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Doses from the consumption of Cardiff Bay flounder containing organically bound tritium

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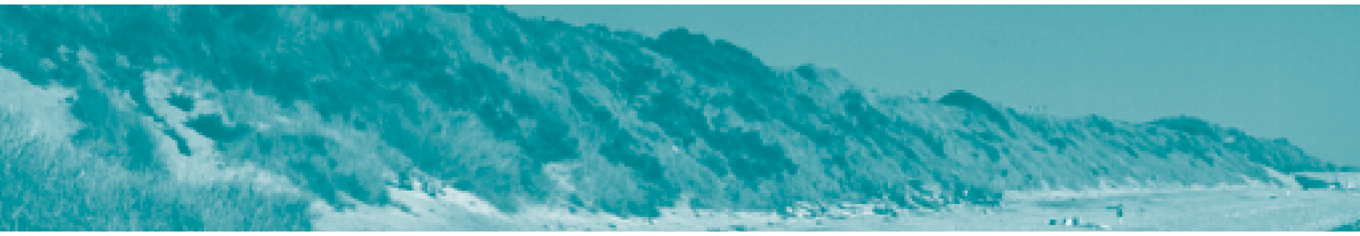

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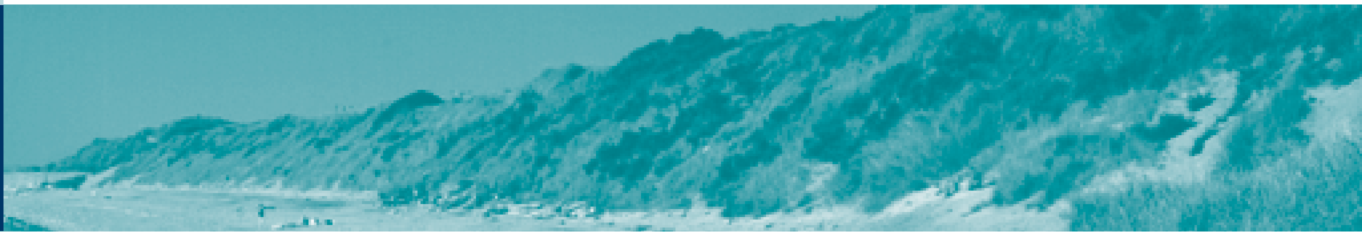

Executive summary

International Commission on Radiological Protection (ICRP) dose coefficients for the ingestion of organically bound tritium (OBT) by human adults and children are intended for general application to unspecified forms of OBT in diet and may not be applicable to intakes of a specific form of OBT. However fish caught in Cardiff Bay have had unexpectedly high levels of tritium, which has been attributed to the different chemical form of OBT, although the mechanisms of accumulation are not fully understood. This study was conducted to determine the uptake and retention of tritium in adult rats after administration as either tritiated water (HTO) or OBT found in dried flounder flesh from fish caught in Cardiff Bay to assess whether the ICRP dose coefficients are applicable to OBT in fish caught in the Bay.

Two components of retention were obtained in either the HTO or OBT uptake experiment. The first component, attributable to tritium equilibrating with body water, had a half-time of retention of 3 days in each case, and accounted for 97% of the intake as tritiated water and 70% after intake of OBT in flounder. The results were consistent with the rapid breakdown of a large proportion of the flounder OBT to tritiated water. The second component of retention, attributable to OBT in rat tissues, accounted for 3% of tritium intake as tritiated water and 30% after intake as flounder OBT; the half-time of retention were 10 and 25 days respectively. The results obtained for tritiated water are consistent with published animal data and correlate with the ICRP assumptions. The results for the OBT experiment suggest that appropriate assumptions for retention in adults are 70% with a 10-day half-time and 30% with a 100-day half-time. These assumptions result in an ingestion dose coefficient of 6 x 10^{-11} Sv/Bq. This is slightly greater than the ICRP value for OBT ingestion by adults of 4.2 x 10^{-11} Sv/Bq.

In conclusion, it is proposed that a revised dose coefficient of 6 x 10^{-11} Sv/Bq^{-1} should be applied to OBT in flounders caught in Cardiff Bay. It is also proposed that this dose coefficient should be applied to all ingestion intakes by adults relating to this source of exposure, unless specific information is available showing that a significant proportion of the intake is HTO. The same proposals apply to dose coefficients derived here for flounder OBT consumption by children.

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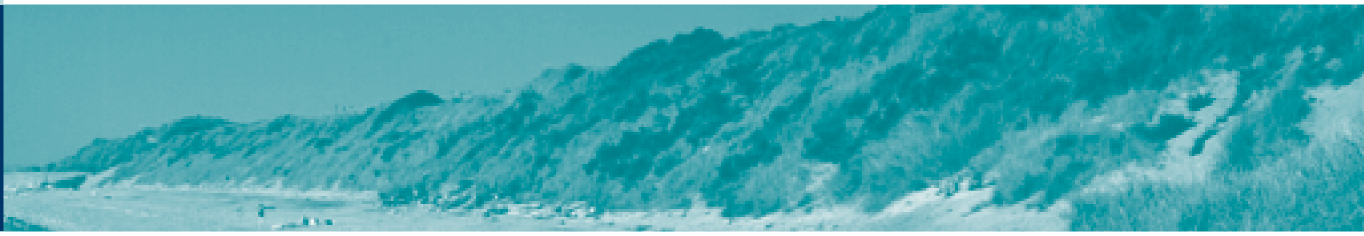


1. Introduction

Tritium is routinely released into the environment from nuclear installations and radiochemical laboratories. In the UK, the greatest discharges are from the nuclear fuel reprocessing plant at Sellafield in Cumbria, the tritium production plant at Chapelcross in Dumfriesshire and the radiochemical laboratories at Cardiff operated by GE Healthcare plc (EA, EHSNI, Food Standards Agency and SEPA, 2004).

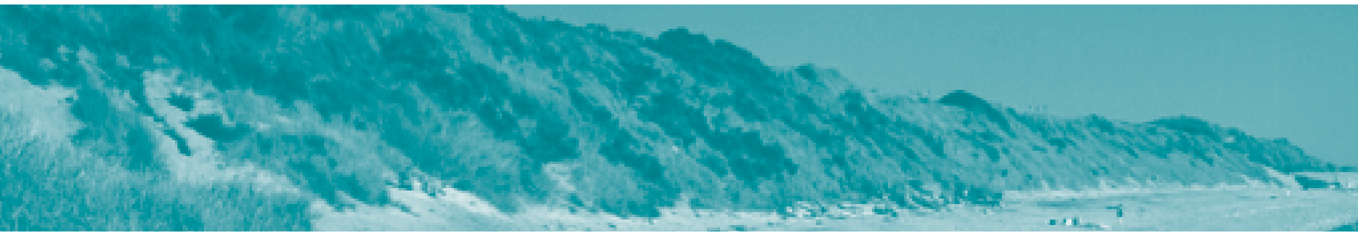
The GE Healthcare plant at Cardiff discharges much less tritium than the other nuclear installations, but it is of different chemical forms. The liquid discharges into the Severn estuary from the GE Healthcare plc plant contain a variety of forms of organically bound tritium (OBT) as well as tritiated water (Williams *et al.*, 2001). The tritium in liquid discharges from the two nuclear installations is dispersed in the environment as tritiated water (HTO).

OBT discharges from the GE Healthcare plant are considered responsible for the unexpectedly high levels of tritium in fish caught in Cardiff Bay, although the mechanisms of accumulation are not fully understood (Lambert, 2001; Williams *et al.*, 2001). Concentrations of tritium in fish flesh have been shown to be more than two orders of magnitude greater than concentrations in sea water, with tritium present in fish mainly as OBT (Lambert, 2001; Williams *et al.*, 2001; EA, EHSNI, Food Standards Agency and SEPA, 2004).

Doses for people eating fish containing tritium are calculated using dose coefficients (Sv per Bq of intake) published by the International Commission on Radiological Protection (ICRP, 1993). The calculated dose coefficients for ingestion of tritiated water or OBT assume that absorption of tritium from the alimentary tract to blood is complete, and that tritium is then uniformly distributed throughout all body tissues.

Two components of retention are assumed in each case. These apply to tritiated water in the body water pool and to tritium that is incorporated into organic molecules in body tissues in a non-exchangeable form (i.e. OBT). For intakes of tritiated water, the two components are assumed to account for 97 per cent and 3 per cent of tritium reaching the blood, with half-times of retention in adults of 10 days and 40 days, respectively. These assumptions are based on human data (ICRP, 1993; Harrison *et al.*, 2002). For intakes of OBT by adults, the same half-times of retention are applied to equal proportions of tritium reaching the blood; i.e. it is assumed that 50 per cent of tritium is non-exchangeably incorporated into organic molecules in body tissues. Substantial uncertainty is associated with this estimate of incorporation of tritium into OBT in body tissues after intake of OBT because it is based on the behaviour of selected chemical forms of OBT in animals (ICRP, 1993; Harrison *et al.*, 2002). In practice, neither the proportion of tritium incorporated into body OBT nor the half-time of retention of 40 days may be applicable to intakes of a specific form of OBT.

In this study, the retention of tritium in adult rats has been determined after administration of either tritiated water or flounder flesh containing tritium. The results have been used to comment on the applicability of the ICRP dose coefficient for ingestion of OBT to the specific case of people eating flounders caught in Cardiff Bay.



2. Methods

2.1 Animals

The animals used were female rats (Fischer 344, Harlan Ltd, UK), aged between 17 and 25 weeks, and weighing about 200 g at the time of exposure. The rats were maintained in social groups other than when they were being fed individually. Water was freely available at all times. Food (Type RMI, Special Diet Services, Witham, Essex, UK) was freely available other than when the rats were being fed fish.

All procedures were carried out in accordance with the Animals (Scientific Procedures) Act 1986.

2.2 Tritium

A calibrated tritiated water standard obtained from Packard Bioscience Ltd, UK was used at a concentration of 33 kBq/ml.

OBT was provided in the form of environmentally contaminated freeze-dried Cardiff Bay flounder (~150 g) obtained from the Centre for Environment, Fisheries and Aquaculture Science (CEFAS, Lowestoft, UK).

Harwell Scientifics Ltd measured the mean dry weight concentration of OBT in six samples of the fish as 32.9 ± 1.7 Bq/g. As the dry to wet weight ratio for this sample was 0.21 (data supplied by CEFAS), then the mean wet weight concentration of OBT was about 7 Bq/g. This was considerably lower than the 27 Bq/g reported recently in RIFE (Food Standards Agency and SEPA, 2002). This low concentration of tritium in the fish imposed limits on the scope of the study.

2.3 Administration of tritium

2.3.1 Tritiated water experiment

Rats were hand-held and conscious while 0.1 ml aliquots of tritiated water were administered from an automatic micropipette into their mouths. Animals to be killed at later time points received additional aliquots, up to a maximum of 1 ml over a period of 3 hours. Table 3.1 gives administered radioactivities.

Animals were placed directly into gridded cages for the first week to prevent them coming into contact with their urine and faeces. They were killed in groups of four at intervals of up to 20 days after exposure.

2.3.2 Organically bound tritium experiment

Powdered freeze-dried fish was administered to rats by two methods.

For rats subject to early kill times, the fish was suspended in a gelatine solution and administered via gavage to conscious animals. The animals were kept in gridded cages and killed in groups of four at intervals of 1 and 3 days after exposure. Table 3.3 gives the administered mass of dried fish and its tritium content.

The mass of fish that rats allocated to later kill times (6, 10, 20 and 40 days) needed to consume to ensure measurable tritium levels (based on estimated retention) proved too large for administration by gavage. Instead, the freeze-dried fish was added to a dilute preparation of strawberry-flavoured jelly (40:60 weight/weight) and fed to individual animals in measured quantities. The strawberry jelly served to present the fish as a solid mixture and to disguise its taste.

Animals to be killed after 6 and 10 days consumed about 3 g of fish during a single night, while those in the 20 and 40-day groups consumed about 4 g of fish during each of three or four consecutive nights (see Table 3.3). For simplicity, all intakes were assumed to have occurred at the same time (Day 0) and the prolonged administration to 20 day and 40 day groups was not taken into account. This could have overestimated the retention at these time points. During the day, the animals were returned to gridded cages and given their normal diet. One week after receiving their final feed of fish, the animals were returned to normal stock cages.

2.4 Radiochemical analysis

2.4.1 Sample preparation

Measurements relate to retention in the whole animal, except that separate analyses were undertaken for liver, gastrointestinal tract, ovaries, kidneys and pelt for two animals from two groups (6 and 20 days after administration).

The pelts were removed from all animals to avoid problems during sample homogenisation and combustion. The whole body was then homogenised, apart for the four animals that were dissected further before the remaining carcass was homogenised.

All samples, including the pelts, were weighed before being frozen as soon as possible in sealed plastic bags to prevent the loss of tritium and to preserve the sample.

The total tritium in a sample is the sum of tritiated water and OBT. This was determined by a combustion technique carried out on the wet sample. A duplicate portion of the sample was then freeze-dried to remove tritiated water and the OBT content determined by combustion of the dried sample. The tritiated water content was taken to be the difference between the two results and was not measured directly.

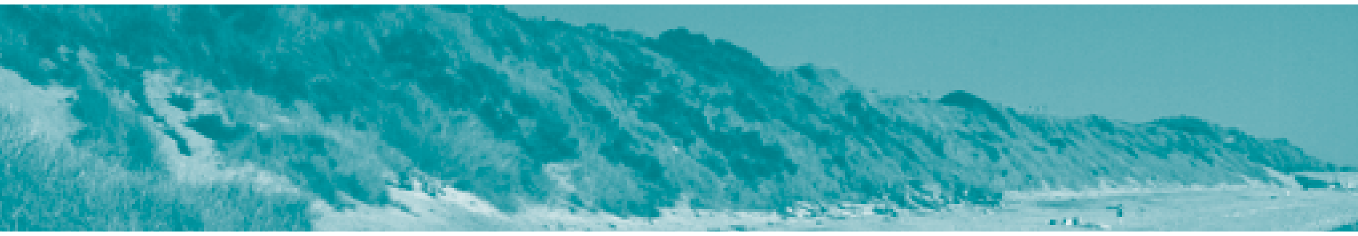
2.4.2 Tritium analysis by combustion

A sub-sample of known weight (approximately 1 g of tissue) was combusted in an oxygen-rich atmosphere in the presence of a copper oxide catalyst. Under these conditions, the hydrogen species present are converted to water vapour. They were then selectively trapped in a series of gas bubblers containing dilute nitric acid. Aliquots of known weight are assessed for their tritium content by liquid scintillation counting. The total recovered tritium was calculated from the total weights of the respective trapping solutions.

Samples were analysed by Harwell Scientifics Ltd using the UKAS-accredited method for the determination of total tritium and OBT in environmental samples.

2.5 Calculation of dose coefficient

The computer code used for calculating the dose coefficient of the form of OBT present in flounder was PLEIADES (Program for LinEar Internal Age-dependent DosES). PLEIADES has been used for calculations undertaken by the ICRP and has been quality assured against codes used by the Oak Ridge National Laboratory (ORNL) in the USA and Bundesamt für Strahlenschutz (Federal Office for Radiation Protection) in Germany.



3. Results and observations

3.1 Tritiated water experiment

3.1.1 Whole body retention

Table 3.1 shows the whole body retention of total tritium and OBT for the rats. The data have been corrected to include the activity associated with the pelt and the organs removed from some of the animals (see section 2.4.1).

The results from the separate analysis of pelts for the day 6 and day 20 groups were used to adjust whole body retention data; the day 6 value was used for the day 1 and day 3 groups and the mean of the day 6 and day 20 values for the day 10 group. The OBT and total tritium content of the pelt was less than 1 % of the carcass content at both 6 and 20 days.

A single exponential function was fitted to the whole body retention data for OBT (Figure 3.1) using the model-fitting program, ModelMaker (ModelKinetix, UK). The best fit to the data was obtained with a 3 per cent component (2.9 ± 0.2%) retained with a half-time of about 10 days (rate of 0.066 ± 0.009 d^{-1}).

Two exponential components fitted the data for total tritium retention (Figure 3.2); the second was constrained to relate to tritium incorporated into OBT, i.e. 3 per cent with a 10-day half-time. The total tritium data imply that, after administration as tritiated water, 97 per cent behaved as tritiated water and was lost from the body with a half-time of 3 days (rate of 0.230 ± 0.005 d^{-1}), corresponding to the turnover of body water. A small proportion, estimated as 3 per cent, was incorporated into organic molecules and retained with a half-time estimated as 10 days.

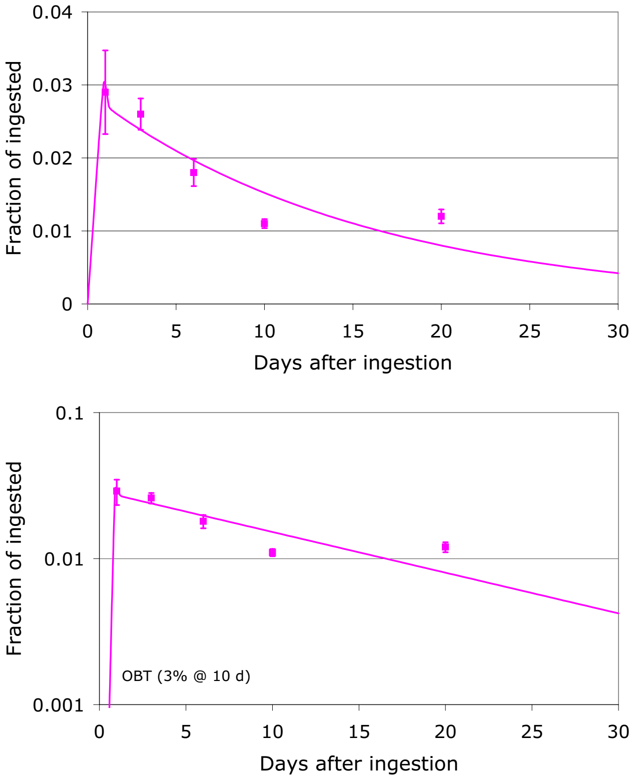


Figure 3.1 Exponential fit to OBT whole body retention data for rats given tritiated water

Table 3.1 Whole body retention of tritium in adult rats given tritiated water

Time (days)	Activity administered (Bq)	Fraction of total administered activity retained*	
		Total tritium	OBT
1	3,300	0.69 ± 0.05	0.029 ± 0.006
3	3,300	0.58 ± 0.04	0.026 ± 0.002
6	6,600	0.24 ± 0.02	0.018 ± 0.002
10	16,600	0.10 ± 0.01	0.011 ± 0.001
20	33,200	0.019 ± 0.002	0.012 ± 0.001

**Mean of four animals ± SD*

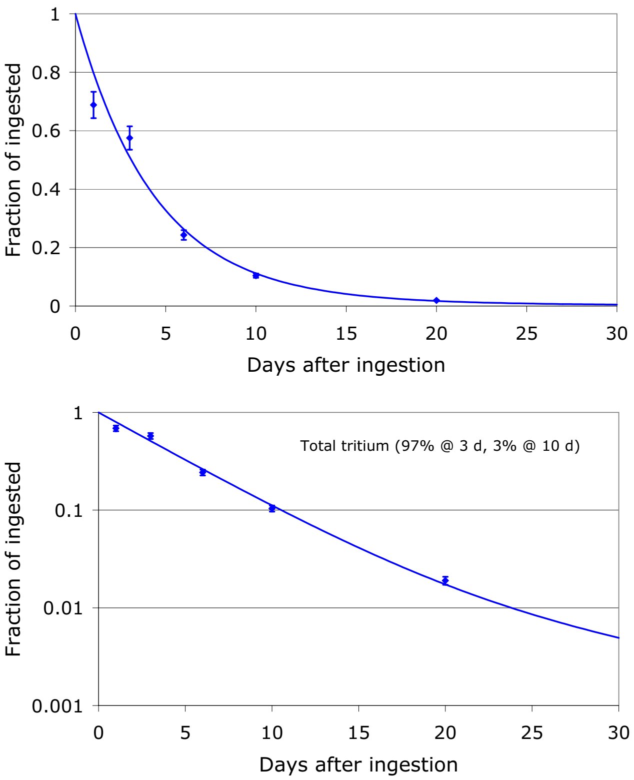


Figure 3.2 Two exponential fit to total tritium whole body retention data for rats given tritiated water

3.1.2 Organ retention

Table 3.2 shows the relative concentrations of total tritium and OBT in organs analysed separately for the day 6 and day 20 groups. Concentrations are expressed relative to a whole body concentration of 1 at each time point.

Due to financial constraints on analysis costs, the values given are the mean of the results for two animals. Errors have not therefore been determined and the values should be interpreted with caution. The results show a maximum variation in the concentrations of total tritium and OBT between organs of a factor of about 3.

3.2 Organically bound tritium experiment

3.2.1 Whole body retention

Table 3.3 shows the whole body retention of total tritium and OBT after administration of fish containing OBT (fish-OBT). The data have been corrected to include the activity associated with the pelt and the organs removed from some of the animals (see section 2.4.1).

The results from the separate analysis of pelts for the day 6 and day 20 groups were used to adjust the whole body retention data; the day 6 value was used for the day 1 and day 3 groups and the mean of the day 6 and day 20 values for the day 10 group. The OBT and total tritium content of the pelt was less than 1 % of the carcass content at both 6 and 20 days.

Table 3.2 Relative concentrations of total tritium and OBT in rat organs/tissues analysed separately at 6 and 20 days after rats given tritiated water*

Organ	Total tritium		OBT	
	6 day	20 day	6 day	20day
Whole body	1.0	1.0	1.0	1.0
Liver	1.9	1.2	1.2	1.4
Pelt	1.1	0.8	1.4	1.5
Kidneys	1.5	1.0	0.9	1.3
Gastrointestinal tract	0.8	1.1	0.6	0.5
Ovaries	0.6	1.0	ND	ND

ND = Not determined (sample lost or below limit of detection of 0.05 Bq/g)

**Normalised to values of 1 for whole body concentrations; mean of two results.*

Table 3.3 Whole body retention of tritium in adults rats fed fish-OBT

Time (days)	Amount of dried fish/activity administered		Fraction of total administered activity retained*	
	g	Bq	Total tritium	OBT
1	0.5	16	0.92 ± 0.44	0.65 ± 0.03
3	1.0	33	0.64 ± 0.25	0.39 ± 0.14
6	3.0	100	0.38 ± 0.07	0.22 ± 0.04
10	3.0	100	0.35 ± 0.08	0.21 ± 0.04
20	12.5	400	0.17 ± 0.02	0.15 ± 0.03
40	15.0	500	0.10 ± 0.01	0.08 ± 0.01

**Mean of four animals ± SD*

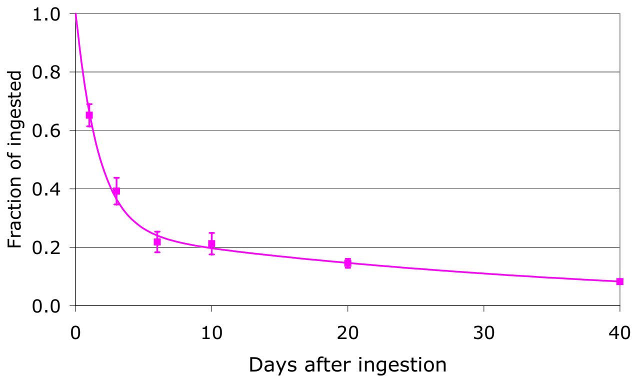
Like the tritiated water experiment described in section 3.1, retention as OBT was considered first. Two exponentials were required to obtain a fit to the data (Figure 3.3).

These data suggest that a large proportion (about 75 per cent) of the administered OBT was broken down rapidly and that the remaining 25 per cent (25.8 ± 3.8%) was incorporated into rat tissue OBT and retained with a half-time of 25 days (rate of 0.028 ± 0.005 d^{-1}).

This half-time value was then applied to the total tritium whole body retention data and a fit obtained to these data (Figure 3.4). Constraining only the half-time of the second component, the fit obtained was

70 per cent with a day 3 half-time and 30 per cent with a day 25 half-time.

The data obtained for the whole body retention of tritium in rats given dried fish containing OBT are consistent with about 70 per cent (69.3 ± 3.4%) behaving as tritiated water and exhibiting a half-time of about 3 days (rate of 0.221 ± 0.019 d^{-1}), and about 30 per cent incorporated into non-exchangeable OBT in rat tissues and retained with a half-time of about 25 days.



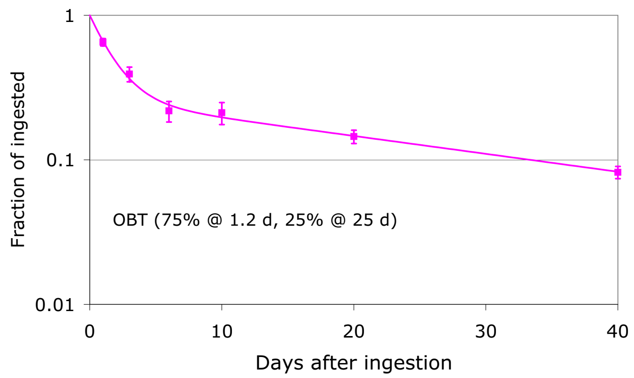
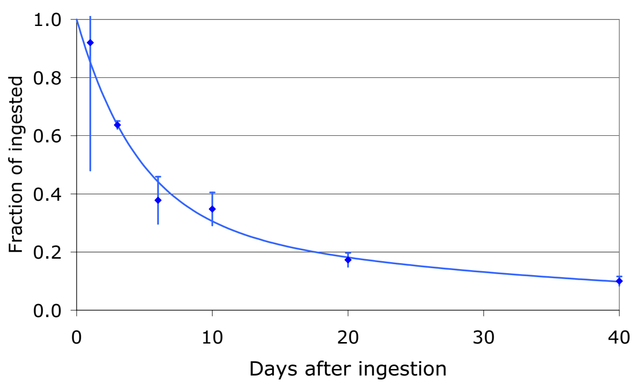


Figure 3.3 Two component exponential fit to OBT whole body retention data for rats fed fish-OBT



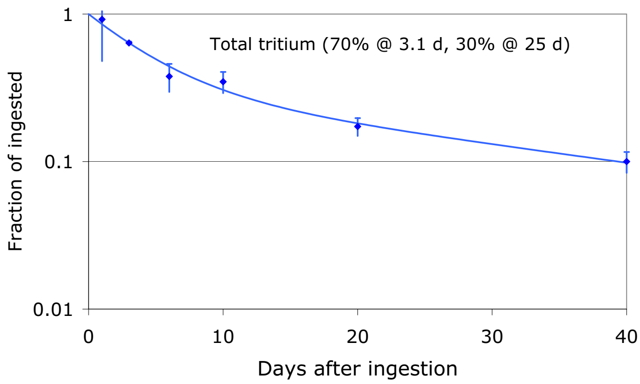


Figure 3.4 Two component exponential fit to total tritium whole body retention data for rats fed fish-OBT

3.2.2 Organ retention

Table 3.4 gives values for the relative concentrations of total tritium and OBT in organs analysed separately for the day 6 and day 20 groups. Concentrations are expressed relative to a whole body concentration of 1 at each time point.

Due to financial constraints on analysis costs, the values given are the mean of the results for two animals. Errors have not therefore been determined and the values should be interpreted with caution. The results show a maximum variation in the concentrations of total tritium and OBT between organs of a factor of 2–3.

Table 3.4 Relative concentrations of total tritium and OBT in rat organs/tissues analysed separately at 6 and 20 days after rats fed fish-OBT*

Organ	Total tritium (Bq/g)		OBT (Bq/g)	
	6 day	20 day	6 day	20day
Whole body	1.0	1.0	1.0	1.0
Liver	1.8	0.9	2.0	0.8
Pelt	0.8	0.9	0.9	0.8
Kidneys	ND	ND	ND	ND
Gastrointestinal tract	0.7	0.4	1.2	0.4
Ovaries	ND	ND	ND	ND

ND = Not determined (sample lost or below limit of detection of 0.05 Bq/g)

**Normalised to values of 1 for whole body concentrations; mean of two results.*

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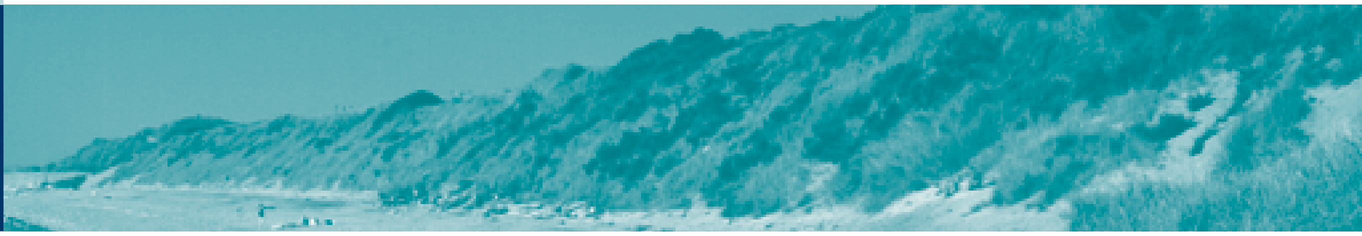


4. Analysis and discussion

The objective of this study was to determine whether the ICRP dose coefficient for the ingestion of OBT by adults is applicable to the specific form of OBT in flounder fish from Cardiff Bay and, if not, to derive a more appropriate value based on experimental data.

To assess likely doses from this form of OBT, the retention of tritium in rats was measured after:

- feeding them tritium as either tritiated water or OBT in dried flounder flesh (fish-OBT);
- obtaining data for the total tritium and OBT components of retention.

The results suggested two exponential components of retention in each case (Table 4.1).

Table 4.1 Tritium retention in the rat after ingestion as tritiated water and OBT

Form of tritium intake	First component		Second component	
	Fraction	Half-time (days)	Fraction	Half-time (days)
Tritiated water	0.97	3	0.03	10
Intake as fish-OBT	0.70	3	0.30	25

The values obtained for retention after administration of tritiated water are consistent with published animal and human data (Takeda and Kasida, 1979; Hill and Johnson, 1993; Harrison *et al.*, 2002), which suggest incorporation of 1–5 per cent into non-exchangeable OBT in body tissues. The more rapid loss of tritiated water and OBT components from the rats than from humans is also consistent with published data (Takeda and Kasida, 1979; Hill and Johnson, 1993; Harrison *et al.*, 2002).

Comparison of the half-times obtained for rats given tritiated water of about 3 days for the first component and 10 days for the second component with the values used by ICRP (1993) for adult man of 10 and 40 days, respectively, suggests that turnover of both components is about four times slower in humans than in rats.

The rat data for the retention of tritium after administration of dried flounder flesh are generally consistent with the limited published data on the behaviour of different forms of OBT in animals (Hill and Johnson, 1993; ICRP, 1993; Harrison *et al.*, 2002). Animal studies comparing the incorporation of tritium into OBT in body tissues after the intake of tritiated water and OBT found that 3–30 times more OBT is present after intake of OBT (Kirchman *et al.*, 1977; Rochalsak and Szot, 1977; Pietrzak-Flis *et al.*, 1978; Mewissen *et al.*, 1979; Takeda, 1982, 1991; Takeda *et al.*, 1985; Komatsu *et al.*, 1990; Rodgers, 1992).

ICRP (1993) concluded, from available evidence, that the assumption of 50 per cent uptake into OBT in body tissues after intake of OBT was conservative. The ICRP dose coefficient for OBT was intended as a general value for application to unspecified dietary intakes. Hence, it is reasonable to assume that a half-time of 40 days should apply to the OBT component in adult man, like the OBT formed after intake of tritiated water.

This half-time was based on the turnover of carbon in the body and is consistent with human data on OBT retention after intakes of tritiated water. Thus, a rounded value of 40 days for adults was obtained from estimates of a daily dietary intake of 300 g/day and a total carbon content of 'reference man' of 16 kg (ICRP, 1975). However, this is an average value, representing a range of half-times for the turnover of different organic molecules.

Assuming that a four-fold difference in retention times between rats and humans applies to OBT in body tissues after ingestion of flounder (Table 4.1), as for HTO and for OBT formed after ingestion of HTO, the value of 25 days in rats corresponds to a value of 100 days in humans. It also seems reasonable to assume that the proportion of tritium incorporated into OBT in body tissues after ingestion of flounder is 30% in humans as for rats; the 50% value used by ICRP (1993) for unspecified forms of OBT was also based on animal data.

For a limited number of animals given either tritiated water or OBT in dried flounder, data were obtained on the retention of tritium in separate organs. This was done to determine whether the distribution of tritium between organs might be different after ingestion of tritium in flounder, such that the standard assumption of uniform distribution of activity between tissues may not be applicable. In each case, the results showed variations between organs in concentrations of total tritium and OBT of factors of up to 2–3. This finding was consistent with published animal data (ICRP, 1993: Harrison *et al.*, 2002).

Table 4.2 shows the ICRP dose coefficients for the ingestion of tritiated water and OBT by adults, together with value obtained here for the ingestion of OBT in flounder flesh. The standard ICRP value for OBT of 4.2 x 10^{-11} Sv/Bq increases by 40 per cent to 6.0 x 10^{-11} Sv/Bq when it is assumed that half-times of 10 days and 100 days apply to components in human tissues that account for 70 and 30 per cent, respectively, of the tritium intake in flounder.

However, this higher value takes no account of the presence of tritiated water in flounder flesh. If 90 per cent of the tritium in flounders is OBT and 10 per cent is tritiated water (Lambert, 2001; Williams *et al.*, 2001; EA, EHSNI, Food Standards Agency and SEPA, 2003) with adult dose coefficients of 6.0 x 10^{-11} and 1.8 x 10^{-11} Sv/Bq, respectively, then the overall dose coefficient for tritium in flounders could be taken as 5.6 x 10^{-11} Sv/Bq. The data on which the OBT value is based are not considered to be sufficiently robust to warrant this adjustment and it is proposed here that a value of 6.0 x 10^{-11} Sv/Bq should be applied to the total tritium content of flounder. Furthermore, it is proposed that, in the absence of specific information for other food materials, this dose coefficient should be applied to all ingestion pathways relating to this source of exposure, unless it is known that the intake is of a higher proportion of tritiated water.

These ICRP dose coefficients (Table 4.3) show that, despite more rapid loss from the body, values for younger children are greater than those for adults due to their smaller body mass. Table 4.3 also shows calculated values for the ingestion of flounder OBT. These assume that components of 70 and 30 per cent behave as tritiated water and OBT in body tissues as in adults, and that the half-time of retention of OBT from flounder is 2.5 times the ICRP OBT value for each age group.

Human data for exposures of adults to HTO provide evidence for a long-term component of retention of OBT in tissues with a half-time of retention of between 140 days and 550 days (Harrison *et al*, 2002; Taylor, 2003). Thus, a number of studies have shown two components of OBT retention after intakes of HTO, although in each case the first component had a half-time of less than 40 days (10 – 30 days) so these data do not invalidate the use by ICRP (1993) of a single average value of 40 days to calculate dose coefficients. Specification of components of retention is clearly of importance in the interpretation of urine measurements in retrospective dose assessments. Taylor (2003) applied a half-time of 350 days to 2% of OBT formed after intakes of HTO by adults. The possibility of a long-term component of OBT retention after ingestion of flounder cannot be ruled out by the data obtained in this study. If 2% of OBT in body tissues after consumption of flounder by adults had a half-time of 350 days, with no change to the half-time of 100 days for the remaining OBT, the dose coefficient would be increased to 6.3 x 10^{-11} Sv Bq^{-1}.

Table 4.2 | Biokinetic assumptions and dose coefficients for ingestion of different forms of tritium by adults

Form of Tritum	Component 1		Component 2		Dose coefficient (Sv/Bq)
	Fraction	Half-time (days)	Fraction	Half-time (days)	
ICRP: triated water	0.97	10	0.03	40	1.8 x 10^{-11}
ICRP: OBT	0.5	10	0.5	40	4.2 x 10^{-11}
Cardiff Bay flounder	0.7	10	0.3	100	6.0 x 10^{-11}

In addition to dose coefficients for the ingestion of tritiated water and OBT by adults, ICRP has published values for intakes by children of different ages (ICRP, 1993). The values for children take account of their smaller mass of body water together with values for daily water balance based on their energy expenditure. Similarly, shorter retention times for the second component are based on carbon content and balance.

Table 4.3 Dose coefficients for tritium ingestion as tritiated water and OBT at different ages

	Dose coefficients (Sv/Bq x 10^{11})		
Age	ICRP: tritiated water*	ICRP: OBT*	Flounder†
3 months	6.3	12	–
1 year	4.8	12	17
5 years	3.0	7.3	10
10 years	2.3	5.7	8.2
15 years	1.8	4.2	6.0
Adult	1.8	4.2	6.0

**ICRP dose coefficients are calculated assuming two components of whole body retention. The half-times of retention for intakes at 3 months, 1, 5, 10 and 15 years and by adults are 3.0, 3.5, 4.6, 5.7, 7.9 and 10 days, respectively, for the first component, and 8, 15, 19, 26, 32 and 40 days, respectively, for the second component. For all age groups, the proportions assigned to the two components are 97:3 for intakes of tritiated water and 50:50 for intakes of OBT.*

†For ingestion of flounder containing tritium, it was assumed that the half-time of the second component is 2.5 times the ICRP value for each age group. The proportions assigned to the two components were 70:30 for all age groups.

In an analysis of uncertainties in the ICRP dose coefficients for tritiated water and OBT, (Harrison *et al.* 2002) used ranges for the uptake of tritium into OBT in body tissues after intake of OBT, and the associated retention times, that encompass the values derived here for OBT in flounder. For OBT ingestion by adults, ranges on central values were taken to be 0.15–0.75 for the proportion of tritium incorporated into OBT in body tissues and 20–200 days for the half-time of retention of this component. The resulting 5th to 95th percentile range in the frequency distribution of the likely value of the dose coefficient for ingestion of OBT by adults was a factor of about 5, with a 50th percentile value of 8.7 x 10^{11} Sv/Bq.

The difference between this central value and the ICRP value of 4.2 x 10^{-11} Sv/Bq was largely due to the inclusion in the analysis of uncertainties in the relative biological effectiveness (RBE) of tritium beta particle irradiation. Thus a range of 1–2.5 was assumed for the RBE of tritium compared with gamma rays, while the ICRP dose coefficient was calculated using a radiation weighting factor (w_R) of 1, as applied to all low linear energy transfer (LET) radiations (X-rays, gamma rays, beta particles, etc.). In fact, as discussed by Harrison *et al* (2002), the values obtained from their uncertainty analysis are strictly dose (Gy Bq^{-1}) x RBE rather than dose coefficients (Sv Bq^{-1}). Considering only uncertainties in biokinetic parameters resulted in a central estimate of 5.6 x 10^{-11} Sv.Bq and a 5–95th percentile range of about a factor of 4.

The most recent report on Radioactivity in Food and the Environment (RIFE-9), compiled by the Centre for Environment, Fisheries and Aquaculture Science (EA, EHSNI, Food Standards Agency and SEPA, 2004), records a critical group dose to high rate fish consumers in the Cardiff area of 24 μSv. Estimates in previous reports from 1997 range from 31 to 64 μSv (MAFF and SEPA, 1998, 1999, FSA and SEPA, 2000, 2001, EA, EHSNI, Food Standards Agency and SEPA, 2002, 2003). The main contributor to dose in each case was tritium in fish.

Values given for tritium concentrations in flounders caught near to the discharge site range from 15 to 54 kBq kg^{-1}, the most recent values being 30 kBq kg^{-1} (EA, EHSNI, Food Standards Agency and SEPA, 2003) and 15 kBq kg^{-1} (EA, EHSNI, Food Standards Agency and SEPA, 2004). It should be noted that the 2003 report (RIFE-8), for example, gives the results of the monitoring programme undertaken in 2002 and that the RIFE-9 report reflects the monitoring data from 2003.

The EA, EHSNI, Food Standards Agency and SEPA reports contain extensive tabulated data on concentrations of radionuclides in foods and environmental samples. Table 4.4 shows data from the 2003 and 2004 reports for the critical group consumption rate for fish and the tritium activity concentrations in flounder and gives illustrative doses calculated using the ICRP dose coefficient for OBT and the dose coefficients derived in this report for OBT in flounder.

Table 4.4 Doses from the consumption of fish only, calculated using either the ICRP dose coefficient for adults or the value derived in this report, assuming activity concentrations of tritium in flounder given in EA, EHSNI, Food Standards Agency and SEPA (2003 and 2004) apply to the total consumption of fish given in those reports.

Year of report	Con-sumption rate for fish (kg y^{-1})	Activity Consent-tration total tritium (kBqkg^{-1})	Dose coefficient for tritium (Sv/Bq)	Dose (μSv)
2003	34	30	4.2 x 10^{-11} (ICRP)	43
2003	34	30	6 x 10^{-11} (this report)	61
2004	24	15	4.2 x 10^{-11} (ICRP)	15
2004	24	15	6 x 10^{-11} (this report)	22

The dose estimates given in Table 4.4 allow a straightforward comparison with the dose estimates calculated in previous work (e.g. Lambert, 2001). They show the effect of changing assumptions regarding dose coefficients, as well as the change between 2003 and 2004 in the concentration of tritium in flounder and in the consumption rate for fish. However the calculations in the EA, EHSNI, Food Standards Agency and SEPA reports are more rigorous, taking into account concentrations of tritium and other radionuclides in different dietary components in the calculation of a critical group dose, including different species of fish. Table 4.5 shows the effect of using the dose coefficient derived in this report on the critical group dose given in the 2003 and 2004 reports. Table 4.6 contains the parameters used from RIFE in the calculation of the doses in Table 4.5.

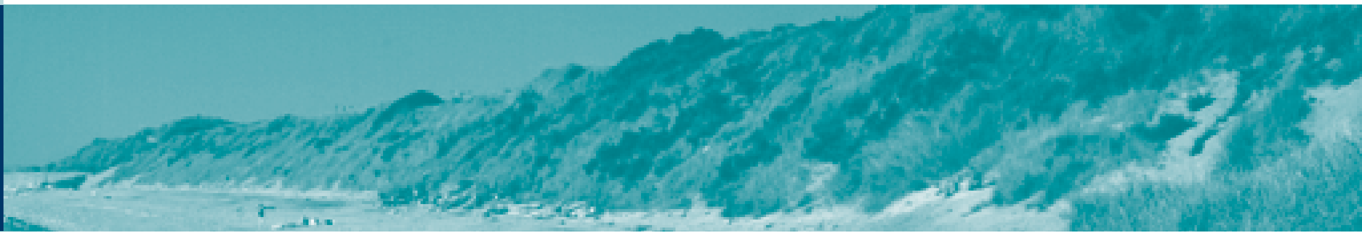
Table 4.5 Doses to the marine critical group from consumption of flounder and other seafood (sole and shellfish). Comparison of the doses given in RIFE using the ICRP dose coefficient and using the dose coefficient derived within this report.

Year of report	Dose coefficient for tritium Sv/Bq	Total dose quoted in RIFE (µSv)	Dose from tritium (µSv)	Total Dose (µSv)
2003	4.2×10^{-11} (ICRP)	31	22	31
2003	6×10^{-11} (this report)		31	40
2004	4.2×10^{-11} (ICRP)	24	19	24
2004	6×10^{-11} (this report)		27	33

The dose estimates given in Table 4.5, calculated in accordance with the methodology described in the RIFE reports using the averaged activity concentrations of tritium and other radionuclides in fish derived from measured concentrations in sole, cod and flounder, and included estimates of dose from consumption of shellfish and exposure to external radiation. They show the effect of applying the dose coefficient of 6×10^{-11} Sv Bq^{-1} to tritium in all seafood consumed from the Cardiff Bay area. The estimates show that the use of this specific dose coefficient for tritium in seafood increases the dose estimate by between 30 and 40%.

Table 4.6 Parameters used from RIFE to calculate the doses from the consumption of fish and shellfish

Parameter	2003	2004
Consumption rate of fish	34 kg/y (RIFE 8 page 206)	24 kg/y (RIFE 9 page 222)
Activity concentration in fish	14.7 kBq/kg (average from value for sole, flounder and cod (12, 30 and 2 kBq/kg respectively	16 kBq/kg (average from value for sole and flounder (17 and 15 kBq/kg respectively)
Consumption rate of shellfish	1.4 kg/y (RIFE 8 page 206 for prawns)	3.8 kg/y (RIFE 9 page 222 prawns and lobsters)
Activity concentration in shellfish	14 kBq/kg (RIFE 8 page 138 for mussels)	19 kBq/kg (RIFE 9 page 151 for mussels)

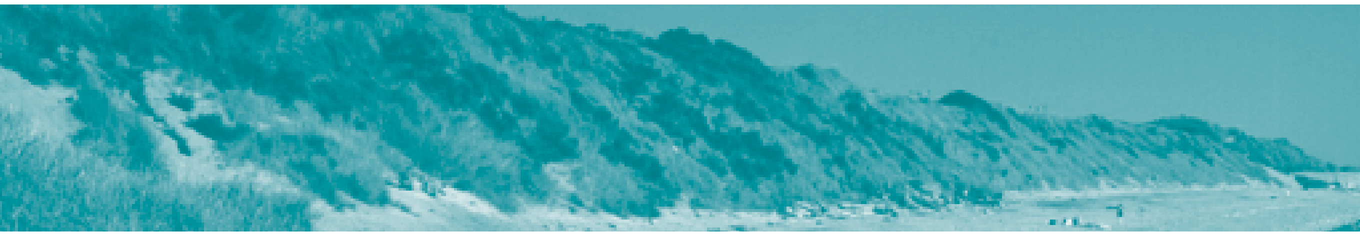


5. Conclusions

The retention of tritium in adult rats was determined after administration as either tritiated water or dried flounder flesh containing OBT. These data gave an ingestion dose coefficient for humans of 6 x 10^{-11} Sv/Bq for the specific case of tritium in flounders consumed by adults.

This value is subject to uncertainties associated with the application of animal data to the behaviour of tritium in humans. However, the data were internally consistent and the comparison between retention after administration of tritiated water and OBT in flounder strengthened confidence in the extrapolation to humans.

It is proposed that the dose coefficient of 6 x 10^{-11} Sv/Bq should be applied to the total tritium content of flounders, despite observations that a small proportion may be present as tritiated water. It is further proposed that, unless specific information is available showing that a significant proportion of the intake is tritiated water, this dose coefficient should be used, rather than the ICRP generic value for unspecified forms of OBT, for all seafood consumption by adults relating to this source of OBT discharge into Cardiff Bay. The same proposals apply to the dose coefficients derived in this report for flounder OBT consumption by children.



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Glossary of terms

Activity
Attribute of an amount of a radionuclide. Describes the rate at which transformations occur in it. Unit Becquerel, symbol Bq. 1Bq = 1 transformation per second.

Becquerel (Bq)
See activity.

Beta particles
An electron emitted by the nucleus of a radionuclide. The electric charge may be positive, in which case the beta particle is called a positron.

Dose coefficient
Dose coefficients represent the effective dose per unit intake of a radionuclide and the incorporation of risk formulations for the assessments of health detriments.

Effective Dose
The quantity obtained by multiplying the equivalent *dose* to various tissues and organs by a weighting factor appropriate to each and summing the products. Unit sievert, symbol Sv. Frequently abbreviated to *dose.*

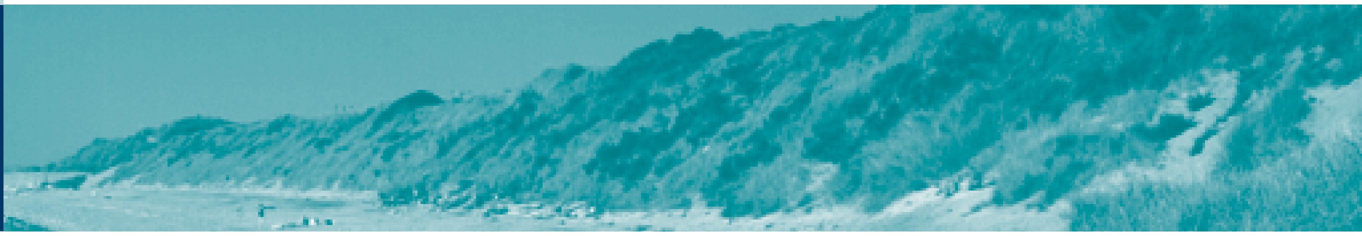
Gamma ray
A discrete quantity of electromagnetic energy without mass or charge. Emitted by a radionuclide.

Radiation weighting factor (w_R)
w_r values (radiation weighting factors) represent the relative biological effectiveness of the different radiation types, relative to X- or γ-rays, in producing endpoints of ecological significance.

Relative biological effectiveness (RBE)
A relative measure of the effectiveness of different radiation types at inducing a specified health effect, expressed as the inverse ratio of the absorbed doses of two different radiation types that would produce the same degree of a defined biological endpoint.

Sievert (Sv)
See effective dose.

X-ray
A discrete quantity of electromagnetic energy without mass or charge. Emitted by an X-ray machine.



List of abbreviations

CEFAS Centre for Environment, Fisheries and Aquaculture Science

IAEA International Atomic Energy Agency

ICRP International Commission on Radiological Protection

OBT organically bound tritium

RBE relative biological effectiveness

SD standard deviation

UKAS United Kingdom Accreditation Service

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