Radionuclide monitoring in Northern Ireland of the Chernobyl nuclear reactor accident

B J Gilmore, K Cranley

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SUMMARY
Northern Ireland received higher radiation doses due to the radionuclide contamination from the Chernobyl nuclear reactor accident than did the south of England. Levels of radioactive iodine (131I) and caesium (137Cs) in cows' milk in Northern Ireland increased to 166 and 120 Bq/l respectively in May 1986, but had decreased by factors of one million, and of twenty-five, respectively, by 1 September 1986. The resultant radiation doses represent less than one per cent of those received by a Northern Ireland individual over a period of 40 years from natural background radiation sources. The added risk to any individual from the Chernobyl accident will therefore be very small and may best be judged in the context of the enormously greater risk of death due to potentially preventable diseases, such as smoking-related lung cancer, and coronary heart disease.

INTRODUCTION
The Chernobyl reactor accident occurred in the Ukraine, USSR, on 26 April 1986 and the radionuclide cloud reached its peak over Northern Ireland on 3 May 1986, based on increased dose rates measured in Newtownards, Co. Down,1,2 retrospective computer modelling,3 and meteorological data.4 A considerable number of radionuclides have been detected in the Chernobyl emissions in the UK,5 of which 131I, 137Cs and 134Cs are major long-lived beta and gamma emitters of great importance in the human food chain. 131I has a physical half-life (see glossary of terms) of eight days and is particularly important, as it is concentrated principally in the thyroid gland, with a biological half-life in the normal thyroid of about 120 days.6 137Cs and 134Cs, which have physical half-lives of 30 years and two years respectively, become uniformly distributed throughout the whole body and are slowly excreted from the body with a biological half-life of about 110 days.6 These radionuclides can enter the human body from a number of sources including rainwater, milk, leafy vegetables and meat. Cows' milk is a particularly sensitive early indicator and a potential major contributor to human radiation dose.

The radiation dose from ingestion of a particular radionuclide is determined by the total radioactivity ingested and the fraction retained, the types and energies of radiations emitted by the radionuclide, the biological pathways for the...
radionuclide throughout the body, its concentration in particular organs and the length of time it remains in the body (the effective half-life). This investigation reports a number of radionuclide measurements made on rainwater, drinking water and cows’ milk, from which estimates are made of typical radionuclide ingestions and resultant radiation doses. Consideration is then given to the possible effects of these radiation doses on the Northern Ireland population.

Thyroid uptake monitoring was also performed on four Northern Ireland students who returned from the USSR following the Chernobyl accident. One of these students was evacuated from Kiev, 100 km from Chernobyl, in the days following the accident. The other three Northern Ireland students were 650–900 km from the affected area and remained in the USSR for a further two months.

METHODS

Levels of $^{131}$I and $^{137}$Cs in rainwater, drinking water and pasteurised cows’ milk from the Belfast, Lisburn and Rostrevor areas were measured at dates between 3 May and 5 June 1986. Further measurements for $^{137}$Cs in cows’ milk were made up to 1 September 1986. Limited facilities precluded measurements of $^{134}$Cs and of radionuclide levels in other food products.

Samples were collected of rainwater draining from roofs in Belfast, Lisburn and Rostrevor. Mains drinking water samples were collected from the taps in the same houses. The water in the mains was supplied from reservoirs of the Department of the Environment, Water Division. Cows’ milk samples were collected as delivered by the milkman in these areas.

Ten millilitres of each sample were placed in a sealed glass test tube and counted in a Tracerlab Gamma Set 500 counter with 3" × 3" NaI(Tl) crystal and 1" × 2" (deep) well. $^{131}$I was measured using a 300–420 keV energy window to detect the 366 keV gamma ray photons of $^{131}$I and a 647–677 keV window was used to detect the 660 keV gamma ray photons of $^{137}$Cs. Each sample was counted for 4–14 hours to achieve acceptable statistical accuracy and these counts were then compared with background counts determined for the same time period for a distilled water sample, prepared before Chernobyl, which contained no radioactivity. The activities of $^{131}$I and $^{137}$Cs in each sample were determined by comparing the significant counts in the appropriate channel with the counts obtained from accurately known standards. A correction was made for Compton scatter of 660 keV photons of $^{137}$Cs to the window used for $^{131}$I. Allowances for radioactive decay from collection time to measurement time were made to give the radionuclide activity in each sample at collection time. The minimum detectable levels were 18 Bq/l for $^{131}$I and 3 Bq/l for $^{137}$Cs and experimental errors for the measurements were ±23 Bq/l for $^{131}$I and ±8 Bq/l for $^{137}$Cs at 99.7% confidence limits.

The effective half-lives of $^{131}$I and $^{137}$Cs in cows’ milk were then determined by applying a computed least-squares exponential fitting procedure to the available experimental data from this investigation and that reported by the Northern Ireland Office for pasteurised milk for all the manufacturing plants in Northern Ireland between 5 and 19 May 1986. These Department of Agriculture samples had been measured by British Nuclear Fuels plc using similar gamma ray spectrometry techniques.

Direct measurements of the amounts of $^{131}$I in the thyroids of local members of the public were not made as these would have been close to the limits of

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detected. The amounts of $^{131}\text{I}$ in the thyroids of typical Northern Ireland adults were estimated instead from the mean measured levels of $^{131}\text{I}$ in fresh milk on 5–19 May on the assumption that these levels continued to decrease with the mean computed effective half-life of $^{131}\text{I}$ in milk. It was assumed that milk was the chief source of $^{131}\text{I}$ and that 30% of ingested $^{131}\text{I}$ is deposited in the thyroid, where it remains with an effective half-life of 7.6 days. Daily milk consumption per person for Northern Ireland is estimated to be 0.36 litres (0.63 pints).7,8

Thyroid activity monitoring for the four Northern Ireland students who returned from the USSR was performed using an Eckco 2" x 2" NaI(Tl) scintillation detector, a J & P high voltage supply, amplifier, pulse height analyser and scaler (Table I). Count measurements were made to detect 330–400 keV and 605–700 keV photons corresponding to $^{131}\text{I}$ and $^{137}\text{Cs}$ respectively. The NaI(Tl) crystal was kept flush with its collimator to increase detection efficiency of photons from the neck. Counting times of 15 minutes were used to achieve acceptable statistical accuracy. Background count measurements were made with the same energy windows to determine whether the counts detected were significant above background. Measurements were also made with accurately known standards in a perspex neck phantom in order to quantify the count-to-becquerel (see glossary) relationship for these radionuclides. Twenty-five millilitre samples of blood and urine obtained from the students were monitored for $^{131}\text{I}$ and $^{137}\text{Cs}$, using the method described for radionuclide level assessment.

### Table I

| Student | A | B | C | D |
|---------|---|---|---|---|
| Sex     | M | F | F | F |
| Age     | 20| 20| 20| 20|
| Residence in USSR | Kiev | Leningrad | Voronezh | Leningrad |
| Distance from Chernobyl (km) | 100 | 900 | 650 | 900 |
| Return date from USSR | 1 May 1986 | Late June 1986 | Late June 1986 | Late June 1986 |
| Monitoring date at Royal Victoria Hospital | 6 May 1986 | 30 June 1986 | 30 June 1986 | 8 July 1986 |

**RESULTS**

For rainwater, the maximum level of $^{131}\text{I}$ found was 94 becquerels per litre (Bq/l) in a sample collected in Lisburn on 3 May 1986. $^{137}\text{Cs}$ data is not available for this sample, which corresponded with the arrival of the Chernobyl cloud over Northern Ireland. $^{131}\text{I}$ levels in rainwater decreased below the levels of detectability (18 Bq/l) within a few days. No drinking water sample was found to contain detectable levels of $^{131}\text{I}$ or $^{137}\text{Cs}$ at any time.

For cows' milk, the maximum level of $^{131}\text{I}$ found for this investigation (Regional Medical Physics Service data) was 91 Bq/l for a sample from Belfast on 7 May 1986, which compares with a maximum value of 104 Bq/l reported in the Greater Belfast area on 5 May 1986,1,2 and the peak value for Northern Ireland of 166 Bq/l (see Table II). The mean $^{131}\text{I}$ levels in cows' milk in three regions of Northern Ireland are shown in Fig 1 with data from this investigation for Belfast,
Fig 1. $^{131}$I levels in fresh pasteurised cows’ milk. Regional Medical Physics Service data (Belfast, Lisburn and Rostrevor) (●). Northern Ireland Office data (mean of all values for Northern Ireland) (○). The curve represents the least-squares exponential fit to Northern Ireland Office data.

Lisburn and Rostrevor areas for comparison. The maximum level of $^{137}$Cs for this investigation was 51 Bq/l found for both Belfast and Rostrevor areas on 11 May, which compares with the maximum value of 78 Bq/l reported for the Greater Belfast area on 8 May,¹ ² and the peak value for Northern Ireland of 120 Bq/l (Table II).

**Table II**

Maximum levels (Bq/l) of $^{131}$I and $^{137}$Cs in cows’ milk in Northern Ireland

| Region                              | $^{131}$I       | Date     | $^{137}$Cs | Date     |
|-------------------------------------|-----------------|----------|------------|----------|
| Belfast, Lisburn and Rostrevor*     | 91              | 7 May 1986| 51         | 11 May 1986|
| Greater Belfast, South Antrim and North Down** | 104         | 5 May 1986| 78         | 8 May 1986|
| South Down and East Armagh**        | 156             | 5 May 1986| 96         | 8 May 1986|
| Co. Fermanagh, Co. Tyrone, Co. Londonderry & N. Antrim** | 166         | 5 May 1986| 120        | 7 May 1986|

*Regional Medical Physics Service data.
**Northern Ireland Office¹ data.

The $^{137}$Cs levels in cows’ milk in the Belfast, Lisburn and Rostrevor areas (Regional Medical Physics Service data), and those from Greater Belfast, South Antrim and North Down (Northern Ireland Office data) are shown in Fig 2. $^{137}$Cs levels in milk delivered in the Belfast, Lisburn and Rostrevor areas had further

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Fig 2. $^{137}$Cs levels in fresh pasteurised cows’ milk.
Regional Medical Physics Service data (Belfast, Lisburn and Rostrevor) (●).
Northern Ireland Office data (Greater Belfast, South Antrim and North Down) (O).
The curve represents the least-squares exponential fit to all data.

decreased to less than 3 Bq/l by 1 September 1986. The effective half-lives for $^{131}$I levels in cows’ milk were 2.3, 3.3 and 4.1 days for the three regions in Northern Ireland defined in Table II, and the mean effective half-life for $^{131}$I was estimated at 3.3 days. The effective half-life for $^{137}$Cs in cows’ milk was 15 days. The radionuclide monitoring data for the four Northern Ireland students who returned from the USSR are given in Table III.

**TABLE III**

*Radionuclide monitoring data for four Northern Ireland students after return from USSR*

| Student | A   | B   | C   | D   |
|---------|-----|-----|-----|-----|
| Thyroid activity (Bq) |     |     |     |     |
| $^{131}$I | 280 ± 50* | < 20 | < 20 | < 20 |
| $^{137}$Cs | 84 ± 47* | < 20 | < 20 | < 20 |
| Blood activity (Bq/l) |     |     |     |     |
| $^{131}$I | Not monitored | < 18 | < 18 | < 18 |
| $^{137}$Cs | monitored | < 3 | < 3 | < 3 |
| Urine activity (Bq/l) |     |     |     |     |
| $^{131}$I | < 18 | < 18 | < 18 | < 18 |
| $^{137}$Cs | < 3 | < 3 | < 3 | < 3 |

*Statistical errors of ± 3sd (99.7% confidence levels) are given. Thyroid activity estimate is subject to a further uncertainty of ± 50% due to possible geometry differences between thyroid depth in subject and $^{131}$I standard depth in the neck phantom.

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DISCUSSION

These measurements and those reported by the Northern Ireland Office\(^1,2\) confirmed that \(^{131}\)I and \(^{137}\)Cs levels in milk were only a small fraction of the respective Derived Emergency Reference Levels of 2000 Bq/l and 3600 Bq/l,\(^9\) at which consideration would be given to introducing counter-measures to reduce radiation doses to the public. The finding that radionuclide levels were below the levels of detection in drinking water is not surprising in view of the large dilution provided by the reservoir water supply system. A knowledge of the effective half-life of a radionuclide in a food source such as milk is one important factor in assessing the potential radiation dose to humans from food consumption. The effective half-lives found for \(^{131}\)I and \(^{137}\)Cs in cows' milk show reasonable agreement, considering experimental errors, with figures of 4.9 days\(^10\) for \(^{131}\)I and 10.5 days\(^11\) for \(^{137}\)Cs reported for Great Britain for the removal of \(^{131}\)I and \(^{137}\)Cs from grassland by both physical decay and natural removal processes following the Windscale nuclear reactor accident in October 1957.

The amount of \(^{131}\)I accumulated in the thyroid of a typical Northern Ireland adult consuming an average of 0.36 litres of fresh pasteurised milk daily is estimated to have increased to 45 Bq in mid-May and then decreased to about 4 Bq by mid-June 1986. This estimated amount for Northern Ireland residents is considerably greater than the mean value of 18 Bq measured for the thyroids of eight adults from South London between 10 and 22 May.\(^12\) These had been measured in a specially constructed room with low background radiation. The higher result for Northern Ireland is readily understandable since there was less rain in the south of England during the passage of the Chernobyl cloud, whereas Northern Ireland had sporadic heavy rain leading to greater radionuclide deposition on vegetation. Radionuclide levels in the south of England\(^5,12\) have been lower than those reported for Northern Ireland in this investigation.

Using the Northern Ireland Office data from 5 to 15 May 1986, and assuming an intake of 0.36 litres of cows' milk daily with effective half-lives of 3.3 days for \(^{131}\)I and 15 days for \(^{137}\)Cs, the figures for radionuclide ingestion of 270 Bq \(^{131}\)I and 780 Bq \(^{137}\)Cs are obtained. 80 Bq \(^{131}\)I would be deposited in the thyroid, resulting in a thyroid committed dose equivalent of 0.12 mSv for an average Northern Ireland adult with a 20 g thyroid.\(^13\) Radioacesium ingestion would contribute a further 0.02 mSv\(^13\) giving a total thyroid dose equivalent of 0.14 mSv. This figure is only 0.3% of the annual dose limit (50 mSv)\(^14\) for the thyroids of members of the public, and may also be compared with a figure of approximately 1 mSv\(^15\) for the population mean annual thyroid dose, which arises due to natural sources. The radiation doses to the thyroids of children would be several times greater, mainly due to the relative size of their thyroid glands\(^11\) and other factors such as greater milk consumption. Ingestion of these radionuclides from milk would result in a committed effective dose equivalent of 0.024 mSv using standard conversion factors\(^13\) for converting ingested radioactivity to effective dose equivalent.

Radiation doses have also been received by the Northern Ireland population from ingestion of radionuclides in other foods and from irradiation by external gamma rays from radioactivity deposited on the ground. Considerably smaller radiation doses have also been received from Chernobyl fall-out through other mechanisms including radionuclide inhalation, external irradiation from the passing Chernobyl cloud, and beta contamination on the skin. The National Radiological Protection Board have estimated the total effective dose equivalent to Northern Ireland...
adults due to the Chernobyl cloud as 0.18 mSv over a lifetime.\textsuperscript{16} This excess radiation dose to the whole body due to the Chernobyl accident represents less than one per cent of a typical dose of 76 mSv\textsuperscript{17} which would be received by a Northern Ireland individual due to natural background radiation sources over a 40-year period.

From the measured thyroid activity of student A on 6 May (Table III), and making the pessimistic assumption that radionuclide ingestion occurred on 26 April, and allowing for \textsuperscript{131}I decay, it is estimated that this student accumulated approximately 700 Bq (±50\%) of \textsuperscript{131}I in his thyroid within a few days of the accident. This is considerably greater than the estimated 80 Bq \textsuperscript{131}I accumulated for a typical Northern Ireland adult within the month following the Chernobyl accident, clearly confirming that the population living within 100 km of Chernobyl was much more severely affected by the accident than the Northern Ireland population.

Student A was one of 99 UK students recalled by the Foreign and Commonwealth Office from the affected Minsk and Kiev regions around Chernobyl. Thyroid monitoring was performed at Heathrow airport by the National Radiological Protection Board\textsuperscript{18} on these 99 students (in seven by a similar gamma ray spectrometry method applied in this investigation and in the remainder using a hand-held portable monitor). The NRPB estimated that the students' thyroids contained between 800 and 6900 Bq of \textsuperscript{131}I at the time of measurement. Allowing for radioactive decay, student A's thyroid would have contained 550 Bq \textsuperscript{131}I (±50\%) and 84 Bq \textsuperscript{137}Cs (±50\%) when monitored at Heathrow, indicating that he was one of the least contaminated of the United Kingdom students evacuated from the USSR. The thyroid dose estimate for student A was 1 mSv, which represents 2\% of the ICRP's annual dose limit for the thyroid of members of the public.\textsuperscript{14} Student A was reassured that the radioactivity in his thyroid was well within recommended limits and need not be a matter for concern.

The finding that radionuclide contamination was below the levels of detection for the other three students is not unexpected in view of their large distance from Chernobyl, and since any \textsuperscript{131}I in their thyroids would have decayed to approximately 1\% in the intervening two-month period before measurement. While it is clearly difficult to attempt a precise dose estimate for these students so long after the accident, the negative findings indicate that radionuclide contamination for the students was not serious.

It is worth considering the long-term consequences of the Chernobyl fallout on the health of the Northern Ireland population. All exposures to ionising radiations carry some risk of radiogenic cancers, which is the main concern in the present circumstances. The mean time for the appearance of radiogenic cancer is 20 years, and it is common practice to evaluate the risk of radiogenic cancer or death due to radiogenic cancer over a period of 40 years. The risk can be expressed numerically as the number of additional cancers or cancer deaths expected, if a population of one million is exposed to 10 mSv of radiation. For thyroid cancer, the risk is estimated at five cancer deaths and 100 non-fatal thyroid cancers per 10,000 man-sieverts to the thyroid,\textsuperscript{14} while the risk for all cancers is 125–150 deaths per 10,000 man-sieverts to the whole body.\textsuperscript{14, 19}

Assuming that milk consumption is the main contributor to thyroid dose, it would appear from the earlier estimates that the Northern Ireland population (1.57 million)\textsuperscript{6} would have received a collective thyroid dose (see glossary) of the order of 200 to 300 man-sieverts. Based on this estimate and the risk factors, it appears...
that there may be a small number of non-fatal thyroid cancers in Northern Ireland as a result of the Chernobyl fall-out. From the NRPB's most recent estimate of 0.18 mSv per person, the Northern Ireland population would have received a collective whole body dose of about 300 man-sieverts. This would suggest a potential of three additional cancer deaths in Northern Ireland due to the Chernobyl accident over a period of 40 years, which may be compared with the 3290 cancer deaths which occurred in Northern Ireland in 1984, giving a projected estimate of 100,000 over 40 years. Even this small number of additional cancer deaths might not all become manifest, since death could occur first due to other causes. Additional cancers due to Chernobyl in Northern Ireland will not be distinguishable from the much greater number of cancers due to other causes. It is evident from this comparison that the added risk to any individual is very small indeed and may best be judged in the context of the enormously greater risk of death due to potentially preventable diseases such as smoking-related lung cancer or coronary heart disease. 

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GLOSSARY

*Physical half-life:* The time taken for the number of atoms of a particular radionuclide in a sample to decay to half that number.

*Biological half-life:* The time taken for the number of atoms of a substance in an organ of the body to decrease to half that number, by biological excretion.

*Effective half-life:* The time taken for the level of a particular radionuclide in subsequent samples (e.g. thyroid or fresh milk) to decrease due to both physical decay and biological or natural removal processes.

*Becquerel (Bq):* The unit of measurement of radioactivity, equivalent to one nuclear transformation per second.

*Committed dose equivalent:* The radiation dose received over a lifetime by an organ from ingested radioactivity. Radiation dose equivalent and radiation dose have specific definitions, but for the present purposes have the same meaning.

*Millisievert (mSv):* The sievert (Sv) is the unit of measurement of radiation dose equivalent.

*Committed effective dose equivalent (Whole body dose):* Some organs and tissues of the body have a greater sensitivity to radiation than others. Calculation of the committed effective dose equivalent takes this into account by multiplying the committed dose equivalent for the organ by an appropriate weighting factor, and then adding the components for each organ to give the effective (whole body) dose. In a similar way, the radiation doses for each radionuclide are calculated separately and then summed to give the whole body dose.

*Collective dose equivalent:* The collective dose equivalent (expressed in man-sieverts) to a population is calculated by multiplying the population total by the mean dose equivalent per person. The collective dose equivalent may apply to the whole body or any specified organ.
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