Human Measurement Data: An Aid to Model Validation

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Abstract

Measurement of radionuclides in individuals provides one of the most direct methods of evaluating the results of modelling procedures used to estimate the uptake and distribution of radionuclides in humans, from both environmental and occupational exposure. An examination of human measurement data may also enable any regional variations in the radionuclide content of individuals to be considered. This paper describes a comparison of human measurement data for inhabitants of Seascale, a village close to the UK Sellafield nuclear reprocessing plant, with model predictions. These model predictions were based on methodology utilised to assess the risks of radiation-induced leukaemia and other cancers in children and young persons living in the village. The benefits and difficulties associated with this approach to model validation are also discussed.

Introduction

Radionuclide measurement in individuals provides the most direct method of estimating the uptake and distribution of radionuclides in humans, from both environmental and occupational exposure. These data can be extremely difficult to obtain, however, and it is usually necessary to estimate radiation exposure using modelling procedures. This is particularly true when estimating radiation doses to members of the public from environmental exposure to radionuclides. One method which can be adopted to establish the adequacy of the results of these modelling procedures, is to compare the predicted radionuclide contents of individuals with measurement data for a subset of the population under examination. This paper summarises an example of one study where such comparisons have been undertaken.

The National Radiological Protection Board (NRPB) has recently completed a study to reassess the risks of radiation induced leukaemia and other cancers in children and young persons in Seascale, at the request of the Committee on Medical Aspects of Radiation in the Environment (COMARE) [17]. As part of this reassessment, the internal radiation doses received by the inhabitants of the village from all sources of ionising radiation were evaluated. Human measurement data were also available for some inhabitants of the village. By comparing the measured concentrations of radionuclides, with the predicted values based on the assessment methodology, some indication of the robustness of the modelling procedure for estimating internal doses can be gained.

A secondary objective of the examination of measurement data for the Seascale population was to determine whether the concentrations of radionuclides in these individuals were elevated relative to populations in other regions of the UK. Seascale measurement data were therefore compared with similar data obtained for other areas of the UK, where available.

Methodology

Modelling predictions: The modelling procedures utilised for the assessment are described in detail elsewhere [17]. Internal doses were assessed for the inhabitants of the village by considering all sources of ionising radiation to which they might be exposed. Evaluations were based on estimations of the annual inhalation and inge-

stion intakes of a range of radionuclides, in association with the most recent dosimetric and metabolic models [8,9,10]. These calculated intakes were derived, as far as possible, from direct measurements of radionuclides in the environment and from habit data. Where insufficient measurement information was available, intakes were estimated using a combination of discharge data and environmental transfer models. For the purposes of this comparative study, the radionuclides of interest were isotopes of plutonium and caesium only. The assessment identified the primary sources of exposure to plutonium for the Seascale population as releases from the Sellafield plant and fallout from nuclear weapons testing. Exposure to radiocaesium also originated from these two sources, in addition to exposures to accidental releases following the fires at Windscale in 1957, and Chernobyl in 1986. The major route of intake for both plutonium and caesium radionuclides is by the ingestion of contaminated foods.

Measurement data: Human measurement data for the Seascale population were available in the form of radionuclide concentrations in tissues *post-mortem*, in fetal tissues and also in vivo whole body monitoring data. The origin and nature of these measurements are summarised in Table 1. Measurements of radionuclide concentrations in *post-mortem* tissues provides an invaluable method of assessing radionuclide intake. Concentrations of plutonium and caesium radionuclides were available for tissues taken from the Seascale population. These measurements derive from a study undertaken in the 1980s [13], which forms part of the NRPB's autopsy programme. All individuals were greater than age 50 at time of death and none had been occupationally exposed to radionuclides. The subjects died during the period 1982-1985: cardiovascular disease was the cause of death in most cases. The risk assessment also considered doses received by individuals in-utero, since fetal development is the most sensitive period of human life [18]. A small number of fetal tissue measurements were also available for the Seascale area [14]. Plutonium concentrations have been measured in whole fetuses terminated during the second trimester of pregnancy. In addition to tissue measurements, a large number of whole body radiocaesium measurements have been undertaken for the Seascale population.

Several data sets were available from the mid-1950s to the present day, numbering some 959 measurements [1,2,3,5,6,7,12,15, 16]. From these the mean radiocaesium body content of individuals in Seascale for each year was determined. It should be noted that data for the period 1957-61 relate to the measurements of individuals resident near to the Sellafield site but who were also employed at the plant [12,16]. The possibility that a contribution to the radiocaesium body burden of these individuals has arisen from occupational exposure cannot therefore be excluded.

Regional variations: The possibility of elevated concentrations of plutonium and caesium radionuclides in Seascale inhabitants, relative to populations in other areas of the UK was examined. Human tissue data have been correlated for several other areas of the UK [4,13,14]. Extensive whole body monitoring data has taken place in many regions of the UK, largely as a consequence of monitoring following the Chernobyl accident in 1986. For the purposes of this study, the whole body radiocaesium levels in Seascale inhabitants were compared with individuals from Oxfordshire only.

Results

A comparison of the mean measured and predicted tissue concentrations for Seascale

inhabitants is presented in Table 2. For *post-mortem* tissues, the results of the comparisons suggest that the modelling procedures employed for the Sellafield reassessment tend to overestimate plutonium-239+240 concentrations in the skeleton and liver, but lead to underestimations of the concentrations of these radionuclides in the lung. In the case of fetal tissue measurements, concentrations of plutonium which would be expected in the fetus at full term, based on estimated annual intakes by the mother, were compared with concentrations measured in fetuses following termination. This comparison proved to be difficult, since the measured concentrations were below the limit of detection of the radioanalytical technique employed. Support is nevertheless given to the values predicted using the assessment methodology, since the measurements were unable to detect the presence of plutonium in these tissues. The comparison of mean measured and predicted whole body radiocaesium contents in groups of subjects for the period 1957-1989 is illustrated in Figure 1. This comparison generally shows good agreement prior to 1969 but, overestimations for the late 1970s and early 1980s.

The results of the investigation into any regional variations in radionuclide tissue concentrations are shown in Table 3. Plutonium tissue mean concentrations only are shown. The mean concentrations derive from a range of measurements, as shown for one organ, liver, in Figure 2. Concentrations of plutonium-239+240 in west Cumbria were increased relative to those determined in tissues acquired from other areas of the UK. Plutonium concentrations in fetal tissues were below the limit of detection of the measurement technique and consequently cannot be compared adequately with results obtained from other areas of the UK. The comparison between Cumbrian and Oxfordshire tissue concentrations however, does not indicate enhanced levels of plutonium in tissues obtained from west Cumbria. It should be stressed that the high detection activity quoted for the fetal tissues obtained from Seascale is purely as a consequence of low chemical yield in the radioanalytical procedure and occurred for one case only. In the other cases examined, detection activities were similar to those for Oxfordshire cases.

In order to investigate any regional variations in the radiocaesium content of individuals, whole body measurements of radiocaesium have been compiled for Oxfordshire and west Cumbria between 1961 and 1968 [11,15], and also post -Chernobyl [6]. These data are shown in Figures 3 and 4, respectively. It should be noted that in Figure 3 the mean values of the caesium-137 to potassium quotient are given, whereas in Figure 4, data are expressed as total radiocaesium content. For both studies, the radiocaesium body content for residents near the Sellafield plant are shown to be approximately twice that of Oxfordshire residents.

Discussion

The results of the comparison of measured and predicted concentrations in tissues *post-mortem*, suggest that the modelling procedures employed for the Seascale reassessment tend to overestimate plutonium concentrations in the skeleton and liver, but lead to underestimations of the concentrations of these radionuclides in the lung. The reason for this discrepancy may be due to the assumption made in the modelling procedure that the absorption to blood of all inhaled plutonium compounds could be characterised as Type M (moderate absorption rate) [10]. In reality, the absorption rate of the inhaled plutonium is likely to be intermediate between that assumed for Type M compounds and that assumed for Type S (slow absorption rate) which would result in a greater retention in the lung and lower concentrations in the liver and skele-

ton. The default absorption parameters for Type M material were used in the modelling procedure since it is the more cautious assumption with regard to dose to the red bone marrow, the tissue thought to be of interest when considering leukaemia induction.

The comparison of predicted and measured fetal tissue concentrations can only provide an indication of the robustness of the modelling procedures used for estimating radionuclide deposition within the fetus, since the tissues available for measurement were terminated during the second trimester of pregnancy, whereas the predicted values relate to concentrations measured at full term. The change in radionuclide content of the fetus which would be expected during the third trimester of pregnancy is unclear, since the variation in placental discrimination throughout pregnancy is unknown. Nevertheless, since the determinations carried out were unable to detect the presence of any plutonium, the comparison does give considerable support to the conclusion that uptake of plutonium to the fetus is unlikely to have been significantly underestimated by the modelling procedure.

The comparison of mean measured and predicted whole body radiocaesium contents generally shows good agreement prior to 1969. The overestimation in the predicted whole-body contents for the late 1970s and early 1980s is probably due to the pessimistic assumption that all fish consumed by the Seascale residents was locally caught: consumption of foods of marine origin providing a large contribution to the radiation dose received during these years. An increase in both measured and predicted values can be observed for 1986, the year of the Chernobyl accident.

The investigation into possible elevated levels of radionuclides in the population of the Seascale area, relative to those in populations from other areas of the UK, indicate higher levels in Seascale residents compared with *some* other regions, where similar data were available. The elevated concentrations of plutonium radioisotopes in *post-mortem* tissues may be due to discharges from the Sellafield site or as a result of higher than average rainfall in the area which would be expected to increase deposition of radionuclides present in the atmosphere as a result of nuclear weapons testing. Regional comparisons of plutonium concentrations in fetal tissues cannot be conclusive, since many of the measured concentrations were below the limit of detection of the radioanalytical technique employed. From the data available, however, there is certainly no evidence of enhanced levels of plutonium in tissues from west Cumbria. Investigations into the regional variations of radiocaesium in populations has shown higher levels in west Cumbria relative to the other regions studied, namely Oxfordshire. For the period 1961-68 shown in Figure 3, the most likely explanations is, once again, the higher deposition of fallout radionuclides as a consequence of higher levels of rainfall. In the risk assessment carried out for COMARE, it has been estimated that the annual average rainfall at Chilton in Oxfordshire was 679 mm during the years 1957-1982; values for the Sellafield area during the period 1945-1970 have been estimated to be 1282 mm. Consequently, deposition of caesium-137 from weapons fallout might be expected to be almost twice that of Oxfordshire. If it is assumed that most of the food consumed by the studied population is locally-produced eg milk, then average body contents near Sellafield due to weapons fallout could be expected to be about twice as high as those in Oxfordshire. The enhanced radiocaesium levels in the Seascale population are once again evident in measurements taken following the Chernobyl accident. This difference is also likely to be due to the high level of rainfall in the area, which would

have increased the deposition of Chernobyl-derived radiocaesium from the atmosphere.

The benefits of using human measurement data for model validation are immediately obvious: it is only measurements of individuals which provide direct evidence of the level of radionuclide uptake by a population. There are disadvantages associated with this approach, however. In order to provide a reliable estimation of the radionuclide uptake by a population it is necessary to have a large number of measurements, to ensure that the distribution of uptake has been adequately represented. Human data are by their very nature scarce and, consequently, the number of individuals in a population for whom direct measurements are available is small. The situation is exacerbated for Seascale, since it is a relatively small community. For the purposes of the comparisons undertaken here, the measured contents of the individuals under study have been taken to be representative of the inhabitants of Seascale as a whole. However, within any population an inherent variation in the radionuclide content of individuals will exist as shown in Figure 2. These variations within populations may be due to biological variations, differences in dietary habits etc. This should be recognised when considering the comparison between predicted and measured values presented here. Nevertheless, it must be emphasised that these human data are direct measurements in members of the Seascale population and, consequently, are invaluable when considering the radionuclide uptake to the residents of this village.

Conclusions

Human measurement data have been shown to be a valuable source of information to substantiate the methods and data utilised in the COMARE reassessment. Indeed, it is only measurements of individuals which provide direct evidence of the level of radionuclide uptake to a population. In general, this comparison has shown that the data and modelling procedures used to determine the radiation doses to the Seascale inhabitants do not underestimate radionuclide intakes and, indeed, for the majority of cases overestimate them. Consequently, the dose estimates used in the COMARE reassessment are more likely to be overestimates than underestimates.

A comparison of human measurement data over different regions suggests that radionuclide levels in the population of Seascale are generally higher than other areas for which data were available. The reason for these enhanced levels are unclear, but may well be due to the relatively high levels of rainfall experienced in the region which increase the deposition of radionuclides from the atmosphere.

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Figure 1: Measured and predicted radiocaesium body contents

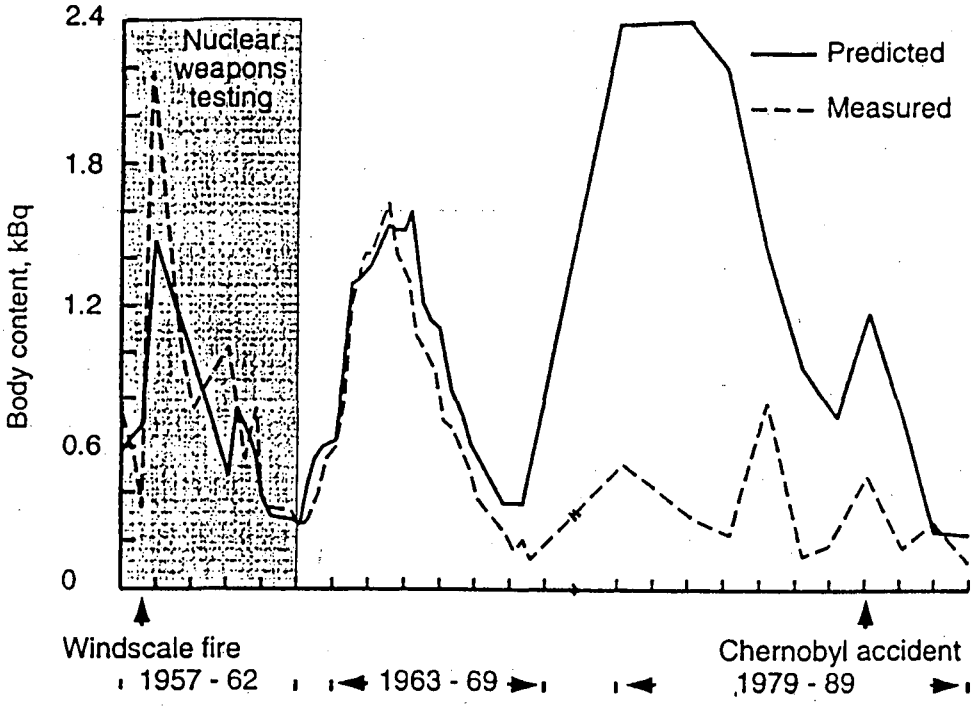

Figure 2: **Plutonium concentralions: liver**

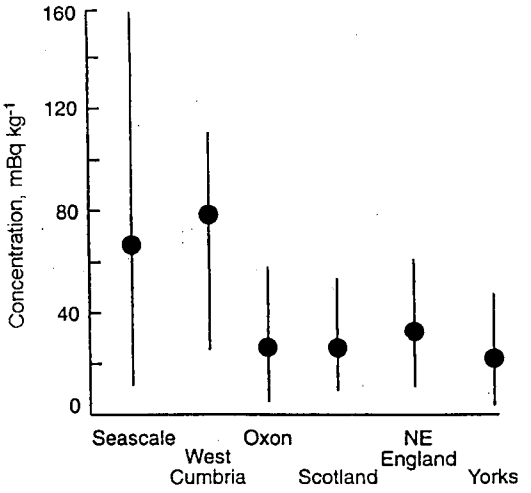

Figure 3: **Radiocaesium body contents, 1961-68**

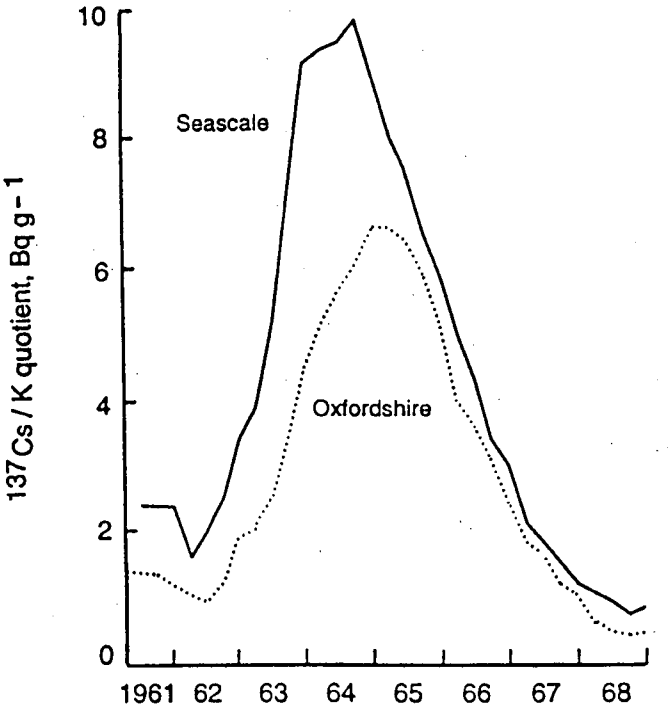

Figure 4: Radiocaesium body content, post-Chernobyl

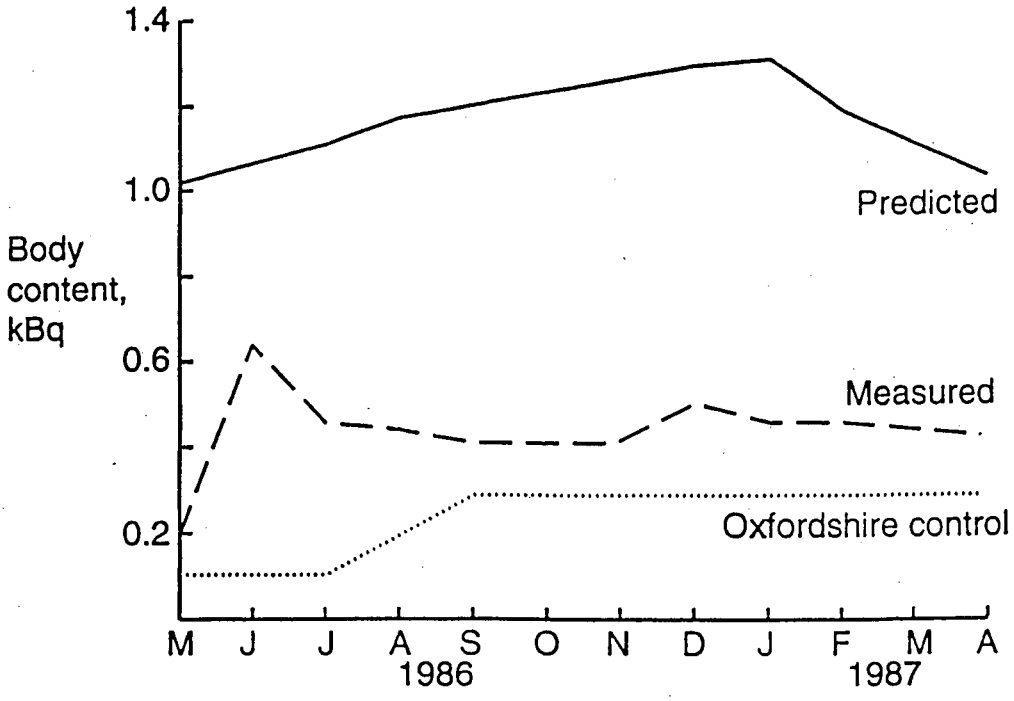

Table 1: Origin and nature of human measurement data

Measurement type	Geographical area	Radionuclides	Number of cases	Reference
Autopsy	Seascale area	$^{239}Pu+^{240}Pu$, ^{137}Cs	7	13
Autopsy	West Cumbria (ex Seascale)	$^{239}Pu+^{240}Pu$, ^{137}Cs	8	13
Autopsy	North East England	$^{239}Pu+^{240}Pu$, ^{137}Cs	16	13
Autopsy	Oxfordshire	$^{239}Pu+^{240}Pu$, ^{137}Cs	16	13
Autopsy	Yorkshire	$^{239}Pu+^{240}Pu$, ^{137}Cs	12	4
Autopsy	Central Scotland	$^{239}Pu+^{240}Pu$, ^{137}Cs	21	13
Fetus	Seascale area	$^{239}Pu+^{240}Pu$	2	14
Fetus	West Cumbria	$^{239}Pu+^{240}Pu$	14	14
Fetus	Oxfordshire	$^{239}Pu+^{240}Pu$	12	14
Whole body measurement	Seascale	^{134}Cs, ^{137}Cs	959	1-3, 5-7, 11,12,15
Whole body measurement	Oxfordshire	^{134}Cs, ^{137}Cs	30	6, 11

Table 2:
Comparison of measured and predicted tissue concentrations for Seascale inhabitants

		Concentration (mBq kg^{-1})		
Tissue	Radionuclide	Measured	Predicted	Predicted/measured ratio
Skeleton	$^{239}Pu+^{240}Pu$	7	153	22
Liver	$^{239}Pu+^{240}Pu$	68	342	5
Lung	$^{239}Pu+^{240}Pu$	12	2	< 1
Fetus	$^{239}Pu+^{240}Pu$	AND <1.5	0.1	-
Liver	^{137}Cs	4,000	11,000	3

Table 3:
Regional variations in mean measured plutonium tissue concentrations

	Concentration (mBq kg^{-1})			
Geographical area	Skeleton	Liver	Lung	Fetus*
Seascale area	7	68	12	AND < 1.5
West Cumbria ex Seascale	9	77	13	AND < 0.02
Oxfordshire	5	27	2	AND < 0.004–0.02
Central Scotland	5	26	2	–
NE England	5	31	3	–
Yorkshire	7	20	3	–

* AND = Activity not detected followed by the 95% detection activity