. ^{134}Cs was measured because the isotope is produced by reprocessing nuclear fuel but not by explosion of nuclear weapons.

Because concentrations of ^{134}Cs were low we collected and concentrated large samples and, where necessary, counted for up to 96 hours. Grasses were concentrated by drying and ashing. Urine samples of up to 15 l were obtained from 12 patients from North Uist and from 12 Glasgow controls (six hypertensive and six normotensive), and radiocaesium was extracted on to potassium hexacyanocobalt ferrate.[13] Recovery of added radioactivity was greater than 95%.[14] A similar extraction procedure was used for milk but with smaller volumes. Food samples up to 1 l were counted without being concentrated.

We corrected observed sample counts for counter background detector efficiency and yield of gamma rays, the background being determined at intervals arranged to bracket groups of samples. The limit of detection for ^{134}Cs (taken as three standard deviations of background count) was 0·1 Bq for samples $\leq$1 l and 0·04 Bq for the concentrated urine samples, for which geometrical counting efficiency was better.

STATISTICAL METHODS

Because most of the data were not normally distributed we have used median values throughout. Comparisons are made by the Mann-Whitney U test. The time trend data in figure 1 were analysed by linear regression with a logarithmic scale.

Results

Patients from the Western Isles had five times higher concentrations of ^{137}Cs than did those from other areas (table I). Concentrations higher than 2 Bq/gK were found in 35 of 60 islanders but in only one of 218 Glaswegians. The patient with the highest value (8·53 Bq/gK) lived in Stornoway, Lewis.

Body ^{137}Cs concentrations were slightly higher in men than in women (median 0·49 and 0·38 Bq/gK respectively, excluding patients from the Western Isles). Patients with primary hyperaldosteronism had higher radiocaesium to potassium ratios than did those with essential hypertension (table I) because of lower concentrations of potassium rather than higher concentrations of caesium. However, only one of the 22 patients with primary hyperaldosteronism was an islander. Mean body potassium concentration of the islanders was 105·6% of predicted normal value; concentrations 104% of normal have been reported in patients with essential hypertension.[7] Thus high ratios of body ^{137}Cs to ^{40}K in islanders were probably not due to low potassium or high aldosterone concentrations.

TABLE I—*Body concentration of caesium-137 according to place of residence and underlying disease*

	No of subjects	Median (interquartile range) ^{137}Cs (Bq/gK)	Difference Mann-Whitney U	p Value
Place of residence:				
Western Isles	60	2·54 (1·25 to 3·73)		
Glasgow	218	0·47 (0·26 to 0·66)	700·5	<0·001
Other parts of Scottish mainland	101	0·42 (0·24 to 0·71)	389·0	<0·001
England	25	0·46 (0·22 to 0·70)	99·0	<0·001
Underlying disease (excluding subjects in Western Isles):				
Essential hypertension	167	0·46 (0·28 to 0·62)		
Renovascular disease	35	0·47 (0·31 to 0·70)	2676·5	0·43
Primary hyperaldosteronism	22	0·68 (0·38 to 0·81)	1389·5	0·06
Other	129	0·40 (0·20 to 0·66)	9764·0	0·17

Caesium concentrations are expressed in relation to body concentration of potassium.

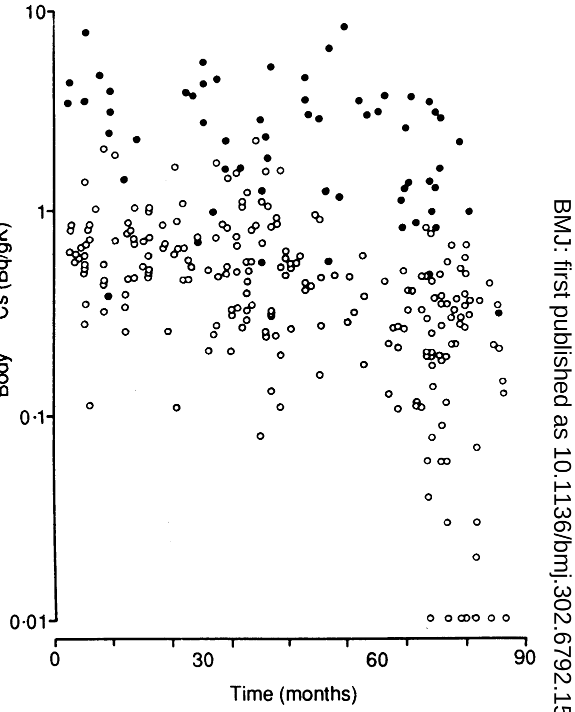

FIG 1—*Body concentrations of caesium-137 in 60 patients from Western Isles (●) (gradient=−0·0053, t=−3·52, p<0·001 by linear regression on log scale) and 218 from Glasgow area (○) (gradient=−0·008, t=−8·72, p<0·001) during 1979-86. All measurements taken before Chernobyl accident*

^{137}Cs concentrations fell significantly during 1979-86 in both islanders (p<0·001) and patients from the Glasgow area (p<0·001) (figure). Discharges of ^{137}Cs from Sellafield into the Irish Sea and fallout of ^{137}Cs also fell during the study (table II).[15,16] Regional differences in fallout usually relate to differences in rainfall, but there were no large differences in rainfall in the Western Isles (Benbecula) and the Glasgow area (table II).

TABLE II—*Discharges of radiocaesium from Sellafield reprocessing plant and rainfall in Western Isles and Glasgow, 1978-1985*

Year	Discharge from Sellafield (Bq/year) ^{137}Cs	^{134}Cs	^{137}Cs:^{134}Cs	Annual rainfall (mm) Western Isles (Benbecula)	Glasgow
1978	$4·0\times10^{15}$	$4·0\times10^{14}$	10·3	1166	1074
1979	$2·6\times10^{15}$	$2·4\times10^{14}$	10·8	1391	1133
1980	$3·0\times10^{15}$	$2·4\times10^{14}$	12·5	1408	1076
1981	$2·4\times10^{15}$	$1·7\times10^{14}$	14·1	1488	1172
1982	$2·0\times10^{15}$	$1·4\times10^{14}$	14·3	1417	1182
1983	$1·2\times10^{15}$	$8·9\times10^{13}$	13·5	1250	1054
1984	$4·3\times10^{14}$	$3·5\times10^{13}$	12·3	1376	1000
1985	$3·3\times10^{14}$	$3·0\times10^{13}$	11·0	1313	1178

DIET AND ENVIRONMENT OF ISLANDERS

North Uist is one of the Outer Hebridean Isles on the north west coast of Scotland (fig 2). It is roughly circular, about 29 km in diameter, and is bordered by the Atlantic Ocean and the Minch. The island's centre is covered with peat, heather, and coarse grasses and has numerous freshwater lochs. Most islanders live on the narrow fertile strip of coastal grassland on the island's northern, western, and southern sides (the machair) or in the small port Lochmaddy.

Twenty two patients lived on the machair, and most owned sheep and cattle with access to the shore (table III). Nearly all the island's sheep and cattle graze on the machair and some also graze inland during summer and winter. The prevailing winds blow seaspray several kilometres inland. Thus most of the island's inhabitants, livestock, and grasslands are exposed to the sea.

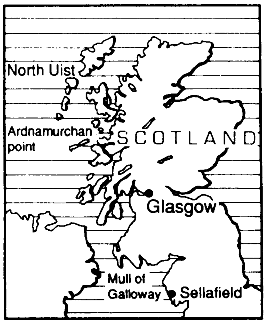

FIG 2—*Map of Scotland and North of England*

TABLE III—*Diet and other characteristics of islanders related to body concentration of* ^{137}*Cs*

	Concentration of radiocaesium		
	Top third	Middle third	Bottom third
No of patients	11	10	11
Body ^{137}Cs (Bq/gK)	3·85-7·78	2·44-3·78	0·59-2·33
Live within 400 m of shore	9	9	10
Live on machair	9	6	7
Own sheep and cattle with access to shore	9	7	6
Use seaweed as food, fertiliser, or livestock feed	10	8	5
Burn peat on open fire	10	9	9
Mean intake local lamb (meals/week)	2·8	1·9	2·0
Mean intake local milk (l/week)	4·3	1·5	0·7
Mean intake local fish (meals/week)	1·1	1·0	1·4
No eating local vegetables (in season)	11	8	8

TABLE IV—*Analysis of radiocaesium concentrations by high resolution gamma ray spectrometry*

	No of samples	Median radiocaesium (Bq/kg or Bq/l)			
		^{137}Cs	^{134}Cs	^{137}Cs:^{134}Cs	Range
Uist lamb*	1	92·9	0·570	164	—
Minch cod*	1	23·1	0·720	32	—
Coastal grasses†	6	21·6	0·250	86	34-192
Moorland grasses†	3	135·9	0·650	209	200-230
Urine from Uist subjects	12	2·01	0·013	155	59-435
Urine from mainland subjects‡	7	0·336	0·004	84	36-100

*Samples chosen because had highest ^{137}Cs concentration. Measured as Bq/kg wet weight.
†Caesium measured as Bq/kg dry weight.
‡Five subjects had no detectable ^{134}Cs and have been excluded from analysis. Median value significantly different from that for urine from Uist subjects ($p<0·001$ for each isotope).

Islanders often ate locally produced foods, particularly milk, mutton, and potatoes (table III). Patients with the highest concentrations of ^{137}Cs drank more local milk than those with lower concentrations, and there were similar trends for consumption of local lamb and vegetables. Local fish was not an important part of the diet. Indeed the patient with the highest ^{137}Cs concentration ate no fish. One patient in the top third of the range for ^{137}Cs ate venison occasionally, and one patient in the bottom third ate local mushrooms, but otherwise these foods, which sometimes contain high levels of radiocaesium,[17 18] were not a feature of the islanders' diet.

RADIOCAESIUM IN FOOD AND OTHER SAMPLES

We found ^{137}Cs in all samples analysed. Comparative data were not available for all foods, but in a small number of samples ^{137}Cs concentrations were higher in Uist milk (median 1·6 Bq/l; n=4) than in mainland milk (0·11 Bq/l; n=2), and in Uist lamb (16·0 Bq/kg) n=4) than in mainland lamb (13·1 Bq/kg; n=2). The ^{137}Cs concentration of Minch fish (20·8 Bq/kg; n=4) was greater than that of fish from the North Sea (7·8 Bq/kg; n=3).[22] High ^{137}Cs concentrations were also found in seaweed (31·9 Bq/kg; n=2), sand (11·0 Bq/kg; n=3), and peat (4·0 Bq/kg; n=6) from North Uist.

Using these data and assuming a half life of ^{137}Cs of 110 days we calculate by first order kinetics that an islander whose regular weekly intake included 0·6 kg local lamb, 4 l (7 pints) local milk, 0·2 kg local fish and 1·4 kg local potatoes would have a ^{137}Cs concentration around 2·1 Bq/gK, with lamb and milk contributing most of this. The patient with the highest body concentration in North Uist (7·78 Bq/gK) lived 50 m from the Minch coast at the southernmost part of the island and owned sheep and cattle with access to the shore and to inland grasses; ^{137}Cs concentrations in the meat from his sheep (92·9 Bq/kg) and in milk (2·8 Bq/l), seaweed (37·2 Bq/kg), sand (12·5 Bq/kg), and peat (4·6 Bq/kg) from his farm were the highest we found on the island. He claimed that he ate meat from his sheep four to six times a week, drank 2 l (3·5 pints) of home produced milk weekly but never ate fish. The concentration of ^{137}Cs in his lamb and milk would be sufficient to maintain his observed body content of ^{137}Cs.

We detected ^{137}Cs in all and ^{134}Cs in most of the samples analysed by high resolution gamma ray spectrometry (table IV). ^{134}Cs was found in Uist lamb and Minch cod, but was not detected in island or mainland milk. The Uist herbage samples all contained measurable amounts of ^{134}Cs, the ratio of ^{137}Cs to ^{134}Cs for the moorland sites (209) being greater than that observed in coastal grasses (86). ^{134}Cs was found in the urine of all islanders tested and in seven of 12 Glasgow controls, the other five controls having low urinary ^{137}Cs concentrations (table IV). The urinary ^{137}Cs concentration in islanders (median 2·01 Bq/l) was six times higher than that in Glasgow controls (0·336 Bq/l), a similar excess to that of total body ^{137}Cs concentrations.

Discussion

Before the Chernobyl accident in 1986 most ^{137}Cs in humans had been assumed to be derived from the atmospheric testing of nuclear weapons; ^{137}Cs fallout is carried to earth in rain and taken up by plants, thereby entering the human food chain. Milk and meat are the principal sources, together accounting for 60-80% of total intake.[11]

Our study confirms a preliminary report that patients from the Western Isles have higher body ^{137}Cs concentrations than do patients from the Scottish mainland.[3] Values similar to those found in island patients were recorded at Harwell, Oxfordshire, in 1964, after atmospheric weapons testing during 1961-2,[16] and values 100 times higher were found in Alaska and Finland, also in 1964.[19]

We measured body ^{137}Cs concentrations in islanders with hypertension but found no evidence (apart from in hyperaldosteronism) that ^{137}Cs concentrations differed in patients with different types of hypertension or in patients with diseases other than hypertension (table I). Because the principal determinant of body ^{137}Cs is dietary intake our results suggest that islanders consume more ^{137}Cs than do people on the mainland.

We considered three explanations for increased ^{137}Cs concentrations in islanders. Firstly, higher rainfall over the islands may produce greater fallout. Figures from the Meteorological Office, however, indicate that during 1978-85 rainfall was only marginally higher in the Western Isles than in the Glasgow area (table II).

The second possibility is that fallout is the same but that conditions on the island provide greater than usual transfer of isotope to the islanders' diet. For example, island milk may contain more ^{137}Cs than mainland milk because Uist cattle graze on peat based grasses and plants grown on peat take up more radiocaesium than do those on clay based soils.[20] Sediments of lochs may also retain and slowly release ^{137}Cs,[21] which could also lead to increased ^{137}Cs concentrations in milk. Thus high body ^{137}Cs in islanders might be explained by unusually prolonged retention and release of ^{137}Cs deposited in the 1960s when fallout was greater. Such mechanisms have resulted in foodchains capable of concentrating radiocaesium up to one hundred fold.[17]

The third possibility is that the excess ^{137}Cs comes from waste discharged into the sea by Sellafield, which is the main source of ^{137}Cs in British coastal waters.[22] ^{137}Cs discharged into the sea has been shown to be taken up by west Cumbrian coastal grasses,[23] and sheep and cattle consuming these grasses have much higher ^{137}Cs concentrations.[24,25] The concentration of ^{137}Cs in seawater around the Western Isles is higher than that in other British seas because discharges from Sellafield are carried northwards up the west coast by gulf stream currents.[26] Dilution of the isotope by lateral movement of water is reduced to the east by the coast and to the west by the Outer Hebridean Islands and onshore westerly winds. From the Mull of Galloway to Ardnamurchan Point at the entrance to the Minch the ^{137}Cs concentration in seawater is diluted less than five times after a journey of 240 km.[26]

The best evidence that Sellafield is an important source of radioactive caesium in the Western Isles is the finding of ^{134}Cs in most of the samples analysed. ^{134}Cs is produced by reprocessing nuclear fuels[22] but not by explosion of nuclear weapons,[27] and thus finding ^{134}Cs confirms reprocessing as the ultimate source.

Further information on the ultimate source and food chain may be derived from an analysis of the ratio of ^{137}Cs to ^{134}Cs. If Sellafield is the source the ratio in different samples along the chain should be higher than that of the discharge, partly because ^{134}Cs has a shorter half life than ^{137}Cs, and partly because ^{137}Cs will be added from bomb fallout. We found ratios of ^{137}Cs:^{134} ranging from 34 to 435, all higher than ratio of discharges from Sellafield (11:1 in 1985).[15] Our studies would have benefited from more samples, but this was prevented by the Chernobyl nuclear accident. Moorland vegetation showed the greatest radiocaesium concentration and highest ^{137}Cs:^{134}Cs ratio (209). The richer coastal soils, which are constantly influenced by seawater showed a lower radiocaesium concentration and ^{137}Cs:^{134}Cs ratio (86). Locally produced lamb (164) and islanders' urine (155) showed intermediate ratios, suggesting similar contributions derived from both types of vegetation.

Unexpectedly we found ^{134}Cs in the urine of seven Glasgow control subjects. We do not know the exact sources of milk and lamb consumed by Glaswegians, but it traditionally comes from south west Scotland and not from the Western Isles. Some of these southern farms are coastal and closer to Sellafield than is North Uist. Thus, radiocaesium from Sellafield could also enter the food chain of Scottish mainlanders. A recent description of increased body radiocaesium concentrations in a Japanese family during a visit to Britain supports these findings. Togo *et al* argued that the Japanese food chain would have a radiocaesium component from fall out similar to that in Britain, and attributed the increased concentrations to discharges from Sellafield.[28]

The amount of additional radioactivity to which our patients were exposed is small. Taking the whole body radiation dose to adults as 5·4 µSv a year for every 1 Bq/gK of ^{137}Cs,[1] the average islander would be exposed to only 13·7 µSv a year from ^{137}Cs, which is much less than the current recommended limit for exposure to members of the public of 1000 µSv a year, including 500 µSv a year from discharges from a single site.[29] Moreover, exposure at 13·7 µSv a year represents only a 7% increase in the radiation already received from the body's naturally occurring ^{40}K (200 µSv/year), which is itself only a small fraction of the total radiation received from all natural sources, currently estimated to be 2500 µSv a year in Britain.[30]

In conclusion, inhabitants of the Western Isles have raised body radiocaesium concentrations. The immediate source is excess dietary intake of isotope. The presence of ^{134}Cs in the food chain and in the urine of western islanders indicates that at least part of the excess comes from discharges of radiocaesium from Sellafield reprocessing plant. Although the radiation risk is small it is important to record that an isotope discharged into the sea as waste may return to land at a considerable distance from the site of discharge and enter the human food chain.

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