The Effects of Food Preparation on the Radionuclide Content of Food

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Abstract
Radionuclides including ^3H, ^{14}C and ^{35}S, are periodically and routinely discharged from nuclear powered electricity generation sites. It is important to assess the radiological impact of such discharges on humans through the pathway of human intake of food-stuffs. Food-stuffs are often prepared before being eaten and this action may reduce the radionuclide content of the food. This paper reports the results of a range of domestic food processing techniques on the radionuclide (^3H, ^{14}C and ^{35}S) content of blackberries, broad beans, cabbage, carrots and potatoes. The effect of a complete range of preparation techniques for one food type which the UK population commonly eats, potato, was examined. In general, preparation of the crops by any of the techniques resulted in reductions in the radionuclide concentrations by at least 30%. The concentrations of sulphur 35 showed the greatest reduction in response to most of the preparation techniques. Roasting resulted in the greatest reductions in levels of HTO and ^{35}S. There were some apparent increases in the concentrations of OBT, but there was always a decline in the total tritium concentration. The apparent increases in OBT could be explained by the exchange of the free and organically bound tritium fractions, as well as experimental error.

Introduction
Radionuclides are periodically and routinely discharged to the atmosphere from nuclear powered electricity generation sites. In the UK, MAGNOX and Advanced Gas Cooled Reactors are currently used and both reactor types use CO_2 as a coolant. ^3H, ^{35}S and ^{14}C are formed in reactor cooling systems either by activation of the coolant or impurities within it and are released in to the environment during controlled discharges. It is important to assess the radiological impact of such discharges on humans through the pathway of human intake of food-stuffs.

The forms of ^3H and ^{14}C when released into the atmosphere will be predominantly HTO [2], and $^{14}CO_2$. A major ^{35}S species in the effluent is carbonyl sulphide, $CO^{35}S$, [8]. $H_2{}^{35}S$ may be released also. These compounds can become incorporated into plant tissue via stomatal uptake although there is an additional contribution from root uptake of soil water for HTO.

Dose assessment models currently used are based on the deterministic critical group „worst case“ approach. With the introduction of dose constraints (guidance by the NRPB [1,7] on the 1990 recommendations of the ICRP [5]), which are likely to be more restrictive than dose targets that are currently used, the NRPB have recommended that dose assessments should be more realistic. Where it is appropriate to provide more realistic dose estimates, it is important that the doses from foodstuffs are accurately assessed, including any effects of food preparation techniques on the radionuclide contents.

Aims
This short paper summarises the results of two studies. The aim of these studies was to examine the effects of a range of food processing techniques on the radionuclide contents of a range of food types. Radionuclide concentrations of tritium (free,

HTO, and organically bound, OBT), ^{14}C and ^{35}S were examined in a selection of fruit and vegetables which would form part of a typical diet. The food-stuffs included: blackberries; broad beans; cabbage; carrots; and potatoes. In addition, the effect of a complete range of preparation techniques was studied for one food type which the UK population commonly eats (potato).

The food-stuffs were grown on or close to the BNFL Sellafield, UK, site since levels of all these radionuclides would be relatively high due to releases from reprocessing and reactor operations.

Preparation of the food stuffs

In all cases, the crops were prepared as they might be in the home, except that distilled water was used for cooking and washing and salt was not added to the water that the food was cooked in. This was in order to reduce the effects of a number of variables.

The crops were prepared in the following manner: blackberries (washed and stewed); broad beans (beans removed from pods and boiled); cabbage (washed and boiled); carrots (washed, sliced and boiled); potatoes (medium sized potatoes for baking, washed and baked; medium and small for boiling, washed, peeled, quartered and boiled; large for frying as chips, washed, peeled, cut and fried; medium for microwaving, washed and microwaved; medium and small for roasting, washed, peeled, part boiled and baked).

Radionuclide analyses

Replicate analyses were undertaken to reduce the uncertainties in the radionuclide concentrations of the food stuffs, although each food preparation technique was normally undertaken only once. Repeat analyses were performed on all the fresh and cooked food-stuffs. The ^{14}C analyses were conducted in duplicate on cabbage and potatoes.

The radionuclide contents of the raw and cooked samples were determined using a LKB 1219 low background liquid scintillation β counter.

Effect of food preparation on radionuclide concentrations

The reduction in the radionuclide contents due to cooking cannot be calculated directly without taking into account the change in weight of the sample. Most of the processes: baking, frying (as chips), microwaving, roasting and stewing, resulted in a reduction of the sample weight. Stewing and frying resulted in substantial reductions in the sample weights. However, the potatoes that were boiled gained a small amount of water. To allow a direct comparison of the radionuclide contents in the raw and processed samples, the concentrations in the processed samples have been multiplied by the mean weight loss ratio (cooked weight/raw weight). These ratios are sometimes described as the processing efficiency, Pe, [4].

The percentage of the radionuclide concentrations that remain after cooking have been calculated and are shown in Tables 1 (potatoes) and 2 (other crops). The changes in the radionuclide contents are expressed as the fraction remaining of the original content of the uncooked material. The significance of the change in radionuclide levels is shown in Tables 1 and 2 also. Where any determination was below the LOD, the means have been calculated assuming that the sample has a radionuclide content equal to half of the LOD.

In general, the techniques used to cook the foodstuffs in this study resulted in moderate to large reductions in HTO, OBT, total tritium and ^{14}C levels, and variable but often large reductions in the ^{35}S levels.

Potatoes were cooked in a variety of ways. Roasting was found to be the most effective technique for reducing HTO and OBT (reductions of 46 and 62%, respectively in one of the studies). The relative effectiveness of the other techniques is variable according to whether HTO or OBT is considered. The reductions in ^{35}S are hard to quantify because levels in the baked and microwaved samples were below the limits of analytical detection (LODs). However, this at least, implies fairly large reductions. Data for similar cooking techniques have been included in Table 1 also, and it is clear that the changes in radionuclide content are very variable even though the preparation techniques were almost identical. For example, roasting the potatoes in the first study resulted in an apparent increase in the OBT levels which was not observed in the second study. Also, boiling was effective at reducing HTO levels in the first study (by 45%), but not in the second one. The higher OBT concentration in the potatoes after roasting may reflect the inherent variability of the radionuclide concentrations in these samples and consequently experimental error. Alternatively, HTO may exchange with OBT during the roasting process. Nevertheless, considering only total tritium, there are differences in the results from the two studies.

Boiling was effective at reducing the ^{35}S and HTO concentrations in the vegetables, and reduced the ^{14}C and OBT concentrations by typically around 30% (see Table 2). Steaming cabbage was found to result in large reductions in HTO and ^{35}S, although it is difficult to fully assess the significance levels of the reductions, since the levels in the cooked samples were below the LODs. There was an apparent increase in the OBT concentration of the steamed cabbage, although this was not significant. Stewing blackberries resulted in significant reductions in the levels of HTO, OBT, total tritium and ^{35}S (45, 44, 45 and 77% respectively). These reductions are clearly related to the juices lost during cooking. The concentration of HTO was determined in the blackberry juice, and a simple inventory of HTO derived. This indicated that nearly all the HTO was lost to the juice.

Comparison with other work

Noordijk and Quinault (1992) have summarised available data on the effects of food preparation on the radionuclide content of foodstuffs. They comment that there are few current data on the effects of food processing, and that most of the measurements they reviewed were made in the 1960s. In addition, the range of radionuclides studied is small with an emphasis on Cs and Sr. Another review by Green and Wilkins (1995) has identified literature containing information not presented by Noordijk and Quinault. Table 3 compares the results of the currently reported work with data which are directly comparable; in this case, only results for ^{35}S.

The values of Fr (fraction of radionuclide retained after processing, or food processing retention factor; [4]) are variable for ^{35}S. The results after steaming cabbage are within the range listed by Green and Wilkins. However, the work from the second study suggested there was no apparent reduction in the ^{35}S levels if the cabbage was boiled. The reduction in ^{35}S concentrations after boiling potatoes was greater than the value listed by Green and Wilkins by a factor of approximately two.

Conclusions

The changes in radionuclide concentrations of HTO and OBT, ^{14}C and ^{35}S due to food preparation have been investigated. The food stuffs were blackberries, broad beans, cabbages, carrots and potatoes, and the effects of a variety of preparation techniques have been assessed.

Potatoes were cooked in a variety of ways (boiling, baking, microwaving, roasting, and frying). All of the cooking techniques reduced the concentrations of the radionuclides assessed. The relative effectiveness of the techniques was variable; roasting was the most effective technique overall and reduced total tritium concentrations by more than 50 %. The reductions in ^{35}S due to cooking potatoes are hard to quantify because levels in the baked and micro-waved samples were below the LODs, although this in itself implies substantial reductions.

In general, preparation of the crops by any of the techniques resulted in reductions in the radionuclide concentrations by at least 30 %. The concentrations of ^{35}S normally fell by at least 60 % and this nuclide showed the greatest reduction in response to most of the preparation techniques. Roasting potatoes resulted in the greatest reductions in levels of HTO and ^{35}S. There were some apparent increases in the concentrations of OBT, but there was always a decline in the total tritium concentration. The apparent increases in OBT could be explained by the exchange of the free and organically bound tritium fractions, as well as experimental error.

Stewing blackberries significantly reduced the concentrations of HTO, OBT and total tritium, and ^{35}S. There was insufficient OBT to analyse in the juices released after stewing the blackberries. An inventory prepared for HTO activity indicated that nearly all the HTO was lost from the blackberries to the juice as a result of stewing.

Acknowledgements

This project was funded by MAFF. The helpful comments of P. Tossell are gratefully acknowledged. The help of R Neal and G Beale in preparing the samples is gratefully acknowledged. We thank C. Collins and A. Gravett of Imperial College for growing the crops and Morag and Tony Sharp for collecting the blackberries.

The views expressed are those of the authors and do not necessarily reflect those of the funding organisation.

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Table 1:
Percentage of radionuclide content in potatoes that remained after cooking

Crop	Process	% of radionuclide content remaining [significance of change]				
		HTO	OBT	Total tritium	^{14}C	^{35}S
Potatoes	Boiling	92 [ns]	41 [ns]	75 [ns]	83 [*]	n/a
	Boiling {2}	55 [*]	74 [*]	57 [*]	n/a	38 {1}
(small)	Roasting	54 [ns]	38 [*]	47 [*]	n/a	n/a
	Roasting {2}	21 [**]	148 [*]	33 [**]	n/a	10 {1}
Potatoes	Baking (oven)	87 [ns]	52 [ns]	77 [ns]	n/a	17 {1}
(medium)	Microwaving	62 [*]	53 [ns]	60 [*]	n/a	13 {1}
Potatoes (large)	Frying (chips)	63 [*]	42 [*]	54 [***]	n/a	n/a

Notes:
Significances from students 't-test'
[ns] Not significant at the 5 % level
[*] Significant at the 5 % level
[**] Significant at the 1 % level
[***] Significant at the 0.1 % level
{1} One or both of the data sets contains a value below the limit of analytical detection. Significance of change in radionuclide content not assessed.
{2} Data from the first of the two studies.
n/a sample not analysed for this radionuclide

Table 2.
Percentage of radionuclide content of food-stuffs that remained after cooking

Crop	Process	% of radionuclide content remaining [significance of change]				
		HTO	OBT	Total tritium	^{14}C	^{35}S
Blackberries	Stewing	55 [***]	56 [**]	55 [***]		23 [*]
Broad beans	Boiling	28 {1}	69 [ns]	53 {1}		12 {1}
Cabbage	Steaming	28 {1}	168 [ns]	44 {1}		32 [ns]
	Boiling	35 [**]	68 [ns]	41 [***]	76 [ns]	100 [ns]
Carrots	Boiling	28 {1}	43 [ns]	33 {1}		30 {1}

Notes:
Significances from students 't-test'
[ns] Not significant at the 5 % level
[*] Significant at the 5 % level
[**] Significant at the 1 % level
[***] Significant at the 0.1 % level
{1} One or both of the data sets contains a value below the limit of analytical detection.
Significance of change in radionuclide content not assessed.

Table 3.
Comparison of radionuclide reduction by food processing

Crop	Process	Nuclide (F_r) [1]	P_e [2]	Reference
Cabbage	Boiling	^{35}S (0.3 - 0.7)	n/a	Green and Wilkins, 1995
	Steaming	^{35}S (0.3)	1.0	This work, first study
	Boiling	^{35}S (1.0)	1.0	This work, second study
Potato	Boiling	^{35}S (0.9)	n/a	Green and Wilkins, 1995
	'Old', Boiling without peel	^{35}S (0.4)	0.9	This work, first study
	'Old', Boiling without peel	^{35}S n/a	1.1	This work, second study

Notes:

[1] F_r fraction of radionuclide retained after processing
[2] P_e ratio of weight of prepared product to original raw product
[3] Assuming total contamination of the plant (internal and external)
n/a Information not presented, or measurement not made