



**Centre for
Ecology & Hydrology**

NATURAL ENVIRONMENT RESEARCH COUNCIL

Radioactivity in the Environment 1984-2014

Abstracts of published papers

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This booklet contains the abstracts of journal papers written by members of the Radioecology Group since 1984. Some relevant publications by members of the Soil Ecology Section are also included. The information is provided to disseminate more widely the results being produced by the Section. The list is not exhaustive. In addition to the titles listed, the staff have also produced contract reports for customers, conference papers, book chapters and articles in the popular press.

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ALLEN, S.E. 1984.

Radionuclides in natural terrestrial ecosystems.

Science of the Total Environment, 35, 285-300.

DOI: [http://dx.doi.org/10.1016/0048-9697\(84\)90009-3](http://dx.doi.org/10.1016/0048-9697(84)90009-3)

Ecosystems to be found in the maritime temperate zone are described. The part played by vegetation, animals and soils in the distribution and movement of radionuclides is discussed, with particular reference to natural systems. Biomass activities have been compiled for ^{137}Cs and $^{239+240}\text{Pu}$ in woodland and moorland ecosystems. The data indicate that these ecosystems are more effective at intercepting and retaining radionuclides than are agricultural systems and that many undisturbed soils function as efficient sinks.

HORRILL, A.D. 1984.

Radionuclide levels and distribution in grazed saltmarsh in west Cumbria.

Environmental Pollution 8, 265-280.

DOI: [http://dx.doi.org/10.1016/0143-148X\(84\)90027-2](http://dx.doi.org/10.1016/0143-148X(84)90027-2)

Radionuclide levels and distribution in the surface silts and vegetation of a grazed saltmarsh have been investigated as they are the basis for pathways to man via grazing animals and, to a lesser extent, wildfowl. Comparisons are made with a previously described ungrazed area in the same estuary complex. Accumulation of radionuclides appears to be primarily a physical process dominated by tidal factors. A second important influence is the physical structure of the vegetation present on the saltmarsh. The high levels of variability found within a distance of a few hundred metres, c. 20-460 pCi g⁻¹ in the case of ^{137}Cs , have important implications when sampling schemes are considered for research or monitoring programmes.

PARKINSON, J.A. & HORRILL, A.D. 1984.

An assessment of variation due to laboratory and field conditions in the measurement of radionuclides.

Nuclear Instruments and Methods in Physics, 223, 598-601.

DOI: [http://dx.doi.org/10.1016/0167-5087\(84\)90717-8](http://dx.doi.org/10.1016/0167-5087(84)90717-8)

One of the main problems with environmental studies is due to the large amount of variation encountered in field materials. Data obtained during studies into the distribution and movement of radionuclides in terrestrial environments in West Cumbria were found to be suitable for assessments of both spatial and analytical variation. Plutonium measurements on vegetation samples taken from samples of grazed and ungrazed saltmarsh and pasture fields having different management regimes were used in the assessment. Bulk samples of *Halimione portulacoides* and *Pteridium aquilinum* were analysed 14 and 11 times respectively and gave coefficients of variation of 9.18% and 7.91%. These were considered to be realistic estimates of analytical variability. Coefficients of variation for results of single plutonium determinations on replicate samples obtained from the pasture sites ranged from 23.4% to 33.1%. The data indicated that for the mean value obtained for a site to fall within 10% of the true mean at 95% probability, the numbers of samples to be taken at these sites ranged from 22 to 44. The grazed and ungrazed saltmarsh sites gave coefficients of variation of 95.70% and 47.2% respectively. These sites, however, would be stratified into vegetation classes, within class coefficients of variation being much lower at 16-24%.

HOWARD, B.J. 1985.

Aspects of the uptake of radionuclides by sheep grazing on an estuarine saltmarsh. 1. The influence of grazing behaviour and environmental variability on daily intake.

Journal of Environmental Radioactivity, 2, 183-198.

DOI: [http://dx.doi.org/10.1016/0265-931X\(85\)90008-6](http://dx.doi.org/10.1016/0265-931X(85)90008-6)

Sea water contaminated with diluted radioactive effluent originating from the Sellafield reprocessing plant inundates salt marshes in the Esk estuary in west Cumbria (UK). Much of the radioactivity on the saltmarsh vegetation was found to be associated with a surface deposit of silt, brought onto the area during tidal inundation. Large temporal variations in the radionuclide concentrations of the vegetation were found, these being due probably to seasonal fluctuation in the extent of silt deposition.

The grazing habits of sheep were studied on one of these salt marshes and the consequent ingestion of radionuclides by the sheep was estimated. The sheep ingested different quantities of radionuclides according to time of year as a result of a combination of radionuclides on the saltmarsh vegetation and the seasonal grazing behaviour of the sheep.

HOWARD, B.J. & LINDLEY, D.K. 1985.

Aspects of the uptake of radionuclides by sheep grazing on an estuarine saltmarsh. 2. Radionuclides in sheep tissues.

Journal of Environmental Radioactivity, 2, 199-213.

DOI: [http://dx.doi.org/10.1016/0265-931X\(85\)90009-8](http://dx.doi.org/10.1016/0265-931X(85)90009-8)

The transfer of ^{137}Cs , ^{238}Pu , $^{239/240}\text{Pu}$ and ^{241}Am to sheep which graze a saltmarsh in the Esk estuary 7 km south of the Sellafield reprocessing plant in west Cumbria (UK), has been estimated.

The concentrations of gamma-emitting radionuclides and of ^{238}Pu , $^{239/240}\text{Pu}$ and ^{241}Am were measured in liver, lung, muscle, kidney and bone from saltmarsh ewes and lambs. ^{137}Cs concentrations in the soft tissues were similar in liver, lung and muscle but were consistently higher in kidney and much lower in bone. The highest concentration of the transuranics was found in liver.

Transfer coefficients and concentration factors were calculated for both ewes and lambs. The concentration of ^{137}Cs in the tissues of 5-month old lambs was higher than in those of their mothers. Therefore, a higher transfer coefficient was obtained for lamb muscle ($1.8 \times 10^{-1} \text{ d kg}^{-1}$) than for ewe muscle ($6.4 \times 10^{-2} \text{ d kg}^{-1}$). Concentration factors were consistently higher for ^{137}Cs than for the transuranics.

(HARKNESS, D.D.), HARRISON, A.F. & BACON, P.J. 1986.

The temporal distribution of bomb 14-C in a forest soil.

Radiocarbon, 28, 328-337.

Patterns of 14C enrichment in the superficial plant debris and mineral soil horizons of an established woodland have been monitored at regular intervals during the past 15 years. These data are compared with a model evaluation of carbon turnover based on the recorded changes in atmospheric 14C concentration since AD 1900.

Leaf litter and decomposing plant debris are characterised by steady-state turnover values of ca 2 and ca 8 years, respectively. A two-component system of 'fast' (ca 20 yr) and 'slow' (ca 350 yr) cycling carbon is indicated for the surface (0-5 cm) soil humus; below 10 cm, the 'fast' component is rare (< 5%).

Selective microbial humification of leaf litter, branch, and root debris is proposed to explain a decay of several years in the peak transfer of 'bomb' 14C to the soil carbon pool.

LOWE, V.P.W. & HORRILL, A.D. 1986.

Transfer of radionuclides to man from greylag geese *Anser anser* and wigeon *Anas Penelope* grazing the salt marshes at Ravenglass.

Journal of Environmental Radioactivity, 4, 101-121.

DOI: [http://dx.doi.org/10.1016/0265-931X\(86\)90036-6](http://dx.doi.org/10.1016/0265-931X(86)90036-6)

The greylag goose and wigeon are both traditional quarry of wildfowlers. Populations of these birds in the Ravenglass estuary feed and roost on salt marshes containing radioactivity originating from the Sellafield reprocessing plant. There is therefore, via the meat, a potential pathway for the transfer of radionuclides to man.

The birds' intake of gamma-emitting fission and activation products, including ^{60}Co , ^{95}Nb , ^{95}Zr , ^{106}Ru , ^{144}Ce , ^{134}Cs , ^{137}Cs , ^{154}Eu , ^{155}Eu and ^{241}Am , was investigated by examining their concentrations in vegetation from the feeding areas and in their faeces. Muscle and liver tissues were also analysed. Only ^{134}Cs and ^{137}Cs were detected and quantified in breast muscle; 58 Bq kg⁻¹ and 158 Bq kg⁻¹ fresh weight were recorded for goose and wigeon respectively. Estimated transfer coefficients for ^{137}Cs were very similar for both species: $5.9 \times 10^{-1} \text{ d kg}^{-1}$ for greylag goose and $5.7 \times 10^{-1} \text{ d kg}^{-1}$ for wigeon.

A single person would have had to consume in excess of the total number of wigeon shot or the total population of geese to obtain even 1% of his or her Annual Limit on Intake. In a 'worst case' scenario, wigeon could have transferred 5.63 MBq (152 μCi) of ^{137}Cs inland from the tidal areas of the estuary but, because they never fed above the tide line, they, in fact, transferred no radionuclides inland during the study period.

HOWARD, B.J., BERESFORD, N.A., (BURROW, L., SHAW, P.V. & CURTIS, E.J.C.) 1987.

A comparison of caesium 137 and 134 activity in sheep remaining on upland areas contaminated by Chernobyl fallout with those removed to less active lowland pasture.

Journal of the Society for Radiological Protection, 7, 71-73.

DOI: <http://dx.doi.org/10.1088/0260-2814/7/2/003>

Caesium contamination of vegetation in some upland areas of the United Kingdom after the Chernobyl accident remained persistently higher than many anticipated. Consequently, some sheep continued to graze vegetation containing sufficiently high caesium activity to maintain tissue activity above the limits adopted for slaughter in the United Kingdom (1,000 Bq kg⁻¹ fresh weight). In this study the caesium activity in lambs remaining on affected upland areas has been compared with that of lambs removed to a lowland site. The former lost very little caesium activity from the end of July to mid September owing to the persistently high caesium activity in the pasture. The transfer coefficient to lamb muscle (0.79 day kg⁻¹) was 6 times higher than that previously estimated from lowland field studies. Lambs removed to much less contaminated lowland pasture rapidly lost their Cs activity with an initial biological half life of 10 days.

JONES, H.E., HARRISON, A.F. & DIGHTON, J. 1987.

A ⁸⁶Rb bioassay to determine the potassium status of trees.

New Phytologist, 107, 695-700.

DOI: <http://dx.doi.org/10.1111/j.1469-8137.1987.tb00907.x>

A bioassay method has been developed to test for potassium deficiency in forest trees; it is based on the metabolic uptake by excised roots of ⁸⁶Rb from 5 x 10⁻⁶ M rubidium chloride solution during a period of 15 min. *Betula pubescens* Ehrh seedlings were grown in sand culture supplied with Hewitt's nutrient solution containing K at concentrations between 1 and 200 mg⁻¹. A negative curvilinear relationship was demonstrated between uptake by the seedlings of ⁸⁶Rb from the rubidium chloride solution and the concentration of K previously supplied in the growth medium. When roots of intact plants were immersed in ⁸⁶Rb-labelled solution for 15 min. less than 1% of ⁸⁶Rb taken up was translocated to the shoots. A similar response curve relating ⁸⁶Rb uptake to K supplied to growing plants, was demonstrated when *Picea sitchensis* (Bong.) Carr seedlings were grown in peat culture with K added at 0 to 400 mg⁻¹. In three field trials of the bioassay, roots were excised from *P. sitchensis* and *Pinus contorta* Douglas ex Loud growing on peat or peaty gley plots where different amounts of fertiliser had been added to give a range of degrees of K deficiency or from unfertilised control plots. The patterns of ⁸⁶Rb uptake by excised roots indicated that the method is potentially useful for the rapid determination of K deficiency in forest trees.

LIVENS, F.R. (BAXTER, M.S.) & ALLEN, SE. 1987.

Association of plutonium with soil organic matter.

Soil Science, 144, 24-28.

DOI: <http://nora.nerc.ac.uk/id/eprint/500671>

A significant association of environmental plutonium with the organic components of U.K. soils has recently been demonstrated by sequential leaching experiments on samples influenced by discharges from both the Dounreay and Sellafield nuclear fuel reprocessing plants. This relationship has been further studied by alkali extraction, fractional precipitation, and dialysis to isolate both the humic and fulvic acid fractions of a Cumbrian soil. The ^{239/240}Pu activities of these extracts were 31 and 7.7 Bq g⁻¹ respectively, greater than the activity of the bulk soil (5.9 Bq g⁻¹). Gel filtration on Sephadex gels G-50 and G-150 further showed that the humic acid extract is composed of relatively large molecules, with approximately 65% of the plutonium in the largest of these; fulvic acid is of lower molecular weight, and its plutonium content is distributed more evenly throughout the molecular weight spectrum. In both humic and fulvic acids, iron is concentrated in the largest molecular weight (>150 000) fractions.

DIGHTON, J. & HORRILL, A.D. 1988.

Radiocaesium accumulation in mycorrhizal fungi *Lactarius rufus* and *Inocybe longicystis* in upland Britain following the Chernobyl accident.

Transactions of the British Mycological Society, 91, 335-337.

DOI: [http://dx.doi.org/10.1016/S0007-1536\(88\)80223-7](http://dx.doi.org/10.1016/S0007-1536(88)80223-7)

Ratios of the radionuclides ^{137}Cs to ^{134}Cs show that a large proportion of the ^{137}Cs present in the fruit bodies is derived from pre-Chernobyl fallout from atomic weapons testing. This suggests accumulation of the radionuclide by fungal mycelia.

LIVENS, F.R. & (BAXTER, M.S.) 1988.

Chemical associations of artificial radionuclides in Cumbrian soils.

Journal of Environmental Radioactivity, 7, 75-86.

DOI: [http://dx.doi.org/10.1016/0265-931X\(88\)90043-4](http://dx.doi.org/10.1016/0265-931X(88)90043-4)

The distributions of radionuclides in the surface layer of four soils of contrasting types from west Cumbria, UK, have been studied in detail. All the soils contain enhanced levels of artificial radionuclides derived from low-level discharges both to sea and to atmosphere from the British Nuclear Fuels reprocessing plant at Sellafield. The bulk of the activity is held in the top 15 cm of soil profiles, suggesting that radionuclide mobility is limited. Sequential extraction experiments have identified major associations of plutonium with organic matter and of caesium with silicates but there is no preferential association of ruthenium with any single soil component.

LIVENS, F.R. & (BAXTER, M.S.) 1988.

Particle size and radionuclide levels in some west Cumbrian soils.

Science of the Total Environment, 70, 1-17.

DOI: [http://dx.doi.org/10.1016/0048-9697\(88\)90248-3](http://dx.doi.org/10.1016/0048-9697(88)90248-3)

Four west Cumbrian soils of contrasting types, together with an estuarine silt sample, have been separated into different particle size fractions by a combination of sieving and settling techniques. The sub samples thus isolated were analysed by quantitative gamma ray spectrometry for several nuclides, principally ^{137}Cs , ^{106}Ru and ^{241}Am , followed by chemical separation and alpha spectrometric determination of $^{238/239}\text{Pu}$ and ^{240}Pu . A simple empirical method of correction for differing sample sizes, and hence counting geometries, was developed for gamma spectrometry and was found to give good results. The correction technique is based on calibrating each detector over a range of sample depths in the container using a multi-nuclide standard, and hence calculating an efficiency correction factor.

In all the samples, the radionuclides were concentrated into the finer size fractions, with the clay-sized ($>2\text{ }\mu\text{m}$) particles showing enrichments of plutonium from 1.5 to 40 times that in the bulk samples, of americium from 2 to 40 times and of ^{137}Cs from 3 to 35 times. The enhancement was greatest for all radionuclides in a sandy soil with very low clay content (0.2% by weight) and it was found that, as the abundance of fine particles increased, so the concentration effect decreased. No evidence was found for a simple relationship between organic content and radionuclide activity, although the organic matter does have some effect.

LIVENS, F.R. & (LOVELAND, P.J.) 1988.

The influence of soil properties on the environmental mobility of caesium in Cumbria.

Soil Use & Management, 4, 69-75.

DOI: <http://dx.doi.org/10.1111/j.1475-2743.1988.tb00739.x>

The interaction of caesium isotopes with soil has been widely investigated and the influence of important soil properties studied. From the results of such work and a detailed knowledge of the physicochemical properties of soils it is possible to classify Cumbrian soil according to its ability to immobilise caesium. The 'immobilisation capacity' is a reflection principally of the clay mineral content and type, organic content, pH, ammonium content and potassium status. Although this is not quantifiable, the immobilisation capacity permits ranking of the soils and indicates which areas may give rise to persistent caesium problems. Combination of the soil sensitivity classification with deposition data for Cumbria indicates that the mountainous region in the southwest of the county is the most vulnerable. This conclusion is supported by field evidence, since the area identified coincides closely with that where sheep movement and slaughter are restricted and where caesium remains persistently available to the plant-animal chain.

LIVENS, F.R. & QUARMBY, C. 1988.

Sources of variation in environmental radiochemical analysis.

Environment International, 14, 271-275.

DOI: [http://dx.doi.org/10.1016/0160-4120\(88\)90002-5](http://dx.doi.org/10.1016/0160-4120(88)90002-5)

Both collection and laboratory treatment of samples contribute to the uncertainty in the final analytical results. A detailed study of a pasture field showed that, for realistic sample numbers, field variation was in the range 20-40%. Routine analysis of a reference soil, coupled with the use of some simple criteria for the acceptance of analytical results, showed that laboratory variation could be maintained at well below 10%, generally much less than the field variation.

LIVENS, F.R. & (RIMMER, D.L.) 1988.

Physiochemical controls on artificial radionuclides in soils.

Soil Use & Management, 4, 63-69.

DOI: <http://dx.doi.org/10.1111/j.1475-2743.1988.tb00738.x>

Radionuclides in the environment come from a wide range of sources, some natural and some artificial. Their biogeochemical behaviour is influenced both by their own physicochemical properties and by those of the soil with which they interact. The source of the radionuclides is important, as are any changes in physicochemical characteristics that occur during transport and deposition. Once in the soil further reactions can occur as the radionuclides equilibrate. These include immobilisation by ion exchange and precipitation and remobilisation by complexing and dissolution. Land management and environmental changes that alter conditions in the soil result in changes in the interactions of radionuclides with the soil and thereby to changes in mobility in the soil.

LOWE, V.P.W. & HORRILL, A.D. 1988.

Ecological half life of caesium in roe deer.

Environmental Pollution B, 54, 81-87.

DOI: [http://dx.doi.org/10.1016/0269-7491\(88\)90138-8](http://dx.doi.org/10.1016/0269-7491(88)90138-8)

Biological half-lives for various radionuclides have been determined for many animals kept in the laboratory or under controlled conditions. Only occasionally has it been possible to determine the ecological half-lives of radionuclides in wild animals, where the contamination has occurred in their natural habitats.

Following the fallout from the Chernobyl accident and its subsequent ingestion by wildlife, no one knew how long it would take for the wild animals to eliminate the radionuclides, and in particular radiocaesium, from their bodies. In this study of roe deer (*Capreolus capreolus*), bucks (males) were shot at weekly/fortnightly intervals from mid May until the end of July, as part of the annual cull on an area, which included some young forestry (Stone Chest - National Grid Reference NY480790), planted in 1971/72.

The ratio of ^{137}Cs : ^{134}Cs typical of the Chernobyl fallout was seldom observed in these animals due to the highly variable concentrations of ^{137}Cs originating from bomb fallout. Therefore, ^{134}Cs was used instead because its presence was almost entirely due to the Chernobyl fallout.

After using a log10 transformation of the ^{134}Cs concentrations, a significant ($P > 0.01$) regression was obtained which accounted for 85% of the variation. From this regression, the ecological half-life for ^{134}Cs was found to be 28.3 days.

BERESFORD, N.A. 1989.

Field observations of ^{110m}Ag , originating from the Chernobyl accident, in west Cumbrian vegetation and soil samples.

Journal of Radiological Protection, 9, 281-283.

DOI: <http://dx.doi.org/10.1088/0952-4746/9/4/008>

During the analyses of sheep and cattle tissues following the Chernobyl accident the only nuclide routinely detected in the short count times being used, apart from the caesium isotopes and ^{131}I , was ^{110m}Ag in the liver. The activity concentration of ^{110m}Ag and ^{134}Cs is compared in the liver of sheep slaughtered during the first four months after deposition from various sites in Cumbria. The ratio of ^{110m}Ag to ^{134}Cs ranged from 0.09 to 1.67 with a coefficient of variation of 102%.

From initial analyses of vegetation samples it was evident that ^{110m}Ag was a relatively minor constituent of the Chernobyl deposit, when compared with isotopes such as ^{134}Cs , ^{137}Cs , ^{103}Ru and ^{106}Ru . The ratio of ^{110m}Ag : ^{134}Cs was typically between 0.03 and 0.05. It was therefore evident that the transfer of ^{110m}Ag to sheep liver was higher than that of ^{134}Cs . Caesium-134 is used in this article in preference to ^{137}Cs as a comparison to ^{110m}Ag since ^{134}Cs is likely to originate solely from Chernobyl, whereas, in the area of Cumbria from which the samples were taken, relatively high levels of ^{137}Cs resulting from weapons testing and the Windscale accident of 1957 could be expected.

A review of the available literature showed that the behaviour of silver in the terrestrial environment is relatively poorly understood. A research programme to study the behaviour of ^{110m}Ag resulting from Chernobyl was therefore put into progress. The most important aspect of this work is the transfer of ^{110m}Ag to the liver of ruminants and results for laboratory and field studies conducted in 1986 and 1987 have been presented elsewhere. In this article, results for field observations of the transfer of ^{110m}Ag to vegetation are discussed.

BERESFORD, N.A. 1989.

The transfer of Ag-110m to sheep tissues.

Science of the Total Environment, 85, 81-90.

DOI: [http://dx.doi.org/10.1016/0048-9697\(89\)90307-0](http://dx.doi.org/10.1016/0048-9697(89)90307-0)

The transfer of ^{110m}Ag from the Chernobyl fallout to sheep tissues is discussed. ^{110m}Ag was only detected in the liver and occasionally the brain of the sheep analysed. The transfer of ^{110m}Ag associated with perennial ryegrass, harvested soon after deposition in 1986, was greater to the liver of both ewes and lambs than that of ^{137}Cs . Transfer coefficients of ^{110m}Ag for lamb liver exceeded those for ewe livers. However, in a 1987 field study there was no difference between transfer coefficients of ^{110m}Ag for ewes and lambs. It is suggested that there is a slow turnover of Ag-110m in the liver of sheep and that, unlike radiocaesium, ^{110m}Ag from the Chernobyl fallout did not become more available once incorporated into plant tissues.

BERESFORD, N.A., (LAMB, C.S., MAYES, R.W.,) HOWARD, B.J. & (COLGROVE, P.M.) 1989.

The effect of treating pastures with bentonite on the transfer of Cs-137 from grazed herbage to sheep.

Journal of Environmental Radioactivity, 9, 251-264.

DOI: [http://dx.doi.org/10.1016/0265-931X\(89\)90047-7](http://dx.doi.org/10.1016/0265-931X(89)90047-7)

The persistence of high levels of ^{134}Cs + ^{137}Cs in vegetation of certain upland areas of the United Kingdom has prompted investigations into possible methods of reducing levels in sheep tissues.

The introduction of the clay mineral, bentonite, into the diet of ruminants has been shown to reduce the uptake of caesium from the gut. The effects of treating pasture with bentonite at two rates (single or repeated application of 80 g m^{-2}) on the intake and transfer of ^{137}Cs to sheep tissues was investigated. Whilst there were reductions in the radiocaesium activity concentrations of tissues of sheep grazing pasture treated at both rates, transfer coefficients were only affected for sheep on the repeated treatment. However, ewes grazing the repeatedly treated pasture experienced a loss in body weight (18%) associated with a decrease in herbage intake (39%).

Considerable variation in the herbage intake by individual ewes and lambs, both between and within treatments, showed the need for direct intake measurements in order to determine relevant transfer coefficients in field experiments.

Transfer coefficients for ^{137}Cs of 0.33 d kg^{-1} and 1.61 d kg^{-1} were obtained for muscle of control ewes and lambs respectively.

HOWARD, B.J. 1989.

A comparison of radiocaesium transfer coefficients for sheep milk and muscle derived from both field and laboratory studies.

Science of the Total Environment, 85, 189-198.

DOI: [http://dx.doi.org/10.1016/0048-9697\(89\)90317-3](http://dx.doi.org/10.1016/0048-9697(89)90317-3)

Radiocaesium transfer coefficients for sheep milk and muscle have been reviewed and recommendations for a range of F_{fs} and F_{ms} for different situations are presented. The inherent problems in determining transfer coefficients from both field and laboratory studies are discussed.

HOWARD, B.J. & BERESFORD, N.A. 1989.

Chernobyl radiocaesium in an upland sheep farm ecosystem.

British Veterinary Journal, 145, 212-219.

DOI: [http://dx.doi.org/10.1016/0007-1935\(89\)90073-0](http://dx.doi.org/10.1016/0007-1935(89)90073-0)

Following the deposition of radiocaesium from the Chernobyl accident the movement and slaughter of sheep in upland areas of west Cumbria, Scotland and Wales was restricted. Studies on the radioecology of ^{137}Cs and ^{134}Cs have been conducted at a farm within the affected area of west Cumbria since July 1986. The radiocaesium activity of upland sheep was found to decline when they were brought on to the farms' enclosed pastures and rise when they were returned to the open fell, where the radiocaesium content of vegetation has remained higher than on the pastures. The ^{137}Cs activity concentration of mixed grassland vegetation samples from the fell has declined over the study period, whereas the ^{137}Cs activity of ewes whilst grazing on the fell was higher in summer of 1987 than in autumn of 1986. A number of factors which may have contributed to this discrepancy were investigated and are discussed. It is suggested that husbandry changes would be effective in reducing the number of lambs leaving the restricted areas with radiocaesium activities over the limit (1000 Bq/kg fresh weight ^{134}Cs + ^{137}Cs) set by the United Kingdom authorities.

HOWARD, B.J. & BERESFORD, N.A. 1989.

Radioecology of caesium in upland sheep pastures following the Chernobyl accident.

Proceedings of the Sheep Veterinary Society, 12, 26-33.

ITE's widely dispersed research stations (from Banchory in the north of Scotland to Wareham in southern England) were used to collect vegetation from 500 locations between 10 and 15 days after the peak deposition of Chernobyl fallout. The survey showed that the highest deposition of ^{137}Cs onto vegetation took place in the north and west of the country and occurred where the contaminated air mass coincided with heavy rainfall. Before Chernobyl, the ^{137}Cs in vegetation was chiefly the residue of nuclear weapons testing. ^{137}Cs activity concentrations were generally less than 5 Bq m⁻², even around the Sellafield Reprocessing Plant; they have rarely recently exceeded 50 Bq m⁻² (except for the special case of the saltmarsh vegetation of nearby estuaries). Over much of the country, the ^{137}Cs deposited from the Chernobyl accident is much less than that already accumulated in soil due to nuclear weapons fallout. It is only in some of the most heavily contaminated areas that the ^{137}Cs deposit due to Chernobyl is comparable with or greater than that already present.

HOWARD, B.J., (MAYES, R.W.), BERESFORD, N.A. & (LAMB, C.S.) 1989.

The transfer of radiocaesium from different environmental sources to ewes and suckling lambs.

Health Physics, 57, 579-586.

Indoor experiments are described that compare the transfer of radiocaesium to ewe and lamb tissues from different sources. Lactating ewes were fed either perennial ryegrass contaminated by Chernobyl fallout, or saltmarsh vegetation contaminated by marine discharges from the Sellafield reprocessing plant. The transfer to ewe tissues and milk was greater from the Chernobyl contaminated herbage than from saltmarsh vegetation. Lambs receiving a mixture of vegetation and milk were given radiocaesium from one of the two vegetation sources or from milk obtained from the experimental ewes. Transfer to lamb tissues declined in the order milk > Chernobyl fallout > Sellafield discharge. The radiocaesium transfer to lamb tissues exceeded that to ewe tissues. Transfer coefficients for ^{137}Cs in the Chernobyl fallout were higher than most previously published figures at 0.12 d kg⁻¹ for ewe muscle and 0.50 d kg⁻¹ for lamb muscle. The transfer coefficient for ^{137}Cs from ewe milk to lamb muscle was 1.20 d kg⁻¹.

LIVENS, F.R. & SINGLETON, D.L. 1989.

An evaluation of methods for the radiometric measurement of americium in environment samples.

The Analyst, 114, 1097-1101.

DOI: <http://dx.doi.org/10.1039/AN9891401097>

The presence of substantial amounts of manganese in a series of soil samples (amount 7000 ppm) led to the failure of an established method for the determination of ^{241}Am in soils and environmental samples. A review of alternative approaches led to the development and optimisation of a more robust technique. After acid dissolution, solvent extraction of iron and anion-exchange separation of plutonium isotopes, manganese is removed by cation exchange. Rare earth elements and americium are co precipitated on $\text{Fe}(\text{OH})_3$, separated by anion exchange in nitric acid - methanol, and the remaining impurities removed by anion exchange in nitric acid. Chemical yields are greatly improved and analysis of reference materials gives satisfactory results.

(ANDERSON, S.S.,) LIVENS F.R. & SINGLETON, D.L. 1990.

Radionuclides in grey seals.

Marine Pollution Bulletin, 21, 343-345.

DOI: [http://dx.doi.org/10.1016/0025-326X\(90\)90796-B](http://dx.doi.org/10.1016/0025-326X(90)90796-B)

Milk from live female grey seals (*Halichoerus grypus*) and tissues from dead individuals were analysed for caesium isotopes and for plutonium and americium. The samples were collected at two sites one in the North Sea and one in the north-east Atlantic. Levels of ^{137}Cs in milk were low (mean value 2.9 Bq kg^{-1}) and were only slightly higher in tissues (range $6.4 - 27.5 \text{ Bq kg}^{-1}$). Plutonium and americium levels were at or below detection limits in most samples. There were no differences between the results from the two locations. Radionuclide levels were similar to those in fish species commonly consumed by grey seals.

HORRILL, A.D. & (MUDGE, S.) 1990.

The influence of grassland management on the radionuclide inventory of soils in west Cumbria, UK.

Journal of Environmental Radioactivity, 12, 143-165.

DOI: [http://dx.doi.org/10.1016/0265-931X\(90\)90004-F](http://dx.doi.org/10.1016/0265-931X(90)90004-F)

The ^{137}Cs , $^{239/240}\text{Pu}$, ^{238}Pu , ^{241}Am and ^{40}K activities in soils and vegetation under grassland management in west Cumbria were investigated. Uptake of these radionuclides by the vegetation is affected by the land management practices employed. The more intensively utilised areas have lower concentrations in soils and the plants show reduced uptakes of the artificial radionuclides. It is proposed that this is due to differences in the physical mixing of the soil, natural and artificial chemical additives, contamination of the vegetation with soil by animal usage and the regular cropping of grass for silage. Comparison of the soil data with samples taken on Exmoor indicates that the west Cumbrian samples were enriched by factors of ~ 2.5 for ^{137}Cs and ~ 10 for $^{239/240}\text{Pu}$.

LIVENS, F.R. 1990.

Biogeochemical cycling of radionuclides in the environment.

Analytical Proceedings, 27, 343-344.

DOI: <http://dx.doi.org/10.1039/AP9902700339>

Radionuclides in the biosphere become entrained in the biogeochemical cycling processes which circulate nutrients and other elements around the components of ecosystems. Within any ecosystem, six components can be identified: firstly, producer organisms, largely green plants, which can manufacture food from simple inorganic materials; secondly, macro consumers, mainly animals, which ingest other organisms of organic matter; thirdly, micro consumers, bacteria or fungi which derive energy from decomposing organic detritus; fourthly, organic compounds, which provide links between biotic and a biotic components of the system; fifthly inorganic materials, which provide reservoirs and are involved in materials cycling; and sixthly, climatic regime, temperature and other physical influences.

Ecosystems are not static. They are characterised by flows of energy, food and materials and their composition and structure change over time as they evolve. They are diverse, that is they are composed of a number of interdependent species, and this diversity also changes as the system develops.

(TYSON, M.J., OUGHTON, D.H.,) CALLAGHAN, T.V., (DAY, J P., & SHEFFIELD, E.) 1990.

The uptake and translocation of caesium-134 and strontium-85 in bracken *Pteridium aquilinum* (Dennstaedtiaceae: Pteridophyta).

Fern Gazette, 13, 381-383.

This is a report of preliminary research in which the study of the morphology and physiology of bracken (*Pteridium aquilinum*) is combined with the investigation of uptake of radionuclides from accidental nuclear release. Monitoring the uptake and translocation of artificially applied radioactive caesium and radioactive strontium in bracken plants should help to indicate how these radionuclides with contrasting behaviour enter and cycle through a long lived element of an important ecosystem.

BERESFORD, N.A. & HOWARD, B.J. 1991.

The importance of soil adhered to vegetation as a source of radionuclides ingested by grazing animals.

Science of the Total Environment, 107, 237-254.

DOI: [http://dx.doi.org/10.1016/0048-9697\(91\)90261-C](http://dx.doi.org/10.1016/0048-9697(91)90261-C)

Soil ingestion has been identified as a potentially important source of radionuclides to grazing animals. Seasonal patterns of soil adherence to vegetation and its implications for the radionuclide intake of grazing animals were measured at two west Cumbrian sites. Soil adhesion to vegetation was highly seasonal, being highest in autumn and winter. At Site 1 (a lowland pasture close to the British Nuclear Fuels plc Sellafield Reprocessing Plant, Cumbria, UK), vegetation samples were found to consist of up to 46% soil (by dry weight). Therefore, the importance of soil as a potential source of radionuclides to grazing animals was also seasonal; soil comprised up to 92% of the ^{137}Cs and potentially all of the $^{239/240}\text{Pu}$ of vegetation samples at Site 1 and up to 62% of the ^{137}Cs at Site 2 (an upland farm contaminated following the Chernobyl accident). Analyses of sheep faecal samples confirmed the seasonal importance of soil as a potential source of radionuclides. The importance of soil adhering to vegetation, as a source of contaminant ^{137}Cs increased with time after the Chernobyl accident. Calculations of soil ingestion must be made when the intake of radionuclides by grazing animals is being studied. In some circumstances, present radioecological models may considerably underestimate the importance of soil ingestion.

CLINT, G.M., DIGHTON, J. & REES, S. 1991.

Influx of ^{137}Cs into hyphae of basidiomycete fungi.

Mycological Research, 95, 1047-1051.

DOI: [http://dx.doi.org/10.1016/S0953-7562\(09\)80544-3](http://dx.doi.org/10.1016/S0953-7562(09)80544-3)

Short-term radiocaesium influx into fungal hyphae was measured for eighteen fungal species by experiments in which hyphal mats were incubated in ^{137}Cs labelled medium. The fungal species investigated included saprotrophic and mycorrhizal basidiomycete fungi together with examples of non-basidiomycete mycorrhizal species. When results were expressed on a dry weight basis, the range of influx values was 85 to 276 nmol Cs g⁻¹ dry weight h⁻¹, with saprotrophic species tending to have the highest values, and non-basidiomycete mycorrhizal species the lowest. When results were expressed on a surface area basis, however, the relationship between species type and Cs influx was less obvious. Influx was measured both in fungi which had had no Cs pre-treatment before the experiment, and in replicate samples which were given a 24 h pre-treatment period in medium containing 5µm-CsCl. No significant differences were found between values of Cs influx measured in the two sets. The wide range of observed Cs influx values obtained here may help to explain the large differences in radiocaesium levels observed in fruiting bodies of different fungal species collected in field surveys after the Chernobyl reactor accident.

(CROUT, N.M.J.,) BERESFORD, N.A. & HOWARD, B.J. 1991.

The radioecological consequences for lowland pastures used to fatten upland sheep contaminated with radiocaesium.

Science of the Total Environment, 103, 73-87.

DOI: [http://dx.doi.org/10.1016/0048-9697\(91\)90354-H](http://dx.doi.org/10.1016/0048-9697(91)90354-H)

Current farming practice in upland areas of Cumbria, England, affected by Chernobyl fallout is to remove lambs to lowland pastures for fattening prior to slaughter. The radiocaesium (^{137}Cs and ^{134}Cs) burden of lambs is rapidly lost via excrete deposited on the pasture. This may increase the radiocaesium activities in vegetation of these pastures. Studies were performed to assess the radioecological consequences of this practice.

Results obtained from experiments were used to calibrate a soil/vegetation model which was used to predict long-term radiocaesium behaviour.

(DESMET, G.M., VAN LOON, L.R.) & HOWARD, B.J. 1991.

Chemical speciation and bioavailability of elements in the environment and their relevance to radioecology.

Science of the Total Environment, 100, 105-124.

DOI: [http://dx.doi.org/10.1016/0048-9697\(91\)90375-O](http://dx.doi.org/10.1016/0048-9697(91)90375-O)

The commonly used terms 'chemical speciation' and 'bioavailability' are discussed and an attempt made to produce both qualitative and quantitative descriptions of their influence on the transfer of elements in the environment. The importance of considering the presence of the many different species of radionuclides which may occur in the environment is emphasised. The limitations of using concentration ratios, which take no account of the differing bioavailability of various chemical species of radionuclides, are discussed.

DIGHTON, J., CLINT, G.M. & POSKITT, J. 1991.

Uptake and accumulation of ^{137}Cs by upland grassland soil fungi: a potential pool of Cs immobilisation.

Mycological Research, 95, 1052-1056.

DOI: [http://dx.doi.org/10.1016/S0953-7562\(09\)80545-5](http://dx.doi.org/10.1016/S0953-7562(09)80545-5)

Reports of high concentrations of fallout radiocaesium in basidiomycete fruit bodies after the Chernobyl nuclear reactor accident and speculation that fungi could be long-term ^{137}Cs accumulators led us to ask if fungi could be long-term ^{137}Cs accumulators. We used six common upland grassland species to try to estimate their importance in the immobilisation of ^{137}Cs . Uptake of Cs by these species ranged from 44 to 235 nmol Cs g⁻¹ DW h⁻¹. Efflux studies indicate that more than 40% of the Cs taken up is bound with the hyphae. We estimate that the fungi component of the soil could immobilise the total radiocaesium fallout received in upland grasslands following the Chernobyl accident.

HORRILL, A.D. & HOWARD, D.M. 1991.

Chernobyl fallout in three areas of upland pasture in west Cumbria.

Journal of Radiological Protection, 11, 249-257.

DOI: <http://dx.doi.org/10.1088/0952-4746/11/4/004>

The concentrations of ^{134}Cs and ^{137}Cs originating from the Chernobyl fallout have been measured in the standing vegetation of three upland pastures over a 3-year period. An exponential decay curve has been used in the past to describe the concentrations on agricultural crops over a short time span (about 200 days). However, a better fit to the later stages of the present 3-year span can be obtained by a power curve or a double exponential. Examples of the curve fitted by different methods are given and a range of predicted values calculated for the time to return to pre-Chernobyl levels.

Total inventories for the three pastures were established with sites at Corney Fell, Ennerdale and Wastwater containing 16 000, 12 200, and 14 100 Bq m⁻² ^{137}Cs , respectively. On these sites the pre-Chernobyl contribution of ^{137}Cs is calculated as 17%, 38% and 34%. In all three soils which are a peat, brown podzolic soil and a brown earth the main deposition of the Chernobyl material is held in the top layers which are highly organic. This has important implications for the long term persistence of the radiocaesium in upland ecosystems: the root mat of the grassy vegetation dominates the top layers and the potential for recycling is large.

HORRILL, A.D., HORRILL, M. & HORRILL, M.D. 1991

Some environmental radioactivity measurements from Harris, Outer Hebrides, UK.

The Environmentalist, 11, 181-184.

DOI: <http://dx.doi.org/10.1007/BF01263231>

Radioactivity related to the Chernobyl fallout cloud of May 1986 is reflected in twenty cored soil samples from Harris, in the Outer Hebrides of north-west Scotland.

HOWARD, B.J., BERESFORD, N.A. & (HOVE, K.) 1991.

Transfer of radiocaesium to ruminants in unimproved natural and semi-natural ecosystems and appropriate countermeasures.

Health Physics, 61, 715-725.

A review of studies conducted before and after the Chernobyl accident is presented, showing that both the duration and the extent of radiocaesium contamination of ruminants will be more severe in unimproved ecosystems compared with agricultural areas. Although such unimproved ecosystems provide comparatively small quantities of food for human consumption, the integrated dose from these areas to the human population can be large. Ecological characteristics which make unimproved ecosystems particularly vulnerable to this form of pollution include the presence of: (i) soils that do not immobilise radiocaesium and therefore allow its uptake into vegetation; (ii) vegetation species with high uptake rates of radiocaesium; (iii) the predominant utilisation by small ruminants which attain higher muscle radiocaesium levels than cattle. Unimproved ecosystems, which often are located at high altitudes, are predisposed to receiving high fallout because of high precipitation rates which enhance the likelihood of deposition. Countermeasures have been developed and used successfully to reduce radiocaesium levels in ruminants grazing in unimproved ecosystems. Apart from decontamination by altering farming practices and feeding uncontaminated feeds, sustained reductions of 50-80% in the radiocaesium concentrations of both milk and meat have been achieved in many ruminant species when AFCF (ammonium ironhexacyanoferrate) is given via a sodium chloride lick or as a sustained-release bolus. Food production in unimproved ecosystems must be evaluated separately from that of ordinary agricultural systems. In addition to detailed studies on the behaviour of radiocaesium, consideration should be given to the collection of aggregated transfer coefficients from various ecosystems which were affected by Chernobyl fallout. By combining bioavailability estimates and aggregated transfer coefficients, based on Chernobyl and nuclear weapons test fallout data, it may in the future be possible to make a rapid assessment of both the immediate and long term impact of a future nuclear accident on food production in unimproved ecosystems.

(HURSTHOUSE, A.S., BAXTER, M.S.,) LIVENS, F.R. & (DUNCAN, H.J.) 1991.

Transfer of Sellafield-derived ^{237}Np to and within the terrestrial environment.

Journal of Environmental Radioactivity, 14, 147-174.

DOI: [http://dx.doi.org/10.1016/0265-931X\(91\)90074-P](http://dx.doi.org/10.1016/0265-931X(91)90074-P)

The vertical distributions of ^{237}Np in soil profiles collected from west Cumbria, UK, have been measured by ICP-MS. They show in general exponential decreases with depth similar to those of the other transuranic and fission product nuclides. The maximum ^{237}Np activity concentration in any of the soil samples was 2.87 ± 0.68 (2σ) Bq kg⁻¹ (dry) for the 0-5 cm section of a gley soil, compared to 3660 ± 460 (2σ) Bq kg⁻¹ (dry) for $^{239/240}\text{Pu}$ in the same sample. A significant proportion of the total ^{237}Np inventory is observed at depth in most sites implying a greater mobility of neptunium than other transuranium nuclides within the profiles studied.

(JOHNSON, E.E., O'DONNELL, A.G.) & INESON, P. 1991.

An auto radiographic technique for selecting Cs-137-sorbing micro-organisms from soil.

Journal of Microbiological Methods, 13, 293-298.

DOI: [http://dx.doi.org/10.1016/0167-7012\(91\)90066-Y](http://dx.doi.org/10.1016/0167-7012(91)90066-Y)

This paper reports on the development of a simple auto radiographic technique for the selective isolation of Cs-137-sorbing micro-organisms from primary isolation plates. Studies on organic soils contaminated with Cs-137 following the Chernobyl nuclear accident in May 1986 have resulted in the isolation of fungi and bacteria capable of sorbing Cs-137 directly from solid media.

JONES, H.E., HARRISON, A.F., POSKITT, J.M., ROBERTS, J.D. & CLINT, G.M. 1991.

The effect of potassium nutrition on ^{137}Cs uptake in two upland species.

Journal of Environmental Radioactivity, 14, 279-294.

DOI: [http://dx.doi.org/10.1016/0265-931X\(91\)90019-C](http://dx.doi.org/10.1016/0265-931X(91)90019-C)

Agrostis capillaris (*Agrostis*) and *Calluna vulgaris* (*Calluna*), two species with differing phenologies and widespread presence in upland areas of Britain where high Chernobyl fallout occurred were grown in pot culture with varying concentrations of potassium in the rooting medium. Tissue content of potassium increased with increasing supply in both species. Roots, excised from these plants, were placed in a solution of ^{137}Cs -labelled caesium chloride for 15 min to determine uptake potential. There were clear negative relationships between the rate of uptake of ^{137}Cs by both species and (a) the concentration of potassium supplied and (b) plant tissue potassium concentrations. With *Agrostis*, there was an approximately tenfold difference in ^{137}Cs uptake between potassium-deficient and optimum plants; with *Calluna*, it was approximately eightfold. These results demonstrate the suppression of ^{137}Cs uptake into plants by potassium supply.

LIVENS, F.R. 1991.

Chemical reactions of metals with humic materials.

Environmental Pollution, 70, 183-208.

DOI: [http://dx.doi.org/10.1016/0269-7491\(91\)90009-L](http://dx.doi.org/10.1016/0269-7491(91)90009-L)

Humic substances are chemically very complex materials whose structure and reactions are not fully understood. They are believed to be macromolecules, spanning a wide range of molecular weights, which are formed from quinones and phenolic compounds. They contain a wide variety of functional groups which may react with metals. Many different physical and chemical procedures have been used to study these interactions, and numerous different reaction mechanisms and products have been postulated. The colloidal properties of humic materials also affect their interactions with metals. Reaction with humic substances profoundly affects the environmental behaviour of metals. Solubility, plant availability and even volatility are all greatly influenced and can be either enhanced or reduced by these reactions.

LIVENS, F.R. & SINGLETON, D.L. 1991.

Plutonium and americium in soil organic matter.

Journal of Environmental Radioactivity, 13, 323-339.

DOI: [http://dx.doi.org/10.1016/0265-931X\(91\)90005-Z](http://dx.doi.org/10.1016/0265-931X(91)90005-Z)

A gley soil from west Cumbria, with specific activities in its surface horizon of 5-10 k Bq kg⁻¹ ^{239/240}Pu and comparable ²⁴¹Am levels has been used as a source of actinide-enriched organic fractions. Humic and fulvic acids were isolated by conventional alkali extraction and investigated by gel filtration, treatment with organic solvents and differential flocculation procedures. All these techniques are capable of resolving the organics into two or more fractions with specific activities up to 80 k Bq kg⁻¹ ^{239/240}Pu. There is evidence for differentiation of plutonium and americium with americium being concentrated to some extent, in the lower molecular weight fractions from gel filtration.

LIVENS, F.R., HORRILL, A.D. & SINGLETON, D.L. 1991.

Distribution of radionuclides in the soil-plant systems of upland areas.

Health Physics, 60, 539-545.

The distribution and behaviour of Cs in the soil-plant systems at some upland sites in north-eastern Italy, Scotland and Norway have been investigated. From the limited range of samples taken, there appears to be no dominant physiochemical control on the plant availability of Cs. The presence of micaceous minerals or illitic clays does not significantly inhibit Cs uptake, either because of recycling in the organic surface horizons or because of clay-organic complex formation. Lower plants (bryophytes and lichens) show the highest Cs accumulation. Of the higher plants, ericaceous species take up Cs more than the others.

LOWE, V.P.W. 1991.

Radionuclides and the birds at Ravenglass.

Environmental Pollution, 70, 1-26.

DOI: [http://dx.doi.org/10.1016/0269-7491\(91\)90128-J](http://dx.doi.org/10.1016/0269-7491(91)90128-J)

Since 1983, concern has been expressed about the apparent decline in numbers of birds in the Ravenglass estuary in west Cumbria, particularly of the black headed gull colony on the Drigg dunes, and suggestions have been made that this decline might be due to excessive radiation in the birds' food and their general environment.

Twelve species of marine invertebrates from Ravenglass, most of them known to be important foods for birds, were analysed, and further samples were taken from sites along the west Cumbrian coast. None of these samples showed excessive contamination with any of the radionuclides analysed.

Analysis of a sample of bird carcasses from the areas showed oystercatchers (*Haematopus ostralegus*) and shelduck (*Tadorna tadorna*) to have some of the highest concentrations of ¹³⁷Cs in their tissues, yet their breeding success and populations were not affected.

Black headed gulls, on the other hand, were found to be feeding mainly inland, and were the least contaminated with radionuclides of all the birds at Ravenglass, yet this species and its breeding success were in decline. Calculations of the total dose equivalent rate to the whole body of the most contaminated black headed gull amounted to 9.8 x 10⁻⁴ mSv h⁻¹ (~8.4 x 10⁻⁴ mGy h⁻¹ whole body absorbed dose rate), and the background exposure dose was of the order of 8.3 x 10⁻⁴ mGy h⁻¹. As a minimum chronic dose of 1000 mGy day⁻¹ has been found necessary to retard growth of nestling birds, and 9600 mGy over 20 days of incubation to cause the death of 50% of embryos in black headed gulls eggs, the concentrations of radionuclides in the foods, body tissues and general environment were at least three orders of magnitude too low to have had any effect.

LOWE, V.P.W. & HORRILL, A.D. 1991.

Caesium concentration factors in wild herbivores and the fox (*Vulpes vulpes* L.).

Environmental Pollution, 70, 93-107.

DOI: [http://dx.doi.org/10.1016/0269-7491\(91\)90082-8](http://dx.doi.org/10.1016/0269-7491(91)90082-8)

A selection of wild animals was sampled in the winter of 1986/87. The sites chosen for sampling were based on information obtained from surveys carried out by the Institute of Terrestrial Ecology in the spring and autumn of 1986. Animals included deer, grouse, hares and rabbits, and foxes which were collected as a top carnivore in the food chain.

Variation in concentration of caesium between species from the same area was unpredictable rabbits, for instance, never exceeded 200 Bq kg⁻¹ (fresh wt) of ¹³⁷Cs in their flesh, even when adjacent to deer forests with over 1000 Bq kg⁻¹ in the venison. The greatest complication arose from areas of peaty uplands where the pre Chernobyl ¹³⁷Cs from weapons testing was much higher than expected. This pre Chernobyl contribution amounted to 630 Bq kg⁻¹ in a red grouse from the Pennines, and 650 Bq kg⁻¹ in a roe deer from near the Borders, being c. 60% of the total.

Concentration factors were calculated using values from freshly ingested vegetation and tissues from individual animals. Significant differences in concentration factors were found, depending on species, food, sex, breeding condition and age.

Contrasting the decrease of the two caesium isotopes in roe deer from forestry on peat with those from woodlands on mineral soils, it appeared that after an initial fall in concentration, the only decrease thereafter occurred on the mineral soils.

Nowhere were radiocaesium concentrations high enough to cause concern amongst consumers of game and other wild animals, even when levels exceed 3000 Bq kg⁻¹ (fresh wt) as they did in red deer, red grouse and the blue hare.

(OUGHTON, D.H., DAY, J.P.,) HOWARD, B.J., BERESFORD, N.A., (LAMB, C.S., MAYES, R.W., PRESTON, T. & EAST, B.W.) 1991.

Caesium dosing reduces uptake of radiocaesium by sheep.

Journal of Environmental Radioactivity, 14, 105-122.

DOI: [http://dx.doi.org/10.1016/0265-931X\(91\)90071-M](http://dx.doi.org/10.1016/0265-931X(91)90071-M)

In sheep grazing pasture contaminated by radiocaesium, administration of stable caesium was found to inhibit the uptake of radiocaesium. Eight lambs feeding on a contaminated pasture received an oral dose of 500 mg CsCl and after 6 days had a radiocaesium load 17% lower than that of a control group on the same pasture. The rate of radiocaesium excretion from 4 lambs, in metabolism cages and fed uncontaminated grass, was unaffected by CsCl dosing in comparison with controls. Thus, caesium dosing appeared to inhibit uptake but did not alter rates of caesium loss by normal processes of metabolism. Measurements of stable and radioactive caesium excretion rates were interpreted using a compartment model, based on the hypothesis of two major caesium reservoirs within the sheep, with derived biological half-lives approximately 4 and 25 days, and capacities 20 and 80% of total, respectively. Caesium dosing appeared to saturate the latter reservoir and consequently inhibit further uptake. If a practicable method of application could be achieved, caesium dosing on radiocaesium contaminated pasture could find application to radiological protection in humans.

SANCHEZ, A.L., (GASTAUD, J., NOSHKIN, V. & BUESSELER, K.O.) 1991

Plutonium oxidation states in the south western Black Sea: evidence regarding the origin of the cold intermediate layer.

Deep-Sea Research, 38, S845-S853.

DOI: [http://dx.doi.org/10.1016/S0198-0149\(10\)80012-3](http://dx.doi.org/10.1016/S0198-0149(10)80012-3)

Water column profiles of reduced Pu (III + IV) and oxidized Pu (V + VI) species at two stations in the south western Black Sea reveal that oxidized Pu predominates even at the suboxic zone, between 50 and 100 m. Reduction of these oxidized species occurs at the base of the suboxic zone, where we noted a shift to the predominance of reduced Pu forms. At anoxic depths (below 150 m), we found only reduced Pu forms, at concentrations significantly less than the total Pu levels we found in the upper 150 m samples. Our data show that Pu oxidation states are useful in interpreting lateral advective processes that occur within the upper 150 m of the Black Sea water column. An additional interesting result of our measurements is that water at the cold intermediate layer (CIL) of the Black Sea is labelled with predominantly oxidized Pu. We believe this feature can be used to trace the origin of CIL water.

BERESFORD, N.A. HOWARD, B.J., BARNETT, C.L. & (CROUT, N.M.J.) 1992.

The uptake by vegetation of Chernobyl and aged-radiocaesium in upland west Cumbria.

Journal of Environmental Radioactivity 16, 181-195.

DOI: [http://dx.doi.org/10.1016/0265-931X\(92\)90015-L](http://dx.doi.org/10.1016/0265-931X(92)90015-L)

The uptake into vegetation of radiocaesium originating from the Chernobyl accident and from previous sources was compared at two upland sites in west Cumbria during November/December 1989. Both sites were in an area where restrictions are in place on the movement and slaughter of sheep due to high radiocaesium activities, and were known to have received comparatively high levels of deposition from both the 1957 Windscale accident and weapons fallout. The proportion of Chernobyl derived radiocaesium in the total radiocaesium inventory at each site was estimated using a ^{134}Cs : ^{137}Cs ratio of 0.53 in Chernobyl fallout. Aged radiocaesium, mostly present for over 20 years, accounted for 59 ± 2.3 and $44 \pm 2.8\%$ (mean \pm SE) of the ^{137}Cs deposit at the two sites. Initially, after the Chernobyl accident, the transfer of the recently deposited radiocaesium was reported to be greater than that of aged deposits. However, four years after the accident, the extent of transfer of Chernobyl radiocaesium from the top 4 cm of soil to vegetation is now similar.

BERESFORD, N.A., (MAYES, R.W.,) HOWARD, B.J., (EAYRES, H.F., LAMB, C.S.,) BARNETT, C.L. & (SEGAL, M.G.) 1992.

The bioavailability of different forms of radiocaesium for transfer across the gut of ruminants.

Radiation Protection Dosimetry, 41, 87-91.

The bioavailability of an ionic and a number of environmental sources of radiocaesium has been assessed using a dual isotope technique to measure the net transfer of radiocaesium across the gut, termed the true absorption coefficient (A_t). Transfer across the gut varied considerably; A_t values ranged from 0.12 to 0.88.

CLINT, G.M. & DIGHTON, J. 1992.

Uptake and accumulation of radiocaesium by mycorrhizal and non-mycorrhizal heather plants.

New Phytologist, 121, 555-561.

DOI: <http://dx.doi.org/10.1111/j.1469-8137.1992.tb01125.x>

Short-term uptake of ^{137}Cs by heather (*Calluna vulgaris* L.) was measured in the laboratory using radio labelled liquid media and plants grown from shoot cuttings. Uptake by mycorrhizal plants and the effects of different external Cs and K concentrations were determined.

At each time point during the 3 h experimental period the content (and hence also the apparent influx) of the mycorrhizal plants in each treatment was found to be lower than that of the non mycorrhizal plants.

An increase of 100-fold in the total external Cs concentration (from 5 to 500 μM) gave between a 35-fold and 96-fold increase in initial influx of Cs. A similar change in external K concentration, however, had little effect on Cs influx. Root-shoot transfer of Cs over the 3 h uptake period was slight; in most cases more than 90% of the radiocaesium remained in the root. The final shoot: root Cs ratio was higher in mycorrhizal than in non mycorrhizal plants, suggesting that in mycorrhizal plants, despite their lower overall accumulation during the first 3 h, a higher proportion of the Cs taken up is translocated to the shoot.

CLINT, G.M., HARRISON, A.F. & HOWARD, D.M. 1992.

Rates of leaching of ^{137}Cs and potassium from different plant litters.

Journal of Environmental Radioactivity, 16, 65-76.

DOI: [http://dx.doi.org/10.1016/0265-931X\(92\)90054-W](http://dx.doi.org/10.1016/0265-931X(92)90054-W)

Mature plants of *Calluna vulgaris*, *Trifolium repens* and *Agrostis capillaris* were dug up from field sites. Plants were artificially labelled with ^{137}Cs by uptake through the roots from a liquid medium. Shoot material was allowed to dry to give plant litters adequately labelled for leaching experiments, using microcosms subjected to a number of applied treatments. Measurements were made of ^{137}Cs activity, potassium content and pH on the leachates from each microcosm obtained every 2 weeks over a 3-month period. The respiration rate of the litter was also measured to give an index of microbial activity. At the end of the experiment, ^{137}Cs and K contents of the residual litter were measured.

Generally, the rate of release of ^{137}Cs from *Calluna* litter was slower than that from *Trifolium* or *Agrostis*. After 3 months, the loss of ^{137}Cs from *Calluna* litter had stabilised at about 30-40% of the original (ie 60-70% remained in the litter). *Trifolium* had lost 60% of the initial ^{137}Cs over the same period, whilst *Agrostis* had lost about 70%. Repeated drying and rewetting treatment, compared to a continuous moistened state, resulted in the stabilisation of ^{137}Cs within *Trifolium* and *Agrostis* litters.

In *Agrostis* and *Trifolium*, the release of potassium was greater and more rapid than the release of ^{137}Cs , with only 10% of the original K remaining in the litter after 2 months. In *Calluna*, the release of K resembled the release of ^{137}Cs more closely.

(HURSTHOUSE, A.S., BAXTER, M.S., McKAY, K.) & LIVENS, F.R. 1992.

Evaluation of methods for the assay of neptunium and other long-lived actinides in environmental matrices.

Journal of Radioanalytical and Nuclear Chemistry, 137, 281-294.

DOI: <http://dx.doi.org/10.1007/BF02047443>

Inductively coupled plasma mass spectrometry (ICP-MS) and neutron activation analysis (NAA) have been investigated as alternatives to alpha-spectrometry for the low-level determination of ^{237}Np and other actinides in environmental matrices. ICP-MS in particular has been shown here to offer suitable sensitivity, precision and accuracy compared to the other techniques, with considerably faster sample throughput relative to radiometric and activation approaches. Added advantages of ICP-MS are found to include the abilities to determine other long-lived actinides simultaneously and to quantify ^{239}Pu : ^{240}Pu ratios. The neutron activation analysis approach was found to be particularly prone to interference especially from uranium nuclides.

LIVENS, F.R., FOWLER, D. & HORRILL, A.D. 1992.

Wet and dry deposition of ^{131}I , ^{137}Cs and ^{134}Cs at an upland site in Northern England.

Journal of Environmental Radioactivity, 16, 243-254.

DOI: [http://dx.doi.org/10.1016/0265-931X\(92\)90003-C](http://dx.doi.org/10.1016/0265-931X(92)90003-C)

Samples of cloud and rain water, soil and vegetation were collected from sites at up to 847 m altitude on Great Dun Fell in northern England during the period 2-6 May 1986. Wet deposition is the dominant depositional process for ^{103}Ru and the caesium isotopes, whilst dry deposition is much more important for ^{131}I . The observed deposition velocity for ^{131}I is 3.4 mm s^{-1} . The patchy distribution of activity is related to the convective nature of the rainfall, and there is evidence of direct deposition of contaminated orographic cloud water at the highest site.

LIVENS, F.R., HORRILL, A.D. & SINGLETON, D.L. 1992.

Sampling and measurement of transuranic elements in interstitial waters of sediments.

Applied Radiation and Isotopes, 43, 361-369.

DOI: [http://dx.doi.org/10.1016/0883-2889\(92\)90106-O](http://dx.doi.org/10.1016/0883-2889(92)90106-O)

The construction and installation of porous cup soil solution samplers and their operation in a saltmarsh is described. Levels of transuranic contamination in the saltmarsh sediments are relatively high (up to 930 Bq m^{-2} for ^{241}Am and 500 kBq m^{-2} for $^{239/240}\text{Pu}$), but levels in the interstitial or sediment-pore, waters are low, generally in the range 1 to 50 mBq l^{-1} both ^{241}Am , $^{239/240}\text{Pu}$ ratios and concentrations of dissolved transuranic elements are affected by the degree of inundation of the sampling site. These parameters also vary over time in an apparently unpredictable manner. The K_d values (solid/solution distribution coefficients) for Pu and Am are comparable with those measured by other workers at this site.

(MAYES, R.W., EAYRES, H.F.,) BERESFORD, N.A., (LAMB, C.S.) & HOWARD, B.J. 1992.

Changes with age in the absorption of radiocaesium by sheep.

Radiation Protection Dosimetry, 41, 83-86.

The absorption of ionic ^{137}Cs was determined in groups of lambs ranging in age from 11 to 59 weeks fed ewes milk or fresh perennial ryegrass. Absorption was measured as either the apparent (A_a) or true absorption coefficient (A_t). Whereas A_a declined with age A_t appeared not to change with age but was higher (1.00) where the ^{137}Cs was incorporated in milk, than when administered in a way which simulates incorporation into solid feed (0.80 - 0.85). Previously observed differences in transfer coefficients for animals of different ages appear not be due to changes in transfer across the gut.

(McGEE, E.J., COLGAN, P.A., KEATINGE, M.,) HORRILL, A.D., KENNEDY, V.H., (JOHANSSON, K.J., AARKROG, A. & NIELSEN, S.P.) 1992.

Bias and measurement errors in radioactivity from four European radiation research laboratories.

The Analyst, 117, 941-945.

DOI: <http://dx.doi.org/10.1039/AN9921700941>

Four radiation research laboratories participated in an intercomparison exercise to assess precision in the measurement of radionuclide concentrations. Each laboratory was required to report results for ^{137}Cs , ^{134}Cs and ^{40}K in accordance with their usual procedures. A normal probability plot of the pooled data showed ten of the 161 readings to be obvious outliers and seven of these were attributed to one of the laboratories. One laboratory consistently overestimated relative to the global mean, another laboratory consistently underestimated while the other two showed positive and negative bias dependent on isotope. Both bias and measurement errors were found to increase in the order ^{137}Cs , ^{134}Cs , ^{40}K . A need for greater standardisation of analytical techniques is identified.

SINGLETON, D.L., LIVENS, F.R., BERESFORD, N A., HOWARD, B.J., (MAYES, R.W.), BARNETT, C.L. & (SEGAL, M.G.) 1992.

Development of a laboratory method to predict rapidly the availability of radiocaesium.

The Analyst, 117, 505-509.

DOI: <http://dx.doi.org/10.1039/AN9921700505>

A simple extraction procedure has been developed to assess rapidly the probable extent of the transfer of radiocaesium into ruminant food products soon after a nuclear accident. The *in vitro* extractions were validated against true absorption measurements of different forms of radiocaesium in the sheep gut. Extractions were performed on a range of different radiocaesium sources. Some of these sources were artificial (ionic radiocaesium absorbed onto bentonite, silica spheres and filter-papers) and others were environmentally contaminated (silt from the Ravenglass Estuary contaminated by effluent from British Nuclear Fuels Limited (BNFL) Sellafield, and upland grass and heather contaminated by Chernobyl fallout. Laboratory experiments concentrated primarily on the use of simple inorganic extractants in competitive ion-exchange processes. Of the reagents used, 0.1 mol d m⁻³ stable caesium chloride solution was the most effective extractant. The proportion of radiocaesium extracted by 0.1 mol d m⁻³ caesium chloride correlated well with measurements of true absorption. Extracting radiocaesium using 0.1 mol d m⁻³ caesium chloride proved to be an inexpensive and rapid method of predicting the availability of radiocaesium for absorption in the ruminant gut, giving results within 24 h. Further extractions were carried out using cellulase/pepsin simulated digestions and ovine rumen fluid. Results suggested that the availability of radiocaesium from some inorganic sources may be underestimated using such techniques.

(CROUT, N.M.J.), BERESFORD, N.A. & HOWARD, B.J. 1993.

Does soil adhesion matter when predicting radiocaesium transfer to animals?

Journal of Environmental Radioactivity, 20, 201-212.

DOI: [http://dx.doi.org/10.1016/0265-931X\(93\)90010-5](http://dx.doi.org/10.1016/0265-931X(93)90010-5)

A sward will often have significant amounts of soil adhered to the vegetation surfaces which will be ingested by grazing animals. If the soil is contaminated by radioactive fallout then it can serve as a dietary source of radionuclides, in addition to any root uptake by the plants. This study is an attempt to quantitatively assess the importance of soil adhesion as a source of radiocaesium to sheep using the RUINS model which simulates radiocaesium transfer in grazing systems.

The method of simulating the contamination of vegetation surfaces used by the RUINS model is described and the importance of the availability of radiocaesium associated with adhered soil relative to plant incorporated radiocaesium discussed. Two sets of simulations are presented. One in which the soil is treated as a medium providing a uniform availability of radiocaesium and the second in which account is taken of the partitioning of radiocaesium in the soil between 'fixed' and labile forms.

The results demonstrate that because of the reduced absorption in the gut of radiocaesium associated with soil animals grazing pastures with significant amounts of adhered soil will not be as contaminated as radiocaesium activity concentrations measured in bulk vegetation would suggest. Therefore the extent of soil adhesion needs to be considered if predictions of radiocaesium contamination of animal products are to be made on the basis of measured activities of sampled vegetation. However soil adhesion is unlikely to be a significant dietary source of *available* radiocaesium, unless the soil concerned exhibits an unusually high bioavailability of radiocaesium. Moreover the simulation results indicate that differences in availability between soil types observed experimentally are consistent with the partitioning between fixed and labile soil compartments made by the RUINS model.

(DAVISON, W., HILTON, J., HAMILTON-TAYLOR, J., KELLY, M.,) LIVENS, F.R., (RIGG, E., CARRICK, T.R.) & SINGLETON, D.L. 1993.

The transport of Chernobyl-derived caesium through two freshwater lakes in Cumbria, UK.

Journal of Environmental Radioactivity, 19, 125-153.

DOI: [http://dx.doi.org/10.1016/0265-931X\(93\)90073-G](http://dx.doi.org/10.1016/0265-931X(93)90073-G)

The specific activities of ^{137}Cs and ^{134}Cs in the waters and sediments of Windermere North Basin (WNB) and Esthwaite Water (EW) in the English Lake District were determined over an 18 month period immediately following the catastrophic accident at the Chernobyl nuclear reactor. Input of Chernobyl derived Cs to the lake surface ($\sim 2000 \text{ Bq of } ^{137}\text{Cs m}^2$) occurred predominantly through direct atmospheric deposition over the period 3-20 May 1986. The initial and highest specific activities (C_0) of ^{137}Cs were $\sim 80 \text{ Bq m}^{-3}$ and $\sim 390 \text{ Bq m}^{-3}$ in WNB and EW respectively reflecting the greater mean depth of WNB (25.1 m) compared with EW (6.4 m). Of the initial input, an estimated 37-41% and 32% was hydraulically flushed from WNB and EW respectively, the remainder accumulating in the sediments. Retention half-life within the lake waters was 70 days in WNB and 15 days in EW. The temporal decline in caesium in surface waters could be modelled by assuming that either direct adsorption to the sediments or association with settling particles occurred in conjunction with hydraulic flushing. Model fits resulted in values of $0.10 \pm 0.05 \text{ cm}$ for the boundary layer thickness, and $10^{-5} \text{ litre kg}^{-1}$ or the partition coefficients, K in both lakes indicating that transport by particles may be the dominant process. A small fraction (0.25%) of the caesium accumulating in the sediment appeared to be remobilised into the overlying waters when they became anoxic. This was the major source of radiocaesium in EW after April 1987 (*ca.* 1 year after the initial input).

ENVIRONMENTAL RADIOACTIVITY SPECIAL TOPIC STEERING COMMITTEE, NATURAL ENVIRONMENT RESEARCH COUNCIL. 1993.

Radiocaesium in natural systems - a UK coordinated study.

Journal of Environmental Radioactivity, 18, 133-149.

DOI: [http://dx.doi.org/10.1016/0265-931X\(93\)90076-J](http://dx.doi.org/10.1016/0265-931X(93)90076-J)

This review summarises the findings of a research programme in the UK following the Chernobyl accident. The projects provide a degree of integrated coverage of environmental transfers of radiocaesium from cloud deposition through studies of soil chemistry and soil-plant uptake to measured and modelled transfers along food chains. The results highlight the spatial and temporal variability of environmental transfer parameters and emphasise the need for care both in experimental design and in generalisations on magnitudes of nuclide transfer.

(GALER, A.M., CROUT, N.M.J.) BERESFORD, N.A., HOWARD B.J., (MAYES, R.W.,) BARNETT, C.L., (EAYRES, H.F. & LAMB, C.S.) 1993.

Dynamic radiocaesium distribution in sheep: measurement and modelling.

Journal of Environmental Radioactivity, 20, 35-48.

DOI: [http://dx.doi.org/10.1016/0265-931X\(93\)90017-2](http://dx.doi.org/10.1016/0265-931X(93)90017-2)

An experiment was carried out to provide a data set specifically designed to allow the development of a model to describe the dynamic behaviour of radiocaesium in sheep tissues. A single intraruminal dose of $^{134}\text{CsCl}$ was given to each of 15 Scottish Blackface ewes aged 1-2 years. Radiocaesium activity concentrations were measured at various time intervals after dosing in blood, faeces and urine and, after slaughter in a range of tissues and digestive tract contents.

A first order compartment model was developed comprising nine compartments representing various organs and tissues in the body. Rate constants for the model were obtained by optimisation to the experimental results.

A limited validation of the model was carried out by using it to calculate tissue transfer coefficients (F_f) and biological half-lives ($T_{0.5}$) of radiocaesium in sheep. The values generated compare favourably with published figures. Applications for the model and constraints on its usage are examined along with possibilities for further development.

(HILTON, J.,) LIVENS, F.R., (SPEZZANO, P. & LEONARD, R.D P.) 1993.

Retention of radioactive caesium by different soils in the catchment of a small lake.

Science of the Total Environment, 129, 253-266.

DOI: [http://dx.doi.org/10.1016/0048-9697\(93\)90322-W](http://dx.doi.org/10.1016/0048-9697(93)90322-W)

Cs-137 activity levels in Devoke Water Cumbria (UK) remained high for much longer than was expected after the Chernobyl accident. This is shown to be due to the release of dissolved ^{137}Cs from the catchment to the lake. Cs-137 inventories in different soil types suggest that fibrous peat soils loose Cs rapidly. Rankers and amorphous peats loose smaller amounts and podzols the least. The concentration of ^{137}Cs at any time in the streams is given by either: $\log A = -0.001064 \text{ time (days)} + 0.302003 \log \text{flow (m}^3 \text{ s}^{-1}) + \text{constant}$ or $\log A = -0.001064 \text{ time (days)} + \text{constant}$ depending on the size of the constant, where the constant is given by: $\text{constant} = (0.0473 \% \text{ fibrous peat} + 4.383) \times \text{deposition (kBq/m}^2) / 9.8$. Possible release mechanisms are discussed.

(HOVE, K., STRAND, P., VOIGT, G., JONES, B.-E.V.,) HOWARD, B.J., (SEGAL, M.G., POLLARIS, K. & PEARCE, J.) 1993.

Countermeasures for reducing radioactive contamination of farm animals and farm animal products.

Science of the Total Environment, 137, 261-272.

DOI: [http://dx.doi.org/10.1016/0048-9697\(93\)90393-K](http://dx.doi.org/10.1016/0048-9697(93)90393-K)

A summary is given of the range and effectiveness of different available countermeasures which can reduce the radiation dose arising from the radioactive contamination of food products from animals. The choice of which countermeasure is suitable for each particular situation will depend on many factors. Consideration should be given not only to the effectiveness of each countermeasure in terms of reduction of radionuclide content but also to its practicality and cost particularly where deposition levels are high or where high contamination levels in animal food products persist for a long period of time. Effective countermeasures which can reduce radiocaesium contamination of milk and meat from farmed animals by more than a factor of 10 have been developed, tested and used during the last 30 years. Less progress has been made in identifying effective binders for reducing levels of the other important contaminating radionuclides, such as I and Sr, in animal food products.

HOWARD, B.J. 1993.

Management methods of reducing radionuclide contamination of animal food products in semi-natural ecosystems.

Science of the Total Environment, 137, 249-260.

DOI: [http://dx.doi.org/10.1016/0048-9697\(93\)90392-J](http://dx.doi.org/10.1016/0048-9697(93)90392-J)

Countermeasures involving changes in management practices which are suitable for use in semi-natural ecosystems are described. Most of the relevant information relates to radiocaesium but the applicability for some other radionuclides has also been evaluated. Improved live-monitoring techniques for radiocaesium, developed since the Chernobyl accident allow the identification of animals whose contamination levels exceed the intervention limits so that countermeasures can be effectively chosen and targeted. Generally the most effective approach for domesticated and semi-domesticated animals is either to remove contaminated animals from the affected area or to provide uncontaminated feed. Uncontaminated feed is given continuously for dairy animals or in the final fattening stages for meat producing animals. The introduction of other effective changes in management practices, such as changing hunting seasons for game, or slaughtering at a time of year when the animals have been grazing on less contaminated herbage, depends on a good understanding of the behaviour of radionuclides in these ecosystems. In practice, the most effective countermeasures which can be used to reduce radionuclide contamination of animals in semi-natural ecosystems will be obtained by a combination of both management changes and the use of chemical binders to prevent gut absorption.

HOWARD, B.J., BERESFORD, N.A., (MAYES, R.W. & LAMB, C.S.) 1993.

Transfer of ^{131}I to sheep milk from vegetation contaminated by Chernobyl fallout.

Journal of Environmental Radioactivity, 19, 155-161.

DOI: [http://dx.doi.org/10.1016/0265-931X\(93\)90074-H](http://dx.doi.org/10.1016/0265-931X(93)90074-H)

The transfer of ^{131}I to sheep milk was measured in a controlled feeding experiment using herbage recently contaminated by fallout from the Chernobyl accident. The transfer coefficient (F_m) of ^{131}I from the Chernobyl-contaminated herbage was $0.29 \pm 0.017 \text{ d l}^{-1}$. The daily proportion of ^{131}I intake which was secreted in milk was $56 \pm 0.035\%$. This is an order of magnitude higher than for cattle and agrees with the higher transfer of stable iodine from plasma to milk which occurs in sheep and goats. At the same time the biological half-life of ^{131}I was measured in ewes which had been grazing outside during deposition of the Chernobyl fallout and were then housed and fed an ^{131}I diet. The loss of ^{131}I in sheep milk was described using a double exponential relationship. The calculated biological half-life for the first component in the milk was 1d, accounting for 97.4% of the reduction in the ^{131}I activity concentration of milk. The ^{131}I -free diet had a comparatively high stable iodine content, since it was saltmarsh vegetation; however, the calculated half-life was similar to previously estimated values for goats. The transfer parameters presented here, which have been estimated using measured dietary intakes and milk outputs, appear to be the first reported for sheep for an environmentally contaminated source.

(NIELSEN, S.P., AARKROG, A., COLGAN, P.A., MCGEE, E., SYNNOTT, H.J., JOHANSSON, K.J.), HORRILL, A.D., KENNEDY, V.H. & (BARBAYIANNIS, N.) 1993.

An intercomparison of sampling techniques for measurements of radiocaesium in upland pasture and soil.

Journal of Radioanalytical and Nuclear Chemistry, 171, 303-317.

DOI: <http://dx.doi.org/10.1007/BF02219855>

An intercomparison of sampling procedures used by five laboratories for the determination of radiocaesium in vegetation and peaty soil was carried out at two locations in Cumbria. The multiple sampling has given information on the homogeneity of the parameters studied at each location. The parameters comprise soil bulk densities, total deposition of ^{137}Cs , deposition of ^{137}Cs in three soil layers, biomass densities, concentrations of ^{137}Cs in pasture, and activity ratios ($^{134}/^{137}\text{Cs}$) in soil and vegetation. The determination of total deposition of ^{137}Cs gave no indication of differences between the laboratories. The results from the soil profiles do indicate significant differences between laboratories. One laboratory using a coring technique observed difficulties during sampling due to compression of the soil. The coring technique should thus be avoided or applied with extreme care for the sampling of depth profiles in peaty soil. The results from the sampling of pasture show no indication of differences between the laboratories. For the parameters studied the observed variabilities across soil depths and locations range from 10% to 81% in terms of relative standard deviation. A comparison across all results at the two locations indicate a 50% higher field variability at one of the sites relative to the other.

(WILKINS, B.T.,) HOWARD, B.J., (DESMET, G.M., ALEXAKHIN, R.M. & MAUBERT, H.) 1993.

Strategies for the deployment of agricultural countermeasures.

Science of the Total Environment, 137, 1-8.

DOI: [http://dx.doi.org/10.1016/0048-9697\(93\)90373-E](http://dx.doi.org/10.1016/0048-9697(93)90373-E)

The aim of the Relative Effectiveness of Agricultural Countermeasures Techniques workshop (REACT) was to provide a forum in which to evaluate current knowledge of different agricultural countermeasures. Initial decisions about the possible need for intervention in a particular area will be made at national or regional government level. The arguments that underlie these decisions were outside the remit of this workshop. Instead, attention was directed towards the basis for practical decisions about countermeasures that could be employed in a particular situation. Countermeasures differ, both in their effectiveness and their economic, ecological and social impact. In certain situations countermeasures developed before and since the Chernobyl accident have general applicability. However this is not always the case and in general a fundamental understanding of the processes involved is needed to predict the effect that a given countermeasure might have under a range of different circumstances.

BERESFORD, N.A., (MAYES, R.W., CROUT, N.M.J.), HOWARD, B.J. & (KANYAR, B.) 1994.

Dynamic behaviour of ^{110m}Ag in sheep tissues.

Health Physics, 66, 420-426.

The transfer coefficient of ^{110m}Ag to a range of sheep tissues and its biological half-life in these tissues has been determined. Liver was shown to be the major site of ^{110m}Ag deposition and retention, with a transfer coefficient of F_f 7.1 kg^{-1} and biological half-life of 79d. These results also suggest that previous estimates of the transfer of silver to muscle were too high, although further work would be required to confirm this. There is a need for accurate data which can be used to predict the transfer of ^{110m}Ag to food producing animals.

(BRYAN, N.D.), LIVENS, F.R. & HORRILL, A.D. 1994.

Biogeochemical behaviour of Plutonium and Americium and geochemical modelling of the soil solution.

Journal of Radioanalytical and Nuclear Chemistry, Articles, 182, No.2, 359-366.

DOI: <http://dx.doi.org/10.1007/BF02037512>

Field observations suggest that plutonium and americium in the environment are present in very different chemical forms in the interstitial waters of an intertidal sediment. Thermodynamic modelling using the PHREEQE code predicts that plutonium is present entirely in oxidation state (V) as the $\text{PuO}_2\text{CO}_3^-$ ion, whereas americium is present entirely in oxidation state (III), largely as the uncharged $\text{Am}(\text{OH})\text{CO}_3$ species, but with significant concentrations of the Am^{3+} and the AmSO_4^+ ions. There are, however, differences between these predictions and those published for a very similar system which apparently arise from uncertainties in the thermodynamic data. Field data cannot resolve these differences unambiguously.

(HILTON, J., DAVISON, W., HAMILTON-TAYLOR, J., KELLY, M., LIVENS, F.R., RIGG, E.) & SINGLETON, D.L. 1994.

Similarities in the behaviour of Chernobyl derived Ru-103, Ru-106 and Cs-137 in two freshwater lakes.

Aquatic sciences, 56, 133-144.

DOI: <http://dx.doi.org/10.1007/BF00877204>

Measurements of the concentrations of ^{103}Ru and ^{106}Ru in the water column and sediments of two productive temperate lakes were made during an eight month period following the Chernobyl accident. ^{103}Ru accumulation in the sediments began simultaneously with that of ^{134}Cs and a constant ratio (approx. 2.0 on a decay corrected basis) of $^{103}\text{Ru}/^{137}\text{Cs}$ was observed in surface waters and sediments throughout the measurement period. The ratio is not statistically different from that reported for atmospheric input and for epilimnetic water. The results suggest that the processes of removal of radioactive ruthenium and caesium from the mixed water column to the sediments are the same.

Enhancement of Cs, compared with Ru, in the isolated bottom waters of one of the lakes in the summer months provided evidence for Cs release from the sediments during a period of hypolimnetic anoxia.

LIVENS, F.R., HORRILL, A.D. & SINGLETON, D.L. 1994.

Plutonium in estuarine sediments and the associated interstitial waters.

Estuarine, Coastal and Shelf Science, 38, 479-489.

DOI: <http://dx.doi.org/10.1006/ecss.1994.1033>

Nine pairs (three different depths in each of three different zones) of porous cup solution samplers have been installed in a saltmarsh in west Cumbria, UK. The sediments of this marsh are well known to contain elevated levels of transuranium elements (up to $16000 \text{ Bq kg}^{-1} \text{ }^{239/240}\text{Pu}$) and it has been used for many years and by many workers as a site for the study of the geochemistry of the transuranium elements. Over a period of approximately 18 months, nine sets of pore water samples were collected. Sediment core samples were also collected from each zone of the marsh. The stable element compositions of the solution phase are generally as expected in an estuarine system, simply reflecting mixing of sea- and freshwaters. The $^{239/240}\text{Pu}$ concentrations in the upper and middle zones of the marsh are low, usually between 2 and 20 mBq l^{-1} , and with mean values of about 5 mBq l^{-1} , whilst those from the seaward zone of the marsh are approximately a factor of 6 higher, probably reflecting a much greater addition of seawater. The K_d values for $^{239/240}\text{Pu}$ in the sediments lie between 10^4 and 10^6 , comparable to the values found by other workers near this site. Nevertheless, there are considerable fluctuations in K_d over time, and also substantial variations in K_d with depth in the sediment profile, and it may be that the assumption of chemical equilibrium underlying the use of K_d values is not valid in this system.

LIVENS, F.R., HORRILL, A.D. & SINGLETON, D.L. 1994.

The relationship between concentrations of plutonium and americium in soil interstitial waters and their uptake by plants.

Science of the Total Environment, 155, 151-159.

DOI: [http://dx.doi.org/10.1016/0048-9697\(94\)90288-7](http://dx.doi.org/10.1016/0048-9697(94)90288-7)

Large soil cores (23.5 cm diameter), containing elevated concentrations of plutonium and americium derived from fuel reprocessing effluents (typically 2000-3000 but up to 10000 Bq kg⁻¹ ^{239/240}Pu and 3000-5000 but up to 15000 Bq kg⁻¹ ²⁴¹Am), were collected from three zones of a salt marsh in west Cumbria. The standing vegetation was removed, the cores placed in a greenhouse and the vegetation allowed to regrow. After 2 months, the regrowth was harvested, and the amount of plutonium and americium taken up determined. These data, combined with data from earlier, in-situ sampling of soil pore waters and from analysis of soil cores, allow estimation of soil-plant transfers. If these are expressed simply as the ratio of the activity concentrations in the plant tissues to those in the soil, the values lie in the range 10⁻⁵-10⁻⁶, comparable to those found by many other workers. However, the ratio of concentrations in plant tissues to those in the soil solution is much higher, 40-110 l kg⁻¹ for ^{239/240}Pu and 210-640 l kg⁻¹ for ²⁴¹Am. There appears to be a consistent relationship between soil-plant transfer and the in-situ solid-solution distribution coefficient (Rd).

(MAYES, R.W.), BERESFORD, N.A., (LAMB, C.S.), BARNETT, C.L., HOWARD, B.J., (JONES, B.-E.V., ERIKSSON, O., HOVE, K., PEDERSEN, Ø.) & STAINES, B.W. 1994.

Novel approaches to the estimation of intake and bioavailability of radiocaesium in ruminants grazing forested areas.

Science of the Total Environment, 157, 289-300.

DOI: [http://dx.doi.org/10.1016/0048-9697\(94\)90592-4](http://dx.doi.org/10.1016/0048-9697(94)90592-4)

It is difficult to measure transfer of radiocaesium to the tissues of forest ruminants because they can potentially ingest a wide range of plant types. Furthermore since some of these animal species are undomesticated they are difficult to study. Existing techniques of estimating radiocaesium intake are imprecise when applied to forest systems. New approaches to measure this parameter are discussed. Two methods of intake estimation are described and evaluated. In the first method radiocaesium intake is estimated from the radiocaesium activity concentrations of plants, combined with estimates of dry-matter (DM) intake and plant species composition of the diet, using plant and orally-dosed hydrocarbons (n-alkanes) as markers. The second approach estimates the total radiocaesium intake of an animal from the rate of excretion of radiocaesium in the faeces and an assumed value for the apparent absorption coefficient. Estimates of radiocaesium intake, using these approaches, in lactating goats and adult sheep were used to calculate transfer coefficients for milk and muscle; these compared favourably with previous data. Potential variations in bioavailability of dietary radiocaesium sources to forest ruminants have rarely been considered. Approaches that can be used to describe bioavailability, including the true absorption coefficient and in-vitro extractability are outlined.

SANCHEZ, A.L., (GASTAUD, J., HOLM, E. & ROOS, P.) 1994.

Distribution of plutonium and its oxidation states in Framvaren and Hellvik fjords, Norway.

Journal of Environmental Radioactivity, 22, 205-217.

DOI: [http://dx.doi.org/10.1016/0265-931X\(94\)90082-5](http://dx.doi.org/10.1016/0265-931X(94)90082-5)

Waters from the Skagerrak Sea entering the system of fjords inside Farsund in the southern tip of Norway (including Lyngsdal, Hellvik and Framvaren fjords) contain plutonium derived from European nuclear fuel reprocessing facilities in the United Kingdom and France, as shown by the ²³⁸Pu/^{239,240}Pu activity ratios measured for water samples from Hellvik and Framvaren fjords. The shallow sills interconnecting this series of fjords, however, severely restrict water exchange. Thus, at the northernmost Framvaren fjord (connected to Hellvik fjord by a 500 m channel of 2 m depth), the ²³⁸Pu/^{239,240}Pu signature for Pu derived from fuel reprocessing is found only in the surface layer (upper 20 m) while global fallout Pu ratios are observed in the permanently anoxic zone of this fjord. Plutonium oxidation state measurements in waters collected from Hellvik and Framvaren fjords show that water exchange occurs between these two basins by a process of interleaving, with subsequent reduction of oxidized Pu species as these reach the anoxic zone. Plutonium serves as a useful tracer for water exchange between these fjords and the Skagerrak Sea.

BERESFORD, N.A., BARNETT, C.L., (MAYES, R.W., POLLARIS, K., VANDECASTEELE, C.M.) & HOWARD, B.J. 1995.

The use of an *in-vitro* technique to predict the absorption of dietary radiocaesium by sheep.

Radiation Environmental Biophysics, 34, 191-194.

DOI: <http://dx.doi.org/10.1007/BF01211547>

The validity of an *in-vitro* technique to predict the availability for absorption of radiocaesium in the sheep gut has been assessed. The technique (a 2 hour extraction with caesium chloride), was found to be valid for sources with a low availability for transfer across the gut, but inappropriate for ionic radiocaesium or radiocaesium incorporated internally within herbage. For such radiocaesium sources, which have a high *in-vitro* availability, no correlation was found between *in-vitro* extraction and true absorption measurements. A true absorption value of 0.80 is recommended, although values for individual sheep in the range 0.60 to 1.00 would be expected.

(HILTON, J., RIGG, E., DAVISON, W., HAMILTON-TAYLOR, J., KELLY, M., LIVENS, F.R.) & SINGLETON, D.L. 1995.

Modelling and interpreting element ratios in water and sediments: A sensitivity analysis of post-Chernobyl Ru: Cs ratios.

Limnology and Oceanography, 40, 1302-1309.

When elements are simultaneously added to lakes, experimentally or by accident, their ratios in the water phase and in bottom sediments can change with time due to differential partitioning between solution and suspended particles or sediments. A number of equations are developed to show the change of ratio with time in water and sediments assuming simultaneous pulse inputs followed by a range of combinations of loss processes from solution (i.e. hydraulic losses, sorption to particles followed by settling, and diffusion into the sediments). The pattern of events is discussed both for pulse events with specific limiting assumptions and for combined continuous and pulse inputs. The models show that elemental ratios in sediments are generally less sensitive indicators of differential partitioning than are elemental ratios in water. For lakes with long residence times, the long-term elemental ratio in the sediments does not differ from that in the initial spike to the water column, but for short residence times, it is directly dependent on the ratio of either partition or diffusion coefficients.

The models are used to interpret Ru: Cs ratios measured in the water and sediments of Esthwaite Water subsequent to the pulse input of Chernobyl fallout. The ratios can be explained by assuming nuclides were lost either by flushing and sorption or by flushing sorption, and diffusion. The process combination of flushing and diffusion is incompatible with the observed constant ratios.

HORRILL, A.D., KENNEDY, V.H., (PATERSON, I.S. & MCGOWAN, G.M.) 1995.

The effect of heather burning on the transfer of radiocaesium to smoke and the solubility of radiocaesium associated with different types of heather ash.

Journal of Environmental Radioactivity, 95, 1-10.

DOI: [http://dx.doi.org/10.1016/0265-931X\(95\)00012-Y](http://dx.doi.org/10.1016/0265-931X(95)00012-Y)

Heather (*Calluna vulgaris*) dominates large tracts of the United Kingdom and fire is used as a management tool to encourage new growth. Heather contaminated with radiocaesium from the Chernobyl accident was burnt under controlled conditions giving a "hot" (660°C) and "cool" (550°C) fire. Losses of up to 40% of the radiocaesium activity were recorded in the smoke and subsequent leaching experiments, using artificial rainwater, demonstrated that a further 20% of the activity could be mobilised in a short period. The implications of using heather burning as a management tool are considered.

BERESFORD, N.A., BARNETT, C.L. (CROUT, N.M.J. & MORRIS, C.) 1996.

Radiocaesium variability within sheep flocks: relationships between the ^{137}Cs activity concentrations of individual ewes within a flock and between ewes and their progeny.

Science of the Total Environment, 177, 85-96.

DOI: [http://dx.doi.org/10.1016/0048-9697\(95\)04863-4](http://dx.doi.org/10.1016/0048-9697(95)04863-4)

As a consequence of radiocaesium deposition following the Chernobyl accident the movement and slaughter of sheep were restricted within some upland areas of the United Kingdom. Considerable variability in the radiocaesium activity concentrations between individual sheep within flocks has been recorded. This paper reports studies conducted to investigate the reasons for this within flock variability on three farms in the restricted area of west Cumbria. On each farm, study sheep were selected and live-monitored over the period 1991-93. Results from all three study farms showed a correlation in the ^{137}Cs activity concentration of individual sheep on different monitoring occasions. This observation suggested that a few sheep on each farm are likely to be responsible for the continuation of restrictions on many of the affected holdings. Comparisons between monitoring data obtained in summer and autumn months were better correlated than those involving data collected in the winter and spring. Prior to weaning there was a linear relationship between the ^{137}Cs levels in the muscle of a lamb and that in the muscle of its ram. Given these observations it is suggested that, in successive years, ewers identified as consistently having high radiocaesium levels in their muscle will produce lambs which will also have comparatively high levels of radiocaesium: the limited data available support the hypothesis. However, no relationship between the ^{137}Cs activity concentration of a ewe and its lamb was evident post-weaning, thereby discounting any possibility of an inherited effect. On one of the farms a significant difference was found between the ^{137}Cs activity concentration of different breeds of sheep.

COOKE, A.I., GREEN, N., RIMMER, D.L., WEEKES, T.E.C., WILKINS, B.T., BERESFORD, N.A. & FENWICK, J.D. 1996.

Absorption of radiocaesium by sheep after ingestion of contaminated soils.

Science of the Total Environment, 192, 21-29.

DOI: [http://dx.doi.org/10.1016/0048-9697\(96\)05288-6](http://dx.doi.org/10.1016/0048-9697(96)05288-6)

The absorption of ^{137}Cs by sheep following ingestion of contaminated soil was studied using an established dual isotope method. Two agricultural soils were studied: an alluvial gley contaminated by discharges to the sea from the Sellafield Reprocessing Plant, and a lowland organic soils that had been artificially contaminated. Values of the true absorption coefficient of radiocaesium of 0.19 ± 0.01 , respectively, were obtained for these soils. This implies that availability of soil-associated radiocaesium for uptake following ingestion is up to about 20% of that when the activity is incorporated in vegetation. These results have been compared to estimates of availability made using an in-vitro approach described previously and found to be in good agreement. However, comparison with in-vitro data obtained for an upland peat indicated that absorption from some upland organic soils could be greater than from the lowland organic soil.

CROUT, N.M.J., BERESFORD, N.A., HOWARD, B.J., (MAYES, R.W., ASSIMAKOPOULOS, P.A. & VANDECASTEELE, C.M. 1996.

The development and testing of a revised dynamic model of radiocaesium transfer to sheep tissues.

Radiation and Environmental Biophysics, 35, 19-24.

DOI: <http://dx.doi.org/10.1007/BF01211238>

The model of radiocaesium transfer to sheep presented by Galer et al. provides reliable predictions only for sheep of a similar body weight to those used in the development of the model (approximately 30 kg). To extend the applicability of the model, it was necessary to re-parameterise it in terms of activity concentrations in tissues rather than total activities within them (although for gut compartments the use of activity has been retained). The rate coefficients for the new model have been estimated by fitting the model to the data used by Galer et al., which was derived from a single "calibration" experiment. The new model was found to account for 94% of the observed variation in the data ($n=42$), a result similar to that obtained by Galer et al. The model has also been tested against data not used in its development but obtained from four separate experiments undertaken by three different laboratories. Good agreement between the predictions of the new model and observations was found for most circumstances and for several breeds of sheep with different body weights. It is concluded that the new model provides a useful dynamic description of radiocaesium transfer to the tissues of sheep of different breeds and under different contamination scenarios.

HOWARD, B.J., LIVENS, F.R. & (WALTERS, B.) 1996.

A review of Radionuclides in tide-washed pastures on the Irish Sea coast in England and Wales and their transfer to food products.

Environmental Pollution, 93, 63-74.

DOI: [http://dx.doi.org/10.1016/0269-7491\(96\)00013-9](http://dx.doi.org/10.1016/0269-7491(96)00013-9)

Close to the Sellafield Reprocessing Plant activity concentrations of many radionuclides including the long-lived ^{137}Cs and actinides on tide-washed pastures bordering the Irish Sea are high compared with other terrestrial ecosystems in the United Kingdom. Despite the comparatively high deposition of radionuclides, contamination of agricultural products from tide-washed pastures is lower than would be predicted from studies in terrestrial ecosystems. This is because the main source of contamination in tide-washed pasture, radionuclides associated with sedimentary particles, has low availability for uptake with sedimentary particles, has low availability for uptake by plant roots and in the gut of ruminants. Generalised Derived Limits (GDLs), published by the National Radiological Protection Board (NRPB) are estimates of environmental radioactivity concentrations, which would potentially be radiologically significant. These provide a benchmark against which environmental measurements can be assessed. In the past, several comparisons of radioactivity concentrations in tide-washed pastures with GDLs have been made, but only some of these comparisons are valid since current approaches used to assess doses are not always strictly appropriate to these ecosystems. Directly applicable GDLs are needed, and are currently being developed by the NRPB.

HOWARD, B.J., (VOIGT, G., SEGAL, M.G. & WARD, G.M.) 1996.

A review of iodine metabolism and available countermeasures to reduce radioiodine transfer to milk.

Health Physics, 71, 663-675.

The most effective countermeasure for radioiodine contamination of milk is to provide dairy animals with uncontaminated feed, with the added advantage that it will be effective for other radionuclides in the fallout. Another effective response is to process the milk into storable dairy products for an appropriate length of time to allow for physical decay. The use of additives given to ruminants to reduce radioiodine in milk is an alternative countermeasure which could be effective. Stable iodine administration is a practically feasible option which has the potential to reduce radioiodine levels in milk by at most a factor of three. Stable iodine supplementation should be at sufficiently high rates to be effective (and at least 1 g d^{-1} for dairy cows), particularly for ruminants already receiving high amounts of iodine in the diet. Currently available data are inadequate to recommend a suitable stable iodine administration rate for different species of ruminants. Other compounds, such as perchlorate and thiocyanate, also reduce the transfer of radioiodine to milk (and thyroid). Some of these compounds seem to be potentially equally as effective as stable iodine. However, currently there is inadequate information on their effectiveness and possible toxicity to both ruminants and humans for these compounds to be considered as suitable countermeasure additives.

(LIVENS, F.R., HOWE, M.T., HEMINGWAY, J.D., GOULDING, K.W.T.) & HOWARD, B.J. 1996.

Forms and rates of release of Cs from two Chernobyl affected peat soils.

European Journal of Soil Science, 47, 105-112.

DOI: <http://dx.doi.org/10.1111/j.1365-2389.1996.tb01377.x>

Cation exchange resin saturated with H^+ and Ca^{2+} was used to extract ^{137}Cs from peat soil at two sites in Britain affected by ^{137}Cs deposition following the Chernobyl accident. The technique identified three classes of ^{137}Cs , similar to those observed for K^+ in soils: 'Fast', 'Intermediate' and 'Slow'. These classes are probably related to the selectivity for ^{137}Cs of the cation exchange sites on the organic matter and the clay minerals, and to the structure of the soil. With one exception, most ^{137}Cs was in the 'Slow' form and was only very slowly released to the resins, if at all. However, there was enough ^{137}Cs in the 'Fast' and 'Intermediate' forms to contaminate pasture and thus grazing animals for some years. Based on the resin technique, it is estimated that contamination will persist for several decades in uplands contaminated at these activity concentrations.

(MAYES, R.W.,) BERESFORD, N.A., HOWARD, B.J., (VANDECASTEELE, C.M. & STAKELUM, G.) 1996.

The use of the true absorption coefficient as a measure of the bioavailability of radiocaesium in ruminants.

Radiation and Environmental Biophysics, 35, 101-109.

DOI: <http://dx.doi.org/10.1007/BF02434032>

Limitations of existing methods to describe bioavailability of dietary radionuclides to ruminants (the transfer coefficient and apparent absorption coefficient) have led to the alternative suggestion of using the true absorption coefficient (A_t). Various approaches to estimating A_t for radiocaesium, involving the intravenous administration of a second isotope, are presented and discussed with reference to results from studies in which a range of radiocaesium sources were examined in sheep. Although estimates of A_t differed between the sources, they were reasonably consistent between measurement techniques. Those methods, which involved the estimation of endogenous faecal excretion of radiocaesium, could be used with previously contaminated animals and did not require continuous administrations of radiocaesium isotopes, but gave unreliable results for sources of low bioavailability. Methods based on estimating the turnover rate of dietary radiocaesium through blood plasma were sufficiently sensitive to measure A_t for the range of sources studied. However, they require previously uncontaminated animals and continuous administration of both isotopes for approximately seven days. Bioavailability is more effectively measured as A_t than as the transfer or apparent absorption coefficients since A_t does not incorporate factors relating to metabolism of radiocaesium in the tissues of the animal. The results of these studies show that differences in transfer coefficients between sheep and cattle and between sheep of differing age are not due to variation in absorption across the gut. The potential for applying these approaches to other radioactive elements is discussed.

(MOSS, R.W.) & HORRILL, A.D. 1996.

Metabolism of radiocaesium in red grouse.

Journal of Environmental Radioactivity, 33, 49-62.

DOI: [http://dx.doi.org/10.1016/0265-931X\(95\)00072-I](http://dx.doi.org/10.1016/0265-931X(95)00072-I)

Red grouse eat a natural diet mostly of heather, a dwarf shrub which accumulates radiocaesium. Captive grouse were fed a diet, comprising 60% heather contaminated with Chernobyl radiocaesium, containing about 1500 Bq kg⁻¹ of radiocaesium. Intake and excretion of radiocaesium reached equilibrium after 20-23 days and its biological half-life was 10-11 days, with about 23% of the radiocaesium in the diet being absorbed by the bird. Transfer coefficients for both captives and wild birds were about 10 days kg⁻¹. Radiocaesium activity concentrations in wild birds reflected those in their diet and it is suggested that the sampling of birds shot for sport could form an efficient means of monitoring radiocaesium levels in heather-dominated uplands in the UK.

SANCHEZ, A.L., HORRILL, A.D., SINGLETON, D.L. & (LEONARD, D.R.P.) 1996.

Radionuclides around nuclear sites in England and Wales.

Science of the Total Environment, 181, 51-63.

DOI: [http://dx.doi.org/10.1016/0048-9697\(95\)04959-2](http://dx.doi.org/10.1016/0048-9697(95)04959-2)

Environmental releases of low levels of radioactivity can occur as a consequence of normal operations at nuclear facilities. In England and Wales, the impact of gaseous discharges on the terrestrial environment is monitored routinely by the site operators as well as by Food Science Division of the Ministry of Agriculture, Fisheries and Food. The terrestrial surveillance programme carried out by MAFF Food Science concentrates on agricultural produce to provide assessments of doses to members of the population derived from the consumption of terrestrial foodstuffs. We present here the results of a survey, undertaken in 1993 to supplement the monitoring data of MAFF, of artificial radioactive contamination around eighteen nuclear establishments in England and Wales. Grass and soil samples were used as indicators of environmental contamination at these sites for the radionuclides ¹³⁷Cs, ⁹⁰Sr, ²³⁹⁺²⁴⁰Pu and ²⁴¹Am. When compared to estimated background radionuclide concentrations close to each site, these data reveal that four of the 18 sites have contributed measurable increases to both the ¹³⁷Cs and ²³⁹⁺²⁴⁰Pu inventory within 500 m outside the boundary fence. Two additional sites showed slight increases above the expected background soils levels of ²³⁹⁺²⁴⁰Pu.

SANCHEZ, A.L. & SINGLETON, D.L. 1996.

A radioanalytical scheme for determining transuranic nuclides and ^{90}Sr in environmental samples.

Journal of Radioanalytical Nuclear Articles, 209, 41-50.

DOI: <http://dx.doi.org/10.1007/BF02063530>

A method is described incorporating the procedures used in the radiochemical assay of Pu, Am and radiostrontium in environmental samples into a single radioanalytical sequential scheme. Sequential schemes have been used for determining the transuranic nuclides (isotopes of Pu and Am) in various types of sample matrices, but do not normally incorporate ^{90}Sr within the same scheme. The method offers potential savings in analyst time and reagents for the analyses of these nuclides, and is particularly suitable for small analytical laboratories where manpower resources coupled with a limited working time (8-hour working day) are constraints, and where limited amounts of sample are submitted for the analyses of all 3 radionuclides.

(AARKROG, A., BAXTER, M.S., BETTENCOURT, A.O., BOJANOWSKI, R., BOLOGA, A., CHARMASSEN, S., CUNHA, I., DELFANTI, R., DURAN, E., HOLM, E., JEFREE, R., LIVINGSTON, H.D., MAHAPANYAWONG, S., NIES, H., OVEATH, I., PINGTY, L.I., POVINEC, P.P.), SANCHEZ, A., (SMITH, J.N. & SWIFT, D.) 1997.

A comparison of doses from ^{137}Cs and ^{210}Po in marine food: a major international study.

Journal of Environmental Radioactivity, 34, 69-90.

DOI: [http://dx.doi.org/10.1016/0265-931X\(96\)00005-7](http://dx.doi.org/10.1016/0265-931X(96)00005-7)

Radioactivity levels of natural ^{210}Po and anthropogenic ^{137}Cs in sea water and biota (fish and shellfish) have been estimated for the FAO fishing areas on the basis of measurements carried out in recent years. Collective doses resulting from seafood consumption are calculated for each FAO area using radioactivity data for water and biota. Good agreement is observed between the results calculated by these two methods, with the exception of the doses from the ^{210}Po via shellfish consumption. The collective effective dose commitment from ^{137}Cs in marine food in 1990 has been estimated at 160 man Sv with an uncertainty of 50%. The corresponding dose from ^{210}Po is 30 000 man Sv with an estimated uncertainty of a factor of 5. The results confirm that the dominant contribution to doses derives from natural ^{210}Po in fish and shellfish and that the contribution from anthropogenic ^{137}Cs (mainly originating from nuclear weapons tests) is negligible.

BERESFORD, N.A., (MAYES, R.W.,) BARNETT, C.L., (LAMB, C.S., WILSON, P.,) HOWARD, B.J. & (VOIGT, G.) 1997.

The effectiveness of oral administration of potassium iodide to lactating goats in reducing the transfer of radioiodine to milk.

Journal of Environmental Radioactivity, 35, 115-128.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(96\)00050-1](http://dx.doi.org/10.1016/S0265-931X(96)00050-1)

Ingestion of milk contaminated by radioiodine (mostly especially ^{131}I) represents an important potential route of radiation exposure to humans in the event of a nuclear accident. Oral administration of stable iodine to dairy ruminants has previously been suggested as an effective countermeasure to reduce radioiodine levels in milk. However, previous data on its effectiveness are contradictory, and little attention has been given to the most appropriate time to administer stable iodine relative to the time that an animal is first exposed to radioiodine. The effectiveness of 1 g KI orally administered to lactating goats 12 h before and 12 h after contamination with pulse doses of radioiodine was investigated. Administration of KI prior to the ingestion of radioiodine was shown to reduce the transfer to milk by 50% compared to a reduction of approximately 40% when KI was administered 12 h after radioiodine. The administration of KI 12 h prior to radioiodine contamination effectively reduced the transfer of radioiodine to the thyroid by approximately 90%. When administered 12 h after radioiodine, the KI stopped subsequent uptake of radioiodine by the thyroid. The maximum level of iodine in milk, as a consequence of the administration of KI, was 20 mg I kg⁻¹. This was 40-fold higher than the maximum permissible level of iodine in milk of 0.5 mg I kg⁻¹ currently set in some countries. Further consideration is required on stable iodine administration regimes for different scenarios and the consequent increase in the stable iodine content of the milk of different dairy animals.

HOWARD, B.J. BERESFORD, N.A., (MAYES, R.W., HANSEN, H.S., CROUT, N.M.J. & HOVE, K.) 1997.

The use of dietary calcium intake of dairy ruminants to predict the transfer coefficient of radiostrontium to milk.

Radiation and Environmental Biophysics, 36, 39-43.

DOI: <http://dx.doi.org/10.1007/s004110050053>

Transfer coefficients (the equilibrium ratio between radionuclide activity concentration in milk or meat and the daily intake of radionuclide) are widely used to predict the contamination of animal products following the release of radionuclides into the environment. For a transfer coefficient to be generally applicable, its value must be constant for a range of circumstances. However, this is not the case of radiostrontium, the behaviour of which is strongly influenced by that of the homeostatically controlled nutrient, calcium. In this study, a relationship is derived between radiostrontium transfer coefficients and dietary calcium intake which takes into account the observed ratio for strontium:calcium transfer to milk. This relationship is tested against a range of observed data collated from the literature ($n=30$) and found to account for 93% of the variability in transfer coefficient values. Model calculations show that a reduction in F_m of at least 40%--60% would be expected if dairy cattle, fed rations typical. For well-managed herds, were supplemented with 100-200 g per day. Larger reductions would be predicted when dietary calcium intake is low.

KENNEDY, V.H., SANCHEZ, A.L., (OUGHTON, D.) & ROWLAND, A.P. 1997.

The use of single and sequential chemical extractants to assess radionuclide and heavy metal availability from soils for root uptake: a critical review.

The Analyst, 122, 89-100.

DOI: <http://dx.doi.org/10.1039/A704133K>

To assess soil radionuclide and heavy metal availability for plant uptake it is necessary to devise a chemical or a biological method that gives a reliable estimate of the mobilisable portion of the pollutant present in the solid phase. This review provides an overview of extraction methods that have been used to estimate radionuclide and heavy metal availability for root uptake from the soil. It discusses their use in pollutant studies and potential problems in the interpretation of data produced. Topics covered include role of extractants in predicting bioavailability; single extractants; sequential extraction schemes; other methods used to estimate soil bioavailability and experimental aspects of extraction techniques.

(RUTTER, S.M.,) BERESFORD, N.A. & (ROBERTS, G.) 1997.

Use of GPS to identify the grazing areas of hill sheep.

Computers and Electronics in Agriculture, 17, 177-188.

DOI: [http://dx.doi.org/10.1016/S0168-1699\(96\)01303-8](http://dx.doi.org/10.1016/S0168-1699(96)01303-8)

Within flocks grazing land contaminated with radioactive fallout following the Chernobyl nuclear accident, certain sheep have comparatively high levels of radiocaesium. To understand why only certain sheep are affected, the precise grazing areas of these animals need to be identified. An animal behaviour and tracking system, that utilises the Global Positioning Systems (GPS), has been developed and was tested in upland West Cumbria, UK. Although there was evidence that hilly terrain did occasionally affect the function of the GPS receiver, this was for only 2.5% of the time in the worst case. The study clearly demonstrates that GPS can be used to track domestic sheep, and could be used to identify home ranges and the specific areas giving rise to contaminated animals.

SANCHEZ, A.L., SINGLETON, D.L., (WALTERS, B. & COBB, J.) 1997.

Radionuclides in whole diets of people living near the Sellafield nuclear complex, UK.

Journal of Radioanalytical Nuclear Chemistry, 226, 267-274.

DOI: <http://dx.doi.org/10.1007/BF02063659>

The British Nuclear Fuels Limited (BNFL) complex (Sellafield) in Cumbria discharges into the atmosphere, under authorisation by the Environment Agency (and previously, the Ministry of Agriculture, Fisheries and Food (MAFF)), radioactive waste consisting of gases, mists and dusts. As part of MAFF's radiological surveillance programme, the intake of radionuclides via food ingestion by members of the public living near this nuclear installation is routinely assessed from measurements made on local food and environmental samples and by using computer models simulating the dispersion and incorporation of radioactivity into foodstuffs. In this study, the individual diets of adults and children living near the Sellafield complex, and those from a control group were assessed for their radionuclide content. The participants were selected via a food survey questionnaire which was aimed at identifying those who consume home grown fruits and vegetables or derive these from local sources. The diets were collected over a one-week period in August 1995 and following radiochemical analyses of the diets for $^{239+240}\text{Pu}$, ^{137}Cs , ^{90}Sr , ^{14}C and ^{129}I , the doses received by the participants from these nuclides were extrapolated over a one-year period and compared to doses calculated from food surveillance data and to doses predicted using the MAFF foodchain computer model.

(SKUTERUD, L., BALANOV, M., TRAVNIKOVA., I., STRAND, P.) & HOWARD, B.J. 1997.

Contribution of fungi to radiocaesium intake of rural populations in Russia.

Science of the Total Environment, 193, 237-242.

DOI: [http://dx.doi.org/10.1016/S0048-9697\(96\)05346-6](http://dx.doi.org/10.1016/S0048-9697(96)05346-6)

In a study of transfer of Chernobyl radiocaesium to man, dietary surveys and whole body monitoring were conducted at two sites in the Bryansk Region of the Russian Federation. Radiocaesium activity concentrations in wild food products, especially mushrooms, were higher than those in agricultural products. The surveys revealed that consumption of highly contaminated wild mushrooms provided a significant contribution to ingested radiocaesium, accounting for 20-40% of the variability of radiocaesium activity concentrations in rural populations 8-9 years after the 1986 accident. Consumption of mushrooms was also the main reason for a 60-70% mean increase in radiocaesium activity concentrations in humans in autumn. Long term dose assessment after accidental releases of radiocaesium should therefore consider the potential contribution by mushrooms to ingested dose.

WRIGHT, S.M., (STRAND, P., SICKEL, M.A.K.), HOWARD, B.J., HOWARD, D.C. & COOKE, A.I. 1997. Spatial variation in the vulnerability of Norwegian Arctic counties to radiocaesium deposition.

Science of the Total Environment, 202, 173-184.

DOI: [http://dx.doi.org/10.1016/S0048-9697\(97\)00114-9](http://dx.doi.org/10.1016/S0048-9697(97)00114-9)

Under the Arctic Monitoring and Assessment Programme (AMAP), studies have been undertaken to compare potential fluxes of radiocaesium via important food products. The results for three Norwegian Arctic counties are presented in this paper. The comparative importance of different foodstuffs in contributing to collective dose varies spatially due to differing rates of production and transfer. Although reindeer meat is an important contributor to the radiocaesium flux following a nuclear release, other food products such as cow milk and lamb have been identified as potentially important. Assuming an even deposition following a nuclear release the radiocaesium flux was estimated to be highest for reindeer meat in Finnmark and Troms, whereas cow milk gave the highest flux in Nordland. The total number, geographical distribution and diet composition of indigenous peoples within different Arctic regions is an important factor affecting individual and collective doses arising from a nuclear release. Finnmark has been shown to be the most vulnerable of the three counties because it has the highest flux of radiocaesium and the largest number of indigenous peoples. The potential contribution of foodstuffs which are known to readily accumulate radiocaesium needs further consideration, in particular for mushroom, freshwater fish and berries.

BERESFORD, N.A., (CROUT, N.M.J., MAYES, R.W. & LAMB, C.S.) 1998.

Dynamic distribution of radioisotopes of cerium, ruthenium and silver in sheep tissues.

Journal of Environmental Radioactivity, 38, 317-338.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(97\)00036-2](http://dx.doi.org/10.1016/S0265-931X(97)00036-2)

A number of radioisotopes of cerium, ruthenium and silver may be released into the environment and potentially contaminate foodstuffs. For ruminants, data on the absorption, transfer and excretion rates of these radionuclides are sparse and were previously insufficient to allow the development of reliable dynamic models to enable the prediction of contamination levels in food products. In this study, groups of sheep were given single oral administrations of radiocerium, rutheruthenium, and radiosilver and slaughtered at various periods up to 1 y. The resulting data were used to develop compartment models to describe the transfer of the three radionuclides to sheep tissues.

Values for gut absorption and transfer to muscle (the most important tissue in terms of contamination of the food chain) derived from the models were considerably lower than previously advised values for the radionuclides studied. For all three radionuclides there were certain organs which contained significantly higher activity concentrations than muscle. The models developed allow prediction of the likely levels of these radionuclides in the tissues of sheep as a result of single or continuous contamination events.

BERESFORD, N.A., (MAYES, R.W., HANSEN, H.S., CROUT, N.M.J., HOVE, K.) & HOWARD, B.J. 1998.

Generic relationship between calcium intake and radiostrontium transfer to the milk of dairy ruminants.

Radiation and Environmental Biophysics, 37, 129-131.

DOI: <http://dx.doi.org/10.1007/s004110050105>

The hypothesis that there is a generic relationship between the calcium intake and the transfer of radiostrontium to milk which can be used for all dairy ruminants is tested. In addition to the daily calcium intake the relationship also requires values for the strontium to calcium observed ratio, which describes the discrimination in transfer of the two elements to milk (a value of 0.11 is used), and the calcium concentration in milk. The relationship had previously only been validated for dairy cattle as there was insufficient data for other ruminant species. Here, we present recently available data for dairy goats, and also a limited amount of data for sheep derived from the literature. From the comparison between these data and predicted values we conclude that it is possible to derive a generic model of the transfer of radiostrontium to the milk of dairy ruminants.

BERESFORD N.A., (MAYES R.W.,) BARNETT C.L., (MACEACHERN P.J. AND CROUT N.M.J.) 1998.

Variation in the metabolism of radiocaesium between individual sheep.

Radiation & Environmental Biophysics, 37, 277-281.

DOI: <http://dx.doi.org/10.1007/s004110050129>

Considerable variability has been recorded in the radiocaesium activity concentration of muscle between individual sheep in the same flocks in upland areas that received fallout from the Chernobyl accident. In a previous paper, we demonstrated that there is a propensity for certain sheep within a flock to always be amongst the most contaminated and others to be consistently the least contaminated. Here we report a study to determine the extent to which variation in the metabolism of radiocaesium by individual sheep may contribute to the observed variability within sheep flocks. The transfer coefficient and biological half-life of orally-administered ionic radiocaesium in muscle were determined, under controlled conditions, in 22 ewes from an upland farm in an area of the UK which received comparatively high levels of Chernobyl fallout. There was considerable variation between individuals in both the transfer coefficient (0.19–0.56 d kg⁻¹; mean 0.34 d kg⁻¹) and biological half-life in muscle (5.2–18.7 d; mean 9.8 d). Changes in liveweight during the study, and feed intake together accounted for 72 % of the variation in the derived transfer coefficients; liveweight change also accounted for 56 % of the observed variation in biological half-life. In a subsequent study, the true absorption coefficient of radiocaesium was determined in 12 of the ewes. There was a positive correlation between transfer and true absorption coefficients (R = 0.57). We conclude that differences in the metabolism of radiocaesium will contribute to the observed variability in radiocaesium activity concentrations within sheep flocks in areas which were contaminated by Chernobyl fallout. We also suggest that for growing animals, the influence of liveweight change and feed intake on radiocaesium transfer may be greater than observed here. Similarly, in dairy cattle, for which feed intake changes considerably during the course of a lactation, large temporal variation in radiocaesium transfer to milk could be expected.

(CROUT, N.M.J., MAYES, R.W.), BERESFORD, N.A., (LAMB, C.S.) & HOWARD, B.J. 1998.

A metabolic approach to simulating the dynamics of C-14, H-3 and S-35 in sheep tissues.

Radiation and Environmental Biophysics, 36, 243-250.

DOI: <http://dx.doi.org/10.1007/s004110050078>

The results of a study in which groups of sheep were given single oral administrations of ^{14}C , ^3H and ^{35}S , and slaughtered over periods of 1 y are reported. The experimental data were used to investigate the potential of metabolically based models for describing the transfer of the three radionuclides to sheep tissues. The structure of these models is based upon a simplified understanding of the transfer of the macro-elements C, H and S by processes such as respiration and protein synthesis/degradation. A consequence of this approach is that the three models have many common parameters. The models reproduced the general trends of the observations, accounting for 74, 66, and 58% of the observed variation in the ^{14}C , ^3H and ^{35}S data respectively, suggesting that they may provide a useful alternative approach to modelling the transfer of these radionuclides. The models presented are limited to the particular experimental situation for which they were developed and further experimental work would be required to extend them. However, such metabolically based models have a large potential, for example, they should be able to account for the influence of dietary intake, physiological status, or the form of the radionuclide in the animals diet (e.g. tritiated water or organically bound tritium).

(CROUT, N.M.J.), BERESFORD, N.A., HOWARD, B.J., (MAYES, R.W. & HANSEN, H.S.) 1998.

A model of radiostrontium transfer in dairy goats based on calcium metabolism.

Journal of Dairy Science, 81, 92-99.

DOI: [http://dx.doi.org/10.3168/jds.S0022-0302\(98\)75555-9](http://dx.doi.org/10.3168/jds.S0022-0302(98)75555-9)

A model of radiostrontium transfer in dairy goats is presented. The novel feature of the model is that it is based on our current understanding of Ca metabolism and assumes that the transfer of radiostrontium is driven by transfers of Ca. Previously published models of radiostrontium transfer in animals have ignored the influence of Ca metabolism. Unknown model parameters were obtained by fitting the model to data from a study of radiostrontium and Ca transfer in goats. The model accounted for 95 and 97% of the observed variation in the data for Ca ($n = 22$) and radiostrontium ($n = 43$) respectively. Unlike previously reported models the model presented here could be applied to simulate the effect of additional dietary Ca as a countermeasure to contamination of milk by radiostrontium under different circumstances.

HOWARD, B.J. & (DESMET, G.M.) 1998.

The achievements of a radioecological environmental research programme arising from the collaboration of the EC and the republics of Russia, Belarus and Ukraine.

Journal of Environmental Radioactivity, 39, 305-326.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(97\)00060-X](http://dx.doi.org/10.1016/S0265-931X(97)00060-X)

The European Radiation Research Programme refocused some of its research effort within EU countries to consider the environmental consequences of the Chernobyl accident within the third framework period from 1985-1989. A gradual improvement in contacts with the Soviet Union occurred from 1990 and allowed the development of research collaboration between EC and Soviet scientists. In response, a programme of Experimental Collaborative Projects (ECP) and Joint Study Projects (JSP) were launched by the EC-DGXII's Radiation Protection Research Action. Within these projects, Western European and Eastern European scientists collaborated on assessing the consequences of the accident, considering remedial actions and acquiring much basic scientific information on the behaviour of radionuclides in the contaminated territories in Ukraine, Belarus and the Russian Federation. The major goal of all these studies was to provide practical and theoretical assistance to the relevant authorities, based on fundamental approach of understanding the environmental factors which control the different exposure rates to both the urban and rural populations living in the contaminated areas. The scientific results of the radioecological projects have been summarised at the First International Conference on the Radiological consequences of the Chernobyl accident. This Conference was organised by the European Commission and the Belarus, Russian and Ukrainian Ministries on Chernobyl affairs, Emergency Situations and Health. This paper summarises the achievements of the radioecological programme.

(RATNIKOV, A.N., VASILIEV, A.V., ALEXAKHIN, R.M., KRASNOVA, E.G., PASTERNAK, A.D.)
HOWARD, B.J., (HOVE, K. & STRAND, P.) 1998

The use of hexacyanoferrates in different forms to reduce radiocaesium contamination of animal products in Russia.

Science of the Total Environment, 223, 167-176.

DOI: [http://dx.doi.org/10.1016/S0048-9697\(98\)00313-1](http://dx.doi.org/10.1016/S0048-9697(98)00313-1)

Hexacyanoferrates have been identified as highly effective radiocaesium binders which effectively reduce radiocaesium uptake and transfer to milk and meat. In Russia a hexacyanoferrate called ferrocyn has been produced for use as a countermeasure. In 1989-1992, experiments were undertaken in Russia to study the effectiveness of four different ferrocyn materials as ^{137}Cs binders, their potential toxicity, effect on production rates of cow milk, effect on animal health and ease of implementation in routine agricultural practice. Four different ferrocyn delivery forms have been used: 98% pure powder, sustained release rumen boli (15% ferrocyn), salt licks (10% ferrocyn) and sawdust with 10 % ferrocyn adsorbed (bifege). In initial experiments with cows, sheep and pigs these four ferrocyn materials were effective in reducing radiocaesium transfer to animal products. Daily administration of ferrocyn powder at a rate of 3-5 g per cow reduced ^{137}Cs transfer by up to 90% in milk. One single administration of 3 boli/cow (containing 30 g ferrocyn per boli) reduced ^{137}Cs transfer by 50-75% for a period of two months. Salt licks containing 10% ferrocyn (0.22 kg ferrocyn per 2.2 kg briquette provided once) reduced transfer of ^{137}Cs up to 2 fold for up to 10 days whilst bifege, given at a rate of 30-60 g d⁻¹ (3-6 g d⁻¹ ferrocyn), reduced ^{137}Cs transfer by 90-95%. However, large-scale application of these ferrocyn materials on collective and private farms in agricultural trials in 1994 resulted in a lower effectiveness. Therefore, in 1996 a comparative assessment of the application of the four ferrocyn forms was made under carefully controlled conditions. The results fully validated the previous experimental data, and showed the importance of meeting recommended procedures for treatment, particularly when hexacyanoferrates are administered on a day to day basis.

SANCHEZ, A.L., HORRILL, A.D., HOWARD, B.J., SINGLETON, D.L. & (MONDON, K.) 1998

Anthropogenic radionuclides in tide-washed pastures bordering the Irish Sea coast of England and Wales.

Water, Air and Soil Pollution, 106, 403-424.

DOI: <http://dx.doi.org/10.1023/A:1005065428994>

The activity concentrations of ^{137}Cs , ^{238}Pu , $^{239,240}\text{Pu}$ and ^{241}Am were measured in root mat and vegetation samples collected from tide washed pastures in 17 estuaries spanning the eastern seaboard of the Irish Sea, extending from the Solway in north-west England to St. David's Head in south Wales. Some of these estuaries had been investigated in previous surveys, but this study is unique in that it covered a wide geographic range using the same sampling and analytical methodology and within a comparatively short time scale. This allows for a valid comparison within the data set of the contamination levels at the different areas. Spatial distributions of the radionuclides were consistent with transport of radionuclides discharged to the Irish Sea from the Sellafield Nuclear Reprocessing Plant, with the highest activities occurring in the Esk estuary (closest to Sellafield) and lowest at the Welsh sites. Measurable activity concentrations of ^{238}Pu and $^{239,240}\text{Pu}$ were found in root mat samples from the Solway estuary to as far south as the Gwyrfaai in Wales and showed an average $^{238}\text{Pu}/^{239,240}\text{Pu}$ ratio of 0.2, consistent with Sellafield-derived Pu. The ratios of $^{137}\text{Cs}/^{241}\text{Am}$ increase with distance from the source, with values of 1:1 in estuaries near Sellafield to ratios between 2 and 5 in estuaries further south and in excess of 10:1 in Wales. This is probably due to the more rapid movement of dissolved ^{137}Cs in Irish Sea waters compared with the actinides. In contrast, ^{241}Am and $^{239,240}\text{Pu}$ behave similarly with consistent ratios of between 2:1 and 3:1, as both are associated with particulates. Dose assessment calculations suggest that external exposure would be a maximum of 530 mSv at the most contaminated spot at the Esk estuary. Relatively lower doses arise from the ingestion of animal products (along the soil-vegetation-grazing animal pathway) due to the low availability of sediment-associated radionuclides for gut transfer. The dose assessment calculations highlight the importance of using the appropriate transfer parameters that take into account this low bioavailability.

(SMITH, J.T.), HOWARD, D.C., WRIGHT, S.M., NAYLOR, C., (BROOKES, A.M., HILTON, J.) & HOWARD, B.J. 1998.

Use of a satellite derived land cover map to estimate flux capacity for radiocaesium contamination of surface waters.

Science of the Total Environment, 209, 1-15.

DOI: [http://dx.doi.org/10.1016/S0048-9697\(97\)00206-4](http://dx.doi.org/10.1016/S0048-9697(97)00206-4)

During the weeks to months after the deposition of radioactive fallout, the initial concentration of radioactivity in rivers and lakes declines as a result of flushing and removal to bottom sediments. In the long term, however, radioactivity in the water body can remain at significant levels as a result of secondary contamination processes. In particular, it is known that soils contaminated by long lived radionuclides such as ^{137}Cs and ^{90}Sr provide a significant source to surface waters over a period of years after fallout.

Using The Land Cover Map of Great Britain, a satellite derived land cover map as a surrogate indicator of soil type, we have related catchment land cover type to long term ^{137}Cs activity concentrations in 27 lakes in Cumbria, UK. The study has shown that satellite-derived maps could be used to indicate areas vulnerable to high long-term ^{137}Cs transport to surface waters in the event of a nuclear accident. In these Cumbrian lakes, it appears that residual ^{137}Cs levels are determined by transfers of ^{137}Cs from contaminated catchments rather than within-lake processes. Only three of the cover types, open shrub moor, bog and dense shrub moor, as identified by the satellite, are needed to explain over 90% of the variation in long term ^{137}Cs activity concentrations in the lakes, and these have been shown to correlate spatially with occurrence of organic soils.

WRIGHT, S.M., HOWARD, B.J., BARNETT, C.L. STEVENS, P. & ABSALOM, J.P. 1998.

Development of an approach to estimating critical loads for radiocaesium contamination of cow milk in Western Europe.

Science of the Total Environment, 221, 75-87.

DOI: [http://dx.doi.org/10.1016/S0048-9697\(98\)00269-1](http://dx.doi.org/10.1016/S0048-9697(98)00269-1)

This paper describes the application of the critical load methodology, developed to set emission targets for atmospheric pollutants, to radioecology. The critical load can be redefined within radioecology as the radionuclide deposition at which radionuclide activity concentrations in a specified food product will exceed the maximum permitted level. An empirically based approach is described which provides estimates of critical load values for cow milk in the mid- to long-term after an accident when soil-to-plant transfer of radiocaesium is largely responsible for plant radiocaesium contamination. The areas identified as being most potentially vulnerable to radiocaesium deposition using this approach are those with extensive areas of organic soils such as western Scotland and parts of Ireland, The Netherlands and Denmark. The classification of European soil types into soil groups with significantly different soil-to-plant transfer of radiocaesium, and the allocation of a transfer value to each soil group provide the greatest uncertainties within this approach. Potential problems and deficiencies affecting the estimation of parameter values are discussed.

BARNETT, C.L., BERESFORD, N.A., SELF, P.L., HOWARD, B.J., FRANKLAND, J.C., (FULKER, M.J.) DODD, B.A. & (MARRIOTT, J.V.R.) 1999.

Radiocaesium activity concentrations in the fruit-bodies of macrofungi in Great Britain and an assessment of dietary intake habits.

Science of the Total Environment, 231, 67-83.

DOI: [http://dx.doi.org/10.1016/S0048-9697\(99\)00085-6](http://dx.doi.org/10.1016/S0048-9697(99)00085-6)

Radiocaesium activity concentrations in the fruit-bodies of some species of macro fungi are higher than in many other foodstuffs. The consumption of fruit-bodies contributes significantly to radiocaesium intake of humans in some countries. In the United Kingdom, the collection of wild fungi has generally been considered to be of minor importance and there are few data on consumption rates or radiocaesium activity concentrations in most edible species. Samples of commonly eaten species in Great Britain have been collected to assess radiocaesium contamination levels and geographical variation. Concurrently, surveys of consumption habits were conducted.

A total of 425 samples representing 37 different species were collected. Significantly higher radiocaesium activity concentrations occurred in mycorrhizal compared to saprotrophic or parasitic species. The highest ^{137}Cs activity concentration of 30.5 kBq kg^{-1} dry weight was determined in a sample of *Hydnum repandum* collected in Wales. The transfer of radiocaesium from soil to fungal fruit-bodies was highly variable, ranging over three orders of magnitude within individual species. A number of approaches to quantifying radiocaesium transfer from soil to fungal fruit-bodies were used. Although these were in general agreement with previously measured values in other countries, all the approaches gave variable results.

Over 200 people responded to the dietary habits questionnaire. The median intake rate was 0.75 kg y^{-1} (fresh weight) and 60% of respondents consumed only one species (generally *Agaricus campestris*). However, intakes of up to 26 kg y^{-1} were recorded and a total of 82 species were consumed. The intake of ^{137}Cs was determined by the amount of mycorrhizal fungi in the diet rather than the total intake of fungi. Assuming median recorded ^{137}Cs activity concentrations in each fungal species, the estimated annual committed effective dose for over 95% of respondents was $<1 \mu\text{Sv}$. Hence, currently, the consumption of wild fungi in the UK would not be expected to significantly increase the dose above that attributable to the normal diet of most consumers. However, the results of this study demonstrate that, in the event of any future accidental release of radiocaesium, the potential ingestion dose received from the consumption of wild fungi would need to be considered.

BERESFORD, N.A., (MAYES, R.W., MACEACHERN, P.J.), DODD B.A & (LAMB C.S.) 1999.

The effectiveness of alginates to reduce the transfer of radiostrontium to the milk of dairy goats.

Journal of Environmental Radioactivity, 44, 43-54.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(98\)00066-6](http://dx.doi.org/10.1016/S0265-931X(98)00066-6)

In the event of a nuclear accident the radiation dose to human populations arising from radiostrontium ingested as contaminated milk is a major cause of concern. We report a study to determine if calcium alginate incorporated into the diet can be used as an effective countermeasure to reduce radiostrontium transfer to the milk of dairy goats.

When Ca-alginate was included into a pelleted ration at 5% dry weight the transfer of radiostrontium to the milk of the goats was reduced by approximately 50%. No effects on diet palatability or the absorption of iron or calcium were observed. Ca-alginate was readily fermentable and hence its potential binding capacity is likely to be reduced in ruminants compared to monogastrics. The Ca-alginate also supplied additional calcium to the diet in an amount which may explain the observed reduction in radiostrontium transfer to milk. Therefore, currently, we cannot be certain if the effect we observed was due to alginate or calcium.

BERESFORD, N.A., (HOVE, K.), BARNETT, C.L., DODD, B.A., (FAWCETT, A. R. & MAYES, R.W.) 1999.

The development and testing of an intraruminal slow-release bolus designed to limit radiocaesium absorption by small lambs grazing contaminated pastures.

Small Ruminant Research, 33, 109-115.

DOI: [http://dx.doi.org/10.1016/S0921-4488\(99\)00010-3](http://dx.doi.org/10.1016/S0921-4488(99)00010-3)

The accident at the Chernobyl nuclear power plant in 1986 resulted in levels of radiocaesium in animal-derived food products above national intervention limits in a number of countries. In upland areas of the United Kingdom (UK) radiocaesium activity concentrations in the meat of some sheep exceeds (in 1998) the local intervention limit of 1000 Bq kg⁻¹ and measures are still in place to restrict the entry of such animals into the human food chain. The use of many established countermeasure techniques is difficult due to the nature of animal management in the affected areas. This paper describes a study to develop and test a bolus containing the radiocaesium binder ammonium ferric hexacyanoferrate (AFCF) suitable for administration to small lambs of hill-sheep breeds used in the UK. It was found that a bolus 14 x 50 mm in size, and containing 20 % AFCF, could be safely administered to lambs of 10 kg. An increase in the AFCF content above 20 % resulted in too rapid a breakdown of the bolus. Administration of three boli per lamb reduced the ¹³⁷Cs activity concentration in muscle by circa 50 % between 3 and 8 weeks following administration of the boli. After 12 weeks the reduction in the ¹³⁷Cs activity concentration was 30 %. We conclude that the AFCF bolus developed could be effectively used to reduce the radiocaesium activity concentration in lambs within hill and upland areas of the UK.

BERESFORD, N.A, (MAYES, R.W, CROUT, N.M.J., MACEACHERN P.J.), DODD, B.A., BARNETT, C.L. & (LAMB, C.S.) 1999.

The transfer of cadmium and mercury to sheep tissues.

Environmental Science and Technology, 33, 2395-2402.

DOI: <http://dx.doi.org/10.1021/es9811041>

Toxic heavy metals such as cadmium and mercury can enter the diet of farm animals by a variety of environmental exposure routes and hence contaminate food products derived from those animals. Therefore, there is a need to be able to predict the likely levels of contamination in animal tissues if exposed to a contaminated diet and also estimate how rapidly an animal will decontaminate once the source of contamination is removed from the diet. Data on the transfer and excretion rates of Cd and Hg from tissues have previously been inadequate to allow the development of dynamic models to predict changes in the degree of contamination of different tissues of ruminants. A study is described during which a group of sheep were given a single oral administration of ¹⁰⁹Cd and ²⁰³Hg. Measurements of the concentrations of the radioisotopes in tissue samples were subsequently made over a period of 1 year. The resultant data were used to develop compartment models to describe the behaviour of the two metals in sheep tissues.

To our knowledge the models developed are the first to allow the time-dependent prediction of the potential Cd and Hg contamination of animal-derived food products. Previously only advised transfer coefficients were available; we demonstrate that these are of little value for cadmium and mercury due to their slow rates of accumulation and excretion.

(BURROUGH, P.A., VAN DER PERK, M.), HOWARD, B.J., (SANSONE, U. & PRISTER, B.) 1999.
Environmental mobility of radiocaesium in the Pripyat catchment, Ukraine, Belarus.

Water, Air and Soil Pollution, 110, 35-55.

DOI: <http://dx.doi.org/10.1023/A:1005028729330>

Evidence from research in the Pripyat catchment, reviewed here, indicates that under the ecological conditions prevalent in this area, radiocaesium (¹³⁷Cs) is highly mobile in both river water and poorly drained organic soils. Data collected at three different spatial and temporal scales demonstrate the effects of hydrological events on ¹³⁷Cs mobility. During the period 1988-1994, ¹³⁷Cs contamination in some poorly drained organic soils in the Pripyat catchment and in the milk from cows grazing on these soils are generally declining much faster than the radioactive half life. However, sharp increases in levels of ¹³⁷Cs in both floodplain soils and milk to 2-3 times that observed immediately after the initial deposition have been measured immediately after summer floods. The processes causing these observed changes have not yet been fully explained but the sites where enhanced ¹³⁷Cs mobility has been detected are clearly associated with the spatial patterns of organic soils and river flooding.

SANCHEZ, A.L., (WALTERS, C.B.), SINGLETON, D.L. (WOOD, N.H. & MONDON, K.) 1999.
Food ingestion doses from artificial radionuclides in Cumbrian diets, ten years post-Chernobyl.

Journal of Environmental Radioactivity, 46, 301-317.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(98\)00149-0](http://dx.doi.org/10.1016/S0265-931X(98)00149-0)

The ingestion of radioactively contaminated foodstuffs is a major pathway of radiation exposure in humans. A duplicate diet approach has been used to assess ingestion doses of the local population of west Cumbria in the United Kingdom. There has been historical interest in this population group, particularly those living close to the Sellafield nuclear installation, and the two major routes of ingestion exposure for them, namely the consumption of either local agricultural produce (the terrestrial pathway) or of locally-derived sea foods (the marine pathway). We examine here the ingestion doses derived using radionuclide data from duplicate diet studies carried out during 1986, 1995 and 1996. The Chernobyl accident occurred during sample collection for the first survey; the latter surveys thus provide data to evaluate any changes in the ingestion dose up to ten years after the accident. The contribution of Chernobyl fallout to the dose in 1986 was mainly due to radiocaesium (^{134}Cs and ^{137}Cs); in 1996, the ^{137}Cs results are comparable to those obtained during the 1986 pre-Chernobyl survey, suggesting that radiocaesium activity concentrations in local foods from around west Cumbria have now decreased to pre-Chernobyl levels. The contributions of other artificial radionuclides (^{90}Sr , $^{239+240}\text{Pu}$, ^{14}C) analysed in the diet samples over the period are also assessed. Carbon-14, measured in the 1995 and 1996 surveys but not in 1986, is currently the most important contributor to the dose; in 1996, it accounted for at least 75% of the total ingestion dose from the radionuclides measured.

SANCHEZ, A.L., WRIGHT, S.M., (SMOLDERS, E., NAYLOR, C., STEVENS, P.A.), KENNEDY, V.H., DODD, B.A., SINGLETON, D.L. & BARNETT, C.L. 1999.

High plant uptake of radiocaesium from organic soils due to Cs mobility and low soil K content.

Environmental Science and Technology, 33, 2752-2757.

DOI: <http://dx.doi.org/10.1021/es990058h>

Post-Chernobyl experience has demonstrated that persistently high plant transfer of ^{137}Cs occurs from organic soils in upland and semi-natural ecosystems. The soil properties influencing this transfer have been known for some time but have not been quantified. A pot experiment was conducted using 23 soils collected from selected areas of Great Britain, which were spiked with ^{134}Cs , and *Agrostis capillaris* grown for 19-45 days. The plant to soil ^{134}Cs concentration ratio (CR) varied from 0.06 – 44; log CR positively correlated to soil organic matter content ($R^2 = 0.84$) and CR values were highest for soils with low distribution coefficients (K_d) of ^{134}Cs . Soils with high organic matter contents and high concentrations of NH_4^+ in solution showed high ^{134}Cs mobility (low K_d). The plant to soil solution ^{134}Cs ratio decreased sharply with increasing soil solution K^+ . A two parameter linear model, used to predict log CR from soil solution K^+ and K_d , explained 94% of the variability in CR values. In conclusion, the high transfer of ^{134}Cs in organic soils is related to both the high ^{134}Cs mobility (low clay content and high NH_4^+ concentrations) and low K availability.

SMITH, J.T., (FESENKO, S.V.), HOWARD, B.J., HORRILL, A.D., (SANZHAROVA, N.I.), ALEXAKHIN, R.M., ELDER, D.G.) & NAYLOR, C. 1999.

Temporal change in fallout ^{137}Cs in terrestrial and aquatic systems: a whole ecosystem approach.

Environmental Science and Technology, 33, 49-54.

DOI: <http://dx.doi.org/10.1021/es980670t>

During the years after a nuclear accident, the bioavailability and environmental mobility of radiocaesium declines markedly, resulting in large changes in contamination of foodstuffs, vegetation, and surface waters. Predicting such changes is crucial to the determination of potential doses to affected populations and therefore to the implementation of radiological countermeasures. We have analysed 77 data sets of radiocaesium (^{137}Cs) activity concentrations in milk, vegetation and surface waters after the Chernobyl accident. Our results show that the rate of decline in ^{137}Cs during the years after Chernobyl is remarkably consistent in all three ecosystem components, having a mean effective half life, $T_{\text{eff}} \approx 2$ years. By comparing changes in ^{137}Cs availability with rates of diffusion of ^{40}K (a close analogue) into the lattice of an illitic clay we have, for the first time, directly linked changes in the environmental availability of ^{137}Cs to fixation processes at a mechanistic level. These changes are consistent with declines in the exchangeable fraction of ^{137}Cs in soils.

(STRAND, P., BALONOV, M., TRAVNIKOVA, I., SKUTERUD, L., RATNIKOV, A., PRISTER, B.,) HOWARD, B.J. & (HOVE, K.) 1999.

Fluxes of radiocaesium in selected rural study sites in Russia and Ukraine.

Science of the Total Environment, 231, 159-171.

DOI: [http://dx.doi.org/10.1016/S0048-9697\(99\)00086-8](http://dx.doi.org/10.1016/S0048-9697(99)00086-8)

The food production and food harvesting systems common in the areas contaminated by the Chernobyl accident in Russia and Ukraine can be grouped into three major categories: collective farm produce, private farming produce and foods collected from natural ecosystems. The contribution of each of these sources to radiocaesium intake by people living in rural settlements in the mid 1990s has been estimated at two major study sites, one in each country. The collective farm system provided the smallest contribution (7-14 %) to the intake of radiocaesium at both sites. Natural food was the major contributor to intake at the Russian site (83 %). Whereas private farm produce was the major contributor (68 %) at the Ukrainian study site. The difference between the two sites was mainly because private milk production was stopped at the Russian site due to the contamination in 1986. A retrospective assessment of the situation one year after the accident shows that collective farming could have been a minor contributor to radiocaesium intake (8 %), whilst private farming would have been the major contributor wherever private milk production and consumption continued. The extent to which inhabitants consume natural foods from forests has a considerable effect on their radiocaesium intake. The comparative importance of food products from natural ecosystems increases with time due to the long effective ecological half lives of radiocaesium in unimproved pastures and forests. Estimation of the fluxes of radiocaesium from the different production and harvesting systems showed that the contribution from private farming and food harvesting from natural ecosystems may be significant, contributing 14-30 % to the total fluxes of radiocaesium from an area even if the quantity of food produced in these systems is small. However the major contributor to the flux exported from an area was the collective farming system, accounting for about 70-86 % of the total.

(WIGLEY, F., WARWICK, P.E., CROUDACE, I.W., CABORN J.) & SANCHEZ A.L. 1999.

Optimised method for the routine determination of technetium-99 in environmental samples by liquid scintillation counting.

Analytica chimica acta, 380, 73-82.

DOI: [http://dx.doi.org/10.1016/S0003-2670\(98\)00676-X](http://dx.doi.org/10.1016/S0003-2670(98)00676-X)

A method has been developed for the routine determination of ^{99}Tc in a range of environmental matrices. Technetium-99m ($t_{1/2} = 6.06$ hours) is added as internal yield monitor. Samples are ignited stepwise to 550°C and the ^{99}Tc is extracted from the ignited residue with 8M nitric acid. Many contaminants are co-precipitated with $\text{Fe}(\text{OH})_3$ and the Tc in the supernate is pre-concentrated and further purified on an anion exchange column. Technetium is finally separated from ruthenium by its extraction into 5% tri-n-octylamine in xylene from 2M sulphuric acid. The xylene fraction can then be mixed directly with a liquid scintillant. The chemical yield is determined through the measurement of $^{99\text{m}}\text{Tc}$ by gamma spectrometry and the ^{99}Tc is determined by liquid scintillation counting after a two week decay interval. Typical recoveries for this method are in the order of 70 -95%. The method has a detection limit (L_D) of 1.74 Bq / kg based on a two hour count time and a 10g sample size. At least sixteen samples per week can easily be processed by one analyst.

WRIGHT, S.M., HOWARD B.J., (STRAND, P., NYLÉN, T. & SICKEL, M.A.K.) 1999.
Prediction of ^{137}Cs deposition from atmospheric nuclear weapons tests within the Arctic.
Environmental Pollution, 104, 131-143.

DOI: [http://dx.doi.org/10.1016/S0269-7491\(98\)00140-7](http://dx.doi.org/10.1016/S0269-7491(98)00140-7)

A method of predicting the spatial distribution of ^{137}Cs deposition in fallout in the Arctic from atmospheric nuclear weapons testing, developed during the Arctic Monitoring and Assessment Programme (AMAP), is described. The method uses a relationship between deposition and precipitation at Tromsø (Norway) calculated for each year since 1959, which is spread over the Arctic using a global precipitation data set within a Geographical Information System. The advantages of this approach includes the ability to cover the whole Arctic area and to predict ^{137}Cs deposition, either integrated or decay corrected (cumulative), for any $0.5^\circ \times 0.5^\circ$ unit for any year. For land north of 60°N , the areas with the lowest estimated ground ^{137}Cs deposition from nuclear weapon testing are the Russian Far North East, North Greenland and Northern Canada. The highest estimated ground deposition occurred in the coastal areas of Alaska, the Southern tip of Greenland, Western Canada, Iceland and the western coast of Norway. Predicted differences in the predicted spatial distribution of global fallout are generally consistent with the trends observed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and with reported measurements in the region above 60°N . A comparison of the predicted cumulative ^{137}Cs deposition with measured values gave a significant correlation ($p < 0.001$). However, the current predicted deposition would probably underestimate global fallout deposition in areas receiving little precipitation and areas close to the test site.

BERESFORD, N.A., BARNETT, C.L. & (MAYES, R.W.) 2000.

Radiocaesium variability within sheep flocks: determination of ^{137}Cs intake in free-ranging sheep.

Radiation & Environmental Biophysics, 39, 207-212.

DOI: <http://dx.doi.org/10.1007/s004110000064>

A study is described in which ^{137}Cs intake by free-ranging sheep was estimated at two farms in the area of west Cumbria (north-west England) which received some of the highest amounts of fallout from the Chernobyl accident within the UK. The faecal excretion of ^{137}Cs was estimated from faecal ^{137}Cs activity concentrations and the use of intra-ruminal controlled release devices containing Cr_2O_3 to determine faecal dry matter output. The intake of ^{137}Cs was estimated by assuming an apparent absorption coefficient appropriate to the herbage grazed. The methodology has the advantage that sampling of herbage representative of that ingested by study animals is not required. Caesium-137 dietary intake explained > 60 % of the observed variability in the ^{137}Cs activity concentration determined in the muscle of sheep. Resultant transfer coefficient (F_f) values to describe the transfer of ^{137}Cs from the diet to muscle were in agreement with previously reported values. At one farm, there was a positive correlation between the ^{137}Cs activity concentration in muscle and F_f whilst at the other farm there was a negative correlation between F_f and ^{137}Cs dietary intake. Potential reasons for these observations are discussed.

BERESFORD, N.A., (GASHCHAK, S., LASAREV, N., ARKHIPOV, A., CHERNY, Y., ASTACHEVA, N., ARKHIPOV, N., MAYES, R.W.,) HOWARD, B.J., (BAGLAY, G., LOGINOVA, L. AND BUROV, N.) 2000.

The transfer of ^{137}Cs and ^{90}Sr to dairy cattle fed fresh herbage collected 3.5km from the Chernobyl nuclear power plant.

Journal of Environmental Radioactivity, 47, 157-170.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(99\)00037-5](http://dx.doi.org/10.1016/S0265-931X(99)00037-5)

A study conducted during summer 1993 to determine the bioavailability and transfer of ^{137}Cs and ^{90}Sr to dairy cattle from herbage collected from a pasture contaminated by particulate fallout is described. The study pasture was located within 5 km of the Chernobyl nuclear power plant. The true absorption coefficient (A_t) determined for ^{137}Cs (0.24) was considerably lower than previous estimates for radiocaesium incorporated into vegetation by root uptake. It is likely that the low dry matter digestibility of the diet and the potential presence of ^{137}Cs associated with adherent soil-associated fuel particles contributed to this low bioavailability. The A_t value determined for ^{90}Sr (0.27) did not indicate a reduced bioavailability. It is suggested that the current and previous calcium status of the animals was the controlling influence on the transfer of ^{90}Sr from the diet to milk.

BERESFORD, N.A., (MAYES, R.W., COLGROVE, P.M.), BARNETT, C.L., (BRYCE, L.), DODD, B.A. & (LAMB, C.S.) 2000.

A comparative assessment of the potential use of alginates and dietary calcium manipulation as countermeasures to reduce the transfer of radiostrontium to the milk of dairy animals.

Journal of Environmental Radioactivity, 51, 321-334.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(00\)00086-2](http://dx.doi.org/10.1016/S0265-931X(00)00086-2)

The potential of using different alginates or supplementary calcium as feed-additives to reduce the transfer of ingested radiostrontium to milk was assessed in dairy cattle fed a haylage/concentrate diet. The feed-additives compared were: calcium alginate (4 % by dry matter), sodium alginate (4 % by dry matter) and four levels of supplementation with CaCO_3 . Both alginates reduced the transfer of radiostrontium to milk by 30 - 40 % without effecting diet palatability. However, the high present cost of alginates precludes their use as countermeasures. Dietary calcium supplementation reduced the transfer of ^{85}Sr to milk broadly in agreement with previous predictions. From data relevant to dairy cattle in the United Kingdom it is suggested that dietary calcium intake could be doubled without exceeding recommended maximum intakes, thus decreasing the transfer of radiostrontium to milk by approximately 50 %.

BERESFORD, N.A., (MAYES, R.W., COOKE, A.I.), BARNETT, C.L., HOWARD, B.J., (LAMB, C.S.) & (NAYLOR, G.P.L.) 2000

The Importance of Source Dependent Bioavailability in Determining the Transfer of Ingested Radionuclides to Ruminant Derived Food Products.

Environmental Science and Technology, 34, 4455-4462.

DOI: <http://dx.doi.org/10.1021/es0000697>

The transfer of radioactivity to the milk and meat of farm animals is likely to be a major exposure pathway of human populations, following an environmental release of radioactivity. The importance of source dependent bioavailability in determining absorption from the ruminant gastrointestinal tract of the radiologically significant radionuclides, radiocaesium, radiostrontium, radioiodine and plutonium is reviewed. The requirements for, and suitability of, *in-vitro* methods of determining bioavailability for absorption of these radionuclides is also assessed. Radiocaesium absorption varies over a 50-fold range,

depending upon dietary source. Source dependent bioavailability is therefore an important factor determining the radiocaesium contamination of ruminant derived food products and reliable *in-vitro* techniques have been developed to rapidly determine its' bioavailability. In contrast, under conditions of adequate calcium intake, the absorption of radiostrontium will not be greatly influenced by the dietary source. Results of *in-vitro* extractions of radiostrontium could be misleading, as they indicate differences in bioavailability which are not observed in the animal. Absorption of radioiodine is complete and independent of source. There is currently a lack of data on plutonium absorption in ruminants. However, on the basis of the limited data available, *in-vitro* incubations provide a measure of the relative bioavailabilities of plutonium from different sources. The applicability of the techniques reviewed to the study of other radionuclides and heavy metals is discussed.

(CROUT, N.M.J.), BERESFORD, N.A., (MAYES, R.W., MACEACHERN, P.J.), BARNETT, C.L., (LAMB, C.S.), & HOWARD, B.J. 2000.

A model of radioiodine transfer to goat milk incorporating the influence of stable iodine.

Radiation & Environmental Biophysics, 39, 59-65.

DOI: <http://dx.doi.org/10.1007/PL00007678>

Previously reported models for radioiodine in ruminants cannot account for the effect of variations in stable iodine intake including large countermeasure doses of stable iodine, on the transfer of radioiodine to goat milk. A metabolically based model of radioiodine transfer in goats has been parameterised using new experimental data on the effect of countermeasure doses of stable iodine on radioiodine transfer to milk. To account for the effect of dietary stable iodine levels the model represents the transfer of iodine from extra cellular fluid to milk with a Michaelis-Menten kinetic. The model shows good agreement with the experimental data, and the estimated parameters compare favourably with values which can be estimated from the literature. The parameterised model accounts for 95% of the variation in the observed data for milk, faeces, urine and thyroid (n=199). The model has been used to predict the effects of variation in stable iodine intake, and the extent of consequent chemical contamination of milk by stable iodine. The time taken for radioiodine to reach peak concentrations in milk following a deposition event is predicted to vary significantly (*circa* 2 d) over a range of expected stable iodine intakes. Doses of stable iodine sufficient to reduce radioiodine transfer to milk will result in stable iodine concentrations in milk greatly in excess of internationally advised limits. Therefore, we recommend that stable iodine supplementation is not used as a countermeasure to reduce radioiodine transfer to milk. Indeed, model predictions suggest that reductions in stable iodine intake would be a more effective countermeasure. However, this is unlikely to be feasible since the short physical half-life of ^{131}I may not allow adequate time to implement changes in feed manufacture. The model described in this paper is freely available in ModelMaker 3.0 format (<http://www.nottingham.ac.uk/environmental-modelling/>).

HOWARD, B.J. 2000

The concept of radioecological sensitivity.

Radiation Protection Dosimetry, 92, 29-34.

It is important to be able to readily identify major routes of exposure, the most highly exposed individuals or populations and the geographical areas of most concern arising from radioactive contamination. The critical group approach is used to identify sub-sections of the population who are likely to be most exposed. In this paper, the concept of radioecological sensitivity is explored with particular reference to methods of identifying spatial variation in radiation exposure. Radioecological sensitivity analysis attempts to integrate current knowledge on pathways, spatially attribute the underlying processes determining transfer and thereby identify the most radioecologically sensitive areas leading to high radiation exposure. This identifies where high exposure may occur and why, not only for humans, but also for other biota. It can consider single food products or species, or a number of key parameters to identify areas where a number of key pathways coincide. An example of radioecological sensitivity analysis is given for the Arctic. Prior identification of such areas and exposed individuals should improve the focus of emergency preparedness and planning, and contribute to environmental impact assessment for future facilities.

(MCGEE, E.J., SYNNOTT, H.J., JOHANSSON, K. J., FAWARIS, B.H., NIELSEN, S.P.,) HORRILL, A.D., KENNEDY, V.H., (BARBAYIANNIS, N., VERESOGLOU, D.S., DAWSON, D.E., COLGAN, P.A. & MCGARRY, A.T.) 2000.

Chernobyl fallout in a Swedish Spruce forest ecosystem.

Journal of Environmental Radioactivity, 48, 59-78.#

DOI: [http://dx.doi.org/10.1016/S0265-931X\(99\)00057-0](http://dx.doi.org/10.1016/S0265-931X(99)00057-0)

An assessment of the distribution of Chernobyl fallout in a Swedish forest was carried out and showed more than 95% of the ^{137}Cs in the system to be of Chernobyl origin. The data show that approximately 87% of total fallout is found in soils, 6% in the bryophyte layer and 7% in standing biomass of trees. The mean deposition of ^{137}Cs in the system (including soils, bryophytes, understorey vegetation, fungi, trees, moose and roe-deer) was 54 kBq m^{-2} . Fungi, understorey vegetation and ruminant populations collectively

contained approximately 1% of total Radiocaesium in the system. However, actual concentrations in these sample types were higher than in any other category, mostly exceeding the limit of 1500 Bq kg⁻¹ for consumption of wild produce in Sweden. These categories represent the principal foodstuffs responsible for radiation transfer to man from the system and though negligible in total biomass there is potential for significant dose transfer to individuals who are regular consumers of wild forest produce.

SANCHEZ, A.L., (PAREKH, N.R.), DODD, B.A., (INSON, P.) 2000

Microbial component of radiocaesium retention in highly organic soils.

Soil Biology & Biochemistry, 32, 2091-2094.

DOI: [http://dx.doi.org/10.1016/S0038-0717\(00\)00099-7](http://dx.doi.org/10.1016/S0038-0717(00)00099-7)

The mobility of radiocaesium in the environment and its availability for plant uptake are strongly dependent on the processes controlling its retention in soils. The role of the soil microbial biomass in radiocaesium retention may be important in highly organic soils, yet this role has received little attention. Currently, the techniques used to assess radiocaesium retention tend to ignore the microbial component and, as a result, may compromise assessment of retention. We present here evidence that the microbial component cannot be ignored in such assays and propose changes that recognise the importance of maintaining biological activity in samples of organic soils.

(SMITH, J.T., COMANS, R.N.J.), BERESFORD, N.A., WRIGHT, S.M., HOWARD, B.J., (CAMPLIN, W.C.) 2000

Chernobyl's legacy in food and water.

Nature, 405, 141.

DOI: <http://dx.doi.org/10.1038/35012139>

Radiocaesium (¹³⁷Cs) from the 1986 Chernobyl accident has persisted in freshwater fish in a Scandinavian lake for much longer than was expected. On the basis of new data generalizing this observation, we propose that the continuing mobility of ¹³⁷Cs in the environment is due to the so-called 'fixation' process of radiocaesium in the soil tending towards a reversible steady state. Our results enable the contamination of foodstuffs by Chernobyl fallout to be predicted over the coming decades. Restrictions in the United Kingdom, for example, may need to be retained for a further 10–15 years — more than 100 times longer than originally estimated.

(VANDECASTEELE, C. VAN HEES, M., HARDEMAN, F., VOIGT, G.) & HOWARD, B.J., 2000.

The true absorption of ¹³¹I, and its transfer to milk in cows given different stable iodine diets.

Journal of Environmental Radioactivity, 47, 301-317.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(99\)00047-8](http://dx.doi.org/10.1016/S0265-931X(99)00047-8)

The influence of the stable iodine content in the diet on the absorption of radioiodine and its transfer to cow's milk was investigated for cows at different stages of lactation. Three different rates of stable iodine: a low intake rate of 4 mg d⁻¹, a moderate intake of 35 mg d⁻¹ and a high rate of 75 mg d⁻¹ were fed to two groups of three lactating cows in mid- and late- lactation. The transfer to milk of a single oral administration of radioiodine was measured for the three different intake rates. The lactation phase had no significant effect on iodine transfer to milk; therefore, the data from the two lactation groups were pooled for further statistical analyses. The mean transfer coefficient values for oral radioiodine to milk increased from 0.020 d L⁻¹ for the low treatment to 0.024 d L⁻¹ for the moderate stable iodine rate. There was a statistically significant decrease in the transfer to milk for the high stable dietary iodine intake rate (mean transfer coefficient = 0.018 d L⁻¹) compared with the moderate treatment. These differences were not due to effects on absorption since true absorption was complete for all three stable iodine treatments, but rather to differential affinities and saturation levels of the thyroid and milk pathways competing for the available iodine. The same behaviour and comparable values of transfer coefficients (range 0.015-0.020 d L⁻¹) were observed for stable iodine.

(VOIGT, G., EGED, K., HILTON, J.,) HOWARD, B. J., (KIS, Z., NISBET, A. F., OUGHTON, D. H. , RAFFERTY, B. SALT, C.A., SMITH, J.T. AND VANDENHOVE, H). 2000

A wider perspective on the selection of countermeasures.

Radiation Protection Dosimetry, 92, 45-48.

In the past, the decision to apply countermeasures following nuclear accidents has been based primarily on their effectiveness in averting doses to man. However, particularly in recent years since the Chernobyl accident in 1986, it has been realised that other factors need to be considered. These include the reasons and justification for introducing the countermeasure, the time scale over which they will be used, their effectiveness and their practicability. Practicability includes factors such as technical limitations and capacity, exposure during implementation, potential environmental impacts, economic implications and acceptability (both social and ethical) as well as a number of site specific issues. These criteria have been used to evaluate a range of commonly used countermeasures and a spreadsheet information system has been prepared by the members of an IUR Action Group. The system highlights factors to be taken into consideration in making a decision on the implementation of countermeasures.

(ABSALOM, J.P., YOUNG, S.D., CROUT, N.M. J.), SANCHEZ, A., WRIGHT, S.M., (SMOLDERS, E., NISBET, A.F. & GILLET, A.G.) 2001

Predicting the transfer of radiocaesium from organic soils to plants using soil characteristics.

Journal of Environmental Radioactivity, 52, 31-43.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(00\)00098-9](http://dx.doi.org/10.1016/S0265-931X(00)00098-9)

A model predicting plant uptake of radiocaesium based on soil characteristics is described. Three soil parameters required to determine radiocaesium bioavailability in soils are estimated in the model: the labile caesium distribution coefficient (k_{dl}), K^+ concentration in the soil solution [m_K] and the soil solution \rightarrow plant radiocaesium concentration factor (CF, $Bq\ kg^{-1}\ plant/Bq\ dm^{-3}$). These were determined as functions of soil clay content, exchangeable K^+ status, pH, NH_4^+ concentration and organic matter content. The effect of time on radiocaesium fixation was described using a previously published double exponential equation, modified for the effect of soil organic matter as a non-fixing adsorbent. The model was parameterised using radiocaesium uptake data from two pot trials conducted separately using ryegrass (*Lolium perenne*) on mineral soils and bent grass (*Agrostis capillaris*) on organic soils. This resulted in a significant fit to observed transfer factor (TF, $Bq\ kg^{-1}\ plant / Bq\ kg^{-1}\ whole\ soil$) ($P < 0.001$, $n=58$) and soil solution K^+ concentration (m_K , $mol\ dm^{-3}$) ($P < 0.001$, $n=58$). Without further parameterisation the model was tested against independent radiocaesium uptake data for barley ($n=71$) using a database of published and unpublished information covering contamination time periods of 1.2 - 10 years (transfer factors ranged from 0.001 to 0.1). The model accounted for 52% ($n=71$, $P < 0.001$) of the observed variation in log transfer factor.

(ÅHMAN, B.), WRIGHT, S.M. & HOWARD, B.J. 2001

Effect of origin of radiocaesium on the transfer from fallout to reindeer meat.

Science of the Total Environment, 278, 171-181.

DOI: [http://dx.doi.org/10.1016/S0048-9697\(01\)00646-5](http://dx.doi.org/10.1016/S0048-9697(01)00646-5)

Data on radiocaesium contamination of reindeer from five regions in Sweden have been used, together with interpolated radiocaesium deposition data, to quantify spatial variation in transfer to reindeer meat and to consider how it changes with time in different areas. Since the regions were contaminated to different extents by global and Chernobyl fallout, it was also possible to determine the influence of the origin or age of radiocaesium fallout on the transfer to reindeer meat. The regions differed significantly with regard to transfer of radiocaesium to reindeer meat. In two regions in the North of Sweden, where there was less Chernobyl ^{137}Cs , aggregated transfer coefficients (Tag), estimated for the main slaughter period in the first year after the Chernobyl fallout, were low (0.15 and $0.36\ m^2\ kg^{-1}$ in January-April). Average Tag values calculated for the winter period (January-April) in two regions in the middle of Sweden, where deposition from Chernobyl dominated (83 and 94%, respectively, of the total deposition), were 0.78 and $0.84\ m^2\ kg^{-1}$ respectively with a maximum Tag for an individual reindeer of $1.87\ m^2\ kg^{-1}$. There was a three fold increase in Tag values from early autumn to late winter reflecting the change in the reindeer diet from less contaminated vascular plants to more contaminated lichens. The decline of ^{137}Cs in reindeer meat from 1986 to 2000 differed between regions with longer effective half-lives (T_{ef}) in the northerly regions (11.0 and 7.1 years respectively) with less Chernobyl fallout, and shorter half-lives in the other three regions (3.5-3.8 years). This observation, together with a lack of a decline in early autumn in the region with least Chernobyl fallout, supports the theory of a gradual, but reversible, fixation of radiocaesium in the soil over the mid-long term. The results suggest that both the extent of transfer of ^{137}Cs to reindeer meat, and its subsequent decline with time, are affected by the differing origins of radiocaesium and that previous contamination may substantially influence radiocaesium transfer in the event of a further accident.

BARNETT, C.L., BERESFORD, N.A., FRANKLAND, J.C., SELF, P. L., HOWARD B. J. & (MARRIOTT, J.V.R.) 2001

Radiocaesium intake in Great Britain as a consequence of the consumption of wild fungi.

Mycologist 15 (3) 98-104.

DOI: [http://dx.doi.org/10.1016/S0269-915X\(01\)80029-X](http://dx.doi.org/10.1016/S0269-915X(01)80029-X)

In Great Britain, the collection of wild fungi for eating has generally been considered to be of minor importance. In this study, two concurrent surveys were conducted. The first assessed the radiocaesium contamination levels present in commonly eaten fungal species in mainland Great Britain (in collaboration with British Mycological Society affiliated groups). The second was a survey of consumption habits. The results show that it is not the actual amount of fungi consumed by individuals, which determine their radiocaesium intake, but rather the species they select; mycorrhizal species have significantly greater ^{137}Cs activity concentrations than saprotrophic and parasitic species. It is concluded that the consumption of wild fungi would not currently be expected to appreciably increase the intake of radioactivity of most consumers above that attributable to the normal diet.

BERESFORD, N.A., (CROUT, N.M.J. & MAYES, R.W.) 2001

The Transfer of Arsenic to Sheep Tissues.

Journal of Agricultural Science, Cambridge, 136, 331-344.

DOI: <http://dx.doi.org/10.1017/S0021859601008784>

There is the potential for arsenic to enter the human foodchain via ingestion by grazing animals. Data on the transfer of arsenic to ruminants has been too sparse to allow the development of dynamic models to predict changes in the arsenic contents of different tissues following ingestion. A study is described during which a group of six-month old lambs were given a single oral administration of $^{73}\text{AsCl}_3$. Subsequently, concentrations of ^{73}As in the tissues of groups of lambs slaughtered at intervals over a period of 181 days were determined. A true absorption coefficient of 0.46 ± 0.055 (mean \pm SE) was determined which is considerably lower than expected from previous studies of monogastric animals which demonstrate complete absorption for inorganic arsenic. The resultant data were used to develop a compartment model to describe arsenic behaviour in sheep tissues. The derived model accounted for 80 % (n=100) of the observed variation in the data. The model predicts that arsenic concentrations in tissues rapidly (<40 days) reach equilibrium with the dietary intake level. Equilibrium transfer coefficient values (the ratio of the arsenic concentration in a tissue to the daily dietary intake of arsenic) for the important foodchain tissues were calculated as: $(2.5 \pm 0.67) \times 10^{-3}$ days/kg for muscle, $(9.1 \pm 1.96) \times 10^{-3}$ days/kg for liver and $(1.1 \pm 0.14) \times 10^{-2}$ days/kg for kidney.

BERESFORD, N.A., (VOIGT, G.), WRIGHT, S.M., HOWARD, B.J., BARNETT, C.L., (PRISTER, B., BALONOV, M., RATNIKOV, A., TRAVNIKOVA, I., GILLET, A.G., MEHLI, H., SKUTERUD, L., LEPICARD, S., SEMIOCHKINA, N., PEREPELIANTNIKOVA, L., GONCHAROVA, N. & ARKHIPOV A.N.) 2001.

Self-help countermeasure strategies for populations living within contaminated areas of Belarus, Russia and the Ukraine.

Journal of Environmental Radioactivity, 56, 215-239.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(01\)00055-8](http://dx.doi.org/10.1016/S0265-931X(01)00055-8)

Countermeasures have been effectively employed within intensive agricultural systems in areas of the Former Soviet Union (FSU) affected by the Chernobyl accident. However, ingestion doses continue to be elevated in some areas as a result of a few foodstuffs which are collected from the wild or produced by the household. Forest fungi and berries, and milk from privately owned cattle are the most notable contributors to ^{137}Cs intakes amongst these foodstuffs. In this paper we consider advice which would help affected populations to both understand the importance of these exposure routes and to reduce their exposure. In addition to the potential radiological benefits, self-help schemes are highly cost-effective and likely to have a positive psychological influence on populations living within contaminated areas of the FSU. Evidence to suggest that the transfer of radiocaesium to cow milk is considerably higher in the FSU than within western Europe and North America is discussed.

(GALERIU, D., CROUT, N. M. J., MELINTESCU, A.) BERESFORD, N. A., (PETERSON, S. R., VAN HEES, M.) 2001.

A Metabolic Derivation of Tritium Transfer Coefficients in Animal Products.

Radiation & Environ. Biophys. 40, 325-334.

DOI: <http://dx.doi.org/10.1007/s00411-001-0116-5>

Tritium is a potentially important environmental contaminant originating from the nuclear industry, and its behaviour in the environment is controlled by that of hydrogen. Animal food products represent a potentially important source of tritium in the human diet and a number of transfer coefficient values for tritium transfer to a limited number of animal products are available.

In this paper we present an approach for the derivation of tritium transfer coefficients which is based on the metabolism of hydrogen in animals. The derived transfer coefficients separately account for transfer, to and from, free (i.e. water) and organically bound tritium. A novel aspect of the approach is that tritium transfer can be predicted to any animal product for which the required metabolic input parameters are available.

The predicted transfer coefficients are compared to available independent data. Agreement is good ($R^2=0.97$) with the exception of the transfer coefficient for transfer from tritiated water to organically bound tritium in ruminants. This may be attributable to the particular characteristics of ruminant digestion. We show that tritium transfer coefficients will vary in response to the metabolic status of an animal (e.g. stage of lactation, diet digestibility etc.) and that the use of a single transfer coefficient from diet to animal product is inappropriate. It is possible to derive concentration ratio values from the estimated transfer coefficients which relate the concentration of tritiated water and organically bound tritium in an animal product to their respective concentrations in the animals diet. These concentration ratios are shown to be less subject to metabolic variation and may be more useful radioecological parameters than transfer coefficients. For tritiated water the concentration ratio shows little variation between animal products

ranging from 0.59 to 0.82. In the case of organically bound tritium the concentration ratios vary between animal products from 0.15 (Goat Milk) to 0.67 (Eggs).

(GILLETT, A.G., CROUT, N.M.J., ABSALOM, S.M.,) WRIGHT, S.M., (YOUNG, S.D.,) HOWARD, B.J., BARNETT, C.L., (MCGRATH, S.P. & VOIGT, G.) 2001.

Temporal and spatial prediction of radiocaesium transfer to food products.

Radiation & Environment Biophysics, 40 227-235.

DOI: <http://dx.doi.org/10.1007/s004110100107>

A recently developed semi-mechanistic temporal model is used to predict food product radiocaesium activity concentrations using soil characteristics available from spatial soil databases (exchangeable K, pH, percentage clay and percentage organic matter content). A raster database of soil characteristics, radiocaesium deposition, and crop production data has been developed for England and Wales and used to predict the spatial and temporal pattern of food product radiocaesium activity concentrations (Bq/kg). By combining these predictions with spatial data for agricultural production, an area's output of radiocaesium can also be estimated, we term this flux (Bq/year per unit area). Model predictions have been compared to observed data for radiocaesium contamination of cow milk in regions of England and Wales which received relatively high levels of fallout from the 1986 Chernobyl accident (Gwynedd and Cumbria). The model accounts for 56% and 80% of the observed variation in cow milk activity concentration for Gwynedd and Cumbria, respectively. Illustrative spatial results are presented and suggest that in terms of food product contamination areas in the North and West of England and Wales are those most vulnerable to radiocaesium deposition. When vulnerability is assessed using flux the spatial pattern is more complex and depends upon food product.

HOWARD, B.J., BERESFORD, B., (VOIGT, G.) 2001.

Countermeasures for animal products: a review of effectiveness and potential usefulness after an accident.

Journal of Environmental Radioactivity, 56, 115-137.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(01\)00050-9](http://dx.doi.org/10.1016/S0265-931X(01)00050-9)

Over the last decade, there has been considerable progress in the development of countermeasures for preventing or reducing contamination of animal products by radioisotopes of iodine, caesium and strontium. In this paper, recent significant technical improvements are summarised and the current availability of countermeasures and their usefulness in the event of a nuclear accident reviewed. An improved understanding of factors controlling the metabolism of radioiodine and radiostrontium has enabled previously suggested countermeasures to be either optimised or dismissed. For radiocaesium in particular, experience since the Chernobyl accident has enabled effective and feasible countermeasures to be identified and successfully implemented in different situations. It has also been more widely understood that countermeasure effectiveness, although important, is not the only criterion which needs to be determined. In addition, cost and practical considerations such as availability, technical feasibility, acceptability and side effects need to be taken into account. Evaluation of these factors has shown that some previously recommended countermeasures are unlikely to be feasible.

BERESFORD, N. A., BARNETT, C., COWARD, P. A., HOWARD, B. J. & (MAYES, R. W.) 2002.

A simple method for the estimation of the bioavailability of radiocaesium from herbage contaminated by adherent soil.

Journal of Environmental Radioactivity, 63, 77-84.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(02\)00017-6](http://dx.doi.org/10.1016/S0265-931X(02)00017-6)

Adherent soil may contribute a large proportion of the radiocaesium content of sampled vegetation. Consequently, inadvertent ingestion of adherent soil can contribute significantly to the radiocaesium intake of grazing animals and needs to be accounted for within radiological assessments. However, accurate estimation of the degree of soil adhesion on vegetation is acknowledged to be difficult. To determine the relative contributions of vegetation and soil to the radiocaesium contamination of milk and tissues, soil-specific estimation of radiocaesium bioavailability values would be required. Here we suggest that a previously developed *in-vitro* bioavailability assay (involving a 2 hour extraction with 0.1M stable CsCl) can be used to estimate the true absorption coefficient of radiocaesium associated with sampled vegetation directly. Using this technique, seasonal trends in bioavailability are demonstrated to vary in accordance with estimations of the degree of soil adherent to vegetation collected from an upland pasture. The use of this technique would negate the need for detailed measurements of the amount of soil adhering to sampled vegetation and soil-specific radiocaesium bioavailability assessments.

BERESFORD, N.A., (MAYES, R.W.), BARNETT, C.L. & (LAMB, C.S.) 2002.

Dry Matter Intake - A Generic Approach To Predict The Transfer Of Radiocaesium To Ruminants?

Radioprotection- colloques, 37, C1, 373-378.

DOI: <http://dx.doi.org/10.1051/radiopro/2002069>

We have previously demonstrated a relationship between dry matter (DM) intake and the degree of transfer of radiocaesium to the muscle of adult sheep. Here, we present the results of an experiment during which we examined the effect of lamb growth and protein turnover rates, brought about by controlling feed DM intakes, on radiocaesium transfer and turnover. Lambs with high DM intakes and, as a consequence, high rates of growth, had a lower mean radiocaesium transfer coefficient from the diet to muscle than lambs with lower intake and growth rates. Furthermore, high rates of dry matter intake decreased the biological half-life of radiocaesium from muscle. The administration of [³⁵S]-methionine to the study lambs enables us to suggest that radiocaesium transfer may be related to protein turnover. When the results were compared with those of other studies using sheep, a consistent relationship between DM intake and radiocaesium transfer across all animals regardless of age or physiological status was observed. Extrapolation of the relationship to DM intake rates appropriate to cattle predict radiocaesium transfer coefficients in broad agreement with reported values.

(GALERIU, D., MELINTESCU, A.,) BERESFORD, N.A., & (CROUT, N.M.J.) 2002

The Derivation Of Tritium Transfer Parameters For Farm Animals On The Basis Of A Metabolic Understanding.

Radioprotection- colloques, 37, C1, 361-366.

DOI: <http://dx.doi.org/10.1051/radiopro/2002067>

In contrast to many radionuclides (which often have no biological function) ³H has a stable analogue which is an elemental component of major nutrients, animal tissues and drinking water. Therefore concepts used to predict the transfer of other radionuclides are not valid for ³H. In this paper we present an approach for the derivation of tritium transfer parameters which is based on the metabolism of hydrogen in animals. The derived transfer parameters separately account for transfer, to and from, free (i.e. water) and organically bound tritium. A novel aspect of the approach is that tritium transfer can be predicted to any animal product for which the required metabolic input parameters are available.

Predicted equilibrium transfer coefficients are compared to available independent data. Agreement is good ($R^2=0.97$) with the exception of the transfer from tritiated water to organically bound ³H in ruminants. This may be attributable to characteristics of ruminant digestion.

Tritium transfer coefficients will vary in response to the metabolic status of an animal and the use of a single transfer coefficient from diet to animal product is inappropriate. However, we demonstrate that concentration ratios are less subject to metabolic variation and are a more useful parameter than transfer coefficients.

HOWARD, B.J., WRIGHT, S.M., BARNETT C.L., (SKUTERUD, L. & STRAND, P.) 2002.

Estimation of Critical Loads For Radiocaesium In Fennoscandia and Northwest Russia.

Journal of Environmental Radioactivity, 60, 209-220.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(01\)00104-7](http://dx.doi.org/10.1016/S0265-931X(01)00104-7)

The application of the critical loads methodology for radioactive contamination of Arctic and sub Arctic ecosystems, where natural and semi-natural food products are important components of the diet of many people, is proposed and discussed. The critical load is herein defined as the amount of radionuclide deposition necessary to produce radionuclide activity concentrations in food products exceeding intervention limits. The high transfer of radiocaesium to reindeer meat gives this product the lowest critical load, even though the intervention limit is relatively high compared with other products. Ecological half-lives of radiocaesium in natural and semi-natural products are often very long, and it is therefore important to take account of contamination already present in the event of an accident affecting areas where such products are important. In particular, the long ecological half-life for radiocaesium in moose meat means that the critical load is highly sensitive to prior deposition. An example of the potential application of the method for emergency preparedness is given for the Chernobyl accident.

HOWARD, B.J., (ANDERSSON, K.G.,) BERESFORD, N.A., (CROUT, N.M.J., GIL, J.M., HUNT, J., LILAND, A., NISBET, A., OUGHTON, D., & VOIGT, G.) 2002.

Sustainable Restoration and Long-Term Management of Contaminated Rural, Urban and Industrial Ecosystems.

Radioprotection-colloques, 37, C1, 1067 – 1072

DOI: <http://dx.doi.org/10.1051/radiopro/2002126>

To sustain acceptable living and working conditions in areas contaminated by radioactivity, robust and effective restoration strategies need to consider different types of environment, land use and ways of life. The allocation of resources must take account of a range of requirements to ensure sustainable use, including social and ethical aspects, environmental considerations and quality of life. Current understanding of public perceptions and communication of technical information also needs to be integrated into the process so that the radiological situation is fully explained and any remediation measures are transparent to, and agreed by, affected populations. Many individual countermeasures have been developed and tested. Previously, the focus has been on evaluating their effectiveness, with some attention to cost. The current STRATEGY project aims to establish a more holistic decision framework for the selection of optimal remediation strategies for long-term sustainable management of contaminated areas. An initial step within this approach is a detailed evaluation of individual countermeasures; examples of which are provided here for an agricultural and urban countermeasure.

HOWARD, B.J., (STRAND, P., ASSIMAKOPOULOS, P., BRÉCHIGNAC, F., GASCÓ, C., MÉTIVIER, H., MOBERG, L.,) SMITH, J.T., (TAMPONNET, C., TRUEBA, C, VOIGHT, G) & WRIGHT, S. 2002.

Estimation Of Radioecological Sensitivity.

Radioprotection-colloques, 37, C1, 1167 – 1173

DOI: <http://dx.doi.org/10.1051/radiopro/2002142>

After the release of radionuclides into the environment it is important to be able to readily identify major routes of radiation exposure, the most highly exposed individuals or populations and the geographical areas of most concern. There have been significant recent improvements in our capability to estimate spatial variation in the environmental behaviour of radionuclides through better understanding of the underlying processes and an ability to spatially apply this knowledge by integrating relevant spatial information in the form of digital data sets using geographical information systems. Thus, it is now possible to refine the estimation of spatial variation in radiation exposure, both for routine releases and in accident situations. Within a recent EC-funded concerted action (the Radioecological Sensitivity Forum), there has been a renewed consideration of the concept of radioecological sensitivity with a particular focus on identifying sensitive areas as well as processes and communities. The concept should be relevant for both terrestrial and aquatic ecosystems, and might even be applied for consideration of doses to biota, although the current focus has been restricted to a consideration of human exposure. The conclusions of the action are outlined, considering the potential usefulness of the concept, and methods by which it can be applied. A framework for the estimation of radioecological sensitivity is proposed and the various measures by which it can be considered, including (i) aggregated transfer coefficients, (ii) action loads, (iii) fluxes and (iv) individual exposure of humans are discussed. The importance of spatial and temporal consideration of each of these outputs is emphasized.

(LOFTS, S.,) TIPPING, E. W., SANCHEZ, A.L, DODD, B. A. 2002.

Modelling the Role of Humic Acid in Radiocaesium Distribution in a British Upland Peat Soil

Journal of Environmental Radioactivity, 61, 133-147.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(01\)00118-7](http://dx.doi.org/10.1016/S0265-931X(01)00118-7)

The significance of exchange sites on organic matter in the retention of radiocaesium in highly organic soils remains unclear. To quantify this retention, we measured the binding of ^{134}Cs to a humic acid isolated from a British upland peat soil, under a range of chemical conditions. We interpreted our results using Humic Ion Binding Model V, a model of humic substance chemistry which simulates ion exchange by non-specific accumulation of cations adjacent to the humic molecules. Model V could simulate the humic acid-solution partitioning of Cs under all the solution conditions used. The model was used to estimate the contribution of organic matter to Cs sorption by the whole soil composite. An estimate of Cs sorption by illite frayed edge sites was also made. These simulations show that organic matter may play only a minor role in binding Cs, even in highly organic soils.

(PÁLSSON, S.E., ARNALDS, Ó, SIGURGEIRSSON, M. Á., GUONASON, J.) HOWARD, B. J, WRIGHT, S, & (PÁLSDÓTTIR, P). 2002.

Cs-137 Fallout Inventories In Iceland - Estimating Deposition From Precipitation Data.

Radioprotection- colloques, 37, C1, 1223-1228.

DOI: <http://dx.doi.org/10.1051/radiopro/2002151>

Iceland was identified in the Arctic Monitoring and Assessment Report as one of the Arctic areas which received the most global fallout from atmospheric nuclear weapons tests, but measurements of contamination were sparse, and are difficult due to the remote and inaccessible terrain of much of the country. Measurements of global ^{137}Cs deposition have been made at sites close to meteorological stations to ensure that precipitation data were of high quality. The measured data have been compared with different methods of predicting ^{137}Cs deposition. The AMAP modeling approach, based on fallout and precipitation data, was used based on a monitoring station near Reykjavik. The availability of good precipitation data and locally based estimates of time dependent ratios of ^{137}Cs deposition to precipitation during the fallout period gave a better correlation between predicted and observed ^{137}Cs deposition ($r^2=0.96$) than that achieved using the heterogeneous set of data collected by AMAP over the whole of the Arctic. The method allows a fallout map to be produced for the whole of Iceland for any time period during or after deposition.

SANCHEZ, A.L., (SMOLDERS, E., VAN DEN BRANDE, K., MERCKX, R.,) WRIGHT, S.M. & (NAYLOR, C.). 2002

Predictions of *in situ* solid/liquid distribution of radiocaesium in soils.

Journal of Environmental Radioactivity, 63, 35-47.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(02\)00013-9](http://dx.doi.org/10.1016/S0265-931X(02)00013-9)

Previous work has demonstrated that plant uptake of radiocaesium (RCs) is related to the activity concentration of RCs in soil solution, which is linked to the soil/soil solution distribution coefficient, K_D . The solid-liquid distribution of RCs is generally studied in soil suspensions in the laboratory and there are few reported measurements for *in situ* soil solutions. From a data set of 53 different soils (contaminated with either $^{134}\text{CsCl}$ or $^{137}\text{CsCl}$) used in pot trials to investigate grass uptake of RCs, we analysed the variation of *in situ* K_D with measured soil properties. The soils differed widely in % clay (0.5-58%), organic matter content (1.9-96%) and pH (2.4-7.0, CaCl_2). The K_D varied between 29 and 375000 L kg^{-1} (median 1460 L kg^{-1}). Stepwise multiple regression analysis showed a significant correlation between the log K_D and pH ($p<0.001$), log %clay ($p<0.01$) and log exchangeable K ($p<0.001$) (overall $R^2=0.70$). The *in situ* K_D values were further compared to K_D s predicted using an existing model, which assumes that RCs sorption occurs on specific sites and regular ion exchange sites on the soil solid phase. Sorption of RCs on specific sites was quantified from the radiocaesium interception potential (RIP) measured for each soil and the soil solution concentrations of K^+ and NH_4^+ . The *in situ* log K_D correlated well with the predicted K_D ($R^2=0.85$ before plant growth, $R^2=0.83$ after plant growth). However, the observations were 5 to 8 fold higher than the predictions, particularly for the mineral soils. We attribute the under-prediction to the long contact times (minimum 4 weeks) between the RCs tracers and our experimental soils relative to the short (24h) contact times used in RIP measurements. We conclude that our data confirmed the model but that ageing of RCs in soil is a factor that needs to be considered to better predict *in situ* K_D values.

(SHUTOV, V.N., TRAVNIKOVA, I.G., BRUK, G.YA., BALONOV, M.I.) HOWARD, B., (BROWN, J., STRAND, P., KRAVTSOVA, E.M., GAVRILOV, A.P., KRAVTSOVA, O.S., MUBASAROV, A.A.) 2002.
Current Contamination by ^{137}Cs and ^{90}Sr of the inhabited part of the Techa River Basin in the Urals.

Journal of Environmental Radioactivity, 61, 91-109.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(01\)00117-5](http://dx.doi.org/10.1016/S0265-931X(01)00117-5)

Previous discharges of radioactivity from the Mayak Production Association plant in the Urals have resulted in considerable radionuclide contamination of the Techa River, and consequent high radiation doses during the late 1940s and 1950s to residents of villages along the Techa river. The most contaminated villages close to the site were evacuated in the period 1954-1962. The objective of this recent study was to conduct a preliminary assessment of the current radioactive contamination of soil, vegetation and foodstuffs in the two remaining villages closest to the Mayak site, Muslyumovo and Brodokalmak. The highest contamination levels in soil were found in the floodplain at 5.5 MBq m^{-2} for ^{137}Cs and 1.0 MBq m^{-2} for ^{90}Sr . Radionuclide contamination in soil of the villages was much lower, but exceeded that expected from global fallout. Data from 1207 measurements of ^{137}Cs in milk and 1180 for ^{90}Sr in milk for the period 1992-1999 were collated. There was no change with time in the ^{90}Sr or ^{137}Cs activity concentration in milk over the measured period. There were significantly higher ^{137}Cs activity concentrations in milk sampled during the housed winter period in Muslyumovo compared with the grazing summer period, but no difference between that for Brodokalmak or for either settlement for ^{90}Sr . The highest measured activity concentrations in food products of ^{137}Cs and ^{90}Sr were found in river fish, waterfowl, poultry and milk. The measured activity concentration of ^{137}Cs and ^{90}Sr in some animal products were higher than that expected from that of soil and vegetation from fields and pasture in the villages (not including the floodplain) confirming that the highly contaminated floodplains are contributing to contamination of some animal products.

SINGLETON, D.L. & SANCHEZ, A.L. 2002.

A comparison of two techniques to determine Carbon-14 in environmental samples.

Journal of Radioanalytical and Nuclear Chemistry, 251, 3, 353-357.

DOI: <http://dx.doi.org/10.1023/A:1014805402966>

We have experience of two methods for the analysis of ^{14}C in environmental samples and have used this experience to directly compare these two techniques. Nine vegetation samples and a sucrose standard were analysed using the benzene synthesis and combustion techniques. The results obtained using both methods were in good agreement and show that ^{14}C data obtained using either are comparable. The analytical requirements for the two techniques vary considerably. In choosing a technique, a variety of factors such as sensitivity, sample size, sample type, carbon content and how the results are to be expressed, need to be considered.

(SMITH J.T., CROSS M.) & WRIGHT S.M. (2002).

Predicting transfers of ^{137}Cs in terrestrial and aquatic environments: a whole-ecosystem approach.

Radioprotection – Colloques, 37, 37-42.

It is well known that during the years after a nuclear accident the bioavailability and environmental mobility of radionuclides may change significantly, resulting in significant changes in contamination of foodstuffs and surface waters. Studies on ^{137}Cs and, to a lesser extent, ^{90}Sr , have quantified these changes in some ecosystems. However, variability in temporal changes of these radionuclides in aquatic and terrestrial systems is not yet well quantified. Estimation of such variability is a key component of any predictive model for long-term transfers of radionuclides in the environment. We have analysed measurements (from both weapons testing and Chernobyl deposits) of ^{137}Cs in runoff waters and in aquatic and terrestrial foodstuffs in order to determine temporal changes in their bioavailability and mobility. Using these empirical data, and the results of parallel modelling studies of vertical migration of radiocaesium in soils, we have quantified the relative importance of transport processes of ^{137}Cs , as compared to slow changes in its chemical availability in the soil. On the basis of these results, we have developed simple models for predicting time changes in activity concentrations of ^{137}Cs in surface water, foodstuffs and the human body during the years to decades after radioactive fallout. Importantly, we also determine uncertainties in model parameter estimates, and highlight the potential causes of this uncertainty.

(STRAND, P.,)HOWARD, B.J., (AARKROG, A. & BALONOV, M.) 2002.

Radioactive contamination in the Arctic – sources, dose assessment and potential risks.

Journal of Environmental Radioactivity, 60, 5-21.

DOI: [http://dx.doi.org/10.1016/S0265-931X\(01\)00093-5](http://dx.doi.org/10.1016/S0265-931X(01)00093-5)

Arctic residents, whose diets comprise a large proportion of traditional terrestrial and freshwater foodstuffs have received the highest radiation exposures to artificial radionuclides in the Arctic. Doses to members of both the average population and selected indigenous population groups in the Arctic depend on the rates of consumption of locally-derived terrestrial and freshwater foodstuffs, including reindeer/caribou meat, freshwater fish, goat cheese, berries, mushrooms and lamb. The vulnerability of arctic populations, especially indigenous peoples, to radiocaesium deposition is much greater than for temperate populations due to the importance of terrestrial, semi-natural exposure pathways where there is high radiocaesium transfer and long ecological half-lives. In contrast, arctic residents with diets largely comprising marine foodstuffs have received comparatively low radiation exposures because of the lower levels of contamination of marine organisms. Using Arctic specific information, the predicted collective dose is five times higher than that estimated by UNSCEAR for temperate areas. The greatest threats to human health and the environment posed by human and industrial activities in the Arctic are associated with the potential for accidents in the civilian and military nuclear sectors. Of most concern are the consequences of potential accidents in nuclear power plant reactors, during the handling and storage of nuclear weapons, in the decommissioning of nuclear submarines and in the disposal of spent nuclear fuel from vessels. It importance to foster interdependence between Risk Assessment and Practical Programmes to improve monitoring, response strategies and the implementation of action plans.

(TAMPONNET, C., MARTIN-GARIN, A., GONZE, M.A.,) SANCHEZ, A., PAREKH, N., (VALLEJO, R., SAURAS, T., CASADESUS, J., PLASSARD, C., STAUNTON, S., MOBERG, L., AVILA, R., SHAW, G. & WELLS, C.) 2002.

The European programme BORIS: Involvement of biological components in the transfer of radioactive nuclides to plants.

Radioprotection – Colloques, 37(C1) 331-336.

DOI: <http://dx.doi.org/10.1051/radiopro/2002062>

The ability to predict the consequences of an accidental release of radioactive nuclides relies mainly on the level of understanding of the mechanisms involved in radioactive nuclides interactions with different components of agricultural and natural ecosystems and their formalisation into predictive models. Numerous studies and databases about contaminated agricultural and natural areas have been obtained but their use to enhance our prediction ability has been largely limited by their unresolved variability. Such variability seems to stem from an incomplete knowledge about radioactive nuclide interactions with the soil matrix, soil moisture, biological elements in the soil and additional pollutants, which may be found in such soils. In this project, we investigate mainly the role of the biological elements (plants, mycorrhiza, microbes) in: radioactive nuclide sorption/desorption in soils and radioactive nuclide uptake/release by plants. Because of the importance of the chemical nature of the involved radioactive nuclides, we will follow the bioavailability of three radioactive nuclides: caesium, strontium, and technetium. The role of additional non-radioactive pollutants will also be scrutinised as they may interfere with the mechanisms governing radioactive nuclide transfer to plants. Knowledge acquired from the experiments will be incorporated into two mechanistic models BIOPHAST and BIORUR specifically modelling radioactive nuclide sorption/desorption from soil matrices and radioactive nuclide uptake by/release from plants. These mechanistic models will be incorporated into assessment models to enhance their prediction ability. One expects to extract from these experiments scientific bases for the development of bioremediation methods of radioactive nuclide-contamination.

WRIGHT, S. M., (CROUT, N. M. J.,) BERESFORD, N. A., SANCHEZ, A., (KANYÁR, B.) 2002.

The Identification of Areas Vulnerable to Radiocaesium Deposition in Hungary

Radioprotection-colloques, 37, C1 1175 -1179

DOI: <http://dx.doi.org/10.1051/radiopro/2002143>

Radiocaesium is an important and persistent environmental contaminant that can be deposited following nuclear accidents. It became apparent after the Chernobyl accident that some regions were vulnerable to radiocaesium deposition. Prior identification of vulnerable areas using spatial models that incorporate variation in radiocaesium soil-to-plant transfer as a function of soil properties would allow post-accident management options to be prioritised and effectively implemented. In this paper, an assessment of the influence of different input soil property data sets for Hungary upon spatial model predictions of cow milk ^{137}Cs activity concentrations and the identification of vulnerable areas is presented. Although predictions of cow milk ^{137}Cs activity concentrations after Chernobyl made using the three input soil property data sets are all broadly similar and in reasonable agreement with national monitoring data, the identification of vulnerable areas is greatly influenced by the input soil property data set used. Our results suggest that using soil property databases derived from amalgamation of soil properties into broad soil categories will lead to vulnerable areas not being identified. The findings presented in this paper have important implications for the use of spatial models in the prediction of radiocaesium transfer, identification of vulnerable areas and management of contaminated areas.

WRIGHT, S. M., HOWARD, D. C., (BARRY, J., SMITH, J. T.) 2002

Spatial variation of radiocaesium deposition in Cumbria

Geophysical and Environmental Modelling, 6, 203-216

DOI: <http://dx.doi.org/10.1080/1361593022000029494>

Over the past 5 decades Cumbria has been subject to radiocaesium deposition from a number of sources. In the event of a future nuclear accident, estimates of baseline radiocaesium deposition in Cumbria would be indispensable. This paper describes the application of ordinary block kriging to estimate the spatial variation of total ^{137}Cs and ^{134}Cs . This study has raised a number of issues regarding the application of kriging. Transformation of input data was necessary to improve the optimality of the standard kriging estimator. Finally, observations of ^{137}Cs and ^{134}Cs from a similar range of locations exhibit different spatial characteristics. This can be explained by differences in radioactive half-lives and differences in the deposition of the two isotopes.

(GALERIU, D.), BERESFORD, N. A., (TAKEDA, H., MELINTESCU, A., CROUT, N. M. J.) 2003

Towards a model for the dynamic transfer of tritium and carbon in mammals

Radiation Protection Dosimetry, 105, 387-390

Available data have been analysed to test the hypothesis that both ^3H and ^{14}C transfer in mammals can be accounted for by an understanding of metabolism. Data obtained from various ^{14}C and ^3H experiments with rats and sheep have been analysed to assess the multi-component retention function of various organs and identify any relationship between half-times and component contribution. Our hypothesis was that component half-times for ^{14}C and ^3H are similar after intakes of organic compounds. Similarities in the tritium and carbon dynamics between rat and sheep were observed supporting the hypothesis. For fast and slow components of muscle half-time allometric relationships have been derived. The results obtained could be used in the development of a human biokinetic model.

McMAMARA, N. P., BLACK, H. I. J., BERESFORD, N. A., PAREKH, N. R. 2003

Effects of acute gamma irradiation on chemical, physical and biological properties of soils

Applied Soil Ecology, 24, 117-132

DOI: [http://dx.doi.org/10.1016/S0929-1393\(03\)00073-8](http://dx.doi.org/10.1016/S0929-1393(03)00073-8)

The use of gamma irradiation as a method for soil sterilisation for laboratory experiments has been recommended over other sterilisation techniques. We reviewed literature dating back over 50 years to investigate the chemical and biological effects on irradiated soils and to determine its practicality for sterilising soils which will subsequently be used for experimental purposes. Typically, irradiation at 10 kGy will eliminate actinomycetes, fungi and invertebrates in most soils. The majority of soil bacteria are eliminated by 20 kGy, however, a dose higher than 70 kGy may be required to kill certain radio-resistant bacteria. We recommend prior to experimentation that the radiosensitivity of soils are determined so as to ensure the desired chemical and biological effects are achieved. Irradiation may not be an appropriate method for all experiments as it can influence soil chemical properties, in particular soil nitrate and ammonium levels. Where chemical stability is required we recommend sterilising soils air-dry rather than moist.

(WEBSTER, S., SALT, C. A.), HOWARD, B. J. 2003

Sea-To-Land transfer of Technetium-99 through the use of contaminated seaweed as an agricultural soil conditioner

Journal of Environmental Radioactivity, 70, 127-137

DOI: [http://dx.doi.org/10.1016/S0265-931X\(03\)00122-X](http://dx.doi.org/10.1016/S0265-931X(03)00122-X)

The use of seaweed as an agricultural soil conditioner gives rise to a potential pathway for the transfer of ^{99}Tc from marine to terrestrial ecosystems and thence to man. However, to date there is little information on the extent of the release of ^{99}Tc from seaweed into soil and the mechanisms involved. This pot experiment has shown that ^{99}Tc is released fairly rapidly from *Fucus vesiculosus* into a sandy coastal soil. Despite low temperature conditions, 60% of the ^{99}Tc added within the seaweed had accumulated in the soil 15 weeks after addition. Concurrent CO_2 monitoring (used as a measure of microbial decomposition or catabolism) suggested that the initial ^{99}Tc release (up to 40% in the first 8 weeks) was due to leaching from the seaweed and that microbial decomposition was responsible for the release of the remaining ^{99}Tc in the latter phase (12-15 weeks).

WRIGHT, S. M., (SMITH, J. T.), BERESFORD, N. A., SCOTT, W. A. 2003

Prediction of changes in areas in west Cumbria requiring restrictions on the movement and slaughter of sheep following the Chernobyl accident using a Monte-Carlo approach.

Radiation and Environmental Biophysics, 42, 41-47

DOI: <http://dx.doi.org/10.1007/s00411-003-0187-6>

Following the 1986 Chernobyl accident radiocaesium levels in sheep meat in some upland areas of the United Kingdom were above the national intervention limit. West Cumbria was one of these areas and restrictions are currently still in place. In addition to deposition from the Chernobyl accident, Cumbria has been subject to radiocaesium deposition from atmospheric nuclear weapons tests, the 1957 Windscale accident and routine releases from the Sellafield nuclear reprocessing plant. A Monte-Carlo approach has been used to try to predict areas in west Cumbria where radiocaesium activity concentrations in lamb meat would require the imposition of restrictions at different times after the Chernobyl accident. The approach models the transfer of radiocaesium from soil to vegetation, based upon soil organic matter (OM), and from vegetation to lamb meat. Spatial inputs are soil OM and total post-Chernobyl ^{137}Cs and ^{134}Cs deposition; a ratio of Chernobyl ^{137}Cs to ^{134}Cs deposition has been used to differentiate Chernobyl and pre-Chernobyl ^{137}Cs deposition. Comparisons of predicted radiocaesium transfer from soil-vegetation and the spatial variation in lamb ^{137}Cs activity concentrations are good and predicted restricted areas with time after Chernobyl compare well to the restricted area set by UK government. We predict that restrictions may be required until 2024 and that in some areas the contribution of pre-Chernobyl ^{137}Cs to predicted lamb radiocaesium activity concentrations is significant, such that restrictions may only have been required until 1994 as a consequence of Chernobyl radiocaesium deposition alone. This work represents a novel implementation of a spatial radioecological model using a Monte-Carlo approach.

(AHMAN, B.), WRIGHT, S.M. & HOWARD, B.J. 2004

Radiocaesium in lynx in relation to ground deposition and diet

Radiation Environ,emt Biophysics, 43, 119-126.

DOI: <http://dx.doi.org/10.1007/s00411-004-0242-y>

The european lynx (*Lynx lynx*) might be expected to have a high intake of radiocaesium in the parts of Sweden where the main prey of the lynx, namely reindeer and roe deer have high activity concentrations of radiocaesium because of high ground deposition. We have measured ^{137}Cs in muscle samples from 733 lynx during 1996–2003. The aim was to quantify the extent to which radiocaesium is transferred from fallout deposition to lynx, to test whether the transfer was higher in areas where there are reindeer present, to see if there was any decline in radiocaesium over time, and to calculate the radiation dose to lynx. Most samples were collected in central and northern Sweden during January–April. Activity concentrations in lynx varied from 13 Bq kg⁻¹ to about 15 kBq kg⁻¹ fresh weight, with the highest value corresponding to a radiation dose at 18 mGy/year. Aggregated transfer coefficients (Tag), calculated by dividing the ^{137}Cs activity concentration in lynx muscle by the average ground deposition (total from Chernobyl and nuclear weapon tests) within a 50 km radius around the location of the lynx, varied from 0.004 to 1.3 m² kg⁻¹ and were significantly higher within the reindeer herding area than outside. The concentration ratio (CR) for lynx/reindeer was 2.6 on average, whilst the average for lynx/roe deer outside the reindeer herding area was lower at 1.3. Based on these results, a CR of around 2 could be considered representative for the general ratio between predator and prey. A long-term decline of radiocaesium in prey species was reflected in lynx, with an effective half-life of 7 years from 1996 to 2003. The study shows that the accumulation of radiocaesium in predators, especially predators of reindeer, makes them more vulnerable to high radiocaesium deposition than most other wild species.

(AVILA R.), BERESFORD N.A., (AGUERO A., BROED R., BROWN J., IOSPIE M., ROBLES B., & SUANEZ A). 2004

Study of the uncertainty in estimation of the exposure of non-human biota to ionizing radiation

Journal of Radiological Protection, 24, A105-A122.

DOI: <http://dx.doi.org/10.1088/0952-4746/24/4A/007>

Uncertainty in estimations of the exposure of non-human biota to ionizing radiation may arise from a number of sources including values of the model parameters, empirical data, measurement errors and biases in the sampling. The significance of the overall uncertainty of an exposure assessment will depend on how the estimated dose compares with reference doses used for risk characterisation. In this paper, we present the results of a study of the uncertainty in estimation of the exposure of non-human biota using some of the models and parameters recommended in the FASSET methodology. The study was carried out for semi-natural terrestrial, agricultural and marine ecosystems, and for four radionuclides (^{137}Cs , ^{239}Pu , ^{129}I and ^{237}Np). The parameters of the radionuclide transfer models showed the highest sensitivity and contributed the most to the uncertainty in the predictions of doses to biota. The most important ones were related to the bioavailability and mobility of radionuclides in the environment, for example soil-to-plant transfer factors, the bioaccumulation factors for marine biota and the gut uptake fraction for terrestrial mammals. In contrast, the dose conversion coefficients showed low sensitivity and contributed little to the overall uncertainty. Radiobiological effectiveness contributed to the overall uncertainty of the dose estimations for alpha emitters although to a lesser degree than a number of transfer model parameters.

BERESFORD N.A., (BROADLEY M.R.), HOWARD B.J., BARNETT C.L., (WHITE P.J.). 2004

Estimating radionuclide transfer to wild species - data requirements and availability for terrestrial ecosystems

Journal of Radiological Protection, 24, A89-A103.

DOI: <http://dx.doi.org/10.1088/0952-4746/24/4A/006>

Assessment of the transfer of radionuclides to wild species is an important component in the estimation of predicted doses to biota. Reviews of available data for the many potential radionuclide–biota combinations which may be required for environmental assessments highlight many data gaps for terrestrial species. Here, we discuss different approaches which have been suggested to compensate for these data gaps. All of the reviewed approaches have merit; however, there is a requirement for transparency in methodology and data provenance which in some instances is currently missing. Furthermore, there is a need to validate the various methodologies to enable their use with confidence. The requirements of improving our ability to predict radionuclide transfer to wild species are discussed and recommendations made. Assessment of the transfer of radionuclides to wild species is an important component in the estimation of predicted doses to biota. Reviews of available data for the many potential radionuclide–biota combinations which may be required for environmental assessments highlight many data gaps for terrestrial species. Here, we discuss different approaches which have been suggested to compensate for these data gaps. All of the reviewed approaches have merit; however,

there is a requirement for transparency in methodology and data provenance which in some instances is currently missing. Furthermore, there is a need to validate the various methodologies to enable their use with confidence. The requirements of improving our ability to predict radionuclide transfer to wild species are discussed and recommendations made.

(COPPLESTONE, D.), HOWARD, B. J. & (BRECHIGNAC, F.) 2004

The Ecological Relevance of Current Environmental Protection from Exposure to Ionising Radiation

Journal of Environmental Radioactivity, 74, 31-41.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2004.01.020>

This paper discusses the current approaches to environmental protection from ionising radiation from an ecological perspective, highlighting the need to understand fully what we are trying to protect. Ecologically relevant endpoints for environmental protection are discussed along with the need to integrate protection from ionising radiation with the approaches adopted for non-radioactive contaminants. A possible integrated assessment approach is outlined.

(CROUT, N. M. J.), BERESFORD, N. A., (DAWSON, J., SOAR, J. MAYES, R. W.) 2004

The transfer of ^{73}As , ^{109}Cd and ^{203}Hg to the milk and tissues of dairy cattle

Journal of Agricultural Science, Cambridge, 142, 203-212

DOI: <http://dx.doi.org/10.1017/S0021859604004186>

By a variety of exposure routes it is possible that the toxic heavy metals, cadmium and mercury, could enter the diet of farm animals and hence contaminate food products derived from those animals. Therefore, there is a need to be able to assess the likely levels of contamination in animal tissues if exposed to contaminated feed and also to estimate how rapidly an animal will decontaminate once the source of contamination is removed from the feed. The development of dynamic models to predict changes in the degree of heavy metal contamination in tissues of ruminants have been hindered by the lack of data on the transfer and excretion rates of these metals from tissues. A study is described during which dairy cows were given a single intraruminal administration of ^{109}Cd , ^{73}As and ^{203}Hg and measurements made of the subsequent concentrations of the radioisotopes in body tissues and milk. The resultant data were used to adapt previously developed compartment models describing the behaviour of the metals in sheep for use with dairy cows. Two changes were made to the sheep models: (i) a new excretion route was included to describe transfer to milk; (ii) the rate coefficients (with the exception of those involving gut absorption and transfer) were adjusted according to the ratio of the metabolic live-weights (live-weight (kg) $^{0.75}$) of the sheep to that of the cattle. The models predicted levels of the metals in the cattle tissues and milk reasonably well.

(GOLIKOV, V., LOGACHEVA, I., BRUK, G., SHUTOV, V., BALONOV, M., STRAND, P., BORGHUIS, S.), HOWARD, B. J. & WRIGHT, S. M. 2004

Modelling of long-term behaviour of caesium and strontium radionuclides in the Arctic environment and human exposure

Journal of Environmental Radioactivity, 74, 159-169.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2004.01.015>

In this paper a compartment model of the highly vulnerable Arctic terrestrial food chain "lichen-reindeer-man" is outlined. Based upon an analysis of ^{137}Cs and ^{90}Sr contents measured in lichen and reindeer meat from 1961 up to 2001, site specific model parameters for two regions in northwestern Arctic Russia and for Kautokeino municipality in Arctic Norway have been determined. The dynamics of radionuclide activity concentrations in the "lichen-reindeer-man" food chain for all areas was satisfactorily described by a double exponential function with short-term and long-term effective ecological half-lives between 1 -2 years and 10 - 12 years, respectively, for both ^{137}Cs and ^{90}Sr . Using parameter values derived from the model, life-time internal effective doses due to consumption of reindeer meat by reindeer-breeders after an assumed single pulse deposit of 1 kBq/m² of ^{137}Cs were estimated to be 11.4 mSv (Kola Peninsula), 5 mSv (Nenets Autonomous area), and 2 mSv (Kautokeino, Norway). Differences in vulnerability to radiocaesium deposition were due to differences in transfer between lichen and reindeer and in diet between the three regions.

HOWARD, B.J., (LILAND, A.), BERESFORD, N. A., (ANDERSSON, K. G., COX, G., GIL, J. M., HUNT, J., NISBET, A., OUGHTON, D. & VOIGT, G.) 2004

A critical evaluation of the STRATEGY project

Radiation Protection Dosimetry 109, Nos 1-2, 63-67

DOI: <http://dx.doi.org/10.1093/rpd/nch245>

The STRATEGY project (Sustainable Restoration and Long-Term Management of Contaminated, Rural, Urban and Industrial Ecosystems; www.strategy-ec.org.uk) addressed the need for a holistic decision framework for the selection of optimal remediation strategies for long-term sustainable management of contaminated areas in Western Europe. The project considered both technical and

social aspects of implementing restoration strategies for urban and rural environments. The importance of considering socially relevant objectives in addition to the dose reduction was emphasised. A critical evaluation was carried out of 101 selected countermeasures, (including rural waste disposal options), a model was developed to aid optimising countermeasure strategies and a method of carrying out participatory decision making suggested. The outputs of the project are described and critically evaluated.

HOWARD, B.J., (SEMIOSCHKINA, N., VOIGT, G., MUKUSHEVA, M.), CLIFFORD, J. 2004

Radiosttrontium contamination of soil and vegetation within the Semipalatinsk test site

Radiation Environment Biophysics, 43, 285-292

DOI: <http://dx.doi.org/10.1007/s00411-004-0261-8>

The Semipalatinsk nuclear test site (STS) in the Republic of Kazakhstan was an important site for testing atomic bombs and other civil and military nuclear devices of the former Soviet Union. Results are presented from investigations on the extent of radiosttrontium contamination in soils and vegetation at the technical areas of the STS, where the tests were conducted and in pastures used by farmers for grazing animals or for hay production. Our data are compared with those reported largely in the recent Russian language literature that has been reviewed. The extent of ^{90}Sr contamination of soil is highly variable over the STS with the highest values associated with the technical areas, particularly the Degelen mountains. Recently measured values in both the present data and the Russian language literature confirm the relatively high current contamination of soil and vegetation in the vicinity of tunnels and associated watercourses in the Degelen area. The proportion of ^{90}Sr in soil which could not be extracted with 6 M HCl was only an average of 20%, which is low compared to other test site areas and possibly indicates a relatively high mobility in this area, because the ^{90}Sr is derived from leakage from explosion tunnels along watercourses rather than being associated with fused silicates. A comparison of relative activity concentrations in soil and vegetation suggests that the transfer of ^{90}Sr to vegetation on the STS is high compared to that of ^{137}Cs and plutonium.

HOWARD, B. J., WRIGHT, S. M., (SALBU, B., SKUTERUD, K. L., HOVE., LOE, R.) 2004

Long-term consequences for northern Norway of a hypothetical release from the Kola Nuclear Power Plant

Science of the Total Environment, 327, 53-68.

DOI: <http://dx.doi.org/10.1016/j.scitotenv.2004.01.007>

The spatial and temporal variation in radiocaesium and ^{90}Sr doses to two population groups of the two most northernmost counties of Norway, Troms and Finnmark, following a hypothetical accident at the Kola Nuclear Power Plant (KNPP) have been estimated using a model implemented within a geographical information system. The hypothetical accident assumes a severe loss of coolant accident at the KNPP coincident with meteorological conditions causing significant radionuclide deposition in the two counties. External doses are estimated from ground deposition and the behaviour of the different population groups, and internal doses from predicted food product activity concentrations and dietary consumption data. Doses are predicted for reindeer keepers and other Norwegian inhabitants, taking account of existing ^{137}Cs and ^{90}Sr deposition but not including the remedial effect of any countermeasures that might be used. The predicted doses, arising mainly from radiocaesium, confirm the Arctic monitoring and Assessment Programme assessment that residents of the Arctic are particularly vulnerable to radiocaesium contamination which could persist for many years. External doses are predicted to be negligible compared to ingestion doses. Ingestion doses for reindeer keepers are predicted to exceed 1mSv y^{-1} for several decades primarily due to their high consumption of reindeer meat. Other Norwegians would be potentially exposed to doses exceeding 1mSv y^{-1} for several years, especially if they consume many local products. Whilst reindeer production is the main exposure pathway, freshwater fish, lamb meat, dairy products, mushrooms and berries are also significant contributors to predicted ingestion doses. Radionuclide fluxes, defined as the total output of radioactivity in food from an area for a unit time, are dominated by reindeer meat. The results show the need for an effective emergency response, with appropriate countermeasures, should an accident of the scale considered in this paper occur at the KNPP.

HOWARD, B.J., (SEMIOSCHKINA, N., VOIGT G, MUKUSHEVA M.) & CLIFFORD, J. 2004

Radiosttrontium contamination of soil and vegetation within the Semipalatinsk test site.

Radiation Environment Biophysics, 43, 285-292.

DOI: <http://dx.doi.org/10.1007/s00411-004-0261-8>

The Semipalatinsk nuclear test site (STS) in the Republic of Kazakhstan was an important site for testing atomic bombs and other civil and military nuclear devices of the former Soviet Union. Results are presented from investigations on the extent of radiosttrontium contamination in soils and vegetation at the technical areas of the STS, where the tests are conducted and in pastures used by farmers for grazing animals or for hay production. Our data are compared with those reported largely

in the recent Russian language literature that has been reviewed. The extent of ^{90}Sr contamination of soil is highly variable over the STS with the highest values associated with the technical areas, particularly the Degelen mountains. Recently measured values in both the present data and the Russian language literature confirm the relatively high current contamination of soil and vegetation in the vicinity of tunnels and associated water courses in the Delegen area. The proportion of ^{90}Sr in soil which could not be extracted with 6 M HCl was only an average of 20%, which is low compared to other test site areas and possibly indicates a relatively high mobility in this area, because the ^{90}Sr is derived from leakage from explosion tunnels along watercourses rather than being associated with fused silicates. A comparison of relative activity concentrations in soil and vegetation suggests that the transfer of ^{90}Sr to vegetation on the STS is high compared to that of ^{137}Cs and plutonium.

(JONES, H. E., WEST, H. M.), CHAMBERLAIN, P., (CROUT, N. M. J.), PAREKH, N. R. & BERESFORD, N. A. 2004

Effects of gamma irradiation on *Holcus lanatus* (Yorkshire Fog grass) and associated soil microorganisms
Journal of Environmental Radioactivity, 74, 57-71.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2004.01.027>

An investigation was conducted to determine the impact of acute doses of gamma radiation on the microbial community structure of a *Holcus lanatus* dominated grassland soil. Mesocosms containing soil and established grass were irradiated using a sealed ^{137}Cs source (7.0 Gy min^{-1}). Doses ranged from 5 to 160 Gy, analyses were conducted on the day of irradiation, then 7 and 30 days later. Plant growth and arbuscular mycorrhizal fungal colonisation of roots were reduced by irradiation. Gram-negative bacteria, and microbial metabolic capacity were also negatively affected by treatment. Microbial biomass measured by phospholipid fatty acid (PLFA) analysis, showed an increase at doses above 20 Gy, 7 and 30 days after treatment. Proportions of Gram-positive bacterial and fungal PLFAs fluctuated inversely to each other, in response to both sampling time and radiation dose. We hypothesise that many of the observed soil microbial responses are indirect effects mediated by the influence of ionising radiation on the plants in this system.

(OUGHTON, D., BAY, I., FORSBERG, E. M., KAISER, M.) & HOWARD, B. J. 2004

An Ethical Dimension To Sustainable Restoration And Long-Term Management Of Contaminated Areas
Journal of Environmental Radioactivity, 74, 171-183.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2004.01.009>

Experience after the Chernobyl accident has shown that restoration strategies need to consider a wide range of different issues to ensure the long-term sustainability of large and varied contaminated areas. Thus, the criteria by which we evaluate countermeasures needs to be extended from simple cost benefit effectiveness and radiological protection standards to a more integrated, holistic approach, including social and ethical aspects. Within the STRATEGY project, the applicability of many countermeasures is being critically assessed using a wide range of criteria. Attention is being given to issues such as practicability, feasibility, capacity and environmental side-effects, as well as social factors such as public perceptions of risk, communication of information and the need for dialogue and consultation with affected communities, and ethical aspects such as informed consent and the fair distribution of costs and doses. Although such socio-ethical factors are now the subject of a substantial field of research, there has been little attempt to integrate them in a practical context for decision makers. Within this paper, we specifically consider the ethical aspects of restoration strategies and suggest practical means by which these can be taken into account in the decision making process, introducing a value matrix. The paper covers two critical areas: evaluation of individual countermeasures, and use of the matrix to ensure transparent and systematic consideration of values in selection of a restoration strategy.

(SMITH, J. T.), WRIGHT, S. M., (CROSS, M. A., MONTE, L., KUDELSKY, A. V., SAXEN, R., VAKULOVSKY, S. M. & TIMMS, D. N). 2004

Global Analysis of the Riverine Transport of ^{90}Sr and ^{137}Cs

Environmental Science and Technology, 38, 850-857.

DOI: <http://dx.doi.org/10.1021/es0300463>

Atmospheric nuclear weapons explosions and large-scale nuclear accidents may contaminate large areas of land with the long-lived radionuclides ^{137}Cs and ^{90}Sr . The mobility and bioavailability of these radionuclides in the environment is dependent primarily on soil characteristics and changes significantly over time after fallout (1-4). Radioisotope concentrations in different rivers and at different times after fallout vary over 2-3 orders of magnitude. many previous studies have concentrated on the interactions of radiocesium and radiostrontium with various environmental components, but there are currently no operative models for their transport over large spatial areas. We collected time-series measurements of ^{90}Sr and ^{137}Cs in 25 major European and Asian rivers and (using digital data sets with global coverage) determined characteristics of each of the rivers catchments. This work has established for the first time, a quantitative link between riverine transport of these radioisotopes and catchment and soil characteristics at a global scale. A generalised predictive model accounting for time changes in river concentrations and variation in catchment characteristics is developed. This can be used to predict the long-term riverine transport of these radiologically important radionuclides following and large-scale nuclear incident in North America, Europe, or (European and Asian) Russia.

N.A. BERESFORD AND S.M. WRIGHT 2005

Non-linearity in radiocaesium soil to plant transfer: Fact or fiction?

Radioprotection, Suppl. 1, vol. 40 S67-S72

DOI: <http://dx.doi.org/10.1051/radiopro:2005s1-011>

The basis premise of many radiological assessments is the assumption that the transfer of many radionuclides from soil to herbage and hence animal derived food products is a positive linear relationship for a given set of ecological conditions. However, a number of authors have published results, which they conclude demonstrate non-linear transfer of radiocaesium to plants and animals with transfer being highest when soil concentrations are lowest. Whilst we may expect non-linear transfer of radionuclides under homeostatic control or present in comparatively large chemical quantities, there appears no credible hypothesis to support such an observation for radiocaesium. In this paper we review those articles, which have reported non-linear radiocaesium transfer and also analyse novel data. We argue that saturation of Cs uptake as suggested by some other authors is unlikely. Sampling bias, statistical data distribution and countermeasure application are suggested as potential contributors. However, we have not been able to provide a conclusive reason for such observations. Given the important implications for foodchain modelling further consideration of available data is required to more comprehensively answer this question.

N.A. BERESFORD, S.M. WRIGHT, C.L. BARNETT, V. GOLIKOV, V. SHUTOV AND O. KRAVTSOVA 2005

Approaches to estimating the transfer of radionuclides to Arctic biota

Radioprotection, Suppl. 1, vol. 40 S285-S290

DOI: <http://dx.doi.org/10.1051/radiopro:2005s1-043>

We review collated data and available models for estimating the transfer of radionuclides to terrestrial biota within the European Arctic. The most abundant data are for radiocaesium and radiostrontium although many data for natural radionuclides are available. For some radionuclides no data are available for describing transfer to Arctic biota. Allometric-kinetic models have been used to estimate transfer for radionuclide-biota combinations. Predicted values were in good agreement with observed data for some radionuclides although less so for others. There are no bespoke models to enable the dynamic prediction of radionuclide transfer to Arctic biota. A human Arctic foodchain model has been adapted to estimate ^{137}Cs and ^{90}Sr transfer to some Arctic biota. There are many factors of Arctic ecosystems which may influence radionuclide behaviour including short growing seasons, prolonged soil freezing, and effects of low temperatures on biological rates. If exposure to ionising radiation in Arctic ecosystems is to be robustly predicted such factors must be fully understood and incorporated into models.

N.A. BERESFORD, S.M. WRIGHT, C.L. BARNETT, M.D. WOOD, S. GASCHAK, A. ARKHIPOV, T.G. SAZYKINA AND R. AVILA 2005

A case study in the Chernobyl zone Part I: Predicting radionuclide transfer to wildlife

Radioprotection, Suppl. 1, vol. 40 S291-S297

DOI: <http://dx.doi.org/10.1051/radiopro:2005s1-044>

A number of frameworks have been proposed to assess the protection of wildlife from ionising radiations. In this paper we compare the predictions of transfer parameters recommended by one of these frameworks (*FASSET*) with observed whole-body ^{90}Sr and ^{137}Cs activity concentrations in a range of mammal and invertebrate species sampled within the Chernobyl exclusion zone.

Predicted activity

concentrations are generally within the observed ranges and mean predictions for reference organisms are similar to, or *circa* one order of magnitude higher than, the observed means.

However, some predictions are more than one order of magnitude lower than observed values.

No data were available for animals to test predictions for the other radionuclides released by the Chernobyl accident. In a separate paper the outputs of this assessment will be used to estimate doses to reference organisms and compare these to observed radiation induced effects reported within the Chernobyl zone.

N.A. BERESFORD, S.M. WRIGHT, C.L. BARNETT, J.L. HINGSTON, J. VIVES I BATLLE, D. COPPLESTONE, I.I. KRYSHEV, T.G. SAZYKINA, G. PRÖHL, A. ARKHIPOV AND B.J. HOWARD 2005

A case study in the Chernobyl zone Part 2: Predicting radiation induced effects in biota

Radioprotection, Suppl. 1, vol. 40 S299-S305

DOI: <http://dx.doi.org/10.1051/radiopro:2005s1-045>

In this paper we use the *FASSET* framework to estimate absorbed dose rates for biota within

the Chernobyl exclusion zone. The estimated doses are compared to observed biological effects within

the Chernobyl exclusion zone and effects expected from summaries of existing knowledge and the extent of contamination. Although paucity of observations under conditions of chronic irradiation makes direct comparison difficult, the biological effects observed in the Chernobyl exclusion zone over the period considered here (1988-2003) are broadly in agreement with those which may have been expected.

BERESFORD, N. A., WRIGHT, S.M., BARNETT, C.L., WOOD, M.D. GASCHAK, S., ARKHIPOV, A., SAZYKINA, T.G. HOWARD, B.J. 2005

Predicting radionuclide transfer to wild animals - an application of a proposed environmental impact assessment framework to the Chernobyl exclusion zone

Radiat Environ Biophys vol 44, 161-168

DOI: <http://dx.doi.org/10.1007/s00411-005-0018-z>

A number of assessment frameworks have been proposed to provide a mechanism to demonstrate protection of the environment from ionizing radiation. Whilst some of these are being used for assessment purposes they have largely not been validated against field measurements. In this paper we compare the predictions of transfer parameters recommended by one of these frameworks (FASSET) with observed whole-body ^{90}Sr and radiocaesium activity concentrations in a range of mammal and invertebrate species sampled within the Chernobyl exclusion zone. Predicted activity concentrations were generally within the observed ranges and mean predictions for reference organisms were similar to, circa one order of magnitude higher than, the observed means. However, some predictions were more than one order of magnitude lower than observed values. No data were available to test predictions for the other radionuclides released by the Chernobyl accident. In a separate paper the outputs of this assessment will be used to estimate doses to reference organisms and compare these to observed radiation induced effects reported within the Chernobyl zone.

BERESFORD, N.A. HOWARD, B.J. 2005

Ecological Systems – Data requirements and availability

Proceedings of Protection of the Environment from the Effects of ionizing radiation; IAEA

A review of available data for the many potential radionuclide-biota combinations which may be required for environmental assessments highlights the many data gaps for terrestrial species. We review the different approaches which have been suggested to compensate for these data gaps. All the reviewed approaches have merit. However, there is a requirement for transparency in methodology and data providence which is not always present. Furthermore, there is a need to validate the various methodologies to enable their use with confidence.

D. COPPLESTONE, M.D. WOOD, P.C. MERRILL, R. ALLOTT, S.R. JONES, J. VIVES I BATLLE, N.A. BERESFORD AND I. ZINGER 2005

Impact assessment of ionising radiation on wildlife: Meeting the requirements of the EU birds and habitats directives

Radioprotection, Suppl. 1, vol. 40 S893-S898

DOI: <http://dx.doi.org/10.1051/radiopro:2005s1-131>

In the UK, research funded by the Environment Agency/English Nature has provided a series of spreadsheet-based assessment tools for calculating doses received by biota in coastal, freshwater and terrestrial ecosystems. The approach uses the reference organism concept where the organism of interest (feature species) is equated to a particular reference organism (based on its physical geometry and ecology). This paper describes the stages followed to collate species-, and site-, specific data and to undertake assessments to determine whether Natura 2000 sites are adequately protected from authorised releases of ionising radiation. The feature species used for the assessment were species listed under the EC Birds and Habitats Directives. The paper will describe the overall assessment process followed by the UK Environment Agency, demonstrating the staged assessment process adopted; how each feature species is mathematically aligned with the most appropriate reference organism geometry; and provide an example of the assessment conducted for the Natura 2000 sites located in the Humber Estuary, UK.

(COX, G.,) BERESFORD, N. A., (ALVAREZ-FARIZO, B., OUGHTON, D., KIS, Z., EGED, K., THØRRING, H., HUNT, J.,) WRIGHT, S., BARNETT, C.L., (GIL, J.M.), HOWARD, B.J., (CROUT, D.M.J.) 2005

Identifying optimal agricultural countermeasure strategies for a hypothetical contamination scenario using the strategy model .

Journal of Environmental Radioactivity 83, 383-397

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2004.05.021>

A spatially implemented model designed to assist the identification of optimal countermeasure strategies for radioactively contaminated regions is described. Collective and individual ingestion doses for people within the affected area are estimated together with collective exported ingestion dose. A range of countermeasures are incorporated within the model, and environmental restrictions have been included as appropriate. The model evaluates the effectiveness of a given combination of countermeasures through a cost function which balances the benefit obtained through the reduction in dose with the cost of implementation. The optimal countermeasure strategy is the combination of individual countermeasures (and when and where they are implemented) which gives the lowest value of the cost function. The model outputs should not be considered as definitive solutions, rather as interactive inputs to the decision making process. As a demonstration the model has been applied to a hypothetical scenario in Cumbria (UK). This scenario considered a published nuclear power plant accident scenario with a total deposition of 1.7×10^{14} , 1.2×10^{13} , 2.8×10^{10} and 5.3×10^9 Bq for Cs-137, Sr-90, Pu-239/240 and Am-241, respectively. The model predicts that if no remediation measures were implemented the resulting collective dose would be approximately 36 000 person-Sv (predominantly from ^{137}Cs) over a 10-year period post-deposition. The optimal countermeasure strategy is predicted to avert approximately 33 000 person-Sv at a cost of approximately £160 million. The optimal strategy comprises a mixture of ploughing, AFCF (ammonium-ferric hexacyano-ferrate) administration, potassium fertiliser application, clean feeding of livestock and food restrictions. The model recommends specific areas within the contaminated area and time periods where these measures should be implemented.

D. GALERIU, A. MELINTESCU, N.A. BERESFORD, N.M.J. CROUT AND H. TAKEDA 2005
 ^{14}C and tritium dynamics in wild mammals: A metabolic model

Radioprotection, Suppl. 1, vol. 40 S351-S357

DOI: <http://dx.doi.org/10.1051/radiopro:2005s1-052>

The protection of biota from ionising radiations needs reliable predictions of radionuclide dynamics in wild animals. Data specific for many wild animal – radionuclide combinations is lacking and a number of approaches including allometry have been proposed to address this. However, for ^{14}C and ^3H , which are integral components of animal tissues and their diets, a different approach is needed. Here we propose a metabolically based model which can be parameterised predominantly on the basis of published metabolic data. We begin with a metabolic definition of the ^{14}C and OBT loss rate (assumed to be the same) from the whole body and specific organs. The mammalian body is conceptually partitioned into compartments (body water, viscera, adipose, muscle, blood and remainder) and a simple model defined using net maintenance and growth needs of mammals. The model is tested with data from studies using rats and sheep. It provides a reliable prediction for whole body and muscle activity concentrations without the requirement for any calibration specific to ^3H and ^{14}C . Predictions from the model for representative wild mammals) are presented. Potential developments of a metabolic model for birds and the application of our work to human foodchain modelling are also discussed.

HOWARD, B.J., BERESFORD, N.A., (NISBET, A., COX, G., OUGHTON, D.H., HUNT, J., ALVAREZ, B., ANDERSSON, K..G., LILAND, A., VOIGT, G) 2005.

The STRATEGY project: decision tools to aid sustainable restoration and long-term management of contaminated agricultural ecosystems.

Journal of Environmental Radioactivity 83, 275-295

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2005.01.013>

The STRATEGY project (Sustainable Restoration and Long-Term Management of Contaminated Rural, Urban and Industrial Ecosystems) aimed to provide a holistic decision framework for the selection of optimal restoration strategies for the long-term sustainable management of contaminated areas in Western Europe. A critical evaluation was carried out of countermeasures and waste disposal options, from which compendia of state-of-the-art restoration methods were compiled. A decision support system capable of optimising spatially

varying restoration strategies, that considered the level of averted dose, costs (including those of waste disposal) and environmental side effects was developed. Appropriate methods of estimating indirect costs associated with side effects and of communicating with stakeholders were identified. The importance of stakeholder consultation at a local level and of ensuring that any response is site and scenario specific were emphasised. A value matrix approach was suggested as a method of addressing social and ethical issues within the decision-making process, and was designed to be compatible with both the countermeasure compendia and the decision support system. The applicability and usefulness of STRATEGY outputs for food production systems in the medium to long term is assessed

NISBET, A., HOWARD, B.J., BERESFORD, N.A., VOIGT, G., 2005

Workshop to extend the involvement of stakeholders in decisions on restoration management.

Journal of Environmental Radioactivity, 83, 3, 259-261

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2005.01.012>

Workshop to extend the involvement of stakeholders in decisions on restoration management
Following a large-scale release of radioactivity into the environment, food production systems and inhabited areas may be contaminated for many years. Accident response throughout Europe has tended to focus on management of the early phase, addressing issues such as evacuation, sheltering, restrictions on food and drinking water and provision of stable iodine tablets. Currently there is little systematic consideration of the long-term management to ensure the sustainability of contaminated areas. To sustain acceptable living and working conditions in such areas it is necessary to construct practicable restoration strategies that take into account the views of a wide range of stakeholders. Under the auspices of the European Commission's 5th Framework Programme, funding was provided for two complementary projects (FARMING1 and STRATEGY2) to develop strategies for maintaining agricultural production and safe food supplies in the long term through stakeholder consultation. The FARMING project, which started in November 2000, established a network of stakeholder groups in the UK, Finland, Belgium, France and Greece, involving more than 100 individual stakeholders. The five national groups belonging to the FARMING network have met regularly since 2000 to discuss and evaluate countermeasure strategies. Much of the information on countermeasures for food 1 Food and Agriculture Restoration Management Involving Networked Groups. 2 Sustainable restoration and long-term management of contaminated rural, urban and industrial ecosystems.

N.R. PAREKH, E.D. POTTER, J.S. POSKITT, B.A. DODD AND N.A. BERESFORD 2005

Detection of irradiation induced changes on the activity and diversity of soil microbial communities:

The effect of soil type

Radioprotection, Suppl. 1, vol. 40 S939-S944

DOI: <http://dx.doi.org/10.1051/radiopro:2005s1-138>

Our aim was to measure the effects of irradiation treatments on soil communities from three different soils. Undisturbed soil cores from three temperate sites (deciduous and coniferous woodland and grassland) were irradiated to give cumulative doses from 0–160 Gy. Cores were incubated at 15°C and three cores from each treatment sampled after <1, 3 and 8 d. Soil fungi and heterotrophic bacteria were enumerated and the activity and functional diversity of soil microbial communities assessed in terms of their potential to utilise a range of C-sources. Although no significant treatment effects were observed in the numbers of cultivable fungi or fast growing heterotrophic bacteria, the numbers of cultivable *Pseudomonas* spp. declined in all three soils after irradiation at 80 and 160 Gy. Microbial communities from the coniferous forest soil also showed a dramatic decrease in the metabolic activity and number of substrates utilised by after irradiation at 160 Gy. Gamma irradiation had a greater affect on microbial communities in the two organic forest soils as compared to the mineral grassland soil, this could be related to variations in the physico-chemical shielding properties and in the indigenous communities in terms of radio-resistant species.

(SIGURGEISSON, M. A., ARNALDS, O., PALSSON, S. E.,) HOWARD, B. J. & (GUDNASON, K.M). 2005

Radiocaesium fallout behaviour in volcanic soils in Iceland

Journal of Environmental Radioactivity 79, 39-53

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2004.05.014>

The retention of ^{137}Cs in various types of Andosols in Iceland was investigated. Soils were sampled at 29 sites with varying precipitation and environmental conditions. Samples were obtained from 0-5, 5-10, and 10-15 cm depths. The amount of radiocaesium present was quite variable, ranging between 300 and 4800 Bq m⁻² and correlated closely to total annual precipitation ($r^2=0.71$). The majority of ^{137}Cs was retained in the uppermost 5 cm of the soil or 82.7% on average. The greatest penetration of ^{137}Cs was observed for organic Histosols (76.3% in top 5 cm). The Icelandic Vitrisols (barren, poorly developed Andosols) are coarse grained with only 2-5% clay content and contain little organic matter (<1%). Yet these soils retained 74% of ^{137}Cs in the top 5 cm. The results indicate that radiocaesium fallout is strongly retained by colloidal materials characteristic of Andosols, such as allophane and ferrihydrite. Most soils in Iceland are subject to severe and prolonged freezing and water logging, despite this ^{137}Cs is retained in the upper soil horizons and vertical migration is negligible in Icelandic Andosols. However, erosion and aeolian activity can markedly influence the amount and vertical distribution of radiocaesium in Icelandic soils.

BERESFORD, N. A. 2006

Land contaminated by radioactive materials

Soil use and Management, 21, 468-474

DOI: <http://dx.doi.org/10.1079/SUM2005346>

Nuclear weapons testing, mineral extraction industries and nuclear power generation are amongst the activities which have led to radioactively contaminated land. In the United Kingdom current activities such as the decommissioning of nuclear licensed sites and the sale of Ministry of Defence land require the legislation, remediation and management of radioactively contaminated land to be addressed. With an emphasis on the UK, this paper reviews potential management/remediation strategies for radioactively contaminated land, including consideration of the environmental mobility of potentially important radionuclides.

FESENKO, S.V., ALEXAKHIN, R.M., BALONOV, M.I., BOGDEVICH, I.M., HOWARD, B.J., KASHPAROV, V.A., SANZHAROVA, N.I., VOIGT, G. & ZHUCHENKA, YU. 2006
Consequences For Agriculture.

Nuclear Engineering International, 51, 34-37.

Link: <http://www.neimagazine.com/features/featureconsequences-for-agriculture>

More than 4.5 billion hectares of agricultural land in Belarus, Russia and Ukraine were contaminated after the Chernobyl accident. In the two decades since, a wide range of large scale measures and remedial options have been implemented.

FESENKO, S.V., ALEXAKHIN, R.M., BALONOV, M.I., BOGDEVICH, I.M., HOWARD, B.J., KASHPAROV, V.A., SANZHAROVA, N.I., PANOV, A.V., VOIGT, G., ZHUCHENKA, YU. 2006
Twenty years application of agricultural countermeasures following the Chernobyl accident: lessons learned.

Journal Radiological Protection, 26, 351-359

DOI: <http://dx.doi.org/10.1088/0952-4746/26/4/R01>

The accident at the Chernobyl NPP (nuclear power plant) was the most serious ever to have occurred in the history of nuclear energy. The consumption of contaminated foodstuffs in affected areas was a significant source of irradiation for the population. A wide range of different countermeasures have been used to reduce exposure of people and to mitigate the consequences of the Chernobyl accident for agriculture in affected regions in Belarus, Russia and Ukraine. This paper for the first time summarises key data on countermeasure application over twenty years for all three countries and describes key lessons learnt from this experience.

LINNIK, V.G., BROWN, J.E., DOWDALL, M., POTAPOV, V.N., NOSOV, A.V., SURKOV, V.V., SOKOLOV, A.V., WRIGHT, S.M., BORGHUIS, S. 2006

Patterns and inventories of radioactive contamination of island sites of the Yenisey River, Russia.

Journal of Environmental Radioactivity, 87, 188-208

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2005.11.011>

The distribution of radioactive contamination at three island sites downstream from the Krasnoyarsk Mining and Chemical Combine (KMCC) was studied with the objectives of mapping contamination levels, interpreting radionuclide distributions through consideration of alluvial processes and determining radionuclide inventories. Contamination was measured using in situ gamma spectrometry and landforms characterised using topographic surveying methods. Maximum ^{137}Cs contamination densities (700kBq m^{-2}) were found on low- and middle-level floodplains and low-lying interconnecting areas of Beriozovy Island (16 km from the KMCC). On Mikhin Island (180 km from the KMCC) maximum total.

PÁLSSON, S.E., HOWARD, B.J., WRIGHT, S.M. 2006

Prediction of spatial variation in global fallout of ^{137}Cs using precipitation.

Science of the Total Environment, 367, 745-756.

DOI: <http://dx.doi.org/10.1016/j.scitotenv.2006.01.011>

Deposition from atmospheric nuclear weapons tests (termed *global fallout*) has been shown to be proportional to the rate of precipitation. Here we describe methods for using precipitation and radionuclide deposition information for a reference site to estimate global fallout at other locations. These methods have been used to estimate global fallout in Iceland, identified during the Arctic Monitoring and Assessment Programme (AMAP) by Wright et al. [Wright, S.M., Howard, B.J., Strand, P., Nylén, T., Sickel, M.A.K., 1999. Prediction of ^{137}Cs deposition from atmospheric nuclear weapons tests within the Arctic. *Environ Pollut* 104, 131-143.] as one of the Arctic areas which received the highest global fallout, but where measurements of contamination were sparse, and difficult to obtain due to the remote and inaccessible terrain of

much of the country. Measurements of global fallout ^{137}Cs deposition have been made in Iceland at sites close to meteorological stations to ensure that precipitation data were of high quality. The AMAP modeling approach, based on measured precipitation and radionuclide deposition data, was applied using a reference monitoring station located close to Reykjavik. The availability of good precipitation data and locally based estimates of time dependent ratios of ^{137}Cs deposition to precipitation during the fallout period gave a better correlation between predicted and measured ^{137}Cs global fallout ($r^2 = 0.96$) than that achieved using the much more heterogeneous set of data collected by AMAP over the whole of the Arctic. Having obtained satisfactory results with the model for a number of calibration sites alongside meteorological stations we then produced a map of estimated ^{137}Cs deposition based on a model of estimated precipitation. This deposition map was then successfully validated ($r^2 = 0.85$) for sites where ^{137}Cs deposition was measured; the associated uncertainty in predictions was also estimated.

PUTYATIN, Y.V., SERAYA, T.M., PETRYKEVICH, O.M., HOWARD, B.J. 2006

Comparison of the accumulation of ^{137}Cs and ^{90}Sr by six spring wheat varieties.

Radiation and Environmental Biophysics, 44, 289-298

DOI: <http://dx.doi.org/10.1007/s00411-006-0026-7>

The uptake of ^{137}Cs and ^{90}Sr by six varieties of spring wheat (*Triticum aestivum*) was compared in field trials on land contaminated by the Chernobyl accident. All the experimental varieties are officially adopted for agricultural use in Belarus and are used in large-scale production. Under identical conditions of nutrition, the productivity of the varieties varied significantly by a factor of 1.3. The extent of ^{137}Cs and ^{90}Sr accumulation by wheat grain, quantified as the concentration ratio, differed between the varieties by as much as a factor of 1.6, for both radionuclides. There was a significant linear positive correlation between the ^{90}Sr activity concentration in grain and straw, and the calcium concentration. The correlation between ^{137}Cs and potassium was not significant. The results suggest that certain varieties of spring wheat used in normal agricultural practice accumulate less ^{137}Cs and ^{90}Sr into grain than others. Some spring wheat varieties accumulated relatively less ^{137}Cs , but did not accumulate less ^{90}Sr . One variety, Quattro, had a significantly lower uptake of both ^{90}Sr (for grain) and ^{137}Cs (for both grain and straw) than that of the other varieties tested. The reduction efficiency achieved by the use of these varieties, however, is not as high as that achieved by soil amelioration techniques in the past. Nevertheless, since there are no additional costs or production losses associated with these varieties, their use in the contaminated areas is worth considering as a simple, practical, and effective contribution to reducing the uptake of both ^{90}Sr and ^{137}Cs and allowing farmers to produce food-grade grain.

BALONOV, M.I., GERNADY, B.Y., VLADISLAV, G.Y., BARKOVSKY, A.N., KRAVTSOVA, E.M., KRAVTSOVA, O.S., MUBASAROV, A.A., SHUTOV, V.N., TRAVNIKOVA, I.G., HOWARD, B.J., BROWN, J.E., STRAND, P. 2007.

Assessment of Current Exposure of the Population Living in the Techa River Basin from Radioactive Releases of the Mayak Facility.

Health Physics, 92, 2, 134-147.

DOI: <http://dx.doi.org/10.1097/01.HP.0000237599.92479.09>

Current doses arising from external and internal pathways have been estimated for the residents of two villages, Muslumovo and Brodokalmak, alongside the Techa River, which was contaminated by radioactive releases from the Mayak production facility. The dose estimates are based on numerous environmental measurements supplemented by further human whole body measurements and studies on occupational and dietary habits of Slavic and Turkish ethnic groups. Estimated doses arise mainly from use of the contaminated floodplains alongside the Techa River. The current average annual effective dose attributable to ^{137}Cs and ^{90}Sr in the environment, under conditions where restrictions on some river-related activities are in place, may exceed the Russian national action level of 1 mSv only in the hypothetical critical group of herdsmen in Muslumovo. The dose to this critical group in Brodokalmak is assessed to be 3 times less than that in Muslumovo and 2 fold below the action level. The external and internal exposures give comparable contributions to the total dose in both settlements and population groups: 47% and 53% in Muslumovo and 40% and 60% in Brodokalmak, respectively. About one quarter to one half of the internal dose in adults arises from the intake of ^{90}Sr . In order to avoid substantial increases in the dose received by Muslumovo residents, it is expedient to prolong the current policy of restriction of some river-related population activities in this village.

BERESFORD, N.A., HOWARD, B.J., VOIGT, G. 2007.

Transfer of radionuclides to food producing animals – preface.

Journal of Environmental Radioactivity, 98, 1-3.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2007.07.001>

BERESFORD, N.A., BARNETT, C.L., WRIGHT, S.M., HOWARD, B.J., CROUT, N.M.J. 2007.
Factors contributing to radiocaesium variability in upland sheep flocks in west Cumbria (United Kingdom).

Journal of Environmental Radioactivity, 98, 50-68.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2007.05.009>

Following the Chernobyl accident in 1986, restrictions were placed on the movement and slaughter of sheep within upland areas of the UK because radiocaesium activity concentrations in their meat exceeded 1000 Bq kg^{-1} fresh weight. Some farms remain under restriction in 2007. From 1991 to 1993 detailed studies were conducted on three sheep farms within the restricted area of west Cumbria to systematically assess the various parameters which may contribute to the observed variability in radiocaesium activity concentrations within sheep flocks. This paper reports the spatial variation in soil and vegetation activity concentrations across the grazed areas at these farms and determines the influence of grazing behaviour on variability in ^{137}Cs activity concentrations between individual sheep within the flocks. Together with previously reported results, these new data are used to draw conclusions on the factors determining variability within the three flocks. However, the factors are too site specific to be able to generalise the findings to other farms within the restricted areas of the UK.

BERESFORD, N.A., HOWARD, B.J., MAYES, R.W., LAMB C.S. 2007.

The transfer of radionuclides from saltmarsh vegetation to sheep tissues and milk.

Journal of Environmental Radioactivity, 98, 36-49.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2006.10.003>

Radionuclides released into the Irish Sea by the Sellafield reprocessing plant are deposited onto tide-washed pastures along the western coast of the United Kingdom. Many of these pastures are grazed by sheep or cattle. This paper describes a controlled feeding study, in which saltmarsh vegetation harvested from close to the Sellafield plant, was fed to lambs and adult female sheep for a period of 8 weeks. Activity concentrations of ^{60}Co , ^{95}Nb , ^{106}Ru , ^{134}Cs , ^{137}Cs , ^{238}Pu , $^{239,240}\text{Pu}$ and ^{241}Am were determined in edible tissues and transfer parameters estimated. The activity concentrations of some of the radionuclides will not have been in equilibrium with those in the diet. Nevertheless, the study was reasonably realistic in terms of agricultural management as the period of the study was similar to that for which lambs graze on the saltmarshes. A field study to

determine the activity concentrations of ^{137}Cs and $^{239,240}\text{Pu}$ in the milk of ewes grazing a saltmarsh close to Sellafield is also described.

BERESFORD, N.A., MAYES, R.W., BARNETT C.L., HOWARD, B.J. 2007.

The transfer of radiocaesium to ewes through a breeding cycle - an illustration of the pitfalls of the transfer coefficient.

Journal of Environmental Radioactivity, 98, 24-35.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2006.10.004>

A study to measure the transfer of radiocaesium to adult female sheep through a breeding cycle is described. The transfer of radiocaesium from the diet to muscle (estimated as the equilibrium transfer coefficient) was significantly lower to pregnant, and especially lactating, animals compared to non-lactating and barren animals. High dry matter intake rates were also associated with significantly lower transfer coefficients. Known relationships between dry matter intake rates and protein turnover could credibly explain some of these differences. However, when described as the concentration ratio, radiocaesium transfer to meat was apparently highest during lactation. The apparent difference in results obtained by the two approaches of determining transfer is the consequence of daily dry matter intake being a denominator within the estimation of transfer coefficient. A wider discussion of transfer coefficients and concentration ratios leads us to suggest that the concentration ratio is the more robust and potentially generic parameter.

FESENKO, S., ISAMOV, N., HOWARD, B.J., VOIGT, G., N.A. BERESFORD, N.A., SANZHAROVA, N. 2007.

Review of Russian language studies on radionuclide behaviour in agricultural animals: part 1: Gut absorption.

Journal of Environmental Radioactivity, 98, 85-103.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2007.02.011>

An extensive programme of experiments was conducted in the former USSR on transfer of radionuclides to a wide range of different agricultural animals. Only a few of these studies were made available in the English language literature or taken into account in international reviews of gastrointestinal uptake. The paper gives extended information on Russian research on radionuclide absorption in the gut of farm animals performed in controlled field and laboratory experiments from the 1960s to the current time. The data presented in the paper, together with English language values, will be used to provide recommended values of absorption specifically for farm animals within the revision of the IAEA *Handbook of Parameter Values* IAEA [International Atomic Energy Agency, 1994. Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments, IAEA technical reports series No. 364. International Atomic Energy Agency, Vienna].

FESENKO, S., HOWARD, B.J., ISAMOV, N., VOIGT, G., BERESFORD, N.A., SANZHAROVA, N., BARNETT. C.L. , 2007.

Review of Russian language studies on radionuclide behaviour in agricultural animals: part 2. Transfer to milk.

Journal of Environmental Radioactivity, 98, 104-136.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2007.06.007>

An overview of original information available from Russian language papers on radionuclide transfer to milk is provided. Most of the data presented have not been taken into account in international reviews. The transfer coefficient (F_m) values for radioactive isotopes of strontium, caesium and iodine are in good agreement with those previously published. The Russian language data, often based on experiments with many animals, constitute a considerable increase to the available data for many less well-studied radionuclides. In some instances, the Russian language data suggest changes in recommended values (e.g. Zr and Ru). The information presented here substantially increases the amount of available data on radionuclide transfer to milk and will be included in the current revision of the IAEA TRS *Handbook of parameter values for radionuclide transfer*.

FESSENKO, S.V., ALEXAKHIN, R.M., BALONOV, M.I., BOGDEVICH, I.M., HOWARD, B.J., KASHPAROV, V.A., SANZHAROVA, N.I., PANOV, A.V., VOIGT, G., ZHUCHENKA, YU. 2007. An extended critical review of twenty years of countermeasures used in agriculture after the Chernobyl accident.

Science of the Total Environment, 383, 1-24.

DOI: <http://dx.doi.org/10.1016/j.scitotenv.2007.05.011>

A wide range of different countermeasures has been used to mitigate the consequences of the Chernobyl accident for agriculture in affected regions in Belarus, Russia and Ukraine. The paper comprehensively brings together key data on countermeasure application over twenty years for all three countries and critically evaluates the response to the accident with respect to agriculture. The extents of countermeasures implementation in various periods following the ChNPP accident are documented. Examples of best practices and drawbacks in remediation of affected areas are identified. Data on the effectiveness of agricultural countermeasures have been evaluated and the impact of countermeasures implementation to mitigate consequences of the accident has been assessed for the period 1986–2006. Implementation of agricultural countermeasures averted 30–40% of the internal collective dose that would have been received by the residents of affected regions without the use of countermeasures. The current situation in agriculture of areas subjected to contamination following the Chernobyl accident is described. Current and future needs for remediation, including a consideration of various strategies of rehabilitation of affected areas are presented.

GALERIU, D., MELINTESCU, A., BERESFORD, N.A., CROUT, N.M.J., PETERSON, R., TAKEDA, H. 2007.

Modelling ^3H and ^{14}C transfer to farm animals and their products under steady state conditions.

Journal of Environmental Radioactivity, 98, 205-217.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2006.11.010>

The radionuclides ^{14}C and ^3H may both be released from nuclear facilities. These radionuclides are unusual, in that they are isotopes of macro-elements which form the basis of animal tissues, feed and, in the case of ^3H , water. There are few published values describing the transfer of ^3H and ^{14}C from feed to animal derived food products under steady state conditions. Approaches are described which enable the prediction of ^{14}C and ^3H transfer parameter values from readily available information on the stable H or C concentration of animal feeds, tissues and milk, water turnover rates, and feed intakes and digestibilities. We recommend that the concentration ratio between feed and animal product activity concentrations be used as it is less variable than the transfer coefficient (ratio between radionuclide activity concentration in animal milk or tissue to the daily intake of a radionuclide).

HOWARD, B.J., BERESFORD, N.A., GASHCHAK, S., ARKHIPOV, A., MAYES, R.W., CABORN, J., STROMANN, G., WACKER, L. 2007.

The transfer of $^{239/240}\text{Pu}$ to cow milk.

Journal of Environmental Radioactivity, 98, 191-204.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2007.01.032>

In summer 1993 we measured the transfer of $^{239/240}\text{Pu}$ to milk from herbage from a pasture located 5 km from the Chernobyl nuclear power plant. In one treatment cows were allowed to graze freely on the pasture. In a second treatment, cows were fed herbage collected from the pasture in stalls. The milk transfer coefficient; F_m did not vary significantly between treatments and the mean value of $7.5 \times 10^{-6} \text{ d l}^{-1}$ was higher than previously reported values. Despite many values of F_m for Pu in the literature we identified few relevant original data sets. Transfer coefficient values for Pu are only appropriate when used in conjunction with a specified time period or an appropriate model which allows for the biological half-life. We recommend for screening purposes an F_m value of $1 \times 10^{-5} \text{ d l}^{-1}$ for Pu, with an order of magnitude lower value being appropriate for cows which are only exposed for one grazing season.

HOWARD, B.J., BERESFORD, N.A., MAYES, R.W., LAMB, C.S., BARNETT, C.L. 2007.

The transfer of different forms of ^{35}S to goat milk.

Journal of Environmental Radioactivity, 98, 177-190.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2006.08.012>

Sulphur-35 is released during the routine operation of UK gas-cooled reactors. An experiment to determine the rates of transfer of different forms of ^{35}S to goat milk is described. Lactating goats received ^{35}S orally as single administrations of sulphate, l-methionine, or grass contaminated either through root uptake of ^{35}S as sulphate or through aerial deposition of ^{35}S as carbonyl sulphide onto the grass. Transfer was higher for ^{35}S administered as methionine compared with ^{35}S administered

as sulphate. Changes in activity concentrations in milk for all sources of ^{35}S demonstrated two components of loss. The first component had a half-life of *circa* 1 d for all sources, the second was longer in goats administered carbonyl sulphide (44 d) than in all of the other treatments (*circa* 10 d). The rate of transfer of ^{35}S to milk of a further group of goats receiving ^{35}S -sulphate daily appeared to reach equilibrium within 30 d. Extrapolation of transfer parameters derived to other dairy ruminants is discussed.

MCNAMARA, N.P. GRIFFITHS, R.I. TABOURNET, A., BERESFORD, N.A., BAILEY, M. J., WHITELEY, A.S. 2007

The sensitivity of a forest soil microbial community to acute gamma-irradiation.

Applied Soil Ecology, 37, 1-9.

DOI: <http://dx.doi.org/10.1016/j.apsoil.2007.03.011>

The community response of soil microbes exposed to acute gamma (g)-irradiation at 0, 1, 5 and 10 kGy doses were examined for 56 days after irradiation. Physiological activity was determined by community substrate utilisation potentials (BIOLOGTM) and a glucose substrate assay. Culture dependant analysis was used to track the changes in fungal and bacteria numbers while culture independent analyses were carried out to assess changes in bacterial community composition. As a consequence of irradiation, bacterial populations initially decreased and then exceeded control populations at the higher radiation doses, while fungal populations did not recover substantially after irradiation. These data suggest that either changes in niche competition between bacteria and fungi or a change in nutrient availability has led to the re-establishment of bacterial populations. The recovery in bacterial populations was mirrored by substrate utilisation potentials increasing in both the rate of utilisation as well as the number of substrates being used. Molecular profiling (DGGE) at later time points showed discrete dominant bands in profiles from the 5 and 10 kGy treatments suggesting outgrowth of certain taxa above background levels. The identities of these taxa were typical of soil environments. In conclusion microbial functioning and physiology can recover from acute doses of g-irradiation, yet higher doses may lead to changes in the underlying community structure, presumably due to competition for recently opened niches.

NEDVECKAITE, T., FILISTOVIC, V., MARCIULIONIENE, D., KIPONAS, D., REMEIKIS, V., BERESFORD N.A. 2007.

Exposure of biota in the cooling pond of Ignalina NPP: hydrophytes.

Journal of Environmental Radioactivity, 97, 137-147.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2007.03.011>

The radiological assessment of non-human biota is now accepted by a number of international bodies. In this connection the scientific basis to assess and evaluate biota internal and external radiation exposure is required. This paper presents the comparison of freshwater biota (hydrophyte species) exposure due to discharged anthropogenic radionuclides with that due to natural background radiation. The radionuclides from Ignalina Nuclear Power Plant (Lithuania) are discharged into cooling pond – Druksiai Lake. Submerged hydrophytes were selected as biota exposure indicators because they represent the largest biomass in this lake and have comparatively high radionuclide activity concentrations. The detailed methodology evaluation of the submerged hydrophyte dose rate is presented. The ionizing radiation exposure dose rates to submerged hydrophyte roots and above sediment parts due to the major radionuclides (^{54}Mn , ^{60}Co , ^{137}Cs , ^{90}Sr) discharged into the INPP cooling pond – Druksiai Lake were $0.044 \mu\text{Gy h}^{-1}$ and $0.004 \mu\text{Gy h}^{-1}$, respectively. The internal exposure dose rate due to natural background α -emitters (^{210}Po , ^{238}U , ^{226}Ra) was estimated to be $1.24 \mu\text{Gy h}^{-1}$, as compared with that of anthropogenic α -emitter ^{240}Pu – $0.04 \mu\text{Gy h}^{-1}$, whereas the external exposure was $0.069 \mu\text{Gy h}^{-1}$. The presented data deepen the knowledge about the concentration of radionuclides and submerged hydrophytes' exposure dose rates in European freshwater ecosystems.

SASINA, N.V., SMITH, J.T., KUDELSKY, AV., WRIGHT, S.M. 2007

“Blind” testing of models for predicting the ^{90}Sr activity concentration in river systems using post-Chernobyl monitoring data.

Journal of Environmental Radioactivity, 92, 2, 63-71.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2006.09.007>

Two different models for predicting the time-dependent mobility of ^{90}Sr in river systems have been evaluated using post-Chernobyl monitoring data for five large Belarusian rivers (Dnieper, Pripyat, Sozh, Besed and Iput) in the period between 1990 and 2004. The results of model predictions are shown to be in good agreement (within a factor of 5) with the measurements of ^{90}Sr activity concentration in river waters over a long period of time after the accident. This verifies the relatively good accuracy of the generalised input parameters of these models which

were derived primarily from measurements of ^{90}Sr deposited after atmospheric nuclear weapons testing (NWT). For the cases studied here, the simpler AQUASCOPE model performed just as well as the more complex “Global” model which used GIS-based catchment data as an input. The reasons for this are discussed. Exponential decay equations were also curve-fitted to the data for each river to help assess the uncertainties in the predictive models.

SAVINKOV, A., SEMIOSCHKINA, N., HOWARD, B.J., VOIGT, G.A. 2007.

Radiostrontium uptake by plants from different soil types in Khazakhstan

Science of the Total Environment, 373, 324-333.

DOI: <http://dx.doi.org/10.1016/j.scitotenv.2006.11.001>

The transfer of ^{90}Sr to a range of different plant species grown on a range of different soil types in Kazakhstan, including three from the Semipalatinsk Test Site (STS), has been measured in a lysimeter experiment. ^{90}Sr uptake by *Stipa* spp was significantly higher than for other vegetation species. The uptake of ^{90}Sr from chernozem was significantly lower than that from the other soil types which is consistent with other literature. There was a significant negative relationship between ^{90}Sr uptake and calcium, humus and CEC concentration in the soil for *Agropyrum* spp, *Artemisia* spp but not for *Stipa* spp or *Bromus* spp. The transfer to vegetation from soil has been quantified using the aggregated transfer coefficients for each species. Tag values range from 0.6 to $11.9 \text{ m}^2 \text{ kg}^{-1} \times 10^{-3}$ over all measurements. The transfer of ^{90}Sr to plants from the Kazakh soils was low compared to previously reported data and to that given from literature reviews.

VIVES I BATLLE, J., BALONOV, M., BEAUGELIN-SEILLER, K., BERESFORD, N.A., BROWN, J.5, CHENG, J-J., COPPLESTONE, D., DOI, M., FILISTOVIC, V., GOLIKOV, V., HORYNA, J., HOSSEINI, A., HOWARD, B.J., JONES, S.R., KAMBOJ, S., KRYSHV, A., NEDVECKAITE, T., OLYSLAEGERS, G., PRÖHL, G., SAZYKINA, T., ULANOVSKY, A., VIVES LYNCH, S., YANKOVICH, T., YU, C. 2007.

Inter-comparison of absorbed dose rates for non-human biota.

Radiation Environment Biophysics, 46, 349-373.

DOI: <http://dx.doi.org/10.1007/s00411-007-0124-1>

A number of approaches have been proposed to estimate the exposure of non-human biota to ionizing radiation. This paper reports an inter-comparison of the unweighted absorbed dose rates for the whole organism (compared as dose conversion coefficients, or DCCs) for both internal and external exposure, estimated by 11 of these approaches for selected organisms from the Reference Animals and Plants geometries as proposed by the International Commission on Radiological Protection. Inter-comparison results indicate that DCCs for internal exposure compare well between the different approaches, whereas variation is greater for external exposure DCCs. Where variation among internal DCCs is greatest, it is generally due to different daughter products being included in the DCC of the parent. In the case of external exposures, particularly to low-energy β -emitters, variations are most likely to be due to different media densities being assumed. On a radionuclide-by-radionuclide basis, the different approaches tend to compare least favourably for ^3H , ^{14}C and the α -emitters. This is consistent with models with different source/target geometry assumptions showing maximum variability in output for the types of radiation having the lowest range across matter. The intercomparison demonstrated that all participating approaches to biota dose calculation are reasonably comparable, despite a range of different assumptions being made.

BERESFORD, N.A., BARNETT, C.L., HOWARD, B.J., SCOTT, W.A., BROWN, J.E., COPPLESTONE D. 2008.

Derivation of transfer parameters for use within the ERICA Tool and the default concentration ratios for terrestrial biota

J. Environ. Radioact., 99, 1393-1407.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2008.01.020>

An ability to predict radionuclide activity concentrations in biota is a requirement of any method assessing the exposure of biota to ionising radiation. Within the ERICA Tool fresh weight whole-body activity concentrations in organisms are estimated using concentration ratios (the ratio of the activity concentration in the organism to the activity concentration in an environmental media). This paper describes the methodology used to derive the default terrestrial ecosystem concentration ratio database available within the ERICA Tool and provides details of the provenance of each value for terrestrial reference organisms. As the ERICA Tool considers 13 terrestrial reference organisms and the radioisotopes of 31 elements, a total of 403 concentration ratios were required for terrestrial reference organisms. Of these, 129 could be derived from literature review. The approaches taken for selecting the remaining values are described. These included, for example, assuming values for similar reference organisms and/or biogeochemically similar elements, and various simple modelling approaches.

BERESFORD, N.A., BARNETT, C.L., JONES, D.G., WOOD, M.D., APPLETON, J.D., BREWARD, N., COPPLESTONE D. 2008.

Background exposure rates of terrestrial wildlife in England and Wales

J. Environ. Radioact., 99, 1430-1439.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2008.03.003>

It has been suggested that, when assessing radiation impacts on non-human biota, estimated dose rates due to anthropogenically released radionuclides should be put in context by comparison to dose rates from natural background radiation. In order to make these comparisons, we need data on the activity concentrations of naturally occurring radionuclides in environmental media and organisms of interest. This paper presents the results of a study to determine the exposure of terrestrial organisms in England and Wales to naturally occurring radionuclides, specifically ⁴⁰K, ²³⁸U series and ²³²Th series radionuclides. Whole-body activity concentrations for the reference animals and plants (RAPs) as proposed by the ICRP have been collated from literature review, data archives and a targeted sampling campaign. Data specifically for the proposed RAP are sparse. Soil activity concentrations have been derived from an extensive geochemical survey of the UK. Unweighted and weighted absorbed dose rates were estimated using the ERICA Tool. Mean total weighted whole-body absorbed dose rates estimated for the selected terrestrial organisms was in the range 6.9 _ 10₋₂ to 6.1 _ 10₋₁ mGy h₋₁.

BERESFORD, N.A., GASCHAK, S., BARNETT, C.L., HOWARD, B.J., CHIZHEVSKY, I., STRØMMAN, G., OUGHTON, D.H., WRIGHT, S.M., MAKSIMENKO, A., COPPLESTONE D. 2008.

Estimating the exposure of small mammals at three sites within the Chernobyl exclusion zone – a test application of the ERICA Tool.

J. Environ. Radioact., 99, 1496-1502.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2008.03.002>

An essential step in the development of any modelling tool is the validation of its predictions. This paper describes a study conducted within the Chernobyl exclusion zone to acquire data to conduct an independent test of the predictions of the ERICA Tool which is designed for use in assessments of radiological risk to the environment. Small mammals were repeatedly trapped at three woodland sites between early July and mid-August 2005. Thermoluminescent dosimeters mounted on collars were fitted to *Apodemus flavicollis*, *Clethrionomys glareolus* and *Microtus* spp. to provide measurements of external dose rate. A total of 85 TLDs were recovered. All animals from which TLDs were recovered were live-monitored to determine ⁹⁰Sr and ¹³⁷Cs whole-body activity concentrations. A limited number of animals were also analysed to determine ^{239,240}Pu activity concentrations. Measurements of whole-body activity concentrations and dose rates recorded by the TLDs were compared to predictions of the ERICA Tool. The predicted ⁹⁰Sr and ¹³⁷Cs mean activity concentrations were within an order of magnitude of the observed data means. Whilst there was some variation between sites in the agreement between measurements and predictions this was consistent with what would be expected from the differences in soil types at the sites. Given the uncertainties of conducting a study such as this, the agreement observed between the TLD results and the predicted external dose rates gives confidence to the predictions of the ERICA Tool.

BERESFORD, N.A., BALONOV, M., BEAUGELIN-SEILLER, K., BROWN, J., COPPLESTONE, D., HINGSTON, J.L., HORYNA, J., HOSSEINI, A., HOWARD, B.J., KAMBOJ, S., NEDVECKAITE, T., OLYSLAEGERS, G., SAZYKINA, T., VIVES I BATLLE, J., YANKOVICH, T.L., YU. C. 2008.

An international comparison of models and approaches for the estimation of the radiological exposure of non-human biota.

Applied Radiation and Isotopes, 66, 1745-1749.

DOI: <http://dx.doi.org/10.1016/j.apradiso.2008.04.009>

Over the last decade a number of models and approaches have been developed for the estimation of the exposure of non-human biota to ionising radiations. In some countries these are now being used in regulatory assessments. However, to date there has been no attempt to compare the outputs of the different models used. This paper presents the work of the International Atomic Energy Agency's EMRAS Biota Working Group which compares the predictions of a number of Such models in model-model and model-data inter-comparisons.

BERESFORD, N.A., BARNETT, C.L., BROWN, J., CHENG, J-J., COPPLESTONE, D., FILISTOVIC, V., HOSSEINI, A., HOWARD, B.J., JONES, S.R., KAMBOJ, S., KRYSHEV, A., NEDVECKAITE, T., OLYSAEGERS, G., SAXÉN, R., SAZYKINA, T. VIVES I BATLLE, J., VIVES-LYNCH, S., YANKOVICH, T., YU, C. 2008.

Inter-comparison of models to estimate radionuclide activity concentrations in non-human biota.

Radiat. Environ. Biophys., 47, 491-514.

DOI: <http://dx.doi.org/10.1007/s00411-008-0186-8>

A number of models have recently been, or are currently being, developed to enable the assessment of radiation doses from ionising radiation to non-human species. A key component of these models is the ability to predict whole-organism activity concentrations in a wide range of wildlife. In this paper, we compare the whole-organism activity concentrations predicted by eight models participating within the IAEA Environmental Modelling for Radiation Safety programme for a range of radionuclides to terrestrial and freshwater organisms. In many instances, there was considerable variation, ranging over orders of magnitude, between the predictions of the different models. Reasons for this variability (including methodology, data source and data availability) are identified and discussed. The active participation of groups responsible for the development of key models within this exercise is a useful step forward in providing the transparency in methodology and data provenance required for models which are either currently being used for regulatory purposes or which may be used in the future. The work reported in this paper, and supported by other findings, demonstrates that the largest contribution to variability between model predictions is the parameterisation of their transfer components. There is a clear need to focus efforts and provide authoritative compilations of those data which are available.

BROWN, J.E., ALFONSO, B., AVILA, R., BERESFORD, N.A., COPPLESTONE, D., PRÖHL, G., ULANOVSKY A. 2008.

The ERICA Tool

J. Environ. Radioact., 99, 1371-1383.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2008.01.008>

The ERICA Tool is a computerised, flexible software system that has a structure based upon the ERICA Integrated Approach to assessing the radiological risk to biota. The Tool guides the user through the assessment process, recording information and decisions and allowing the necessary calculations to be performed to estimate risks to selected animals and plants. Tier 1 assessments are media concentration based and use pre-calculated environmental media concentration limits to estimate risk quotients. Tier 2 calculates dose rates but allows the user to examine and edit most of the parameters used in the calculation including concentration ratios, distribution coefficients, percentage dry weight soil or sediment, dose conversion coefficients, radiation weighting factors and occupancy factors. Tier 3 offers the same flexibility as Tier 2 but allows the option to run the assessment probabilistically if the underlying parameter probability distribution functions are defined. Results from the Tool can be put into context using incorporated data on dose effects relationships and background dose rates.

HOWARD, B.J., LARSSON, C-M. 2008.

Preface: The ERICA Integrated Approach and its contribution to protection of the environment from ionising radiation.

J. Environ. Radioact., 99, 1361-1363

DOI : <http://dx.doi.org/10.1016/j.jenvrad.2008.04.013>

The ERICA Project (environmental risks from ionising radiation: assessment and management) was carried out between 2004 and 2007, as a joint effort between 15 institutions in seven European countries, and under the umbrella of the EC 6th Framework Programme.

The objective of the project was to “provide and apply an integrated approach of addressing scientific, managerial and societal issues surrounding environmental effects of ionising contamination, at a community level, with emphasis on biota and ecosystems. The final outcome of the project will be the delivery of the ERICA Integrated Approach to assessment, risk characterisation and management of environmental risks of ionising radiation at a European level”. The two major outputs were the ERICA Integrated Approach and the ERICA Tool. The Integrated Approach seeks to combine exposure-dose-effect assessment with risk characterisation and managerial considerations, hence the Integrated Approach. The use of the Integrated Approach is facilitated by the ERICA Tool, which is a software programme that guides the user through the various steps, keeps records and communicates with a number of purpose-built databases. The general structure of the Integrated Approach is presented by Larsson (in this issue). In addition to these two deliverables, the project resulted in a number of reports as listed in Larsson (in this issue) and in new, updated and extended knowledge and methodology in many relevant areas. This special issue highlights some of the developments. All project documents can be accessed via the PROTECT web site (www.ceh.ac.uk/protect).

LEVCHUK S., KASHPAROV V., LAZAREV N. , COLLE C., HOWARD B., YOSCHENKO V., YOSCHENKO L. 2008.

Transfer of chlorine from herbage into tissues and milk products of dairy cattle and pigs.

Radiat. Environ Biophys., 47, 111-119.

DOI: <http://dx.doi.org/10.1007/s00411-007-0137-9>

Cl-36 is an important component of nuclear waste. The concentrations of stable chlorine (Cl) in pig and cow tissues were measured to provide information which can be used to parameterize models of ^{36}Cl transfer into agricultural animals. The concentration of stable Cl in cows' milk was $1.0 \pm 0.2 \text{ g L}^{-1}$, in cow muscle it was $0.7 \pm 0.2 \text{ g kg}^{-1}$ wet mass (wm) and in pig muscle $0.4 \pm 0.1 \text{ g kg}^{-1}$ wm. The concentration of stable Cl in cow and pig liver was $0.9 \pm 0.3 \text{ g kg}^{-1}$ wm, which was about two-fold higher than that in the kidney and lung. Due to homeostatic control, stable Cl concentrations in animal tissues are not related to the amount ingested daily in herbage at intake rates in the normal physiological range of up to 188 g day^{-1} for cows and up to 40 g day^{-1} for pigs. Therefore, the commonly used transfer coefficient is not suitable for use in quantifying the transfer of ^{36}Cl to milk and meat. Since the metabolism of stable Cl and ^{36}Cl in an animal's body is identical, the average equilibrium ratios of ^{36}Cl to stable Cl in the daily ration ($^{36}\text{Cl} (\text{g kg}^{-1})/\text{Cl} (\text{g kg}^{-1})$) and animal tissues will be the same. We therefore conclude that the average equilibrium Cl isotopic ratio in the dietary daily intake should be used to predict the contamination of meat and milk with ^{36}Cl .

MIETELSKI, J.W., OLECH, M.A., SOBIECH-MATURA, K., HOWARD, B.J., GACA, P., ZWOLAK, M., BŁAŻEJ, S., TOMANKIEWICZ, E. 2008.

^{137}Cs , ^{40}K , ^{238}Pu , $^{239+240}\text{Pu}$ and ^{90}Sr in biological samples from King George Island (Southern Shetlands) in Antarctica

Polar Biology, 31, 1081-1089.

DOI: <http://dx.doi.org/10.1007/s00300-008-0449-5>

There are few data reported on radionuclide contamination in Antarctica. The aim of this paper is to report ^{137}Cs , ^{90}Sr and $^{238,239+240}\text{Pu}$ and ^{40}K activity concentrations measured in biological samples collected from King George Island (Southern Shetlands, Antarctica), mostly during 2001–2002. The samples included: bones, eggshells and feathers of penguin *Pygoscelis papua*, bones and feathers of petrel *Daption capense*, bones and fur of seal *Mirounga leonina*, algae *Himantothallus grandifolius*, *Desmarestia anceps* and *Cystosphaera jacquinotii*, fish *Notothenia corriceps*, sea invertebrates *Amphipoda*, shells of limpet *Nacella concina*, lichen *Usnea aurantiaco-atra*, vascular plants *Deschampsia antarctica* and *Colobanthus quitensis*, fungi *Omphalina pyxidata*, moss *Sanionia uncinata* and soil. The results show a large variation in some activity concentrations. Samples from the marine environment had lower contamination levels than those from terrestrial ecosystems. The highest activity concentrations for all radionuclides were found in lichen and, to a lesser extent, in mosses, probably because lichens take up atmospheric pollutants

and retain them. The only significant correlation (except for that expected between ^{238}Pu and $^{239+240}\text{Pu}$) was noted for moss and lichen samples between plutonium and ^{90}Sr . A tendency to a slow decrease with time seems to be occurring. Analyses of the activity ratios show varying fractionation between various radionuclides in different organisms. Algae were relatively more highly contaminated with plutonium and radiostrontium, and depleted with radiocesium. Feathers had the lowest plutonium concentrations. Radiostrontium and, to a lesser extent, Pu accumulated in bones. The present low intensity of fallout in Antarctic has a lower $^{238}\text{Pu}/^{239+240}\text{Pu}$ activity ratio than that expected for global fallout.

WOOD, M.D., MARSHALL, W.A., BERESFORD, N.A., JONES, S.R., HOWARD, B.J., COPPLESTONE, D., LEAH, R.T. 2008.

Application of the ERICA Integrated Approach to the Drigg coastal sand dunes

J. Environ. Radioact., 99, 1484-1495.

DOI : <http://dx.doi.org/10.1016/j.jenvrad.2008.03.008>

The EC-funded project 'Environmental Risks from Ionising Contaminants: Assessment and Management' (ERICA) developed an 'Integrated Approach' for assessing the impact of ionising radiation on ecosystems. This paper presents the application of the ERICA Integrated Approach, supported by a software programme (the ERICA Tool) and guidance documentation, to an assessment of the Drigg coastal sand dunes (Cumbria, UK). Targeted sampling provided site-specific data for sand dune biota, including amphibians and reptiles. Radionuclides reported included ^{90}Sr , ^{99}Tc , ^{137}Cs , ^{238}Pu , $^{239+240}\text{Pu}$ and ^{241}Am . Site-specific data were compared to predictions derived using the ERICA Tool. Some under- and over-predictions of biota activity concentrations were identified but can be explained by the specific ecological characteristics and contamination mechanism of the dunes. Overall, the results indicated no significant impact of ionising radiation on the sand dune biota and the Integrated Approach was found to be a flexible and effective means of conducting a radiation impact assessment.

ZINGER, I., COPPLESTONE, D., HOWARD B.J. 2008.

Decision-making in environmental radiation protection: using the ERICA Integrated Approach

J. Environ. Radioact., 99, 1510-1518.

DOI : <http://dx.doi.org/10.1016/j.jenvrad.2008.01.021>

The ERICA Integrated Approach and its associated tool and databases provide a method by which the likely impact of radioactive discharges on the environment can be evaluated, see Fig. 1. The various factors, which should be taken into account when making decisions both during and after an assessment has been made, are discussed for each stage in the assessment process for a hypothetical case study. The assessment will demonstrate the issues associated with the decision-making process at Tiers 1 and 2 within the ERICA Tool and how they may vary. The case study, set in England, evaluates the environmental impact of radioactive substances released under authorisation in response primarily to conservation legislation, because of the need to demonstrate that no adverse impacts will occur on Natura 2000 sites as a result of the release of an authorised substance.

ÁLVAREZ-FARIZO, B., GIL, J.M., HOWARD, B.J. 2009.

Impacts from restoration strategies: Assessment through valuation workshops.

Ecological Economics, 68, 787-797.

DOI: <http://dx.doi.org/10.1016/j.ecolecon.2008.06.012>

Recent decades have seen a wide range of pollutant spills affecting natural, industrial, urban and rural areas (Exxon Valdez, Amoco Cadiz, Erika, Prestige, the Chernobyl nuclear power plant, and the Aznalcollar mines in Spain, to name a few). The extent of damage covers both time and space. Therefore, in order to mitigate the effects of pollution, it is necessary to adopt integrated management of both productive and natural areas. However, to be effective it is necessary to consider not only the health or biophysical effects of the countermeasures, but also the response of individuals to these changes. The purpose of this study is to assess the potential social and environmental impacts derived from the implementation of restoration strategies resulting from spills. Our approach is based on a choice experiment applied within the context of a citizens' valuation workshop or market stall in Cumbria (UK) and Zaragoza (Spain). The results highlight the advantages of this participatory technique versus traditional surveys.

ANDERSSON, P., GARNIER-LAPLACE, J., BERESFORD, N.A., COPPLESTONE, D., HOWARD, B.J., HOWE, P., OUGHTON, D., WHITEHOUSE, P. 2009.

Protection of the environment from ionising radiation in a regulatory context (PROTECT): proposed numerical benchmark values.

J. Environ. Radioact., 100, 1100-1108.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2009.05.010>

Criteria are needed to be able to judge the level of risk associated with dose rates estimated for nonhuman biota. In this paper, European guidance on the derivation of predicted no-effect chemical concentrations has been applied to appropriate radiation sensitivity data. A species sensitivity distribution fitted to the data for all species resulted in a generic predicted no-effect dose rate of $10 \mu\text{Gy h}^{-1}$. Currently, data are inadequate to derive screening values for separate organism groups. A second, higher, benchmark could aid in decision making by putting results into context on the scale of no effect to a risk of 'serious' effect. The need for, meaning and use of such a value needs to be debated by the wider community. This paper explores potential approaches of deriving scientific input to this debate. The concepts proposed in this paper are broadly consistent with the framework for human protection.

BARNETT, C.L., GASCHAK, S., BERESFORD, N.A., HOWARD, B.J., MAKSIMENKO, A. 2009.
Radionuclide activity concentrations in two species of reptiles from the Chernobyl exclusion zone.

Radioprotection, 44, 5, 537-542.

DOI: <http://dx.doi.org/10.1051/radiopro/20095099>

Assessments of radiation exposure of reptiles may be required in some countries as many species are protected. However, there are few data available for the transfer of radionuclides to them, especially in terrestrial ecosystems, and consequently, no specific peer reviewed reptile data have been used in the derivation of default transfer parameters in the ERICA Tool. Twenty samples of *Lacerta agilis* (sand lizard) and five of *Natrix natrix* (grass snake) were collected from two sites within the Chernobyl Exclusion Zone and analysed for Pu-isotopes, ^{137}Cs and ^{90}Sr . Corresponding activity concentrations for soil from the sampling sites were available. These data have been used to derive concentration ratios (CR) (i.e. reptile whole-body fresh weight activity concentration relative to the dry weight activity concentration in soil). CR values for *N. natrix* tended to be lower than those for *L. agilis*. The CR values derived in this paper will be used to improve the default values provided within the ERICA Tool. Whole-body activity concentrations determined in the reptile samples were broadly comparable with data available from the same sampling sites for small mammal species.

BERESFORD, N.A., BARNETT, C.L., BEAUGELIN-SEILLER, K., BROWN, J.E., CHENG, J.-J., COPPLESTONE, D., GASCHAK, S., HINGSTON, J.L., HORYNA, J., HOSSEINI, A., HOWARD, B.J., KAMBOJ, S., KRYSHEV, A., NEDVECKAITE, T., OLYSLAEGERS, G., SAZYKINA, T., SMITH, J.T., TELLERIA, D., VIVES I BATLLE, J., YANKOVICH, T.L., HELING, R., WOOD, M.D., YU, C. 2009.

Findings and recommendations from an international comparison of models and approaches for the estimation of radiological exposure to non-human biota.

Radioprotection, 44, 5, 565-570.

DOI: <http://dx.doi.org/10.1051/radiopro/20095104>

There is general international acceptance of the need to demonstrate that the environment

is protected from ionising radiation. In some countries requirements and guidelines for the protection of non-human biota are already in place. As a consequence a number of models and approaches have been proposed for the estimation of the exposure of non-human biota to ionising radiation. The IAEA EMRAS programme's Biota Working Group has conducted the most comprehensive intercomparison of the predictions of these approaches to date. In this paper, we present an overview of the activities of the Biota Working Group concentrating on its conclusions and recommendations.

BERESFORD, N.A., BEAUGELIN-SELLER, K., BROWN, J.E., COPPLESTONE, D., HOSSEINI, A., ANDERSSON, P. HOWARD, B.J. 2009.

Protection of the environment from ionising radiation in a regulatory context (PROTECT): assessment approaches – practicality, relevance and merits.

Radioprotection, 44, 5, 623-628.

DOI: <http://dx.doi.org/10.1051/radiopro/20095115>

In common with the assessment of chemical stressors many of the methods used for the assessment of risk of non-human biota exposed to radiation use tiered approaches. The initial tier within these approaches is designed to be simple and conservative with the aim to identify sites of negligible concern which can be excluded from more detailed assessment with a high degree of confidence. In this paper we compare the outputs of the screening tiers of three tools which are freely available as software packages. Outputs were compared for terrestrial and freshwater ecosystems assuming 1 Bq per unit media. Considerable variability between the risk quotients (RQ) estimated by the three approaches used was seen for some radionuclide-organism-ecosystem combinations. Reasons for this are explored with differences in transfer parameters used by the models being a common contributor. The large variation within RQ values estimated by the approaches requires further investigation as it does not promote the level of confidence required by the user. The practicalities of applying a single generic screening dose rate in assessments are also explored.

COPPLESTONE, D., ANDERSSON, P., BERESFORD, N.A., BROWN, J., DYSVIK, S., GARNIER-LAPLACE, J., HINGSTON, J., HOWARD, B.J., OUGHTON, D., WHITEHOUSE, P. 2009.

Protection of the environment from ionising radiation in a regulatory context (PROTECT): review of current regulatory approaches to both chemicals and radioactive substances.

Radioprotection, 44, 5, 881-886.

DOI: <http://dx.doi.org/10.1051/radiopro/20095157>

Assessment tools and frameworks have been developed that allow environmental assessments to be conducted and which can be used to demonstrate whether non-human species are protected from the impact of exposure to ionising radiation released under regulation. Frameworks are often tiered, increasing in the level of complexity, input data requirements and need for expert involvement as the assessment moves to successively higher tiers. These are, conceptually, similar to assessment approaches available for chemical risk assessment. What criteria (e.g. numeric benchmarks) should be used, and how these should be defined, are currently under debate, but it is likely that use will be made of approaches developed for setting assessment criteria for chemicals. However it will be necessary to ensure that any assessment criteria developed are fit for use in a regulatory context. This paper reviews the similarities and differences between regulation of, and assessment methods for, chemicals and radioactive substances and presents recommendations regarding how components of chemicals risk assessment may be adopted for radioactive substances.

FESSENKO, S., ISAMOV, N., HOWARD, B.J., BERESFORD, N.A., BARNETT, C.L., SANZHAROVA, N., VOIGT, G. 2009.

Review of Russian language studies on radionuclide behaviour in agricultural animals: 3. Transfer to muscle.

J. Environ. Radioact., 100, 215-231.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2008.12.003>

Over 150 publications reporting studies conducted in the former USSR were reviewed to provide transfer coefficients (F-f) to the muscle of domestic animals from experiments using chronic administration, often for long timescales in large scale experiments. Only a few of these studies were made available in the English language literature or taken into account in international reviews. The values derived have been compared with expected values reported by the IAEA's Handbook of parameter values for the prediction of radionuclide transfer in temperate environments (TRS 364) where possible. The information presented here has been used in the current updating of parameters recommended for environmental assessments by the IAEA. Many of the reported values are for Sr due to the Mayak accident and Cs due to the Chernobyl accident.

Nevertheless, the reported data for a wide range of radionuclides, in particular for Ru, Sb, and Zn markedly improve the extent of available data.

FESENKO, S., HOWARD, B.J., ISAMOV, N., BERESFORD, N.A., BARNETT, C.L., SANZHAROVA, N., VOIGT, G. 2009.

Review of Russian language studies on radionuclide behaviour in agricultural animals: 4. Transfer to poultry

J. Environ. Radioact., 100, 815-822.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2009.06.009>

Data on radionuclide transfer to domestic chickens and ducks obtained from research performed in the former Soviet Union were reviewed to provide transfer coefficient values (Ff) to poultry and edible egg contents. The majority of the data are from experiments with Sr-90 and Cs-137, reflecting the importance of these radionuclides after global fallout and major radiation accidents. Data for H-3, Mn-54, Fe-59, Co-60, Na-22 Zn-65, I-131 and U are also given. The values derived have been compared with those in the current IAEA Handbook of parameter values for the prediction of radionuclide transfer in temperate environments (TRS 364) and the recent revision which incorporates the values from this paper. The Russian-language data give improved estimates for many radionuclides and the revised handbook is now based on the better quality data given for chronic administration.

GALERIU, D., MELINTESCU, A., BERESFORD, N.A., TAKEDA, H., CROUT, N.M.J. 2009.
The dynamic transfer of ^3H and ^{14}C in mammals: a proposed generic model.

Radiat. Environ. Biophys., 48, 29-45.

DOI: <http://dx.doi.org/10.1007/s00411-008-0193-9>

Associated with the present debate regarding the potential revival of nuclear energy there is an increased interest in assessing the radiological risk to the public and also the environment. Tritium and C-14 are key radionuclides of interest in many circumstances (e.g. heavy water reactors, waste storage and fusion reactors). Because the stable analogues of these two radionuclides are integral to most biological compounds, their modelling should follow general principles from life sciences. In this paper, a model of the dynamics of C-14 and H-3 in mammals is proposed on the basis of metabolic understanding and of, as far as possible, readily available data (e.g. for organ composition and metabolism). The model is described together with validation tests (without calibration) for a range of farm animals. Despite simplifications, the model tests are encouraging for a range of animal types and products (tissues and milk), and further improvements are suggested.

HOWARD, B.J., BERESFORD, N.A., BARNETT, C.L., FESENKO, S. 2009.

Radionuclide transfer to animal products: revised recommended transfer coefficient values.

J. Environ. Radioact., 100, 263-273.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2008.12.015>

A compilation has been undertaken of data which can be used to derive animal product transfer coefficients for radionuclides, including an extensive review of Russian language information. The resultant database has been used to provide recommended transfer coefficient values for a range of radionuclides to (i) cow, sheep and goat milk, (ii) meat (muscle) of cattle, sheep, goats, pigs and poultry and (iii) eggs. The values are used in a new IAEA handbook on transfer parameters which replaces that referred to as 'TRS 364'. The paper outlines the approaches and procedures used to identify and collate data, and assumptions used. There are notable differences between the TRS 364 'expected' values and the recommended values in the revised Handbook from the new database. Of the recommended values, three milk values are at least an order of magnitude higher than the TRS 364 values (Cr, Pu (cow) Pu (sheep)) and one milk value is lower (Ni (cow)). For meat, four values (Am, Cd, Sb (beef) I (pork)) are at least an order of magnitude higher than the TRS 364 values and eight values are at least an order of magnitude lower (Ru, Pu (beef), Ru, Sr, Zn (sheep), Ru, Sr (pork), Mn (poultry)). Many data gaps remain.

HOWARD, B.J., BERESFORD, N.A., BARNETT, C.L., FESENKO, S. 2009.

Quantifying the transfer of radionuclides to food products from domestic farm animals.

J. Environ. Radioact., 100, 767-773

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2009.03.010>

Databases have been compiled to derive parameter values relevant to the transfer of radionuclides from feedstuffs to domestic animal products to provide a revision to the IAEA Handbook on transfer parameters TRS 364. Significant new data inputs have been incorporated into the databases from an extensive review of Russian language information and inclusion of data published since the early 1990s. Fractional gastrointestinal absorption in adult ruminants presented in the revised handbook are generally similar to those recommended for adult humans by the ICRP. Transfer coefficient values are presented in the handbook for a range of radionuclides to farm animal products. For most animal products, transfer coefficient values for elements additional to those in TRS 364 are provided although many data gaps remain. Transfer coefficients generally vary between species with larger species having lower values than smaller species. It has been suggested that the difference is partly due to the inclusion of dietary dry matter intake in the estimation of transfer coefficient and that whilst dietary intake increases with size nutrient concentrations do not. An alternative approach to quantifying transfer by using concentration ratios (CR), which do not consider dietary intake, has been evaluated. CR values compiled for the handbook vary considerably less between species than transfer coefficient values. The advantage of the CR approach is that values derived for one species could be applied to species for which there are no data. However, transfer coefficients will continue to be used as few studies currently report CR values or give data from which they can be estimated.

HOWARD, B.J., BERESFORD, N.A., BARNETT, C.L., FESENKO, S. 2009.

Gastrointestinal fractional absorption of radionuclides in adult domestic ruminants.

J. Environ. Radioact., 100, 1069-1078.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2009.03.023>

Information has been compiled on the fractional absorption of a range of radionuclides by adult domestic ruminants. Critical analysis of these data has enabled the derivation of recommended values for fractional absorption which will form part of the new handbook of parameter values for the prediction of radionuclide transfer in terrestrial and freshwater environments to be published by the International Atomic Energy Agency. Whilst most data considered were for caesium, strontium and iodine, values for 23 other radionuclides are also given. The recommended fractional absorption Values are presented here, together with descriptions of the literature used to derive them. The values for domestic ruminants are compared with those derived by the International Commission for Radiological Protection for adult humans.

JONES, D.G., APPLETON, J.D., BREWARD, N., MACKENZIE, A.C., SCHEIB, C., BERESFORD, N.A., BARNETT, C.L., WOOD, M.D., COPPLESTONE, D. 2009.

Assessment of naturally occurring radionuclides around England and Wales: application of the G-BASE dataset to estimate doses to non-human species.

Radioprotection, 44, 5, 629-634.

DOI: <http://dx.doi.org/10.1051/radiopro/20095116>

An assessment of the natural radiation dose to wildlife in England and Wales was made to determine the contribution it may make to the total radiation dose estimated during environmental impact assessments. Significant use was made of systematic datasets for environmental media (stream sediments, stream waters and soils), in particular those produced by the Geochemical Baseline Survey of the Environment (G-BASE) project. This provided extensive, although variable, coverage for different elements and sample types after normalisation of data to account for changes in sampling and analysis over time. Almost complete coverage for K in stream sediments was achieved by merging G-BASE and Wolfson Atlas data. This required normalisation of the Wolfson data to the G-BASE results. Coverage was improved greatly for U and Th in sediments, and K, U and Th in soils, by using the strong relationship between soils and sediments and geology (both solid and superficial) to extrapolate the data. The total U, Th and K data were used to derive activity concentrations of ²³⁸U and ²³²Th series radionuclides and ⁴⁰K. External dose rates to wildlife were then estimated from derived media concentrations; internal dose rates were estimated from measured activities in biota or activities predicted using recommended concentration ratios.

WOOD, M.D., BERESFORD, N.A., BARNETT, C.L., COPPLESTONE, D., LEAH, R.T. 2009.
Assessing radiation impact at a protected coastal sand dune site: an intercomparison of models for estimating the radiological exposure of non-human biota.

J. Environ. Radioact., 100, 1034-1052.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2009.04.010>

This paper presents the application of three publicly available biota dose assessment models (the ERICA Tool, R&D128/SP1a and RESRAD-BIOTA) to an assessment of the Drigg coastal sand dunes. Using measured Sr-90, Tc-99, Cs-137, Pu-238, Pu239+240 and Am-241 activity concentrations in sand dune soil, activity concentration and dose rate predictions are made for a range of organisms including amphibians, birds, invertebrates, mammals, reptiles, plants and fungi. Predicted biota activity concentrations are compared to measured data where available. The main source of variability in the model predictions is the transfer parameters used and it is concluded that developing the available transfer databases should be a focus of future research effort. The value of taking an informed user approach to investigate the way in which models may be expected to be applied in practice is highlighted and a strategy for the future development of intercomparison exercises is presented.

BERESFORD, N.A., BARNETT, C.L., BROWN, J.E., CHENG, J.-J., COPPLESTONE, D., GASCHAK, S., HOSSEINI, A., HOWARD, B.J., KAMBOJ, S., NEDVECKAITE, T., OLYSLAEGERS, G., SMITH, J.T., VIVES I BATLLE, J., VIVES-LYNCH, S., YU, C. 2010.
Predicting the radiation exposure of terrestrial wildlife in the Chernobyl exclusion zone: an international comparison of approaches.

J. Radiol. Prot., 30, 341–373.

DOI: <http://dx.doi.org/10.1088/0952-4746/30/2/S07>

There is now general acknowledgement that there is a requirement to demonstrate that species other than humans are protected from anthropogenic releases of radioactivity. A number of approaches have been developed for estimating the exposure of wildlife and some of these are being used to conduct regulatory assessments. There is a requirement to compare the outputs of such approaches against available data sets to ensure that they are robust and fit for purpose. In this paper we describe the application of seven approaches for predicting the whole-body (^{90}Sr , ^{137}Cs , ^{241}Am and Pu isotope) activity concentrations and absorbed dose rates for a range of terrestrial species within the Chernobyl exclusion zone. Predictions are compared against available measurement data, including estimates of external dose rate recorded by thermoluminescent dosimeters attached to rodent species. Potential reasons for differences between predictions between the various approaches and the available data are explored.

BERESFORD, N.A., HOSSEINI, A., BROWN, J.E., CAILES, C., BEAUGELIN-SEILLER, K., BARNETT, C.L., COPPLESTONE, D. 2010.

Assessment of risk to wildlife from ionising radiation: can initial screening tiers be used with a high level of confidence?

J. Radiol. Prot., 30, 265–281.

DOI: <http://dx.doi.org/10.1088/0952-4746/30/2/S04>

A number of models are being used to assess the potential environmental impact of releases of radioactivity. These often use a tiered assessment structure whose first tier is designed to be highly conservative and simple to use. An aim of using this initial tier is to identify sites of negligible concern and to remove them from further consideration with a high degree of confidence. In this paper we compare the screening assessment outputs of three freely available models. The outputs of these models varied considerably in terms of estimated risk quotient (RQ) and the radionuclide–organism combinations identified as being the most limiting. A number of factors are identified as contributing to this variability: values of transfer parameters (concentration ratios and K_d) used; organisms considered; different input options and how these are utilised in the assessment; assumptions as regards secular equilibrium; geometries and exposure scenarios. This large variation in RQ values between models means that the level of confidence required by users is not achieved. We recommend that the factors contributing to the variation in screening assessments be subjected to further investigation so that they can be more fully understood and assessors (and those reviewing assessment outputs) can better justify and evaluate the results obtained.

BERESFORD, N.A. 2010.

EDITORIAL: The transfer of radionuclides to wildlife.

Radiat. Environ. Biophys., 49, 505–508

DOI: <http://dx.doi.org/10.1007/s00411-010-0325-x>

COPPLESTONE, D., BERESFORD, N.A., HOWARD, B.J. 2010.

EDITORIAL: Protection of the Environment from Ionising Radiation: developing criteria and evaluating approaches for use in regulation

J. Radiol. Prot., 30, 191–194.

DOI: <http://dx.doi.org/10.1088/0952-4746/30/2/E03>

COPPLESTONE, D., BROWN, J.E., BERESFORD, N.A. 2010.

Considerations for the integration of human and wildlife radiological assessments.

J. Radiol. Prot., 30, 283–297.

DOI: <http://dx.doi.org/10.1088/0952-4746/30/2/S05>

A number of tools and approaches have been developed recently to allow assessments of the environmental impact of radiation on wildlife to be undertaken. The International Commission on Radiological Protection (ICRP) has stated an intention to provide a more inclusive protection framework for humans and the environment. Using scenarios, which are loosely based on real or predicted discharge data, we investigate how radiological assessments of humans and wildlife can be integrated with special consideration given to the recent outputs of the ICRP. We highlight how

assumptions about the location of the exposed population of humans and wildlife, and the selection of appropriate benchmarks for determining potential risks can influence the outcome of the assessments. A number of issues associated with the transfer component and numeric benchmarks were identified, which need to be addressed in order to fully integrate the assessment approaches. A particular issue was the lack of comparable benchmark values for humans and wildlife. In part this may be addressed via the ICRP's recommended derived consideration reference levels for their 12 Reference Animals and Plants.

DRAGOVIĆ, S., HOWARD, B.J., CABORN, J.A., BARNETT, C.L, MIHAILOVIĆ, N. 2010.
Transfer of natural and anthropogenic radionuclides to ants, bryophytes and lichen in a semi natural ecosystem.

Environ. Monit. Assess., 166, (1-4), 677-686.

DOI: <http://dx.doi.org/10.1007/s10661-009-1032-4>

Few data are available to quantify the transfer of both natural and anthropogenic radionuclides to detritivorous invertebrates to facilitate estimation of the internal dose to such biota in models used to assess radiation exposure. To enhance the available data, activity concentrations of ^{137}Cs , ^{40}K , ^{90}Sr , $^{239+240}\text{Pu}$, ^{241}Am , ^{235}U and ^{238}U were measured in ants (*Formicidae*) and corresponding undisturbed soil collected from the Zlatibor mountain in Serbia and ant/soil concentration ratios (CR) calculated. The ^{241}Am concentration ratios for ants were fourfold higher than those calculated for ants in a previous study whereas they are similar to the more numerous data previously reported for a range of detritivorous invertebrates in other studies. CR values for ^{137}Cs in ants were similar to the few other reported values and slightly lower than those for a range of detritivorous invertebrates. Those for $^{239+240}\text{Pu}$ were slightly higher than those for ants in two other studies but they were close to upper limit of a range of data reported for detritivorous invertebrates. All the CR values will be included in a future revision of the ERICA Tool database and will particularly improve the information available for uranium.

GARNIER-LAPLACE, J., DELLA-VEDOVA, C., ANDERSSON, P., COPPLESTONE, D., CAILES, C., BERESFORD, N.A., HOWARD, B.J., HOWE, P., WHITEHOUSE, P. 2010.
A multi-criteria weight of evidence approach for deriving ecological benchmarks for radioactive substances.

J. Radiol. Prot., 30, 215–233.

DOI: <http://dx.doi.org/10.1088/0952-4746/30/2/S02>

Dose rate benchmarks are required in the tiered approaches used to screen out benign exposure scenarios in radiological ecological risk assessment. Such screening benchmarks, namely the predicted no-effect dose rates (PNEDR), have been derived by applying, as far as possible, the European guidance developed for chemicals. To derive the ecosystem level (or generic) PNEDR, radiotoxicity EDR10 data (dose rates giving a 10% effect in comparison with the control) were used to fit a species sensitivity distribution (SSD) and estimate the HDR5 (the hazardous dose rate affecting 5% of species with a 10% effect). Then, a multi-criteria approach was developed to justify using an assessment factor (AF) to apply to the HDR5 for estimating a PNEDR value. Several different statistical data treatments were considered which all gave reasonably similar results. The suggested generic screening value of $10 \mu\text{Gy h}^{-1}$ (incremental dose rate) was derived using the lowest available EDR10 value per species, an unweighted SSD, and an AF of 2 applied to the estimated HDR5. Consideration was also given to deriving screening benchmark values for organism groups but this was not thought to be currently appropriate due to few relevant data being currently available.

GASHCHAK, S., BERESFORD, N.A., MAKSIMENKO, A., VLASCHENKO, A.S. 2010.
Strontium-90 and caesium-137 activity concentrations in bats in the Chernobyl exclusion zone.

Radiat. Environ. Biophys., 49, 635-644

DOI: <http://dx.doi.org/10.1007/s00411-010-0322-0>

Bats are a protected species and as such may be an object of protection in radiological assessments of the environment. However, there have previously been only few radioecological studies of species of bats. In this paper, results for 140 measurements of ^{90}Sr and ^{137}Cs in 10 species of bats collected within the Chernobyl zone are presented. There was some indication of a decreasing transfer of ^{90}Sr with increasing deposition, although this was inconsistent across species and explained little of the observed variability. There was no difference between male and female bats in the transfer (expressed as the ratio of whole-body activity concentrations to those in soil) of either radionuclide. There was considerable variability in transfer across all species groups. At two sites where there were sufficient data, *Eptesicus serotinus* was found to have higher transfer than other species.

HOSSEINI, A., BERESFORD, N.A., BROWN, J.E., JONES, D.G., PHANEUF, M., THØRRING, H., YANKOVICH, T. 2010.

Background dose-rates to reference animals and plants arising from exposure to naturally occurring radionuclides in aquatic environments.

J. Radiol. Prot., 30, 235–264.

DOI: <http://dx.doi.org/10.1088/0952-4746/30/2/S03>

In order to put dose-rates derived in environmental impact assessments into context, the International Commission on Radiological Protection (ICRP) has recommended the structuring of effects data according to background exposure levels. The ICRP has also recommended a suite of reference animals and plants (RAPs), including seven aquatic organisms, for use within their developing framework. In light of these propositions, the objective of this work was to collate information on activity concentrations of naturally occurring primordial radionuclides for marine and freshwater ecosystems and apply appropriate dosimetry models to derive absorbed dose-rates. Although coverage of activity concentration data is comprehensive for sediment and water, few, or in some cases no, data were found for some RAPs, e.g. for frogs (*Ranidae*) and freshwater grasses (*Poaceae*) for most radionuclides. The activity concentrations for individual radionuclides in both organisms and their habitat often exhibit standard deviations that are substantially greater than arithmetic mean values, reflecting large variability in activity concentrations. To take account of variability a probabilistic approach was adopted. The dominating radionuclides contributing to exposure in the RAPs are ^{40}K , ^{210}Po and ^{226}Ra . The mean unweighted and weighted dose-rates for aquatic RAPs are in the ranges $0.07\text{--}0.39\ \mu\text{Gy h}^{-1}$ and $0.37\text{--}1.9\ \mu\text{Gy h}^{-1}$ respectively.

HOWARD, B.J., BERESFORD, N.A., ANDERSSON, P., BROWN, J.E., COPPLESTONE, D., BEAUGELIN-SEILLER, K., GARNIER-LAPLACE, J., HOWE, P.D., OUGHTON, D., WHITEHOUSE, P. 2010.

Protection of the environment from ionising radiation in a regulatory context—an overview of the PROTECT coordinated action project.

J. Radiol. Prot., 30, 195–214.

DOI: <http://dx.doi.org/10.1088/0952-4746/30/2/S01>

The outcome of the PROTECT project (Protection of the Environment from Ionising Radiation in a Regulatory Context) is summarised, focusing on the protection goal and derivation of dose rates which may detrimentally affect wildlife populations. To carry out an impact assessment for radioactive substances, the estimated dose rates produced by assessment tools need to be compared with some form of criteria to judge the level of risk. To do this, appropriate protection goals need to be defined and associated predefined dose rate values, or benchmarks, derived and agreed upon. Previous approaches used to estimate dose rates at which there may be observable changes in populations or individuals are described and discussed, as are more recent derivations of screening benchmarks for use in regulatory frameworks. We have adopted guidance and procedures used for assessment and regulation of other chemical stressors to derive benchmarks. On the basis of consultation with many relevant experts, PROTECT has derived a benchmark screening dose rate, using data on largely reproductive effects to derive species sensitivity distributions, of $10\ \mu\text{Gy h}^{-1}$ which can be used to identify situations which are below regulatory concern with a high degree of confidence.

NISBET, A.F., BROWN, J.B., HOWARD, B.J., BERESFORD, N.A., OLLAGNON, H., TURCANU, C., CAMPS, J., ANDERSSON, K., RANTAVAARA, A., IKÄHEIMONEN, T., DURANOVA, T., OUGHTON, D., KIRCHNER, G., PAPACHRISTODOULOU, C., IOANNIDES, K., WAKMAN, P. 2010

Decision aiding handbooks for managing contaminated food production systems, drinking water and inhabited areas in Europe.

Radioprotection., 45, S23-S37.

DOI: <http://dx.doi.org/10.1051/radiopro/2010014>

Three handbooks have been developed, in conjunction with a wide range of stakeholders to assist in the management of contaminated food production systems, inhabited areas and drinking water following a radiological incident. The handbooks are aimed at national and local authorities, central government departments and agencies, emergency services, radiation protection experts, the agriculture and food production sectors, industry and others who may be affected. The handbooks include management options for application in the different phases of an incident. Sources of contamination considered in the handbooks include nuclear accidents and radiological dispersion devices; the most relevant radionuclides are included. The handbooks are divided into several sections which provide supporting scientific and technical information; an analysis of the

factors influencing recovery; compendia of comprehensive, state-of-the-art datasheets for around 100 management options and guidance on planning in advance. A decision-aiding framework comprising colour coded selection tables, look-up tables and decision trees and several worked examples are also included. The handbooks can be used as a preparatory tool, under non-crisis conditions, to engage stakeholders and to develop local and regional plans. The handbooks can also be applied as part of the decision-aiding process to develop a recovery strategy following an incident. In addition, the handbooks are useful for training purposes and during emergency exercises. To realise their full potential, the handbooks should be customised at national, regional and local levels.

WOOD, M.D., BERESFORD, N.A., SEMENOV, D.V., YANKOVICH, T.L., COPPLESTONE, D. 2010.

Radionuclide transfer to reptiles.

Radiat. Environ. Biophys., 49, 509-530

DOI: <http://dx.doi.org/10.1007/s00411-010-0321-1>

Reptiles are an important, and often protected, component of many ecosystems but have rarely been fully considered within ecological risk assessments (ERA) due to a paucity of data on contaminant uptake and effects. This paper presents a meta-analysis of literature-derived environmental media (soil and water) to whole-body concentration ratios (CRs) for predicting the transfer of 35 elements (Am, As, B, Ba, Ca, Cd, Ce, Cm, Co, Cr, Cs, Cu, Fe, Hg, K, La, Mg, Mn, Mo, Na, Ni, Pb, Po, Pu, Ra, Rb, Sb, Se, Sr, Th, U, V, Y, Zn, Zr) to reptiles in freshwater ecosystems and 15 elements (Am, C, Cs, Cu, K, Mn, Ni, Pb, Po, Pu, Sr, Tc, Th, U, Zn) to reptiles in terrestrial ecosystems. These reptile CRs are compared with CRs for other vertebrate groups. Tissue distribution data are also presented along with data on the fractional mass of bone, kidney, liver and muscle in reptiles. Although the data were originally collected for use in radiation dose assessments, many of the CR data presented in this paper will also be useful for chemical ERA and for the assessments of dietary transfer in humans for whom reptiles constitute an important component of the diet, such as in Australian aboriginal communities.

YANKOVICH, T.L., BERESFORD, N.A., WOOD, M., AONO, T., ANDERSSON, P., BARNETT, C.L., BENNETT, P., BROWN, J., FESENKO, S., HOSSEINI, A., HOWARD, B.J., JOHANSEN, M., PHANEUF, M., TAGAMI, K., TAKATA, H., TWINING, J., UCHIDA, S. 2010.

Whole-body to tissue concentration ratios for use in biota dose assessments for animals.

Radiat. Environ. Biophys., 49, 549-565

DOI: <http://dx.doi.org/10.1007/s00411-010-0323-z>

Environmental monitoring programs often measure contaminant concentrations in animal tissues consumed by humans (e.g. muscle). By comparison, demonstration of the protection of biota from the potential effects of radionuclides involves a comparison of whole-body doses to radiological dose benchmarks. Consequently, methods for deriving whole-body concentration ratios based on tissue-specific data are required to make best use of the available information. This paper provides a series of look-up tables with whole-body:tissue-specific concentration ratios for non-human biota. Focus was placed on relatively broad animal categories (including molluscs, crustaceans, freshwater fishes, marine fishes, amphibians, reptiles, birds and mammals) and commonly measured tissues (specifically, bone, muscle, liver and kidney). Depending upon organism, whole-body to tissue concentration ratios were derived for between 12 and 47 elements. The whole-body to tissue concentration ratios can be used to estimate whole-body concentrations from tissue-specific measurements. However, we recommend that any given whole-body to tissue concentration ratio should not be used if the value falls between 0.75 and 1.5. Instead, a value of one should be assumed.

YANKOVICH, T.Y., VIVES I BATLLE, J., VIVES-LYNCH, J., BERESFORD, N.A., BARNETT, C.L., BEAUGELIN-SEILLER, K., BROWN, J.E., CHENG, J-J., COPPLESTONE, D., HELING, R., HOSSEINI, A., HOWARD, B.J., KAMBOJ, S., KRYSHEV, A. I., NEDVECKAITE, T., SMITH, J.T., WOOD, M.D. 2010.

An international model validation exercise on radionuclide transfer and doses to freshwater biota.

J. Radiol. Prot., 30, 299–340.

DOI: <http://dx.doi.org/10.1088/0952-4746/30/2/S06>

Under the International Atomic Energy Agency (IAEA)'s EMRAS (Environmental Modelling for Radiation Safety) programme, activity concentrations of ^{60}Co , ^{90}Sr , ^{137}Cs and ^3H in Perch Lake at Atomic Energy of Canada Limited's Chalk River Laboratories site were predicted, in freshwater primary producers, invertebrates, fishes, herpetofauna and mammals using eleven modelling approaches. Comparison of predicted radionuclide concentrations in the different species types with measured values highlighted a number of areas where additional work and understanding is required to improve the predictions of radionuclide transfer. For some species, the differences could be explained by ecological factors such as trophic level or the influence of stable analogues. Model predictions were relatively poor for mammalian species and herpetofauna compared with measured values, partly due to a lack of relevant data. In addition, concentration ratios are sometimes under-predicted when derived from experiments performed under controlled laboratory conditions representative of conditions in other water bodies.

BARNETT, C.L., HOWARD, B.J., OUGHTON, D.H., COUTRIS, C., POTTER, E.D., FRANKLIN, T., WALKER L.A., WELLS C. 2011

Transfer of elements to owls (*Tyto Alba*, *Strix Aluco*) determined using neutron activation and gamma analysis

Radioprotection, 46, S79-S84.

DOI: <http://dx.doi.org/10.1051/radiopro/20116703s>

The IAEA is currently preparing a new Technical Reports Series (TRS) Handbook on the Transfer of Radionuclides to Wildlife. Key deficiencies have been identified and one is the lack of data for birds. In this study we measured the transfer of a range of elements measured by neutron activation analysis (NAA) and gamma analysis in four Barn owls (*Tyto alba*) and one Tawny owl (*Strix aluco*) from archived samples available from the Predatory Bird Monitoring Scheme, <http://pbms.ceh.ac.uk>. Transfer was quantified as the whole organism concentration ratio (CR_{wo-soil}) and values for Co, Fe, Rb, Sc, Zn and ¹³⁷Cs are presented. The work demonstrates the potential for existing sample archives to be exploited for radioecological purposes. They represent a cost effective means to derive CR_{wo}-media values for organism-radionuclide combinations relevant to radiological assessments without the requirement of field sampling.

BERESFORD, N.A., COPPLESTONE, D. 2011

Effects of Ionizing Radiation on Wildlife: What Knowledge Have We Gained Between the Chernobyl and Fukushima Accidents?

Integer. Environ. Assess. Manag., 7, 371–37.

DOI: <http://dx.doi.org/10.1002/ieam.238>

The recent events at the Fukushima Daiichi nuclear power plant in Japan have raised questions over the effects of radiation in the environment. This article considers what we have learned about the radiological consequences for the environment from the Chernobyl accident, Ukraine, in April 1986. The literature offers mixed opinions of the long-term impacts on wildlife close to the Chernobyl plant, with some articles reporting significant effects at very low dose rates (below natural background dose rate levels in, for example, the United Kingdom). The lack of agreement highlights the need for further research to establish whether current radiological protection criteria for wildlife are adequate (and to determine if there are any implications for human radiological protection).

BERESFORD, N.A., HOWARD, B.J. 2011

An Overview of the Transfer of Radionuclides to Farm Animals and Potential Countermeasures of Relevance to Fukushima Releases.

Integer. Environ. Assess. Manag., 7, 382–84.

DOI: <http://dx.doi.org/10.1002/ieam.235>

Initial information since the releases of radioactive materials from the Fukushima Daiichi nuclear power plant, in Japan, shows that some animal food products are contaminated with ¹³¹I (mostly milk) and, to a lesser extent with ¹³⁴Cs and ¹³⁷Cs. Current knowledge on the transfer of these radioisotopes to animal products and available relevant countermeasures and management options to reduce radiation doses to humans are summarized. Much of this knowledge was obtained during the years of global fallout from atmospheric nuclear weapons tests and the response to the Chernobyl accident, in Ukraine in 1986.

NEDVECKAITE, T., FILISTOVIC, V., MARCIULIONIENE, D., PROKOPTCHUK, N., PLUKIENE, R., GUDELIS, A., REMEIKIS, V., YANKOVICH, T., BERESFORD, N.A. 2011

Background and anthropogenic radionuclide derived dose rates to freshwater ecosystem - Nuclear power plant cooling pond - Reference organisms.

J. Environ. Radioact., 102, 788-795.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2011.04.012>

The radiological assessment of non-human biota to demonstrate protection is now accepted by a number of international and national bodies. Therefore, it is necessary to develop a scientific basis to assess and evaluate exposure of biota to ionizing radiation. Radionuclides from the Ignalina Nuclear Power Plant (Lithuania) were discharged into Lake Druksiai cooling pond. Additional radionuclide migration and recharge to this lake from a hypothetical near-surface, low-level radioactive waste disposal, to be situated 1.5 km from the lake, had been simulated using RESRAD-OFFSITE code. This paper uses ERICA Integrated Approach with associated tools and databases to compare the radiological dose to freshwater reference organisms. Based on these data, it can be concluded that background dose rates to non-human biota in Lake Druksiai far exceed those attributable to anthropogenic radionuclides. With respect the fishery and

corresponding annual committed effective human dose as a result of this fish consumption Lake Druksiai continues to be a high-productivity water body with intensive angling and possible commercial fishing.

VIVES I BATLLE, J., BEAUGELIN-SEILLER, K., BERESFORD, N.A., COPPLESTONE, D., HORYNA, J., HOSSEINI, A., JOHANSEN, M., KAMBOJ, S., KEUM, D.-K., KUROSAWA, N., NEWSOME, L., OLYSLAEGERS, G., VANDENHOVE, H., RYUFUKU, S., VIVES LYNCH, S., WOOD, M.D., YU, C. 2011

The estimation of absorbed dose rates for non-human biota: an extended intercomparison

Radiat. Environ. Biophys., 50, 231–251.

DOI: <http://dx.doi.org/10.1007/s00411-010-0346-5>

An exercise to compare 10 approaches for the calculation of unweighted whole-body absorbed dose rates was conducted for 74 radionuclides and five of the ICRP's Reference Animals and Plants, or RAPs (duck, frog, flatfish egg, rat and elongated earthworm), selected for this exercise to cover a range of body sizes, dimensions and exposure scenarios. Results were analysed using a nonparametric method requiring no specific hypotheses about the statistical distribution of data. The obtained unweighted absorbed dose rates for internal exposure compare well between the different approaches, with 70% of the results falling within a range of variation of $\pm 20\%$. The variation is greater for external exposure, although 90% of the estimates are within an order of magnitude of one another. There are some discernible patterns where specific models over- or under-predicted. These are explained based on the methodological differences including number of daughter products included in the calculation of dose rate for a parent nuclide; source–target geometry; databases for discrete energy and yield of radionuclides; rounding errors in integration algorithms; and intrinsic differences in calculation methods. For certain radionuclides, these factors combine to generate systematic variations between approaches. Overall, the technique chosen to interpret the data enabled methodological differences in dosimetry calculations to be quantified and compared, allowing the identification of common issues between different approaches and providing greater assurance on the fundamental dose conversion coefficient approaches used in available models for assessing radiological effects to biota.

WOOD M.D., BERESFORD, N.A., YANKOVICH, T.L., SEMENOV D.V., COPPLESTONE, D. 2011

Addressing current knowledge gaps on radionuclide transfer to reptiles

Radioprotection, 46, S521–S527.

DOI: <http://dx.doi.org/10.1051/radiopro/20116792s>

Model intercomparison exercises have identified radionuclide transfer predictions as the greatest source of uncertainty in biota dose assessments. One wildlife group for which few transfer data exist is reptiles. Given that reptiles are an important, and often protected, component of many ecosystems and that assessments of radiation impact on ecosystems are becoming increasingly necessary due to the current nuclear renaissance, there is a need to further develop our current database on transfer to reptiles or find alternative approaches to estimate reptile transfer parameters. Three approaches that have the potential to increase the availability of parameters to predict radionuclide transfer to reptiles are the use of non-lethal sampling techniques, phylogenetic relationships and allometric relationships. Non-lethal sampling is an attractive long term option for deriving transfer parameters, but the derivation of phylogenetic and allometric relationships could provide ways of predicting transfer in the interim.

WOOD M.D., BERESFORD, N.A., COPPLESTONE, D. 2011

Limit of detection values in data analysis: Do they matter?

Radioprotection, 46, S85–S90.

DOI: <http://dx.doi.org/10.1051/radiopro/20116728s>

Data sets containing values below the limit of detection (LOD) are known as ‘censored data sets’. Such data sets are encountered regularly in most fields of environmental contaminant research. The current norm within environmental radioactivity research is to use substitution methods when analysing data sets that include values below the LOD, commonly replacing each LOD value with a value equal to half the LOD (LOD/2). However, this approach has no statistical basis and has implications when summarising or comparing data sets because it can lead to underestimates or overestimates of both the mean and the standard deviation. To remove the need to apply substitution methods, over the last four decades other fields of environmental science have been adopting statistical techniques developed for medical research applications. Despite the long history of applying these techniques in other fields and two recent environmental radioactivity publications that have used survival analysis techniques, there still seems to be reluctance within

the environmental radioactivity research community to adopt these ‘new’ methods. This paper introduces the statistical techniques that can be used in place of LOD substitution, presents some guidance on the applicability of these techniques for different levels of data censoring and provides some examples of the use of these methods in various contexts. It is hoped the present paper will contribute to the evidence-base supporting the use of survival analysis within the field of environmental radioactivity research and go some way to changing the current norm of substitution using LOD/2.

BERESFORD, N.A., BARNETT, C.L., VIVES I BATLLE, J., POTTER, E.D., IBRAHIMI, Z.-F., BARLOW, T.S., SCHIEB, C., JONES, D.G., COPPLESTONE, D. 2012

Exposure of burrowing mammals to ^{222}Rn

Science of the Total Environment. 431, 252-261

DOI: <http://dx.doi.org/10.1016/j.scitotenv.2012.05.023>

Estimates of absorbed dose rates to wildlife from exposure to natural background radionuclides are required to put estimates of dose rates arising from regulated releases of radioactivity and proposed benchmarks into context. Recent review papers have estimated dose rates to wildlife from ^{40}K , and ^{238}U and ^{232}Th series radionuclides. However, only one study previous has considered the potential dose rates to burrowing animals from inhaled ^{222}Rn and its daughter products. In this paper we describe a study conducted at seven sites in northwest England. Passive track etch detectors were used to measure the ^{222}Rn concentrations in artificial burrows over a period of approximately one year. Results suggest that absorbed dose rates to burrowing mammals as a consequence of exposure to ^{222}Rn are likely to be at least an order of magnitude higher than those suggested in previous evaluations of natural background exposure rates which had omitted this radionuclide and exposure pathway. Dose rates in some areas of Great Britain will be considerably in excess of incremental no-effects benchmark dose rates suggested for use as screening levels. Such advised benchmark dose rates need to be better put into context with background dose rates, including exposure to ^{222}Rn , to ensure credibility; although the context will be determined by the purpose of the benchmark and the assessment level.

BERESFORD, N.A., BARNETT, C.L., HOWARD, B.J., HOWARD, D.C., WELLS, C., TYLER, A.N., BRADLEY, S., COPPLESTONE, D. 2012

Observations of Fukushima fallout in Great Britain

J. Environ. Radioact. 114, 48-53.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2011.12.008>

Following the Fukushima accident in March 2011, grass samples were collected from 42 sites around Great Britain during April 2011. Iodine-131 was measurable in grass samples across the country with activity concentrations ranging from 10 to 55 Bq kg⁻¹ dry matter. Concentrations were similar to those reported in other European countries. Rainwater and some foodstuffs were also analysed from a limited number of sites. Of these, ^{131}I was only detectable in sheep's milk (c. 2 Bq kg⁻¹). Caesium-134, which can be attributed to releases from the Fukushima reactors, was detectable in six of the grass samples (4e8 Bq kg⁻¹ dry matter); ^{137}Cs was detected in a larger number of grass samples although previous release sources (atmospheric weapons test and the 1986 Chernobyl and 1957 Windscale accidents) are likely to have contributed to this.

JOHANSEN, M.P., BARNETT, C.L., BERESFORD N.A., BROWN, J.E., ČERNE, M., HOWARD, B.J., KAMBOJ, S., KEUM, D-K., SMODIŠ, B., TWINING, J.R., VANDENHOVE, H., VIVES I BATLLE, J., WOOD, M.D., YU, C. 2012

Assessing doses to terrestrial wildlife at a radioactive waste disposal site: inter-comparison of modelling approaches.

Science of the Total Environment. 427-428, 238-246

DOI: <http://dx.doi.org/10.1016/j.scitotenv.2012.04.031>

Radiological doses to terrestrial wildlife were examined in this model inter-comparison study that emphasized factors causing variability in dose estimation. The study participants used varying modelling approaches and information sources to estimate dose rates and tissue concentrations for a range of biota types exposed to soil contamination at a shallow radionuclide waste burial site in Australia. Results indicated that the dominant factor causing variation in dose rate estimates (up to three orders of magnitude on mean total dose rates) was the soil-to-organism transfer of radionuclides that included variation in transfer parameter values as well as transfer calculation methods. Additional variation was associated with other modelling factors including: how participants conceptualised and modelled the exposure configurations (two orders of magnitude); which progeny to include with the parent radionuclide (typically less than one order of magnitude); and dose calculation parameters, including radiation weighting factors and dose conversion coefficients (typically less than one order of magnitude). Probabilistic approaches to model parameterisation were used to encompass and describe variable model parameters and outcomes. The study confirms the need for continued evaluation of the underlying mechanisms governing soil-to-organism transfer of radionuclides to improve estimation of dose rates to terrestrial wildlife. The exposure pathways and configurations available in most current codes are limited when considering instances where organisms access subsurface contamination through rooting, burrowing, or using different localized waste areas as part of their habitual routines

OUGHTON, D.H., HOWARD B.J. 2012.

The Social and Ethical Challenges of Radiation Risk Management.

Ethics, Policy and Environment 15, 71 - 76.

DOI: <http://dx.doi.org/10.1080/21550085.2012.672690>

Thousands of people died in the tsunami, nearly half a million were made homeless, but since the first few days of the Japanese earthquake, most of the world media's attention was, and remains, focused on the radiological consequences of the Fukushima nuclear plant failure. In the immediate aftermath, the loss of control and radiation releases at the plant sparked responses spanning from initial predictions of apocalyptic devastation (Bromley, 2011), through rocketing sales of Geiger counters and iodine tablets in Europe, to frustration at the focus given to the radiation risks, particularly by the media outside Japan. While the releases have caused significant contamination of marine and terrestrial environments (Busseler et al., 2011), the general consensus from scientific experts is that the actual radiological risks to the general population remain relatively small, that the serious long-term contamination problems have been contained (that is, within 50 km), and that the biggest current challenge is the clean-up of the contaminated agricultural and populated areas (Wakeford, 2011). These problems are serious, and the radiation risk management is still confounded by the tsunami and earthquake disasters. However, rather than helping to put radiation risks into perspective, the much larger direct injuries from the earthquake and tsunami seem to be overshadowed by the, at least on paper, farless fatal radiation risks.

In this respect, Fukushima illustrates why radiation is one of the most difficult environmental stressors to deal with. This should not come as a great surprise, since Chernobyl demonstrated how the social, psychological and economic consequences of an accident can outweigh any direct health effects for radiation exposure (Bay & Oughton, 2005; International Atomic Energy Agency, 2005), and in recent years authorities have acknowledged the importance of social aspects in the assessment of radiation risks.

PÁLSSON S.E., HOWARD, B.J., GUDNASONA, K., SIGURGEIRSSON, M.A. 2012

Long term transfer of global fallout ^{137}Cs to cow milk in Iceland.

Environmental Monitoring and Assessment. 184, 7221-7234.

DOI: <http://dx.doi.org/10.1007/s10661-011-2498-4>

The aim of this study was to provide improved information on the long-term transfer of global nuclear weapons ^{137}Cs fallout to cow's milk in Iceland many years after deposition. The spatial variation in deposition was confirmed to be explained by precipitation. Soil samples showed a significant difference in ^{137}Cs deposition density between the main agricultural areas, with the South having the highest values, then the West and North and the lowest in the Northeast. There was no significant difference between the effective half-lives in ^{137}Cs activity concentrations in milk and milk powder from the main dairies in Iceland based on data for milk from 1990 to 2007 and for milk powder from 1986 to 2007. There was, however, a significant difference between the effective half-lives obtained for these two regions, 13.5 years for the Northern and 10.5 years for the Southern regions. These half-lives for global fallout are longer than those previously reported for similar time periods in other Arctic areas. The transfer of ^{137}Cs to cow's milk was quantified for different agricultural regions using aggregated transfer coefficients (Tag) for the period of peak global fallout soil inventory in 1965–1967. The values ranged from 2.8×10^{-3} to $10.6 \times 10^{-3} \text{ m}^2 \text{ kg}^{-1}$. By 2001–2004, the Tag values had only declined, in the main agricultural areas, to $0.6 \times 10^{-3} - 1.0 \times 10^{-3} \text{ m}^2 \text{ kg}^{-1}$. Long-term transfer rates to milk many years after deposition were high in Iceland compared with most other reported data. The transfer is potentially relevant for some of the contaminated areas around the Fukushima Nuclear Power Plant after the accident in March 2011 since limited information is available on uptake from Andosols and associated effective half-lives.

BERESFORD, N.A., YANKOVICH, T., WOOD, M.D., FESENKO, S., ANDERSSON, P., MUIKKU, M., WILLEY, N.J. 2013

A new approach to predicting environmental transfer of radionuclides to wildlife: A demonstration for freshwater fish and caesium

Sci. Tot. Environ. 463-464, 284-292.

DOI: <http://dx.doi.org/10.1016/j.scitotenv.2013.06.013>

The application of the concentration ratio (CR) to predict radionuclide activity concentrations in wildlife from those in soil or water has become the widely accepted approach for environmental assessments. Recently both the ICRP and IAEA have produced compilations of CR values for application in environmental assessment. However, the CR approach has many limitations, most notably, that the transfer of most radionuclides is largely determined by site-specific factors (e.g. water or soil chemistry). Furthermore, there are few, if any, CR values for many radionuclide-organism combinations. In this paper, we propose an alternative approach and, as an example, demonstrate and test this for caesium and freshwater fish. Using a Residual Maximum Likelihood (REML) mixed-model regression we analysed a dataset comprising 597 entries for 53 freshwater fish species from 67 sites. The REML analysis generated a mean value for each species on a common scale after REML adjustment taking account of the effect of the inter-site variation. Using an independent dataset, we subsequently test the hypothesis that the REML model outputs can be used to predict radionuclide, in this case radiocaesium, activity concentrations in unknown species from the results of a species which has been sampled at a specific site. The outputs of the REML analysis accurately predicted ¹³⁷Cs activity concentrations in different species of fish from 27 Finnish lakes; these data had not been used in our initial analyses. We recommend that this alternative approach be further investigated for other radionuclides and ecosystems.

BERESFORD, N.A., VIVES I BATLLE, J. 2013

Estimating the biological half-life for radionuclides in homeothermic vertebrates: a simplified allometric approach

Radiat. Environ. Biophys. 52, 505-511.

DOI : <http://dx.doi.org/10.1007/s00411-013-0481-x>

The application of allometric, or mass-dependent, relationships within radioecology has increased with the evolution of models to predict the exposure of organisms other than man. Allometry presents a method of addressing the lack of empirical data on radionuclide transfer and metabolism for the many radionuclide-species combinations which may need to be considered. However, sufficient data across a range of species with different masses are required to establish allometric relationships and this is not always available. Here, an alternative allometric approach to predict the biological half-life of radionuclides in homeothermic vertebrates which does not require such data is derived. Biological half-life values are predicted for four radionuclides and compared to available data for a range of species. All predictions were within a factor of five of the observed values when the model was parameterised appropriate to the feeding strategy of each species. This is an encouraging level of agreement given that the allometric models are intended to provide broad approximations rather than exact values. However, reasons why some radionuclides deviate from what would be anticipated from Kleiber's law need to be determined to allow a more complete exploitation of the potential of allometric extrapolation within radioecological models.

BROWN, J.E., BERESFORD, N.A., HOSSEINI, A. 2013

Approaches to providing missing transfer parameter values in the ERICA Tool - How well do they work?

J. Environ. Radioact. 126, 399-411.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2012.05.005>

A required parameter for the ERICA Tool is the concentration ratio (CR), which is used to describe the transfer from environmental media to a range of organisms. For the original parameterisation of the ERICA Tool, 60% of these values were derived using a variety of extrapolation approaches, including the application of allometric models, the use of values for a similar organism or element with similar biogeochemical behaviour and the use of values from a different ecosystem. Although similar approaches are applied in other assessment systems, there has been little attempt to see how well these approaches perform. In this paper, CR values in the ERICA Tool derived using extrapolation approaches are compared to more recently available empirical data from the IAEA wildlife transfer database. The primary purpose of the default CR database in the ERICA Tool, and other models, is to enable the user to conduct conservative screening assessments. Conservatism was therefore introduced to the analyses by selecting the 95th percentile CR values for subsequent calculations.

The extrapolation methodologies are not guaranteed to provide conservative estimates of empirical 95th percentile CRs. For the terrestrial ecosystem, the extrapolation methods provide underpredictions of empirical 95th percentiles as often as they produce overpredictions. In a few cases the underestimation of CR values, when considering all ecosystems, is substantial - by orders of magnitude - which is clearly unacceptable for a screening assessment. Thus, although extrapolation approaches will remain an essential component of screening assessments in the future, because data gaps will always be present, diligence is important in their application. Finally, by synthesizing the results from the current analyses and through other considerations, some recommendations are provided with regards to modifying the original guidance on use of extrapolation approaches in the ERICA Tool.

HINTON, T. G., GARNIER-LAPLACE, J., VANDENHOVE, H., DOWDALL, M., ADAM-GUILLERMIN, C., ALONZO, F., BARNETT, C., BEAUGELIN-SEILLER, K., BERESFORD, N.A., BRADSHAW, C., BROWN, J., EYROLLE, F., FEVRIER, L., GARIEL, J.-C., GILBIN, R., HERTEL-AAS, T., HOREMANS, N., HOWARD, B.J., IKÄHEIMONEN, T., MORA, J.C., OUGHTON, D., REAL, A., SALBU, B., SIMON-CORNU, M., STEINER, M., SWEECK, L., VIVES I BATLLE, J. 2013

An Invitation to Contribute to a Strategic Research Agenda in Radioecology.

J. Environ. Radioact. 115, 78-82.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2012.07.011>

With intentions of integrating a portion of their respective research efforts into a trans-national programme that will enhance radioecology, eight European organisations recently formed the European Radioecology ALLIANCE (www.er-alliance.org). The ALLIANCE is an Association open to other organisations throughout the world with similar interests in promoting radioecology. The ALLIANCE members recognised that their shared radioecological research could be enhanced by efficiently pooling resources among its partner organizations and prioritising group efforts along common themes of mutual interest. A major step in this prioritisation process was to develop a Strategic Research Agenda (SRA). An EC-funded Network of Excellence in Radioecology, called STAR (Strategy for Allied Radioecology), was formed, in part, to develop the SRA. This document is the first published draft of the SRA. The SRA outlines a suggested prioritisation of research topics in radioecology, with the goal of improving research efficiency and more rapidly advancing the science. It responds to the question: “*What topics, if critically addressed over the next 20 years, would significantly advance radioecology?*” The three Scientific Challenges presented within the SRA, with their 15 associated research lines, are a strategic vision of what radioecology can achieve in the future. Meeting these challenges will require a directed effort and collaboration with many organisations the world over. Addressing these challenges is important to the advancement of radioecology and in providing scientific knowledge to decision makers. Although the development of the draft SRA has largely been a European effort, the hope is that it will initiate an open dialogue within the international radioecology community and its stakeholders. This is an abbreviated document with the intention of introducing the SRA and inviting contributions from interested stakeholders. Critique and input for improving the SRA are welcomed *via* a link on the STAR website (www.star-radioecology.org).

HOSSEINI, A., STENBERG, K., AVILA, R., BERESFORD, N.A. & BROWN, J.E. 2013

Application of the Bayesian approach for derivation of PDFs for concentration ratio values.

J. Environ. Radioact. 126, 376-387.

DOI : <http://dx.doi.org/10.1016/j.jenvrad.2013.04.007>

Concentration ratios (CRs) are used to derive activity concentrations in wild plants and animals. Usually, compilations of CR values encompass a wide range of element–organism combinations, extracted from different studies with statistical information reported at varying degrees of detail. To produce a more robust estimation of distribution parameters, data from different studies are normally pooled using classical statistical methods. However, there is inherent subjectivity involved in pooling CR data in the sense that there is a tacit assumption that the CRs under any arbitrarily defined biota category belong to the same population. Here, Bayesian inference has been introduced as an alternative way of making estimates of distribution parameters of CRs. This approach, in contrast to classical methods, is more flexible and also allows us to define the various assumptions required, when combining data, in a more explicit manner. Taking selected data from the recently compiled wildlife transfer database (<http://www.wildlifetransferdatabase.org/>) as a working example, attempts are made to refine the pooling approaches previously used and to consider situations when empirical data are limited.

HOWARD, B.J. 2013

A new IAEA handbook quantifying the transfer of radionuclides to wildlife for assessment tools

J. Environ. Radioact. 126, 284–287.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2013.04.007>

A number of approaches are now being used to assess the exposure and associated risk to organisms other than humans from ionizing radiation. The assessment of the exposure of wildlife to ionizing radiation requires (i) quantification of the transfer of radionuclides to wildlife and (ii) dose conversion coefficients relating internal and media activity concentrations to estimate absorbed dose rates to wildlife. Most commonly used models estimate dose rates to the whole organism (Beresford et al., 2008 and Vives i Batlle et al., 2010). This approach allows model outputs to be put into context with the available data on the effects of ionizing radiation, which are typically presented as absorbed dose rates to the whole organism so that the risk to wildlife can then be considered (International Commission on Radiation Protection, 2008, Copplestone et al., 2008, Andersson et al., 2009 and Howard et al., 2010). Through model testing and comparison using scenarios, the Biota Working Group (BWG) during the first International Atomic Energy Agency's (IAEA) EMRAS Programme (2003–2007) demonstrated that the dosimetric components of the various available models gave broadly comparable results, but that differences in the transfer components used within the models resulted in large variations in predicted whole organism activity concentrations and resultant internal doses (Beresford et al., 2008, Beresford et al., 2009, Beresford et al., 2010, Yankovich et al., 2010, International Atomic Energy Agency, 2012 and Vives I Batlle et al., 2007). Therefore, the EMRAS BWG recommended that an international handbook on estimating transfer of radionuclides to wildlife be developed. In response, Working Group 5 (WG5) was created within the EMRAS II Programme (2009–2011) to prepare a handbook of readily available quantitative information on the transfer of radionuclides to wildlife (<http://www-ns.iaea.org/projects/emras/emras2/>). The Wildlife Transfer Technical report Series Handbook (Wildlife TRS) (IAEA, in press) provides transfer parameter values for estimating the transfer of radionuclides from environmental media (soil, and water) to generic wildlife groups, for the purpose of assessing potential internal absorbed dose rates. It is analogous to Technical Report Series No. 472 (IAEA, 2010), which presents transfer parameter values for human foodstuffs. Equilibrium transfer parameter values are provided for wildlife groups in terrestrial, freshwater, marine and brackish (low salinity) environments. The data are intended for use where site-specific data are not available, and to parameterise the initial screening assessment levels of models. The derivation and content of the Wildlife TRS has been briefly described and summarised by Howard et al. (2013a).

HOWARD, B.J., BERESFORD, N.A., COPPLESTONE, D., TELLERIA, D., PROEHL, G., FESENKO, S., JEFFREE, R., YANKOVICH, T., BROWN, J., HIGLEY, K., JOHANSEN, M., MULYE, H., VANDENHOVE, H., GASHCHAK, S., WOOD, M.D., TAKATA, H., ANDERSSON, P., DALE, P., RYAN, J., BOLLHÖFER, A., DOERING, C., BARNETT, C.L., AND WELLS, C. 2013

The IAEA Handbook on Radionuclide Transfer to Wildlife.

J. Environ. Radioact. 121, 55–74.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2012.01.027>

An IAEA handbook presenting transfer parameter values for wildlife has recently been produced. Concentration ratios (CR_{wo-media}) between the whole organism (fresh weight) and either soil (dry weight) or water were collated for a range of wildlife groups (classified taxonomically and by feeding strategy) in terrestrial, freshwater, marine and brackish generic ecosystems. The data have been compiled in an on line database, which will continue to be updated in the future providing the basis for subsequent revision of the Wildlife TRS values. An overview of the compilation and analysis, and discussion of the extent and limitations of the data is presented. Example comparisons of the CR_{wo-media} values are given for polonium across all wildlife groups and ecosystems and for molluscs for all radionuclides. The CR_{wo-media} values have also been compared with those currently used in the ERICA Tool which represented the most complete published database for wildlife transfer values prior to this work. The use of CR_{wo-media} values is a pragmatic approach to predicting radionuclide activity concentrations in wildlife and is similar to that used for screening assessments for the human food chain. The CR_{wo-media} values are most suitable for a screening application where there are several conservative assumptions built into the models which will, to varying extents, compensate for the variable data quality and quantity, and associated uncertainty.

HOWARD, B.J., WELLS, C., BERESFORD, N.A., COPPLESTONE, D. 2013

Exploring methods to prioritise concentration ratios when estimating weighted absorbed dose rates to terrestrial Reference Animals and Plants.

J. Environ. Radioact. 126, 326-337.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2013.05.005>

The ICRP and IAEA have recently reported Concentration Ratio values (CRwo-media = equilibrium radionuclide activity concentration in whole organism divided by that in media) for Reference Animals and Plants (RAPs) and a wide range of organism groups, respectively, based on a common online database. Given the large number of data gaps in both publications, there is a need to develop methods for identifying the relative importance of improving currently available CRwo-media values. A simple, transparent approach involving the derivation and comparison of predicted internal and external weighted absorbed dose rates for radionuclides considered by ICRP (2009) for terrestrial RAPs is presented. Using the approach of applying a reference value of CRwo-soil $\frac{1}{4}$ or using the maximum reported values where CRwo-soil >1 , we provisionally identify terrestrial radionuclide RAP combinations which could be considered low priority, notably: Ca, Cr and Ni consistently; Mn for all RAPs except Deer and Pine Tree; and Tc for all RAPs but Wild Grass. Equally, we can systematically identify high priority elements and radioisotopes, which largely, but not exclusively, consist of alpha-emitters (especially isotopes of Ra and Th, but also consistently Am, Cf, Cm, Np, Pa, Po, Pu, U). The analysis highlights the importance of the radiation weighting factor default assumption of 10 for alpha-emitters in the ERICA Tool when comparing the magnitude of the internal dose and trying to identify high priority RAP-isotope combinations. If the unweighted Dose Conversion Coefficient (DCC) values are considered, those for alpha-emitters are often one order of magnitude higher than those due to some beta-gamma emitters for terrestrial RAPs, whereas with the radiation weighting factor applied they are two orders of magnitude higher.

KEUM, D-K., JUN, I., LIM, K-M, CHOI, Y-H., HOWARD, B.J. 2013

Time dependent transfer of ^{137}Cs , ^{85}Sr and ^{65}Zn to earthworms in highly contaminated soils.

J. Environ. Radioact. 126, 427-433.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2012.07.017>

The transfer characteristics of ^{137}Cs , ^{85}Sr and ^{65}Zn to earthworms (*Eisenia andrei*) in soils with different amounts of the radionuclides have been investigated. The time-dependent whole-body concentration ratios (CR) were derived for worms in artificially contaminated soils with three different activity concentrations. Two parameters of a first order kinetic model, the equilibrium concentration ratio (CReq) and the effective loss rate constant (k), were estimated by a comparison of experimental CR results with model predictions. The estimated CReq (Bq/kg fresh worm per Bq/kg dry soil) ranged from 3.9×10^{-4} to 4.1×10^{-3} for ^{137}Cs , 1.39×10^{-3} to 2.94×10^{-2} for ^{85}Sr , and 1.39×10^{-3} to 5.0×10^{-2} for ^{65}Zn , and consistently decreased with increasing soil activity concentration but the trend was not statistically significant. The CReq for ^{137}Cs was one to two orders of magnitude lower than previously reported CRwo-soil values (based on field data with much less contaminated soil), that for ^{85}Sr was comparable with other reported values and for ^{65}Zn was less two to three orders of magnitude lower than CRwo-soil values for stable zinc. The estimated k (d^{-1}) values ranged from 9×10^{-2} to 1.4×10^{-1} for ^{137}Cs , 7×10^{-2} to 2×10^{-1} for ^{85}Sr , and 6×10^{-2} to 1.8×10^{-1} for ^{65}Zn , and did not show a relationship with soil activity concentration. The effect of CReq on the total dose rate was insignificant for ^{137}Cs or ^{65}Zn because external dose rates to the soil dwelling earthworms due to these radionuclides were much greater than the internal dose rate. In contrast, the total dose from ^{90}Sr was determined by the internal dose rate and therefore proportional to the CReq.

PÁLSSON, S.E., HOWARD, B.J., BERGAN, T., PAATERO, J., ISAKSSON, M., NIELSEN, S.P. 2013

A simple model to estimate deposition based on a statistical reassessment of global fallout data.

J. Environ. Radioact. 121, 75-86.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2012.03.006>

Atmospheric testing of nuclear weapons began in 1945 and largely ceased in 1963. Monitoring of the resulting global fallout was carried out globally by the Environmental Measurements Laboratory and the UK Atomic Energy Research Establishment as well as at national level by some countries. A correlation was identified between fallout deposition and precipitation and an uneven distribution with latitude. In this study, the available data from 1954 to 1976 for ^{90}Sr and ^{137}Cs were reanalysed using analysis of covariance (ANCOVA) and logarithmically transformed values of the monthly deposition density as the response variable. Generalized additive models (GAM) were used to explore the relationship of different variables to the response variable and quantify the explanatory power that could be achieved. The explanatory variables

which consistently explained most of the variability were precipitation at each site, latitude and change with time and a simple linear model was produced with similar explanatory power as the GAM. The estimates improved as the temporal resolution of the precipitation data increased. A good loglog fit could be obtained if a bias of about 1e^6 mm precipitation per month was added; this could be interpreted as dry deposition which is not otherwise accounted for in the model. The deposition rate could then be explained as a simple non-linear power function of the precipitation rate ($r^{0.2-0.6}$ depending on latitude band). A similar non-linear power function relationship has been the outcome of some studies linking wash-out and rain-out coefficients with rain intensity. Our results showed that the precipitation rate was an important parameter, not just the total amount. The simple model presented here allows the recreation of the deposition history at a site, allowing comparison with time series of activity concentrations for different environmental compartments, which is important for model validation.

PSALTAKI, M., BROWN, J.E, HOWARD, B.J. 2013

CR_{wo-water} values for the marine environment: analysis, applications and comparisons

J. Environ. Radioact. 126, 367-375.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2012.07.001>

A new TRS document on Transfer of radionuclides to Wildlife has compiled equilibrium CR_{wo-media} values for a variety of radionuclides and ecosystems. Assessment tools such as the ERICA Tool use equilibrium whole organism concentration ratios (CR_{wo-media}) to predict radionuclide activity concentrations in wildlife from those in media (e.g. water). The aim of this paper is to compare and contrast model predictions of doses from ^{137}Cs to marine organisms using three different approaches: (i) the ERICA Tool utilising the new TRS values to estimate internal and external doses to reference organisms for the Black sea and the Aegean Sea and for the sea close to the Fukushima Dai-ichi plant. (ii) a hydrodynamic site specific model for seawater for parts of the Aegean Sea, Greece which estimates radionuclide concentrations using site specific data and (iii) a biokinetic model for fish applied to the Fukushima releases to the Pacific. The advantages and limitations of these approaches are discussed with respect to determining doses to pelagic fish. The applicability of the three approaches will vary with the objective of an assessment. The site specific model can predict variation in ^{137}Cs with depth and uses site specific CR values. The application of the biokinetic model to predicted ^{137}Cs activity concentrations in seawater and fish due to near coastal inputs from Fukushima Dai-ichi showed that the maximum internal dose-rates in fish attributable to ^{137}Cs would be substantially lower than those determined using equilibrium assumptions in ERICA but the accumulative doses over 100 days were similar.

WOOD, M.D., BERESFORD, N.A., HOWARD, B.J., COPPLESTONE, D. 2013

Evaluating summarised radionuclide concentration ratio datasets for wildlife

J. Environ. Radioact. 126, 314-325.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2013.07.022>

Concentration ratios (CR_{wo-media}) are used in most radioecological models to predict radionuclide activity concentrations in wildlife from those in environmental media. This simplistic approach amalgamates the various factors influencing transfer within a single generic value and, as a result, comparisons of model predictions with site-specific measurements can vary by orders of magnitude. To improve model predictions, the development of 'condition-specific' CR_{wo-media} values has been proposed (e.g. for a specific habitat). However, the underlying datasets for most CR_{wo-media} value databases, such as the wildlife transfer database (WTD) developed within the IAEA EMRAS II programme, include summarised data. This presents challenges for the calculation and subsequent statistical evaluation of condition-specific CR_{wo-media} values. A further complication is the common use of arithmetic summary statistics to summarise data in source references, even though CR_{wo-media} values generally tend towards a lognormal distribution and should be summarised using geometric statistics. In this paper, we propose a statistically-defensible and robust method for reconstructing underlying datasets to calculate condition-specific CR_{wo-media} values from summarised data and deriving appropriate summary statistics. This method is applied to terrestrial datasets from the WTD. Statistically significant differences in sub-category CR_{wo-media} values were identified, which may justify the use of these CR_{wo-media} values for specific assessment contexts. However, biases and limitations within the underlying datasets of the WTD explain some of these differences. Given the uncertainty in the summarised CR_{wo-media} values, we suggest that the CR_{wo-media} approach to estimating transfer is used with caution above screening-level assessments.

YANKOVICH, T., BERESFORD, N.A., FESENKO S., FESENKO, J., PHANEUF, M., DAGHER, E., OUTOLA, I., ANDERSSON, P., THIESSEN, K., RYAN, J., WOOD, M.D., BOLLHÖFER, A., BARNETT, C.L., COPPLESTONE, D. (2013)

Establishing a database of radionuclide transfer parameters for freshwater wildlife.

J. Environ. Radioact. 126, 299-313

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2012.07.014>

Environmental assessments to evaluate potential risks to humans and wildlife often involve modelling to predict contaminant exposure through key pathways. Such models require input of parameter values, including concentration ratios, to estimate contaminant concentrations in biota based on measurements or estimates of concentrations in environmental media, such as water. Due to the diversity of species and the range in physicochemical conditions in natural ecosystems, concentration ratios can vary by orders of magnitude, even within similar species. Therefore, to improve model input parameter values for application in aquatic systems, freshwater concentration ratios were collated or calculated from national grey literature, Russian language publications, and refereed papers. Collated data were then input into an international database that is being established by the International Atomic Energy Agency. The freshwater database enables entry of information for all radionuclides listed in ICRP (1983), in addition to the corresponding stable elements, and comprises a total of more than 16,500 concentration ratio (CR_{wo-water}) values.

Although data were available for all broad wildlife groups (with the exception of birds), data were sparse for many organism types. For example, zooplankton, crustaceans, insects and insect larvae, amphibians, and mammals, for which there were CR_{wo-water} values for less than eight elements. Coverage was most comprehensive for fish, vascular plants, and molluscs. To our knowledge, the freshwater database that has now been established represents the most comprehensive set of CR_{wo-water} values for freshwater species currently available for use in radiological environmental assessments.

YANKOVICH, T., BERESFORD, N.A., WOOD, M.D., SHARP, K.J., BENZ, M.L., CARR, J. & KILLEY, R.W.D. 2013

Do Site-specific Radiocarbon Measurements Reflect Localized Distributions of ¹⁴C in Biota Inhabiting a Wetland with Point Contamination Sources?

J. Environ. Radioact. 126, 352-366.

DOI: <http://dx.doi.org/10.1016/j.jenvrad.2013.04.012>

Duke Swamp is a wetland ecosystem that receives ¹⁴C via a groundwater pathway originating from a waste management area on Atomic Energy Canada Limited's Chalk River Laboratories site. This groundwater reaches the surface of the swamp, resulting in relatively high ¹⁴C levels over an area of 146 m². The objective of this study was to quantify ¹⁴C concentrations in flora and fauna inhabiting areas of Duke Swamp over the gradient of ¹⁴C activity concentrations in moss to determine whether ¹⁴C specific activities in receptor biota reflect the localized nature of the groundwater source in the swamp. Representative receptor plants and animals, and corresponding air and soil samples were collected at six sites in Duke Swamp with ¹⁴C specific activities in air that ranged from 1140 to 45,900 Bq/kg C. In general, it was found that specific activities of ¹⁴C in biota tissues reflected those measured in environmental media collected from the same sampling site. The findings demonstrate that mosses could be used in monitoring programs to ensure protection of biota in areas with elevated ¹⁴C, negating the need to capture and euthanize higher organisms.

**BARNETT, C.L., BERESFORD, N.A., WALKER, L.A., BAXTER, M., WELLS, C.,
COPPLESTONE, D. (2014)**

Transfer parameters for ICRP reference animals and plants collected from a forest ecosystem

Radiat. Environ. Biophys. 53, 125-149.

DOI:10.1007/s00411-013-0493-6

The International Commission on Radiological Protection (ICRP) have suggested the identification of a series of terrestrial, marine and freshwater sites from which samples of each Reference animal and plant (RAP) could be systematically collected and analysed. We describe the first such study in which six of the eight terrestrial RAPs, and associated soil samples, were collected from a site located in a managed coniferous forestry plantation in north-west England. Adult life stages of species representing six of the terrestrial RAPs (Wild grass, Pine tree, Deer, Rat, Earthworm and Bee) were sampled and analysed to determine concentrations of 60 elements and gamma emitting radionuclides. The resultant data have been used to derive concentration ratios (CR_{wo-soil}) relating element/radionuclide concentrations in the RAPs to those in soil. This paper presents the first-reported transfer parameters for a number of the RAP–element combinations. Where possible, the derived CR_{wo-soil} values are compared with the ICRPs-recommended values and any appreciable differences discussed.

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