National Compliance Assessment Service
Technical Report

ENVIRONMENT AGENCY

Radiological Assessment - Amersham plc (Cardiff site) Variation Application 2001

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To support the determination of the application to vary the radioactive waste discharge authorisations for Amersham plc (Cardiff site).

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EXECUTIVE SUMMARY

A prospective radiological assessment has been undertaken for future discharges of radioactive wastes from the Amersham plc Cardiff laboratories. Amersham plc have made an application to vary their discharge authorisations and new discharge limits from the site have been proposed by the Environment Agency. Discharges are made to atmosphere via stacks on site and to the Severn Estuary via the Cardiff sewage system. A new sewage treatment works is under construction to treat sewage produced in the Cardiff area, including sewage containing discharges from Amersham plc. It is expected that sewage sludge pellets produced by this works will be used to condition farmland in the Cardiff area and treated effluents will be discharged to the Severn Estuary. During periods of high rainfall the sewage system is designed to overflow into the Whitchurch Brook and into the River Taff. A sewage improvement scheme is under construction to reduce the frequency of overflow events to the Whitchurch Brook.

The authorisations held currently by Amersham plc have annual and daily limits for specified radionuclides. The Environment Agency has proposed new annual and daily limits on the discharges of these radionuclides. This report provides an assessment of the doses to members of the public from future authorised discharges from the site.

For discharges at the Agency's proposed annual limits and with all sewage improvement schemes completed, the critical group has been identified as a farming family who consume food produced on farmland conditioned by sewage sludge from the new sewage works. Doses of 24 to 47 μSv/y have been assessed for adult, child and infant members of such a family. Doses to other groups exposed to atmospheric discharges and discharges to sewer reaching the Severn Estuary were 24 μSv/y and 17 μSv/y respectively. All the assessed doses are less than the source constraint of 300 μSv/y and the annual public dose limit of 1000 μSv/y.

Doses from short duration discharges to atmosphere at the proposed daily limits were assessed as 47 μSv/y to allotment holders at Radyr.

The world collective dose (per year of discharge) truncated at 500 years for discharges to atmosphere at Agency proposed limits is 52 manSv. The world collective dose (per year of discharge) truncated at 500 years for discharges to sewer passing through the new sewage works and direct to the Severn Estuary were 13.3 manSv and 11 manSv respectively. The highest per caput dose has been assessed as 36 nSv per year of discharge to atmosphere.

CONTENTS

INTRODUCTION

1. Amersham plc (previously Nycomed Amersham) submitted an application to the Environment Agency in January 2001 for a variation to their radioactive waste discharge authorisations granted under the Radioactive Substances Act 1993 for their Cardiff site [Ref 1]. All supporting documentation necessary for the Agency to determine the variation request was provided by June 2001.

2. This report provides an assessment of the radiological implications of discharges at the current limits and limits proposed by the Agency. It has been prepared by the National Compliance Assessment Service at the request of Environment Agency Wales to support their determination of the application. The radiological assessment has been conducted in accordance with the Agency's Management System.

BACKGROUND

3. Amersham plc's site is located on the Forest Farm industrial estate, north of Cardiff, close to the River Taff and the M4 motorway. It is located in a valley, with hills rising to about 50 m above the site to the west and to the north east.

4. Amersham plc owns the Cardiff Laboratories site and holds the nuclear site licence. Radioactive products, primarily containing carbon-14 and tritium are manufactured on the site in building RP1. Research and development work using small quantities of these and other radionuclides is carried out in building RP2.

AUTHORISED DISCHARGES OF RADIONUCLIDES

5. Authorised discharges are made to atmosphere and to sewer from the site by Amersham plc. The majority of discharges to atmosphere are made through a 50 m tall stack adjacent to building RP1.

6. Discharges made to sewer become mixed with general sewage from Cardiff and are transported by pipeline approximately 10 km before discharge into the Severn Estuary at Orchard Ledges. Starting in 2002, Cardiff's sewage will be treated at a new sewage treatment works. Treated sewage effluents from the works will be discharged to the Severn Estuary and treated sewage sludges from the works will be dried to a pellet and applied to farmland as a soil conditioner.

7. The radionuclides and quantities discharged to atmosphere at the current annual limits and the future annual limits proposed by the Agency as a result of its determination process to date are shown in Table 1. The radionuclides discharged to sewer at the current limits and the Agency proposed annual limits on the discharges are shown in Table 2. Current daily limits and Agency proposed daily limits for discharges to atmosphere are provided in Table 3.

EXPOSURE PATHWAYS

8. Members of the public can be exposed to releases of radionuclides discharged to atmosphere and sewer via a variety of exposure pathways. The exposure pathways considered were based on critical group habit surveys, Agency knowledge of the site through inspection activities and radiological assessments by the National Radiological Protection Board (NRPB), the Food Standards Agency (FSA) and Amersham plc. Allowance was made for planned changes to the sewage system, including commissioning of a sewage works at Cardiff and improvement to the overflow to Whitchurch Brook. The exposure pathways considered were:

- For liquid discharges to sewer and subsequently to Severn Estuary with no sewage treatment:
  - Internal irradiation following the ingestion of radionuclides in fish, shellfish and duck caught in and around the Severn Estuary.
  - External irradiation following incorporation of radionuclides in sediment.
  - Internal irradiation following the inhalation of sea spray incorporating radionuclides blown inland.
- For liquid discharges to sewer with sewage treatment works in operation:
  - All the above pathways, but with some of the radionuclides being removed from the effluent during sewage treatment.
  - Internal irradiation of sewage workers following inhalation of resuspended radionuclides and inadvertent ingestion of sewage sludge containing radionuclides.
  - External irradiation of sewage workers from radionuclides incorporated into sewage sludge.
  - Internal irradiation following the consumption of food produced on land conditioned by sewage sludge incorporating radionuclides.
  - Internal irradiation following the inhalation of gaseous radionuclides and resuspended sewage sludge or inadvertent ingestion of sewage sludge incorporating radionuclides as it is spread on land.
- For liquid discharges to sewer that may occasionally overflow into the Whitchurch Brook and then into the River Taff.
  - Internal irradiation from inadvertant ingestion of water and sediments from Whitchurch Brook and the River Taff and fish consumption of fish caught in the river Taff.
- For discharges to atmosphere:
  - Internal irradiation following inhalation of radionuclides discharged to atmosphere via the stacks and of radionuclides in resuspended dusts.
  - External irradiation from radionuclides in the atmosphere and deposited on the ground following discharge from the stacks.
  - Internal irradiation from the ingestion of radionuclides incorporated into locally produced food following deposition of discharges to atmosphere.
- For direct radiation from the site:
  - External irradiation due to direct radiation from the site.

9. The NII have confirmed in writing that direct radiation cannot be detected at the site boundary [Ref 2]. This is because the radionuclides in the radioactive material held on the site do not emit radiation that would lead to a direct radiation dose offsite. Hence, doses from direct radiation has not been considered any further in this assessment.

CANDIDATE CRITICAL GROUPS AND HABITS

10. The mode of radioactive waste discharge, information from population habit surveys, Agency knowledge of the site through inspection activities and radiological assessments by NRPB, FSA and Amersham plc have been used to identify the following realistic candidate critical groups:

- ***Allotment holders at Radyr*** who are exposed to the atmospheric discharges made by Amersham plc and eat produce from an allotment. These persons are considered unlikely to be exposed to aquatic discharges reaching the Severn Estuary due to the distance from the discharge point.
- ***Farming family near to site*** who are exposed to the atmospheric discharges from the Amersham plc site and eat foods produced on their farm. These persons are considered unlikely to be exposed to aquatic discharges reaching the Severn Estuary due to the distance from the discharge point. It is also considered unlikely that this farm would regularly receive sewage sludge from the new sewage treatment works because it is located more than 10 km from the farm.
- ***Fisherman in the Severn Estuary*** exposed to discharges of radionuclides to the Severn Estuary. Fisherman are assumed to have high rates of consumption of seafood from the local area and spend a considerable proportion of their time on the shores of the estuary collecting bait and angling. These persons are considered unlikely to live near the site and are therefore unlikely to be exposed to atmospheric discharges from the site.
- ***Farming family close to new sewage treatment works*** who are exposed to the radionuclides incorporated into sewage sludge used to condition their land. The sewage treatment works is 10 km from the Amersham plc site and therefore it is considered unlikely that members of this family would be exposed to atmospheric discharges from the site. It is also considered unlikely that they would be high consumers of seafood caught in the Severn Estuary near Cardiff.
- ***Sewage workers (at new sewage works)*** exposed to discharges from the Amersham plc site for a period of a working year. It is considered unlikely that they live near enough to the Amersham plc site to be exposed to atmospheric discharges from the site. It is also unlikely that they would be high consumers of seafood caught in the Severn Estuary near Cardiff.
- ***Anglers and children*** undertaking recreational activities in and around Whitchurch Brook and River Taff exposed to radionuclides in sewers overflowing into the Brook.

11. In addition the following population groups were defined to be more representative of a typical person living in the Cardiff area:

- ***Average consumer of seafood*** caught in the Severn Estuary near Cardiff. These persons also spend an average amount of time per year on the shores of the estuary.
- ***Average consumer of local food*** produced on the farm near Amersham plc site.
- ***Average consumer of local food*** produced on farms treated with sewage sludge.

ASSESSMENT METHODOLOGY

12. The assessments of the radiological impact of gaseous discharges to atmosphere and liquid discharges from the site reaching the Severn Estuary were performed using the PC CREAM software [Ref 3] as described in Appendices 1 and 2. PC CREAM was used to derive the doses to allotment holders at Radyr, a farming family near to the site and fisherman in the Severn estuary (see Appendices 1 and 2).

13. The assessment of the radiological impact on sewage workers of liquid discharges from site at the sewage works and to the public from the disposal of sludges to land used methods and data given in recent R&D [Ref 4] and a new dynamic sewage sludge disposal to land model, as described in Appendices 3 and 4. Doses were calculated to sewage workers at the new sewage works and a farming family from a farm where sludge pellets from the sewage treatment works were used to condition their land (see Appendices 3 and 4).

14. During periods of high rainfall, the sewer overflows to the Whitchurch Brook and then to the River Taff. Discharges to sewer from the site may then enter the brook and the River Taff. Doses to anglers and children playing around the brook and river have been assessed using the methods detailed in Appendix 5. The resulting doses are presented in Appendix 5.

15. The radiological impact of short term releases to atmosphere for discharges at daily limits have been assessed using the methodology described in Appendix 6 and the results provided in the same appendix.

16. Collective doses to the UK and Europe from discharges to sewer and to atmosphere were derived using an established methodology [Ref 5] (see Appendix 7).

RESULTS OF ASSESSMENT OF INDIVIDUAL DOSES

17. The individual doses to the candidate critical groups are summarised in Table 4 for current and proposed limits and in Figure 1 and Figure 2 for proposed limits. For discharges to sewer, doses have been assessed before and after the sewerage improvement schemes have been implemented (ie commissioning of the new sewage works at Cardiff and reduction in frequency of overflow of sewage to Whitchurch Brook).

18. The individual doses to the candidate critical groups for discharges at the proposed limits, prior to the completion of the sewerage improvement schemes are as follows:

- ***Allotment holder at Radyr*** - 22 μSv/y for infants, 23 μSv/y to children and 24 μSv/y to adults.
- ***Farming family near to site*** – 7.1 μSv/y to infants, 4.1 μSv/y to children and 3.8 μSv/y for adults.
- ***Fishermen in the Severn Estuary*** - 76 μSv/y to an adult.
- ***Playing in Whitchurch Brook*** - 0.024 μSv/y to children and 0.014 μSv/y to adults.
- ***Anglers on River Taff*** - 11 μSv/y to children and 32 μSv/y to adults.

19. The individual doses to the candidate critical groups for discharges at the proposed limits, following the completion of the sewerage improvement schemes are as follows:

- ***Fishermen in the Severn Estuary*** - 17 µSv/y to an adult.
- ***Farming family using sewage sludge pellets to condition land*** - 47 µSv/y for infants, 24 µSv/y to children and 24 µSv/y to adults.
- ***Sewage workers (at new sewage works)*** - 0.097 µSv/y to a sewage worker.
- ***Playing in Whitchurch Brook*** - 0.0012 µSv/y to children and 0.00066 µSv/y to adults.
- ***Anglers on River Taff*** - 0.54 µSv/y to children and 1.6 µSv/y to adults.

20. The doses to the allotment holders and farming family in the farm near the site from short term discharges to atmosphere at the proposed daily limits are as follows:

- ***Allotment holder at Radyr*** - 47 µSv/y to infants, 44 µSv/y to children and 43 µSv/y to adults.
- ***Farming family near to site*** - 3.9 µSv/y to infants, 3.0 µSv/y to children and 2.6 µSv/y to adults.

21. Before the sewage works becomes operational the critical group for the Amersham plc site in Cardiff is predicted to be fishermen in the Severn Estuary exposed to radionuclides in discharges to sewer reaching the Severn Estuary. Once the sewage works becomes operational, the critical group is likely to become a farming family near the sewage works consuming food produced on land conditioned by sewage sludge pellets. The change in the critical group is caused by the removal of some of the radionuclides in the sewage effluent to sewage sludge pellets during sewage treatment. The discharge of radionuclides to the Severn is expected to be reduced whilst sewage sludge pellets containing some of the radionuclides will be created.

22 At the proposed limits, the doses to the critical group and all candidate critical groups are much less than the dose constraint (for a single source) of 300 µSv/y and the dose limit for members of the public of 1000 µSv/y.

23. At the current limits the doses to the candidate critical groups from discharges are predicted to be between a factor of about three and twenty higher than those at the proposed limits (see Table 4, Figure 3, Figure 4 and Figure 5). All the predicted doses for discharges at the current limits are less than the dose limit of 1000 µSv/y and in most cases are below the dose constraint (for a single source) of 300 µSv/y.

24. The doses to the allotment holders at Radyr, fisherman on the Severn Estuary and farming family using land conditioned with sewage sludge are totally dominated by tritium and carbon-14 (see Figure 6, Figure 7 and Figure 8). The main dose pathways are consumption of fish, animal products and foods from the allotment.

RESULTS OF ASSESSMENT OF COLLECTIVE DOSES

25. The collective doses per year of discharge (truncated to 500 years) arising from discharges to atmosphere, discharges to the Severn Estuary and disposals of sewage

sludge to land at the proposed limits, prior to the completion of the sewerage improvement schemes are as follows:

- ***Discharges to atmosphere*** - 2.0 manSv for the UK, 10 manSv for Europe and 52 manSv for the world.
- ***Discharges to sewer passing direct to the Severn Estuary*** - 0.1 manSv for the UK, 1.0 manSv for Europe and 11 manSv for the world.

26. The collective doses (truncated to 500 years) arising from discharges to sewer passing through the new sewage works are as follows:

Discharges to sewer passing via the sewage works: 0.47 manSv for the UK, 1.6 manSv for Europe and 13.3 manSv for the world.

27. The collective dose from discharges to sewer passing through the sewage works is made up as follows:

- ***Reaching the Severn Estuary*** - 0.070 manSv for the UK, 0.70 manSv for Europe and 7.7 manSv for the world.
- ***Disposal of sludge to land*** - 0.4 manSv to the UK, 0.9 manSv for Europe and 5.6 manSv for the world.

28. There is no legal dose limit on collective doses. The International Atomic Energy Agency (IAEA) have presented dose criteria which are considered sufficiently low that doses arising from sources or practices that meet these criteria may be exempted from regulatory control. One of the criteria is that collective dose should be less than about 1 man Sv per year of practice [Ref 6,7]. The collective doses calculated from discharges from the Amersham plc site are, however, above this level.

29. Collective doses may be used to derive the average dose to members of different population groups, known as per caput doses. NRPB have stated [Ref 8] that discharges giving rise to per caput doses of less than a few nanosieverts per year of discharge can be regarded as trivial. Higher annual per caput doses, up to say a few microsievert per year of discharge can be considered trivial but may require some consideration of alternative discharge options, particularly if at the higher end of the range.

30. The per caput doses for discharges at the proposed limits from the Cardiff site are highest for the UK population, being 36 nSv per year of discharge to atmosphere, 1.8 nSv per year of discharges to the Severn Estuary (prior to sewerage improvement scheme), 1.3 nSv per year of discharge to the Severn Estuary (following completion of sewerage improvement scheme) and 6.5 nSv per year of disposal of sewage sludge to land. These per caput doses can be regarded as trivial.

SENSITIVITY OF RESULTS

31. The sensitivity of the results to uncertainties and variabilities in the key assessment assumptions has been examined and the results recorded in Appendix 8. This assessment has focused on those candidate critical groups which are predicted to receive a dose of more than about 10 μSv/y. Furthermore, it has been based on the predicted doses for discharges at proposed limits with all sewer improvement schemes completed.

The results of the study cannot be directly translated to doses assessed for other scenarios, since assumptions with a relatively large uncertainty may be attributable to that particular scenario (eg impact of sewer improvement schemes).

32. The likely range of underestimate or overestimate of the dose and overall overestimate of the doses are as follows for each candidate critical groups:

- ***Allotment holder at Radyr*** - Up to a factor of 4.4 higher than predicted to a factor of 7.3 lower than predicted. Overall the predicted doses may be a factor of 1.7 lower than predicted.

- ***Fisherman in the Severn Estuary*** - Up to a factor of 4.5 higher than predicted to a factor of 6.1 lower than predicted. Overall the predicted doses may be a factor of 1.4 lower than predicted.

- ***Farming family close to new sewage treatment works*** - Up to a factor of 5.0 higher than predicted to a factor of 5.8 lower than predicted. Overall the predicted doses may be a factor of 1.1 lower than predicted.

- ***Anglers on the River Taff*** - Up to a factor of 5.6 higher than predicted to a factor of 5.5 lower than predicted.

CONCLUSIONS

33. A radiological assessment has been undertaken for future discharge limits proposed by the Agency for the Amersham plc site at Cardiff, following an application by Amersham plc to vary their discharge authorisations. Discharges are currently made from the site to atmosphere and to sewer from the Cardiff site. Discharges to sewer are currently discharged to the Severn Estuary near Cardiff. A new sewage treatment works is under construction to treat sewage produced in the Cardiff area, including sewage containing Amersham plc's discharges. It is expected that sewage sludge pellets produced by this works will be used to condition farmland in the Cardiff area and treated effluents will be discharged to Severn Estuary. From time to time sewage overflows into the Whitchurch Brook and into the River Taff.

34. The following candidate critical groups were identified who could be exposed to discharges from the Cardiff site:

- ***Allotment holder at Radyr*** who are exposed to discharges of radionuclides to atmosphere from the site.
- ***Farming family near to site*** who are exposed to discharges of radionuclides to atmosphere from the site.
- ***Fisherman in the Severn Estuary*** exposed to discharges of radionuclides to the Severn Estuary.
- ***Farming family close to new sewage treatment works*** who are exposed to the radionuclides incorporated into sewage sludge pellets used to condition their farm land.
- ***Sewage workers*** exposed to discharges reaching the new sewage treatment works.

- ***Anglers and children*** undertaking recreational activities in and around Whitchurch Brook and River Taff exposed to radionuclides in sewers overflowing from the sewer.

35. For discharges at the Agency's proposed annual limits and with all sewage improvement schemes completed, the critical group has been identified as a farming family who consume food which has been produced on their farmland conditioned by sewage sludge. Doses of 24-47 μSv/y have been assessed for different age groups within such a family. Doses to allotment holders at Radyr are 24 μSv/y and the dose to a fisherman on the Severn Estuary (once the sewage treatment works becomes operational) is 17 μSv/y. All these doses are less than the source constraint of 300 μSv/y and the annual public dose limit of 1000 μSv/y.

36. Doses from short duration discharges to atmosphere have also been assessed, with the highest dose is predicted to be 47 μSv/y to allotment holders at Radyr.

37. Collective doses, truncated at 500 years, have been assessed for releases to atmosphere and discharges to sewer (with sewage treatment) at Agency proposed limits; the world collective doses being 52 manSv and 13 manSv respectively. The highest per caput dose has been assessed as 36 nSv per year of discharge to atmosphere. On the basis of advice from NRPB, per caput doses at this level can be regarded as trivial.

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9 Nycomed Amersham Cardiff Laboratories (2001). Critical Group Dose Assessment for Routine Atmospheric Discharges from Cardiff Laboratories. RSA93/CL/RFI/0021. June 2001. Issue 1.

10 Nycomed Amersham Cardiff Laboratories (2001). Summary of Doses Resulting from Liquid Discharges. RSA93/CL/RFI/004. June 2001. Issue 1.

Table 1 Annual Limits for Radionuclide Discharges to Atmosphere

Radionuclide	Current Limits (TBq/y)	Agency Proposed Limits (TBq/y)
Soluble tritium[a]	400	156
Insoluble tritium[b]	1000	600
Carbon-14	6	2.38
Phosphorus-32/33	0.0002	0.000005
Iodine-125	0.0005	0.00018
Other activity[c]	0.04	0.001

[a] Assumed to be tritiated water.
[b] Assumed to be tritium gas of which 10% is converted to tritiated water and becomes available for uptake into plants (see Appendix 1).
[c] Assumed to be sulphur-35 as the most radiologically significant radionuclide in this category [Ref 9].

Table 2 Annual Limits for Radionuclide Discharges to Sewer

Radionuclide	Current Limits (TBq/y)	Agency Proposed Limits (TBq/y)
Total tritium	900	99
Carbon-14	2	0.91
Phosphorus-32/33	0.01	0.000085
Iodine-125	0.05	0.0003
Others[a]	0.0005	0.00012

[a] Assumed to be selenium-75 as the most radiologically significant radionuclide in this category [Ref 10].

Table 3 Short Term Radionuclide Limits for Discharges to Atmosphere

Radionuclide	Current Daily Limits (TBq/day)	Proposed Daily Limits (TBq/day)
Soluble tritium[a]	9	6.75
Insoluble tritium[b]	50	37.5
Carbon-14	0.18	0.135
Phosphorus-32/33	-	-
Iodine-125	-	-
Other activity[c]	0.005	0.000025

[a] Assumed to be tritiated water.
[b] Assumed to be tritium gas of which 10% is converted to tritiated water and becomes available for uptake into plants (see Appendix 1).
[c] Assumed to be sulphur-35 as the most radiologically significant radionuclide in this category [Ref 9].

Table 4 Summary of Individual Doses to Candidate Critical Groups (μSv/y)

Candidate Critical Group	Age Group	Current Limits		Proposed Limits	
Allotment holder at Radyr	Infant	55		22	
	Child	55		23	
	Adult	59		24	
Farming family near to site	Infant	18		7.1	
	Child	10		4.1	
	Adult	9.3		3.8	
		Before Sewerage Improvement Scheme	**After Sewerage Improvement Scheme**	**Before Sewerage Improvement Scheme**	**After Sewerage Improvement Scheme**
Fisherman in the Severn Estuary	Adult	100	35	76	17
Farming family using sludge conditioner	Infant	N/A	408	N/A	47
	Child	N/A	209	N/A	24
	Adult	N/A	210	N/A	24
Sewage workers (at new sewage works)	Adult	N/A	0.97	N/A	0.097
		Before overflow improvement scheme	**After overflow improvement Scheme**	**Before overflow improvement Scheme**	**After overflow improvement Scheme**
Playing in Whitchurch Brook	Child	0.094	0.0046	0.024	0.0012
	Adult	0.064	0.0031	0.014	0.00066
Anglers on River Taff	Child	17	0.83	11	0.54
	Adult	49	2.4	32	1.6

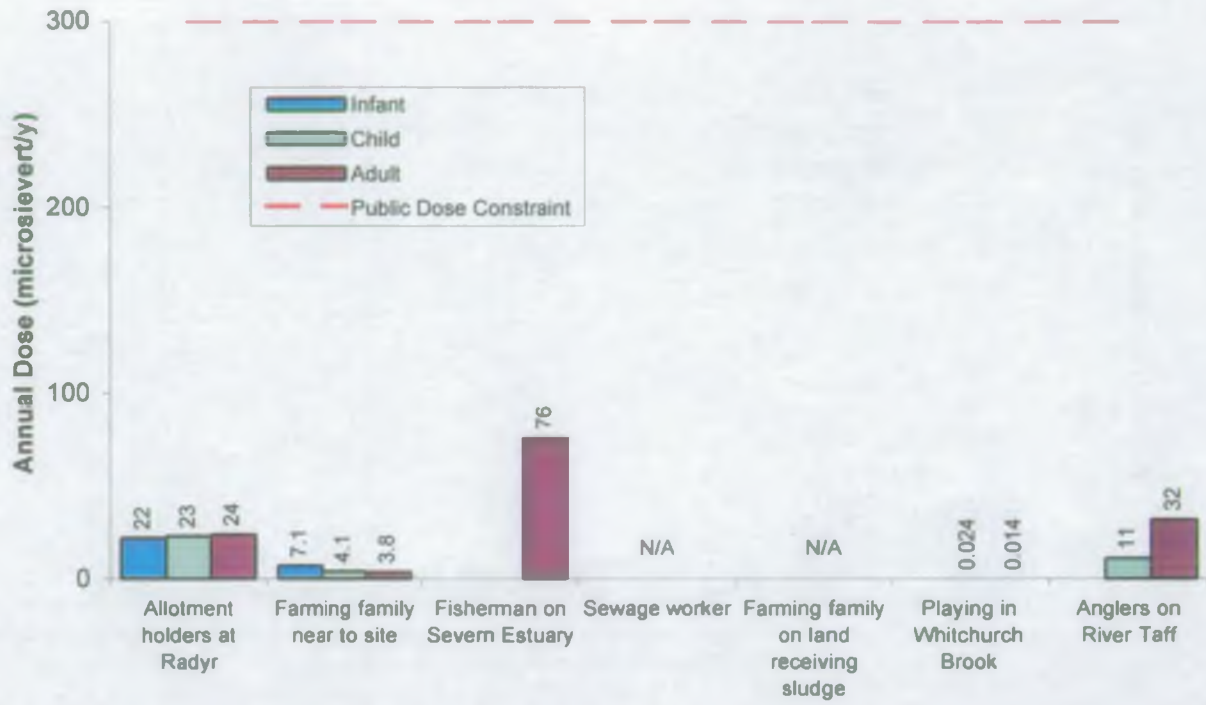

Figure 1 Summary of Doses to Candidate Critical Groups at the Proposed Discharge Limits before Sewage Improvement Schemes are Completed

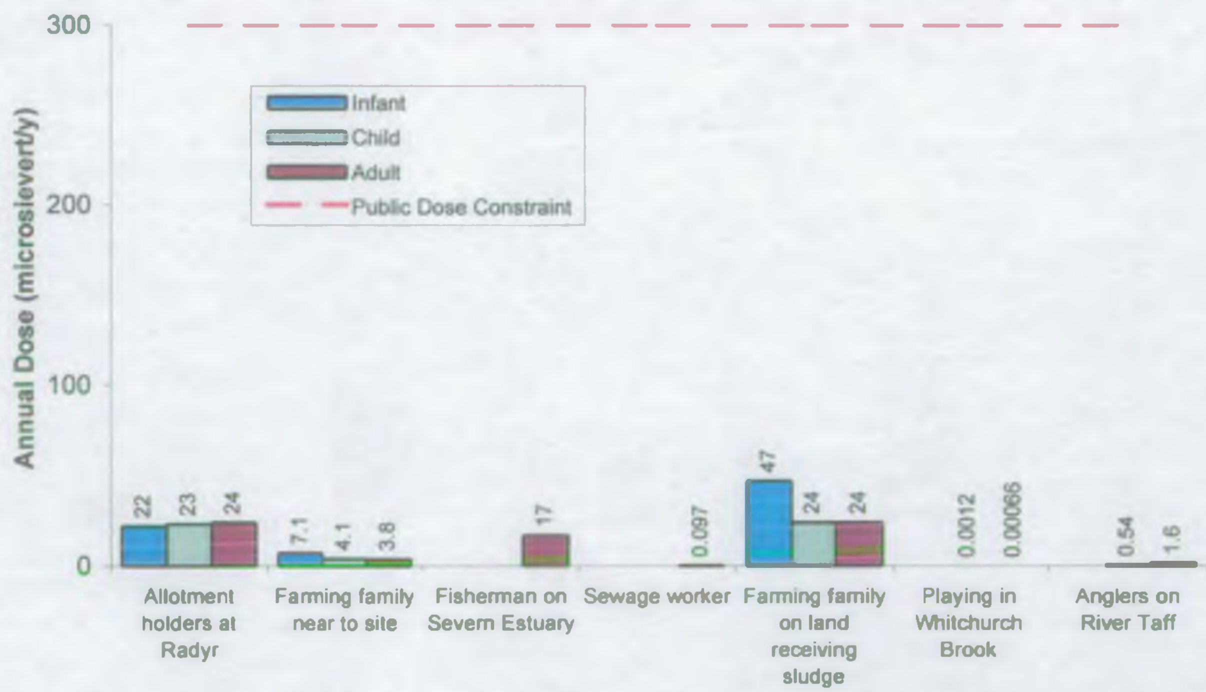

Figure 2 Summary of Doses to Candidate Critical Groups at the Proposed Discharge Limits after Sewage Improvement Schemes are Completed

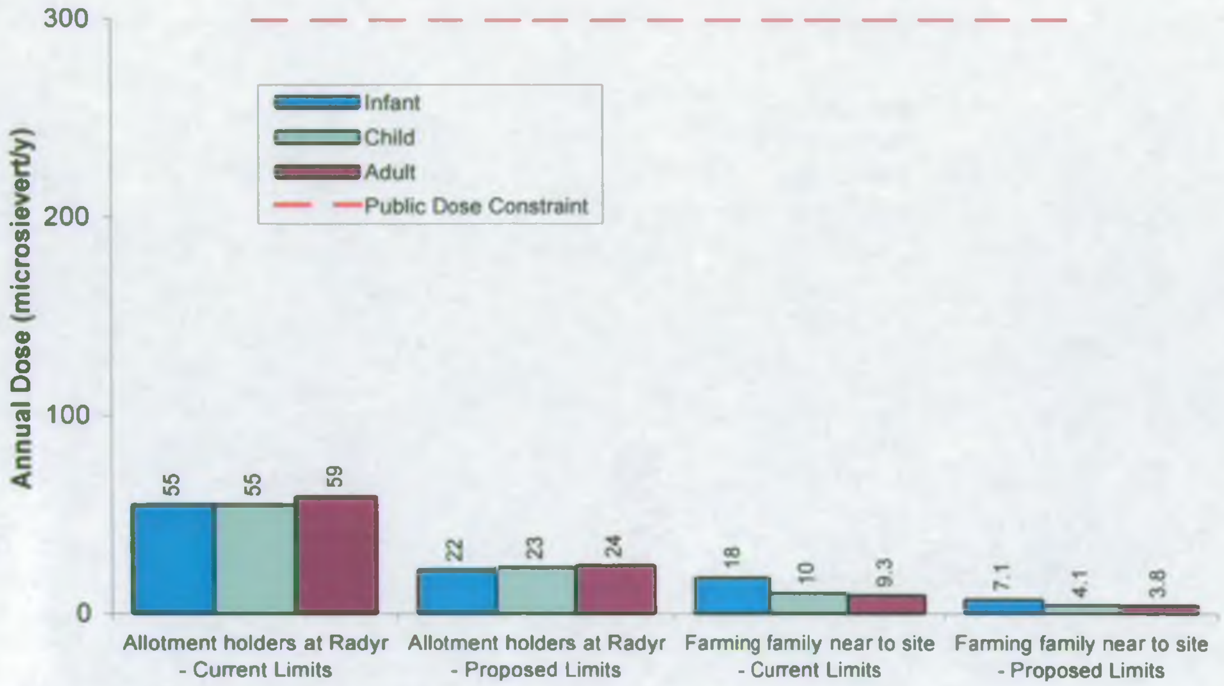

Figure 3 Doses to Candidate Critical Groups Exposed to Atmospheric Discharges at the Current and Proposed Discharge Limits

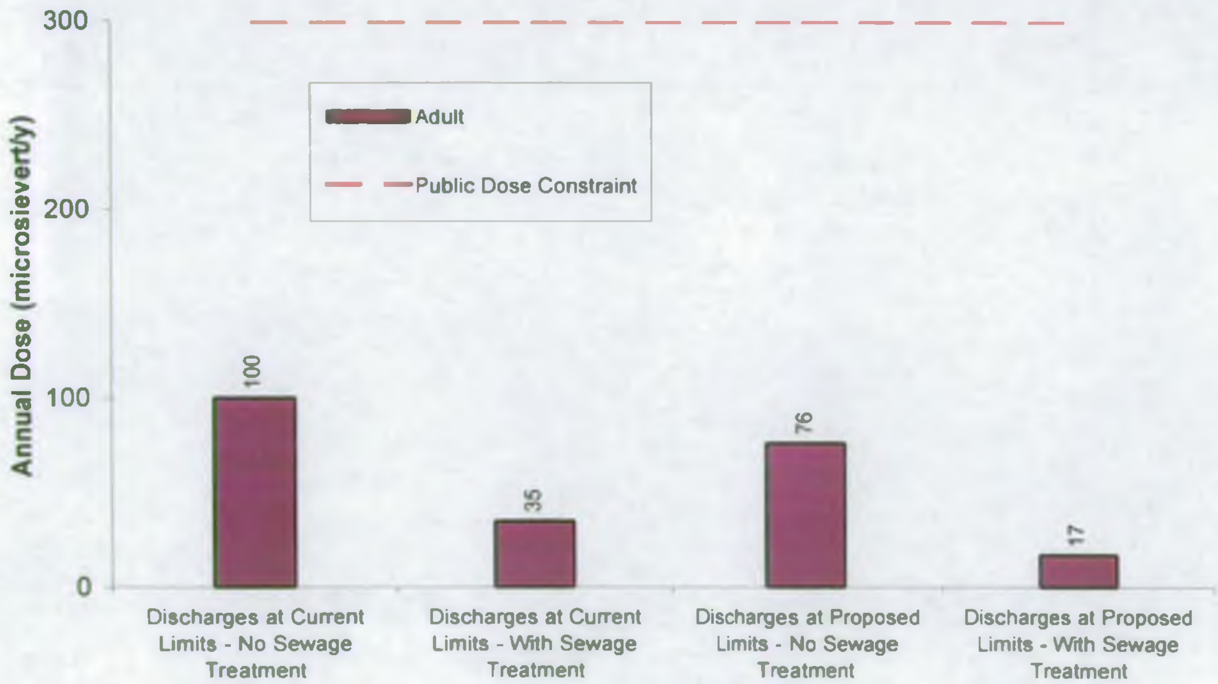

Figure 4 Doses to Fisherman at Current and Proposed Limits, with and without Sewage Treatment

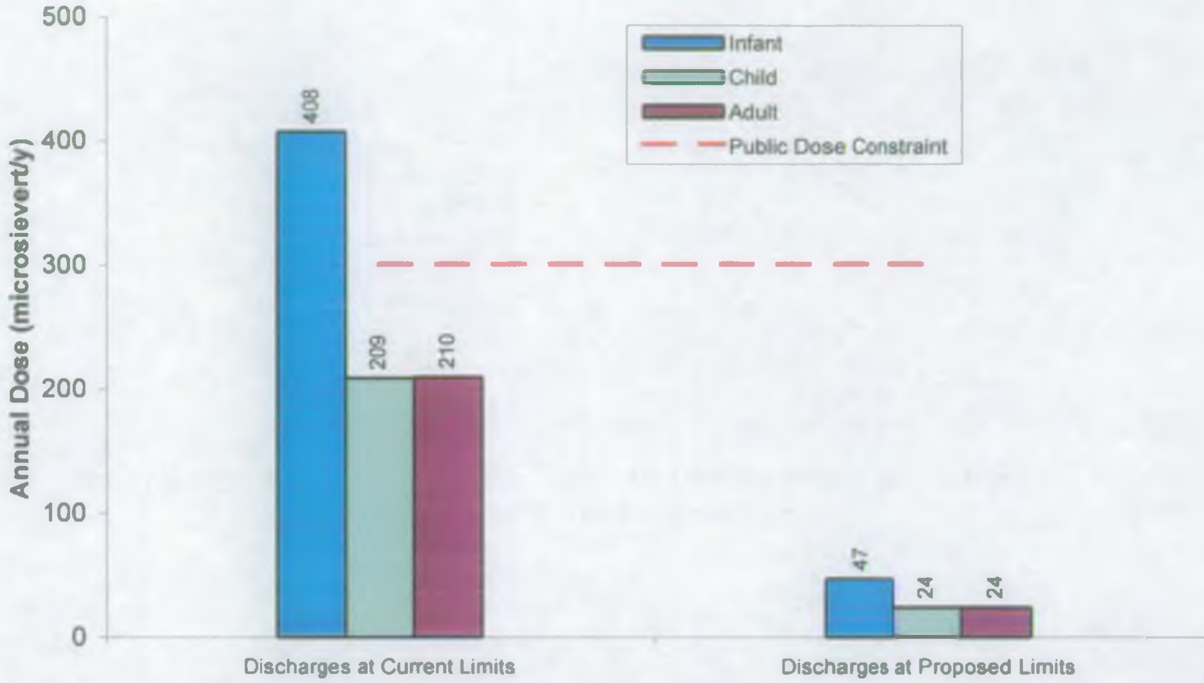

Figure 5 Doses to Farming Family using Sewage Sludge Pellets to Condition Land at the Current and Proposed Discharge Limits

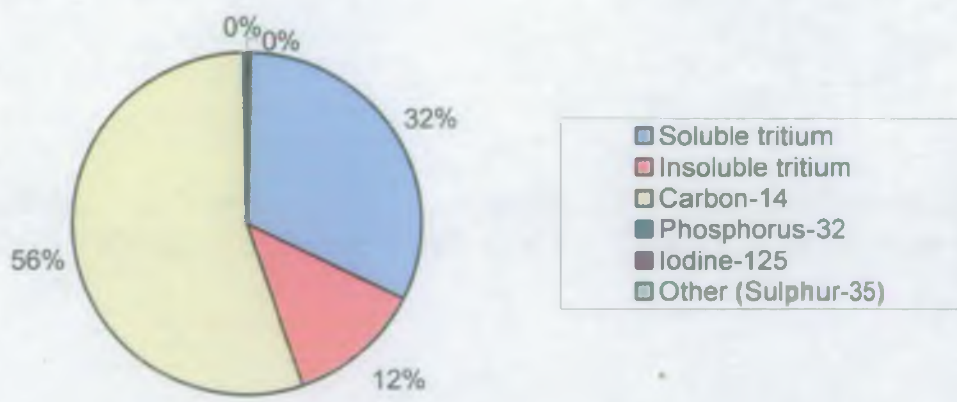

Figure 6 Contribution of Doses to Allotment Holders at Radyr for Discharges at Proposed Limits

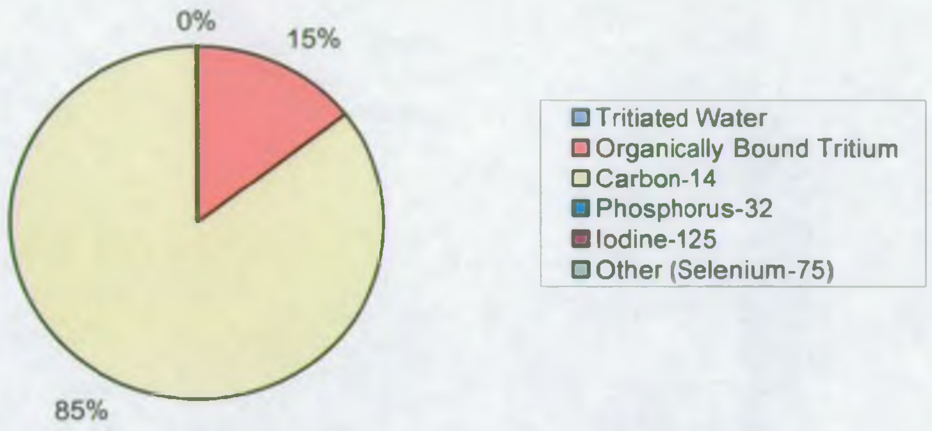

Figure 7 Contribution of Doses to Fisherman for Discharges at Proposed Limits with Operational Sewage Treatment Works

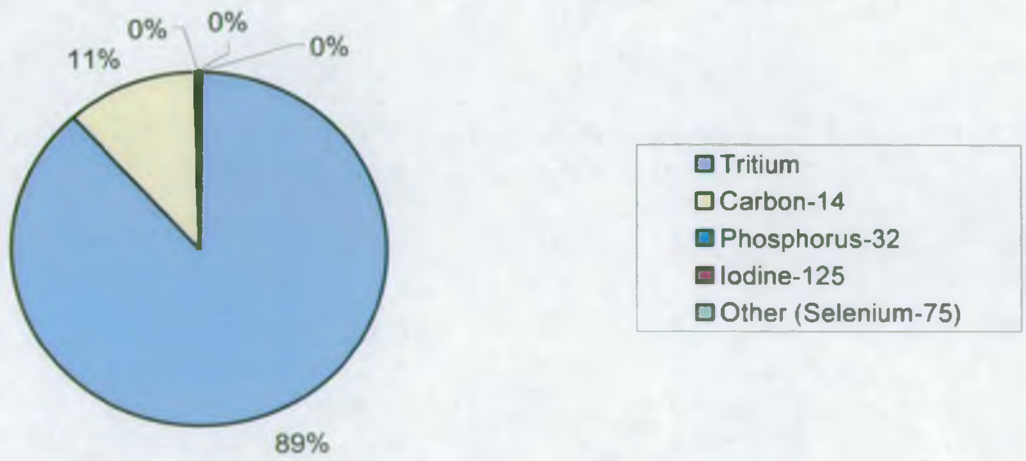

Figure 8 Contribution of Doses to Infant Member of Farming Family using Sewage Sludge Pellets to Condition Land with Discharges at Proposed Limits

APPENDIX 1 – METHODOLOGY AND DOSES FOR RADIOLOGICAL ASSESSMENT OF DISCHARGES TO ATMOSPHERE

Discharges to Atmosphere

A1.1 The current radionuclide limits and future radionuclide limits proposed by the Agency for discharges to atmosphere from the Cardiff site are detailed in Table 1. The categories for the limits include soluble tritium, insoluble tritium and 'others'. The soluble tritium will be largely tritiated water, insoluble tritium will be tritium gas and the 'others' category can be assumed to be sulphur-35 as the most radiologically significant radionuclide in this category [Ref A1.1].

A1.2 For the purpose of the radiological assessment, it has been assumed that up to 10% of the tritium gas is converted to tritiated water which is then available for take up into plants. A review of conversion rates for tritium into tritiated water indicates conversion rates of up to 0.02% per day (7.3% per year) [Ref A1.2].

A1.3 The majority of the atmospheric discharges from the site (95%) are made through the RP1 stack [Ref A1.3] which has a height of 50 m. It has been assumed that all discharges are made through this stack.

Modelling of Environmental Concentrations

A1.4 Environmental concentrations of radionuclides in the terrestrial environment from the discharges to be made under the current and proposed authorisations were predicted using PC CREAM [Ref A1.4]. PC CREAM calculates air activity concentrations, ground deposited activity and activity concentrations in food for each radionuclide at defined receptor points.

A1.5 The receptor points defined for the atmospheric discharges are those applicable to the terrestrial candidate critical groups and consist of the following:

- Residents in Radyr who produce food on nearby allotments.
- Farming family at closest farm and farmland.

A1.6 The distance, bearing and height of these locations above sea-level are given in Table A1.1. The stack RP1 is 50 m high and the site is 30 m above sea-level. However, the site is located at the bottom of the River Taff valley, and the receptor locations are on the valley sides at greater heights above sea level. An effective stack height has therefore been used in the assessment, taking into account the height of the receptor points relative to the top of the stack.

A1.7 The Gaussian plume atmospheric dispersion model in PC CREAM was used to calculate air activity concentrations for each radionuclide. Average annual weather with a uniform windrose has been used for the baseline assessment, taken to be 65%D weather for the Cardiff area [Ref A1.5] and confirmed by meteorological data.

A1.8 Concentrations in foods at Radyr and the nearest farm were predicted from the air concentration and deposition velocity and an equilibrium food chain model.

Habit Data

A1.9 The exposure pathways considered in the assessment were: Inhalation of radionuclides from the plume, beta and gamma radiation from the plume, beta and gamma radiation from radionuclides deposited on the ground, inhalation of radionuclides resuspended from the ground following deposition, and ingestion of foods produced on land affected by radionuclides in the plume.

A1.10 Doses to candidate critical groups were calculated using the predicted environmental concentrations and information of food intakes and occupancy of the environment at Radyr and the nearest farm, occupancy at the locations, time spent indoors and outdoors and breathing rates. It has been assumed that the candidate critical group at Radyr have allotments which produces sufficient fruit, green vegetables and root vegetables to provide 100% of the annual intakes of one or more families at critical rates. The nearest farm is assumed to raise beef and dairy cows, sheep and a range of fruit and vegetables to provide the entire food supply of a family living at the farm. The candidate critical group at the farm is assumed to eat two foods giving the highest doses at critical consumption rates and all other foods at mean consumption rates. Intake rates established from UK surveys reported by NRPB [Ref A1.6] have been used in the assessment. These are summarised in Table A1.2 for candidate critical group at Radyr and Table A1.3 for candidate critical group at the nearest farm.

A1.11 Average groups have also been defined who consume foods from the farm (Table A1.3) or from the allotment (Table A1.2) at mean rates.

Calculation of Doses to Candidate Critical Groups

A1.12 Effective doses to infant, child and adult candidate critical groups were calculated using PC CREAM using ingestion dose coefficients from the Euratom Basic Safety Standards Directive [Ref A1.7], habit data and the predicted concentrations of radionuclides in air and foods.

Assessed Doses to Candidate Critical Groups

A1.13 The doses to candidate critical groups and groups with mean habits for a unit discharge of 1TBq/ per year at Radyr and at the closest farm are shown in Tables A1.4 and A1.5 respectively. Doses to candidate critical groups at Radyr and the closest farm at the current and proposed discharge limits are shown in Tables A1.6 and A1.7 respectively. Doses to the mean consumers at Radyr and the closest are shown in Tables A1.8 and A1.9 respectively.

A1.14 The highest doses are to the candidate critical group at Radyr. The contribution of each exposure pathway to the adult members of the candidate critical group at Radyr at proposed limits are shown in Table A1.10.

References

A1.1 Nycomed Amersham Cardiff Laboratories (2001). Critical Group Dose Assessment for Routine Atmospheric Discharges from Cardiff Laboratories. RSA93/CL/RFI/0021. June 2001. Issue 1.

A1.2 N A Higgins, P V Shaw, S M Haywood and J A Jones (1996). A Dynamic Model for Predicting the Transfer of Tritium through the Terrestrial Foodchain. NRPB-R278.

A1.3 Nycomed Amersham Cardiff Laboratories (2001). Atmospheric Dispersion Modelling for Routine Atmospheric Discharges at Cardiff Laboratories. RSA93/CL/RFI/0024. June 2001. Issue 1.

A1.4 Mayall A, Cabianca T, Attwood C, Fayers CA, Smith JG, Penfold J, Steadman D, Martin G, Morris TP and Simmonds JR. PC CREAM-97 (PC CREAM-98 code update) NRPB Chilton NRPB-SR-296 (EUR 17791) (1997).

A1.5 R H Clarke (1979). The First Report of a Working Group on Atmospheric Dispersion: A Model for Short and Medium Range Dispersion of Radionuclides Released to the Atmosphere. NRPB-R91.

A1.6 Robinson CA (1996). Generalised Habit Data for Radiological Assessments. NRPB-M636.

A1.7 Council Directive 96/29 Euratom of 13 May 1996, Laying Down Basic Safety Standards for the Protection of the Health of Workers and the General Public Against the Dangers Arising from Ionising Radiation. Official Journal of the European Communities, L159, Volume 39, 29 June 1996.

Table A1.1 Location of Receptor Points Compared to the Main Stack RP1

Receptor location	Height above sea level (m)	Effective height of stack compared to receptor location[a]	Distance from Stack RP1 (m)	Bearing from Stack RP1 (deg)
Dwelling and allotment in Radyr on hillside facing site	60	20	400	270°
Closest farm and farmland	65	15	1900	190°

[a] Stack RP1 is at a height of 50 m above ground-level which is at a height of 30 m above sea level, giving a height above sea-level of 80 m.

Table A1.2 Critical and Mean Food Consumption and Occupancy Rates for Dwelling at Radyr

Food and Occupancy types	Consumption Rates or Occupancy Rates					
	Infant		Child - 10y		Adult	
Food Types (kg/y)	**Critical**	**Mean[b]**	**Critical**	**Mean[b]**	**Critical**	**Mean[b]**
Green vegetables[c]	15	5	35	15	80	35
Root vegetables[d]	45	15	95	50	130	60
Fruit[e]	35	10	50	15	75	20
Occupancy Types[a] (h/y)						
Inside building in Radyr area	7090		6300		6080	
Outside building in Radyr area	790		1580		680	

[a] Assumes infants and children spend 90% of their time in the Radyr area (eg at school), of which 90% is spent indoors for infants and 80% indoors for children. Adults spend 2000 hours away from the Radyr area at work, and 90% of the remaining time is spent indoors and 10% outdoors.
[b] Mean consumers
[c] Green vegetables and other domestic vegetables
[d] Root vegetables and potatoes
[e] Domestic fruit

Table A1.3 Critical and Mean Food Consumption and Occupancy Rates at Nearest Farm

Food and Occupancy types	Population Groups and Habit Types					
	Infant		Child		Adult	
Food Types (kg/y)	**Critical[f]**	**Mean[b]**	**Critical[f]**	**Mean[b]**	**Critical[f]**	**Mean[b]**
Milk	320	130	240	110	240	95
Milk products	0	0	0	0	0	0
Beef	3	3	15	15	15	15
Beef offal	0.5	0.5	1.5	1.5	2.75	2.75
Mutton	0.8	0.8	4	4	8	8
Sheep offal	0.5	0.5	1.5	1.5	2.75	2.75
Green vegetables[c]	5	5	15	15	35	35
Root vegetables[d]	45	15	95	50	130	60
Fruit[e]	9	9	15	15	20	20
Occupancy Types[a] (h/y)						
Inside on farm	7090	0	6300	0	3880	0
Outside on farm	790	0	1580	0	4000	0
Total	**7880**	**0**	**7880**	**0**	**7880**	**0**

[a] Assumes infants and children spend 90% of their time at a similar distance from the site as the farm (eg at school), of which 90% is spent indoors for infants and 80% indoors for children. Adults spend 90% of their time on the farm of which 4000 hours is spent outside.
[b] Mean consumers
[c] Green vegetables and other domestic vegetables
[d] Root vegetables and potatoes
[e] Domestic fruit
[f] Worst two foods at critical rates, remainder at mean

Table A1.4 Dose per Unit Discharge for Candidate Critical Group and Mean Group at Radyr (µSv/y per TBq)

Radionuclide	Infant		Child		Adult	
	Critical	Mean	Critical	Mean	Critical	Mean
Soluble tritium	4.23E-02	2.08E-02	4.43E-02	2.82E-02	5.01E-02	2.85E-02
Insoluble tritium	4.23E-03	2.08E-03	4.43E-03	2.82E-03	5.01E-03	2.85E-03
Carbon-14	5.52E+00	2.06E+00	5.41E+00	2.74E+00	5.64E+00	2.54E+00
Phosphorus-32	4.56E+01	1.60E+01	2.63E+01	1.41E+01	1.76E+01	8.45E+00
Others[a]	4.79E+00	1.92E+00	3.25E+00	1.88E+00	2.52E+00	1.39E+00
Iodine-125	3.01E+02	9.81E+01	3.18E+02	1.45E+02	2.56E+02	1.07E+02

[a] Assumed to be sulphur-35

Table A1.5 Dose per Unit Discharge for Candidate Critical and Mean Group at Closest Farm (µSv/y per TBq)

Radionuclide	Infant		Child		Adult	
	Critical	Mean	Critical	Mean	Critical	Mean
Soluble tritium	1.65E-02	6.54E-03	8.89E-03	3.88E-03	8.23E-03	3.34E-03
Insoluble tritium	1.65E-03	6.54E-04	8.89E-04	3.88E-04	8.23E-04	3.34E-04
Carbon-14	1.46E+00	6.27E-01	9.22E-01	5.08E-01	8.30E-01	4.35E-01
Phosphorus-32	4.44E+01	1.81E+01	1.21E+01	6.23E+00	6.31E+00	3.01E+00
Others[a]	2.39E+01	1.12E+01	8.45E+00	5.73E+00	4.94E+00	3.40E+00
Iodine-125	2.14E+02	9.01E+01	1.06E+02	5.63E+01	5.92E+01	3.01E+01

[a] Assumed to be sulphur-35

Table A1.6 Doses to Candidate Critical Group at Radyr Dwelling/Allotment at Current Limits and Proposed Limits (µSv/y)

Radionuclide	Current Limits			Proposed Limits		
	Infant	Child	Adult	Infant	Child	Adult
Soluble tritium	1.69E+01	1.77E+01	2.00E+01	6.60E+00	6.91E+00	7.81E+00
Insoluble tritium	4.23E+00	4.43E+00	5.01E+00	2.54E+00	2.66E+00	3.01E+00
Total tritium	*2.11E+01*	*2.21E+01*	*2.50E+01*	*9.14E+00*	*9.57E+00*	*1.08E+01*
Carbon-14	3.31E+01	3.25E+01	3.38E+01	1.31E+01	1.29E+01	1.34E+01
Phosphorus-32	9.11E-03	5.26E-03	3.53E-03	2.28E-04	1.31E-04	8.82E-05
Others[a]	1.91E-01	1.30E-01	1.01E-01	4.79E-03	3.25E-03	2.52E-03
Iodine-125	1.51E-01	1.59E-01	1.28E-01	5.42E-02	5.73E-02	4.61E-02
Total	**5.46E+01**	**5.49E+01**	**5.91E+01**	**2.23E+01**	**2.25E+01**	**2.43E+01**

[a] Assumed to be sulphur-35

Table A1.7 Doses to Candidate Critical Group Farming Family at Closest Farm from Discharges at Current and Proposed Limits (μSv/y)

Radionuclide	Current Limits			Proposed Limits		
	Infant	Child	Adult	Infant	Child	Adult
Soluble tritium	6.62E+00	3.56E+00	3.29E+00	2.58E+00	1.39E+00	1.28E+00
Insoluble tritium	1.65E+00	8.89E-01	8.23E-01	9.93E-01	5.33E-01	4.94E-01
Total tritium	*8.27E+00*	*4.44E+00*	*4.11E+00*	*3.57E+00*	*1.92E+00*	*1.78E+00*
Carbon-14	8.76E+00	5.53E+00	4.98E+00	3.48E+00	2.19E+00	1.98E+00
Phosphorus-32	8.89E-03	2.42E-03	1.26E-03	2.22E-04	6.05E-05	3.15E-05
Others[a]	9.57E-01	3.38E-01	1.97E-01	2.39E-02	8.45E-03	4.94E-03
Iodine-125	1.07E-01	5.32E-02	2.96E-02	3.85E-02	1.92E-02	1.07E-02
Total	**1.81E+01**	**1.04E+01**	**9.32E+00**	**7.11E+00**	**4.14E+00**	**3.77E+00**

[a] Assumed to be sulphur-35

Table A1.8 Doses to Mean Group at Radyr Dwelling/Allotment at Current Limits and Proposed Limits (μSv/y)

Radionuclide	Current Limits			Proposed Limits		
	Infant	Child	Adult	Infant	Child	Adult
Soluble tritium	8.31E+00	1.13E+01	1.14E+01	3.24E+00	4.40E+00	4.45E+00
Insoluble tritium	2.08E+00	2.82E+00	2.85E+00	1.25E+00	1.69E+00	1.71E+00
Total tritium	*1.04E+01*	*1.41E+01*	*1.43E+01*	*4.49E+00*	*6.09E+00*	*6.16E+00*
Carbon-14	1.24E+01	1.65E+01	1.53E+01	4.91E+00	6.53E+00	6.05E+00
Phosphorus-32	3.21E-03	2.82E-03	1.69E-03	8.02E-05	7.04E-05	4.23E-05
Others[a]	7.69E-02	7.54E-02	5.56E-02	1.92E-03	1.88E-03	1.39E-03
Iodine-125	4.90E-02	7.26E-02	5.36E-02	1.76E-02	2.61E-02	1.93E-02
Total	**2.29E+01**	**3.07E+01**	**2.96E+01**	**9.41E+00**	**1.26E+01**	**1.22E+01**

[a] Assumed to be sulphur-35

Table A1.9 Doses to Mean Consumers of Produce from Closest Farm from Discharges at Current and Proposed Limits (μSv/y)

Radionuclide	Current Limits			Proposed Limits		
	Infant	Child	Adult	Infant	Child	Adult
Soluble tritium	2.62E+00	1.55E+00	1.33E+00	1.02E+00	6.05E-01	5.21E-01
Insoluble tritium	6.54E-01	3.88E-01	3.34E-01	3.92E-01	2.33E-01	2.00E-01
Total tritium	*3.27E+00*	*1.94E+00*	*1.67E+00*	*1.41E+00*	*8.37E-01*	*7.21E-01*
Carbon-14	3.76E+00	3.05E+00	2.61E+00	1.49E+00	1.21E+00	1.04E+00
Phosphorus-32	3.62E-03	1.25E-03	6.03E-04	9.05E-05	3.12E-05	1.51E-05
Others[a]	4.48E-01	2.29E-01	1.36E-01	1.12E-02	5.73E-03	3.40E-03
Iodine-125	4.51E-02	2.81E-02	1.50E-02	1.62E-02	1.01E-02	5.42E-03
Total	**7.53E+00**	**5.24E+00**	**4.43E+00**	**2.93E+00**	**2.06E+00**	**1.77E+00**

[a] Assumed to be sulphur-35

Table A1.10 Doses by Pathway and Radionuclide to the Candidate Critical Group (Adults) (μSv/y) at Radyr from Discharges at Proposed Limits

Radionuclide	Inhalation	Cloud gamma	Deposited gamma	Inhalation of resuspended activity	Cloud beta	Deposited beta	Green vegetables	Root vegetables	Fruit	Total	Percent
H-3 soluble	2.17E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.72E+00	2.50E+00	1.44E+00	**7.81E+00**	32.16%
H-3 insoluble	8.33E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.60E-01	9.60E-01	5.52E-01	**3.01E+00**	12.37%
Total tritium	*3.00E+00*	*0.00E+00*	*0.00E+00*	*0.00E+00*	*0.00E+00*	*0.00E+00*	*2.38E+00*	*3.46E+00*	*1.99E+00*	***1.08E+01***	*44.53%*
C-14	1.19E+00	0.00E+00	0.00E+00	0.00E+00	3.57E-05	0.00E+00	2.00E+00	6.43E+00	3.81E+00	**1.34E+01**	55.27%
Phosphorus-32	1.58E-06	0.00E+00	0.00E+00	6.50E-10	4.95E-09	2.75E-06	5.50E-06	7.50E-05	3.40E-06	**8.82E-05**	0.00%
Others (S-35)	5.79E-04	0.00E+00	0.00E+00	4.10E-07	5.60E-08	0.00E+00	7.00E-04	8.90E-04	3.50E-04	**2.52E-03**	0.01%
I-125	3.75E-04	3.24E-08	3.78E-05	1.98E-06	0.00E+00	0.00E+00	1.66E-02	1.98E-02	9.36E-03	**4.61E-02**	0.19%
Total	**4.20E+00**	**3.24E-08**	**3.78E-05**	**2.39E-06**	**3.58E-05**	**2.75E-06**	**4.39E+00**	**9.90E+00**	**5.80E+00**	**2.43E+01**	100.00%
Percent	17.27%	0.00%	0.00%	0.00%	0.00%	0.00%	18.08%	40.76%	23.89%	100.00%	

APPENDIX 2 – METHODOLOGY AND DOSES FOR RADIOLOGICAL ASSESSMENT OF LIQUID DISCHARGES TO THE SEVERN ESTUARY

Discharges Reaching the Severn Estuary

A2.1 The current radionuclide limits and future radionuclide limits proposed by the Agency for discharges to sewer from the Amersham plc site are given in Table 2.

A2.2 Currently, discharges to the sewer are mixed with other sewage from the Cardiff area and the resultant effluent is discharged into the Severn Estuary. However, a sewage treatment works is under construction to treat this sewage, prior to discharge of the treated effluent to the Severn Estuary. This sewage treatment works is due to commence operation in early 2002.

A2.3 Consequently, there are four discharge scenarios:

- Discharges of radionuclides at current limits, with no sewage treatment.
- Discharges of radionuclides at current limits, with sewage treatment.
- Discharges of radionuclides at proposed limits, with no sewage treatment.
- Discharges of radionuclides at proposed limits, with sewage treatment.

A2.4 Discharges of radionuclides into the Severn Estuary arising from these four scenarios assumed for the assessment are provided in Table A2.1. In deriving, these discharges, assumptions have to be made concerning the chemical form of the radionuclides, their behaviour during sewage treatment and in the environment.

A2.5 Discharges of tritium are a mixture of different chemical compounds containing tritium. For the purposes of the assessment the compounds have been divided into two groups, tritiated water and organic compounds termed, organically bound tritium or OBT. The two compound types behave differently in the environment. Tritium as tritiated water is thought to be fairly mobile and does not concentrate significantly, levels in sediments, fish and shellfish are broadly similar to those in the surrounding waters. Tritium as OBT is less mobile and there is evidence that tritium concentrations in sediments, fish and shellfish may be significantly higher than the corresponding concentrations in the surrounding waters. Around other sites that discharge tritium but not as OBT, there is very little enhancement of tritium in fish and shellfish (e.g. around Sellafield) [Ref A2.1, A2.2].

A2.6 The presence of organically bound tritium (OBT) in the effluent from the Cardiff site and its subsequent uptake by marine organisms in the Severn Estuary has been the subject of fairly intensive studies over the last few years (eg Ref A2.3) and monitoring results have been reported in the Agency's Radioactivity in the Environment Report [Ref A2.1] and the Food Standards Agency's Radioactivity in Food and the Environment [Ref A2.4].

Chemical Composition of Tritium in the Discharges

A2.7 The likely chemical composition of tritium in the discharges were determined from recent measurements in the effluents from the Amersham site. The Agency undertakes independent analysis of the liquid effluent, and since autumn 1997, the analysis included tritiated water and total tritium. An estimate of the OBT concentrations can be made from the difference between the measurements of the total tritium concentration and tritiated water concentration (Table A2.2). The errors in the estimated OBT concentrations are quite large because they are derived by subtracting two numbers with relatively large errors.

A2.8 The results indicate that between 1997 and 2000 the OBT in the tritium discharge ranged from 0 to 21% of the total tritium (see Table A2.2).

A2.9 Two other samples of effluent taken in 1998 were analysed by CEFAS as part of studies on the uptake of OBT into fish [Ref A2.5, A2.6]. For a sample representing post May 1998 discharges, the OBT content was found to be about 55% of the total tritium, whereas a sample taken on 27/8/98 had an OBT content of about 2%.

A2.10 The monitoring shows considerable variation in the OBT analytical results. The variability is due in part to variations in discharges of OBT from the site and the immiscibility of organic and water phases within the liquid waste stream which can make collecting a representative sample difficult.

A2.11 The discharges of total tritium from the site are known to have reduced quite considerably since 1997 and most of this reduction was achieved by withholding tritiated water from discharge. The discharge of waste liquid OBT at the site has remained relatively constant. Taking these factors into account, an upper bound (95% confidence level) of annual OBT discharges into the Severn Estuary has been derived in Table A2.3, based on the reported annual discharges of total tritium and the average percentage of OBT in samples analysed by the Agency during those years. The average upper bound discharge over the last four years has been 24 TBq/y of OBT. Discharges of OBT are likely have been fairly constant in the past and are likely to remain constant in the future. Therefore the discharge of OBT at 24 TBq/y has been used as the OBT discharge for current and proposed limits in the assessments prior to operation of the sewage treatment works. The remainder of the limits for total tritium have been assumed to be tritiated water (see Table A2.4).

Behaviour of Radionuclides during Treatment at Sewage Treatment Works

A2.12 Experimental studies have been undertaken by WRc [Ref A2.7] on the likely fate of tritium and carbon-14 during treatment of sewage at the new sewage works. The study showed that on average, 12% of the tritium and carbon-14 in raw effluent were transferred to solid matter. Other research suggested that 10% of tritium and 30% of carbon-14 would be transferred to sludge. The studies by WRc showed that about 1% of the tritium would be lost to the gaseous phase and up to 40% of the carbon-14 would be released to the gaseous phase. However, it has been cautiously assumed for the purposes of assessing discharges to the Severn Estuary, that the remainder of the radionuclides not incorporated in sewage sludge are discharged to the estuary. The

WRc study also showed that 95% of the OBT in the raw sewage effluent was converted to tritiated water and tritiated bicarbonate during treatment.

A2.13 The results of other studies on the behaviour of phosphorus-32 and iodine-125 at sewage works were used to determine the most likely behaviour during treatment.

A2.14 The assumptions made in this assessment concerning the behaviour of radionuclides during treatment are summarised in Table A2.5.

Modelling of Environmental Concentrations

A2.15 The assessment of environmental concentrations in the Severn Estuary and doses to candidate critical groups was performed using PC CREAM [Ref A2.8]. This is a software system for assessing the consequences of radionuclide discharges to the environment. The PC CREAM system employs a set of pre-defined regional water compartments around the UK, into which was inserted a 'local' compartment for the Severn Estuary. A range of parameter values are required for this local compartment to enable PC CREAM to model seawater and sediment concentrations.

A2.16 A key parameter is the volumetric exchange of water in the local compartment with the regional compartment. In a previous radiological assessment undertaken by NRPB, a volumetric exchange rate of $5\ 10^9\ m^3/y$ was derived on the basis of two tides per day, the tidal reach and the cross-sectional area of the local compartment. Given that the site discharges tritium, predominantly in the form of tritiated water, the known discharges of total tritium and measured concentrations of total tritium in seawater can be used to establish the volumetric exchange rate (see Table A2.6). The remaining parameter values used for the local compartment are summarised in Table A2.7.

A2.17 PC CREAM uses concentration factors between sea water and marine organisms to derive the concentrations of radionuclides in different marine organisms which are consumed as seafood. Default concentration factors, as defined in Reference A2.9, have been used for fish, crustacea and molluscs for all radionuclides except OBT.

Behaviour of OBT

A2.18 Concentration factors for OBT between Severn Estuary water and fish and shellfish have been derived by modelling the expected OBT concentration in seawater in the Severn Estuary from the upper bound estimates of annual discharges of OBT (Table A2.3) and the volumetric exchange rate for the local compartment (Table A2.6) and then comparing the predicted seawater concentrations of OBT with the measured concentrations of total tritium in fish and shellfish (see Table A2.8). The percentage of OBT in fish is greater than 90% [Ref A2.6], thus the total tritium monitoring data for fish and shellfish are a reasonable estimate of the OBT concentration. The resulting average concentration factor between sea water and fish and shellfish for OBT is 14000 Bq/kg per Bq/l. Concentrations factors have been derived in a similar manner for OBT uptake into duck (see Table A2.8).

A2.19 The concentration factors of 14000 Bq/kg per Bq/l are more consistent with the default concentration factors for carbon-14 in fish and shellfish used by PC CREAM of about 20 000 Bq/kg per Bq/l [Ref A2.9].

A2.20 These values for the concentration factors are clearly higher than concentration factors of less than about 1000 which may be derived from a comparison of total tritium monitored concentrations of tritium in fish and shellfish with seawater [Ref A2.2, A2.10]. This is to be expected, since the OBT concentration within seawater is a fraction of the total tritium concentrations. It is more likely that the organic forms of tritium are concentrating within marine organisms and therefore the higher concentration factors have been used in the assessment as shown in Table 2.9.

Habit Data

A2.21 The main dose pathways are intakes of radionuclides via ingestion of marine foods. External doses from the radionuclides discharged from Amersham is a less important dose pathway because the radionuclides discharged from the site do not emit significant gamma radiation. Doses from intakes of radionuclides in seaspray and sediment are usually less important than seafoods because the quantities of material ingested or in haled are relatively small and the concentration of radionuclides are low relative to sea foods. The candidate critical group is therefore likely to be comprised of fishermen and anglers who spend time in the estuary fishing and consume much of what they catch.

A2.22 Doses to the candidate critical group from discharges to the Severn estuary were calculated using habit data for consumption rate of seafoods from the Severn, occupancy over sediment and intakes rates of seaspray and sediment. Habit data was obtained from habit surveys undertaken by the Food Standards Agency (previously MAFF) which are reported in the Radioactivity in Food and the Environment series of reports (Ref A2.11, A2.12, A2.13, A2.14, A2.4). The published habit data around Cardiff have been collated in Table A2.10 and the seafood highest consumption and occupancy rates for the Severn over the last 5 years have been selected.

A2.23 There is no data for consumption of local duck around Cardiff and so data have been taken from UK wide habit data. It is considered likely that a fisherman would consume seafood at high (critical) rates, but that duck consumption rates would be average. Thus, it has been assumed that a fisherman consumes local duck at UK mean consumption rates for game meat (Table A2.10).

A2.24 Habit data for mean consumers of fish and shellfish have also been calculated based on UK wide habit data (Table A2.11).

Calculation of Doses to Candidate Critical Group

A2.25 Ingestion and inhalation dose coefficients from the Euratom Basic Safety Standards Directive [Ref A2.15] and habit data and environmental concentrations specified above were used to calculate doses to the marine candidate critical groups and to average groups.

Assessed Doses to Candidate Critical Group

A2.26 Doses to the marine candidate critical group (fisherman) and mean group per unit discharge (TBq/y) are shown in Tables A2.12, A2.13, A2.14 and A2.15.

A2.27 Doses to the fisherman at current and proposed discharge limits with and without the sewage works (Table A2.1) are shown in Table A2.16. The contribution of exposure pathways to the fisherman are shown in Table A2.17.

A2.28 Doses to the mean group infants, children and adults are shown in Tables A2.18, A2.19 and A2.20.

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Table A2.1 Discharges reaching the Severn Estuary Before and After the Introduction of the Sewage Treatment Works assumed for the assessment

Radionuclide	Current Limits (TBq/y)		Agency Proposed Limits (TBq/y)	
	Prior to operation of STW	STW operational	Prior to operation of STW	STW operational
Total tritium	900	810	99	89.1
Tritiated water	876	808.92[b]	75	88.02[b]
Organically bound tritium	24	1.08[b]	24	1.08[b]
Carbon-14	2	1.4	0.91	0.637
Phosphorus-32/33	0.01	0.002	0.000085	0.000017
Iodine-125	0.05	0.045	0.0003	0.00027
Others[a]	0.0005	0.0005	0.00012	0.00012

[a] Assumed to be selenium-75 as the most radiologically significant radionuclide in this category [Ref A2.10].
[b] Assuming 95% of the OBT converted to HTO at the works.

Table A2.2 Agency Independent Analysis of Amersham plc Cardiff's Liquid Effluent[a]

Sample Date	Total Tritium[b] (Bq/l)	Tritiated Water[b] (Bq/l)	OBT[c] (Bq/l)
Q4 97	13660000 ± 1020000	15740000 ± 10000	0 ± 1020049
Q1 98	19020000 ± 1430000	19140000 ± 10000	0 ± 1430035
Q2 98	23010000 ± 1730000	23250000 ± 1160000	0 ± 2082907
Q3 98	4330000 ± 320000	4450000 ± 230000	0 ± 394081
Q4 98	2060000 ± 150000	2050000 ± 100000	10000 ± 180278
Q1 99	2240000 ± 170000	2200000 ± 110000	40000 ± 202485
Q2 99	4060000 ± 300000	3800000 ± 190000	260000 ± 355106
Q3 99	1950000 ± 150000	1820000 ± 90000	130000 ± 174929
Q4 99	467000 ± 35000	436000 ± 22000	31000 ± 41340
Q1 00	2610000 ± 130000	2510000 ± 60000	100000 ± 143178
Q2 00	991035 ± 74370	965685 ± 48285	25350 ± 88670
Q3 00	1932100 ± 48300	1673200 ± 49800	258900 ± 69375
Q4 00	1790000 ± 72000	670000 ± 35000	1120000 ± 80056

[a] Errors at 95% confidence level
[b] From Reference A2.2
[c] Calculated from the difference between total tritium and tritiated water analytical results.

Table A2.3 Estimate of OBT Discharge from Amersham plc Cardiff

Year	%OBT in Effluent[a]	Upper Bound (95% confidence level)	Discharge of Total Tritium[b] (TBq/y)	Estimated Discharge of OBT (TBq/y)	
				Average	Upper Bound (95% confidence level)
1997	0.0 ± 7.5	7.5	473	0	35
1998	0.1 ± 8.6	8.7	277	0.3	24
1999	5.4 ± 8.9	14.3	105	6	15
2000	20.6 ± 5.6	26.2	87	18	23
Average	**6.5**	-	-	6	24

[a] Derived from average values for each year in Table A2.2
[b] Reference A2.17, A2.18, A2.1, A2.19

Table A2.4 Implied Composition of Current and Proposed Tritium Discharge Limits (TBq/y)

Radionuclide	Current Limits	Agency Proposed Limits
Total tritium	900	99
Tritiated water	876	75
Organically bound tritium	24	24

Table A2.5 Partitioning of Radionuclides into treated effluent during treatment at sewage works

Radionuclide	Percentage transfer to treated effluent			
	Porous Pot Experiments by WRc [Ref A2.7]	Activated Sludge Best Estimate [Ref A2.20]	Percolating Filters Best Estimate [Ref A2.20]	Assumed in this assessment
Tritiated water	-	90%	90%	90%
Mixture of tritiated water and OBT	Average 88% (78% to 91%) (95% of OBT is converted to tritiated water in effluent)	-	-	90%
Carbon-14	Average 88% (80% to 94%)	70%	70%	70%
Phosphorus-32/33	-	15%	25%	20%
Iodine-125	-	90%	90%	90%
Others[a]	-	-	-	100%

[a] Assumed to be selenium-75 as the most radiologically significant radionuclide in this category [Ref A2.10]. However, no data is available for transfer to effluent. Therefore cautiously assumed that selenium-75 remains in effluent.

Table A2.6 Estimation of the Volumetric Exchange for the Severn Estuary off Cardiff

Year	Total Tritium Discharged[a] (TBq/y)	Measured Total Tritium Concentration in Seawater[b] (Bq/l)	Total Tritium Concentration in Seawater (excluding background)[c] (Bq/l)	Volumetric Exchange rate (l/y)[d]
1996	542	91	90	$6.0\ 10^{12}$
1997	473	66	65	$7.3\ 10^{12}$
1998	277	40	39	$7.1\ 10^{12}$
1999	105	9	8	$1.3\ 10^{13}$
2000	87	7	6	$1.5\ 10^{13}$
			Average	**$1\ 10^{13}$ ($1\ 10^{10}$ m^3/y)**

[a] Reference A2.16, A2.17, A2.18, A2.1, A2.19
[b] Reference A2.2
[c] Background concentrations of tritium in seawater are of the order of 1 Bq/l [Ref A2.4].
[d] Calculated as total tritium discharge (Bq/y) divided by total tritium seawater concentration (Bq/l).

Table A2.7 Marine Local Compartment Parameters for Severn Estuary

Compartment parameter	Severn Estuary Local Compartment	Source of data
Volume (m^3)	$2\ 10^7$	NRPB-M1161 [Ref A2.22]
Depth (m)	5	NRPB-M1161 [Ref A2.22]
Volumetric exchange ($m^3\ y^{-1}$)	$1\ 10^{10}$	See Table A1.3. NRPB [Ref A2.22] used a value of $5\ 10^9$ m^3/y, derived from two tides per day and cross-section of estuary.
Suspended sediment load ($t\ m^{-3}$)	$5\ 10^{-4}$	NRPB-M1161 [Ref A2.22]
Sedimentation rate ($t\ m^{-2}\ y^{-1}$)	$5\ 10^{-5}$	NRPB-M1161 [Ref A2.22]
Sediment density ($t\ m^{-3}$)	2.6	NRPB-M1161 [Ref A2.22]
Bioturbation rate ($m^2\ y^{-1}$)	$3.6\ 10^{-5}$	NRPB-M1161 [Ref A2.22]
Diffusion rate ($m^2\ y^{-1}$)	$3.15\ 10^{-2}$	NRPB-M1161 [Ref A2.22]
Proportion of fish from local box	1.0	Cautious assumption
Proportion of crustacea from local box	1.0	Cautious assumption
Proportion of mollusca from local box	1.0	Cautious assumption

Table A2.8 Predicted and Measured Concentrations of OBT in Seawater, Fish, Shellfish and Duck from the Severn Estuary and Derived Concentration Factors

Year	Estimated upper bound discharge of OBT[a] (TBq/y)	Predicted OBT seawater conc[b] (Bq/l)	Average concentrations[c] (measured) of OBT (Bq/kg wet)			Derived concentration factors (Bq/kg per Bq/l)		
			Fish	Shellfish	Duck	Fish	Shellfish	Duck
1998	24	2.4	26310	36820	-	10900	15200	-
1999	15.0	1.5	20275	19176	14876	13500	12800	10000
2000	22.8	2.3	42927	32097	-	18800	14000	-
					Average	14000	14000	10000

[a] See Table A2.3.
[b] Derived from a volumetric exchange rate given in derived in Table A2.6.
[c] Reference A2.2

Table A2.9 Concentration Factors between Seawater and Marine Organisms used in the Assessment

Radionuclide	Fish	Molluscs	Crustacea	Duck[b]
Tritiated water	1	1	1	1
OBT	14000	14000	14000	10000
Carbon-14	20000	20000	20000	20000
Phosphorus-32/33	20000	10000	10000	10000
Iodine-125	10	10	10	10
Others[a]	6000	5000	6000	6000

[a] Assumed to be selenium-75
[b] Assumed to be the same as crustacea for all radionuclides except tritium as OBT

Table A2.10 Recent Habit data for Fisherman (adults) in Severn Estuary and Candidate Critical Group Data used in Assessment

Data Source	Fish (kg/y)	Mussels (kg/y)	Prawns (kg/y)	Duck (kg/y)	Sediment (h/y)	Handling nets (h/y)	Occupancy for Seaspray (h/y)
RIFE-1 (1995) [Ref A2.11]	28	2.9	-	-	650	-	-
RIFE-2 (1996) [Ref A2.12]	28	2.9	-	-	650	-	-
RIFE-3 (1997) [Ref A2.13]	28	2.9	-	-	650	-	-
RIFE-4 (1998) [Ref A2.14]	34	-	1.4	-	990	-	-
RIFE-5 (1999) [Ref A2.4]	34	-	1.4	-	990	-	-
NRPB-M636 (mean game consumers) [Ref A2.21]	-	-	-	6	-	-	-
Marine Candidate Critical Group habits used in assessment	**34**	**2.9**	**1.4**	**6**	**990**	**990**	**8760**

Table A2.11 Mean Seafood Consumption Data for Members of the UK Population used in the Assessment

Year	Ref	Fish (kg/y)	Shellfish (kg/y)	Duck (kg/y)	Sediment (h/y)	Occupancy for Seaspray (h/y)
Adult	NRPB-M636 [Ref A2.21]	15	3.5	6	30	8760
Child	NRPB-M636 [Ref A2.21]	6.5	2.5	4	30	8760
Infant	NRPB-M636 [Ref A2.21]	3.5	0	0	30	8760

Table A2.12 Doses per Unit Discharge (µSv/y per TBq/y Reaching the Severn Estuary) to Candidate Critical Group Fishermen

Radionuclide	Fish	Crustacea	Mollusca	Duck	Gamma (sediment)	Beta (sediment)	Gamma (fishing gear)	Beta (fishing gear)	Seaspray
Tritiated water	6.12E-05	5.22E-06	2.52E-06	1.57E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-11
OBT	2.00E+00	1.71E-01	8.23E-02	3.65E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-11
Carbon-14	1.97E+01	1.74E+00	8.40E-01	5.22E-01	0.00E+00	0.00E+00	0.00E+00	1.70E-04	7.40E-10
Phosphorus-32	1.56E+02	6.67E+00	3.22E+00	2.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-07	4.20E-10
Iodine-125	5.10E-01	4.21E-02	2.03E-02	1.26E-02	2.00E-05	0.00E+00	2.00E-07	0.00E+00	2.90E-09
Others	3.40E+01	2.47E+00	1.47E+00	7.40E-01	1.70E-03	0.00E+00	1.70E-05	0.00E+00	5.70E-10

Table A2.13 Doses per Unit Discharge (µSv/y per TBq/y Reaching the Severn Estuary) to Mean Adult

Radionuclide	Fish	Crustacea.	Mollusca	Duck	Gamma (sediment)	Beta (sediment)	Gamma (fishing gear)	Beta (fishing gear)	Seaspray
Tritiated water	2.70E-05	3.15E-06	3.15E-06	9.45E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-11
OBT	8.82E-01	1.03E-01	1.03E-01	2.21E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-11
Carbon-14	8.70E+00	1.05E+00	1.05E+00	3.15E-01	0.00E+00	0.00E+00	0.00E+00	1.70E-04	7.40E-10
Phosphorus-32	6.90E+01	4.03E+00	4.03E+00	1.21E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-07	4.20E-10
Iodine-125	2.25E-01	2.54E-02	2.54E-02	7.61E-03	2.00E-05	0.00E+00	2.00E-07	0.00E+00	2.90E-09
Others	1.50E+01	1.49E+00	1.84E+00	4.46E-01	1.70E-03	0.00E+00	1.70E-05	0.00E+00	5.70E-10

Table A2.14 Doses per Unit Discharge (μSv/y per TBq/y Reaching the Severn Estuary) to Mean Child

Radionuclide	Fish	Crustacea	Mollusca	Duck	Gamma (sediment)	Beta (sediment)	Gamma (fishing gear)	Beta (fishing gear)	Seaspray
Tritiated water	1.50E-05	3.00E-06	3.00E-06	2.40E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.80E-12
OBT	5.19E-01	1.04E-01	1.04E-01	5.95E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.80E-12
Carbon-14	5.20E+00	1.00E+00	1.00E+00	8.00E-01	0.00E+00	0.00E+00	0.00E+00	1.70E-04	7.80E-10
Phosphorus-32	6.50E+01	6.25E+00	6.25E+00	5.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-07	7.40E-10
Iodine-125	1.98E-01	3.75E-02	3.75E-02	3.00E-02	2.00E-05	0.00E+00	2.00E-07	0.00E+00	4.70E-09
Others	1.56E+01	2.50E+00	3.00E+00	2.00E+00	1.70E-03	0.00E+00	1.70E-05	0.00E+00	1.10E-09

Table A2.15 Doses per Unit Discharge (μSv/y per TBq/y Reaching the Severn Estuary) to Mean Infant

Radionuclide	Fish	Crustacea	Mollusca	Duck	Gamma (sediment)	Beta (sediment)	Gamma (fishing gear)	Beta (fishing gear)	Seaspray
Tritiated water	1.68E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.10E-12
OBT	5.88E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.10E-12
Carbon-14	5.60E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-04	6.10E-10
Phosphorus-32	1.26E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-07	1.10E-09
Iodine-125	1.96E-01	0.00E+00	0.00E+00	0.00E+00	2.00E-05	0.00E+00	2.00E-07	0.00E+00	3.40E-09
Others	1.82E+01	0.00E+00	0.00E+00	0.00E+00	1.70E-03	0.00E+00	1.70E-05	0.00E+00	8.80E-10

Table A2.16 Doses (μSv/y) to Candidate Critical Group Fishermen With and Without a Sewage Works at Current Limits and at Agency Proposed Limits

Radionuclide	Without sewage works		With sewage works	
	Current Limits	Proposed Limits	Current Limits	Proposed Limits
Tritiated water	6.18E-02	5.29E-03	5.70E-02	6.21E-03
OBT	5.49E+01	5.49E+01	2.47E+00	2.47E+00
Total tritium	*5.50E+01*	*5.49E+01*	*2.53E+00*	*2.48E+00*
Carbon-14	4.56E+01	2.08E+01	3.20E+01	1.45E+01
Phosphorus-32	1.68E+00	1.43E-02	3.37E-01	2.86E-03
Iodine-125	2.92E-02	1.75E-04	2.63E-02	1.58E-04
Others	1.93E-02	4.64E-03	1.93E-02	4.64E-03
Total	**1.02E+02**	**7.57E+01**	**3.49E+01**	**1.70E+01**

Table A2.17 Main Doses Pathways (µSv/y) to Adult Fisherman at Proposed Limits Assuming Sewage Works is Operational

Nuclide	Fish	Crustacea	Mollusca	Duck	Gamma (sediment)	Beta (sediment)	Gamma (fishing gear)	Beta (fishing gear)	Seaspray	Total
Tritiated water	5.39E-03	4.59E-04	2.22E-04	1.38E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.80E-10	**6.21E-03**
OBT	**2.16E+00**	**1.84E-01**	**8.89E-02**	**3.95E-02**	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.08E-11	**2.47E+00**
Total tritium	*2.16E+00*	*1.85E-01*	*8.91E-02*	*3.96E-02*	*0.00E+00*	*0.00E+00*	*0.00E+00*	*0.00E+00*	*8.91E-10*	***2.48E+00***
Carbon-14	1.26E+01	1.11E+00	5.35E-01	3.33E-01	0.00E+00	0.00E+00	0.00E+00	1.08E-04	4.71E-10	**1.45E+01**
Phosphorus-32	2.66E-03	1.13E-04	5.47E-05	3.40E-05	0.00E+00	0.00E+00	0.00E+00	6.29E-12	7.14E-15	**2.86E-03**
Iodine-125	1.38E-04	1.14E-05	5.48E-06	3.41E-06	5.40E-09	0.00E+00	5.40E-11	0.00E+00	7.83E-13	**1.58E-04**
Others	4.08E-03	2.96E-04	1.76E-04	8.87E-05	2.04E-07	0.00E+00	2.04E-09	0.00E+00	6.84E-14	**4.64E-03**
Total	**1.47E+01**	**1.29E+00**	**6.24E-01**	**3.72E-01**	**2.09E-07**	**0.00E+00**	**2.09E-09**	**1.08E-04**	**1.36E-09**	**1.70E+01**

Table A2.18 Doses (μSv/y) to Mean Group Infant With and Without a Sewage Works at Current Limits and at Agency Proposed Limits

Nuclide	Without sewage works		With sewage works	
	Current Limits	Proposed Limits	Current Limits	Proposed Limits
Tritiated water	1.47E-02	1.26E-03	1.36E-02	1.48E-03
OBT	1.41E+01	1.41E+01	6.35E-01	6.35E-01
Total tritium	*1.41E+01*	*1.41E+01*	*6.49E-01*	*6.37E-01*
Carbon-14	1.12E+01	5.10E+00	7.84E+00	3.57E+00
Phosphorus-32	1.26E+00	1.07E-02	2.52E-01	2.14E-03
Iodine-125	9.80E-03	5.88E-05	8.82E-03	5.29E-05
Others	9.10E-03	2.18E-03	9.10E-03	2.18E-03
Total	**2.66E+01**	**1.92E+01**	**8.76E+00**	**4.21E+00**

Table A2.19 Doses (μSv/y) to Mean Group Child With and Without a Sewage Works at Current Limits and at Agency Proposed Limits

Nuclide	Without sewage works		With sewage works	
	Current Limits	Proposed Limits	Current Limits	Proposed Limits
Tritiated water	2.05E-02	1.75E-03	1.89E-02	2.06E-03
OBT	1.89E+01	1.89E+01	8.49E-01	8.49E-01
Total tritium	*1.89E+01*	*1.89E+01*	*8.68E-01*	*8.51E-01*
Carbon-14	1.60E+01	7.28E+00	1.12E+01	5.10E+00
Phosphorus-32	8.25E-01	7.01E-03	1.65E-01	1.40E-03
Iodine-125	1.52E-02	9.10E-05	1.36E-02	8.19E-05
Others	1.16E-02	2.77E-03	1.16E-02	2.77E-03
Total	**3.57E+01**	**2.62E+01**	**1.23E+01**	**5.95E+00**

Table A2.20 Doses (μSv/y) to Mean Group Adult With and Without a Sewage Works at Current Limits and at Agency Proposed Limits

Nuclide	Without sewage works		With sewage works	
	Current Limits	Proposed Limits	Current Limits	Proposed Limits
Tritiated water	3.00E-02	2.57E-03	2.77E-02	3.01E-03
OBT	2.66E+01	2.66E+01	1.20E+00	1.20E+00
Total tritium	*2.67E+01*	*2.66E+01*	*1.23E+00*	*1.20E+00*
Carbon-14	2.22E+01	1.01E+01	1.56E+01	7.08E+00
Phosphorus-32	7.83E-01	6.65E-03	1.57E-01	1.33E-03
Iodine-125	1.42E-02	8.50E-05	1.28E-02	7.65E-05
Others	9.39E-03	2.25E-03	9.39E-03	2.25E-03
Total	**4.97E+01**	**3.68E+01**	**1.70E+01**	**8.29E+00**

APPENDIX 3 – METHODOLOGY AND DOSES FOR RADIOLOGICAL ASSESSMENT OF LIQUID DISCHARGES IN SLUDGES DISPOSED OF TO AGRICULTURAL LAND

Radionuclide Discharges to Sewers Transferred to sludges

A3.1 Discharges of radionuclides are authorised to the sewer system serving Cardiff. The current radionuclide limits and future radionuclide limits proposed by the Agency for discharges to sewer from the Cardiff site are detailed in Table 2.

A3.2 Currently, discharges to the sewer are mixed with other sewage from the Cardiff area and the resultant effluent is discharged into the Severn Estuary. However, a sewage treatment works is under construction to treat Cardiff's sewage, before discharge of the treated effluent to the Severn Estuary. This sewage treatment works is due to commence operation in early 2002. When the sewage works comes into operation, incoming effluent will be treated to reduce the biological oxygen demand (BOD). BOD typically occurs in the form of suspended solid matter and dissolved carbon compounds. The treatment involves settling out of the suspended solids from the effluent followed by biological digestion of the remaining dissolved organic matter in the effluent. Two waste streams will be produced by the sewage works, a treated effluent stream which will be discharged to the Severn Estuary and sludge waste, which will be digested and dried to a pellet (94% dry matter). The pellets will be disposed of by applying to agricultural land.

A3.3 During treatment, radionuclides in the incoming sewage effluent will be divided (partitioned) between the treated effluent and the treated sludges. Part of the radionuclides discharge is expected to attach to the sludges, resulting in a lower concentration in the discharged effluent relative to the current untreated effluent. The sludges will be subject to further treatment and will be dried to a pellet (94% dry matter). Data on radionuclide partitioning between effluent and sludges has been reviewed recently, and experiments have been conducted by Amersham plc. These data and the partitioning values used in the assessment are summarised in Table A3.1.

A3.4 The expected annual arisings of radionuclides in sludge pellets at current limits and Agency proposed limits are summarised in Table A3.2. The sewage works is planned to produce 45 tonnes of dried pellets per day (1.64 10^7 kg/y) [Ref A3.1]. The predicted concentrations of radionuclides in the pellets are summarised in Table A3.3.

Application of Sewage Sludge Pellets to Farmland

A3.5 The pellets from the new sewage works will have been treated to a sufficient standard that they will meet the highest standard set in the ADAS sewage sludge matrix [Ref A3.2] for sewage sludges that are to be applied to soil used in food production. The sewage sludge matrix indicates that sludges treated to the highest standard can be applied to most types of farmland. Surface application to pasture is not prohibited. For food crops that can be eaten raw, including fruit, green vegetables and root vegetables, an interval of 10 months between application of the sludge and harvesting is required. The requirement for a harvest interval can lead to logistical problems for the production of these foods.

A3.6 In this assessment it has been assumed that application of sewage sludge pellets from the new treatment works will be disposed of to pasture used to raise dairy cattle, beef cattle and sheep. The assessment has assumed that application of sludges to land used for root vegetables, fruit and green vegetables will not occur.

A3.7 It is not known what the rate of application to land of sludge pellets produced at the Cardiff sewage treatment works will be. The average application rate of sewage sludge pellets to agricultural land in the UK is 0.8 kg dry solids per m^2 [Ref A3.1]. Previous radiological assessments have assumed an application rate of 1.5 kg/m^2 [Ref A3.1]. The frequency of application is also not known though once a year is likely and twice a year is possible. Taking these factors into account, this assessment assumed an annual application at a rate of 1.5 kg/m^2. The resulting application rates of radionuclides at current and proposed limits are as shown in Table A3.4.

Environmental concentrations

A3.8 Radionuclides applied to farmland in sludge will be transferred into soil, released to air, taken up by plants, ingested directly and through grass by grazing animals. Models are available for predicting concentrations of radionuclides in plants and animals products; grass and cereals, beef, mutton and lamb, sheep and cow offal, milk and milk products following application to farmland.

A3.9 A model developed by NRPB for the Environment Agency under R&D [Ref A3.3,A3.4] was used to predict environmental concentrations of radionuclides following application to land as sludge. For the most mobile radionuclides tritium and carbon-14, a second model was developed specifically for the Agency's assessment to provide an alternative independent assessment of the doses from these two radionuclides [Ref A3.5].

Dynamic Model predictions

A3.10 The predicted concentrations of radionuclides in cow meat, cow offal, milk, milk products, sheep meat and sheep offal using the model based on the Agency's R&D [Ref A3.3] were as shown in Table A3.5.

New model for Carbon-14 and Tritium

A3.11 A new model was developed to predict concentrations of tritium and carbon-14 in cow meat, cow offal, milk, milk products, sheep meat and sheep offal following application of sewage sludge to agricultural land [Ref A3.5]. The main processes modelled are degradation of the sludge and release of carbon-14 and tritium into soil and air, migration through soil, uptake by plants via root, inadvertent ingestion of soil and sludge by grazing animals and photosynthetic uptake of carbon-14 released from the soil.

A3.12 Key parameters that have potential to significantly influence the concentrations of radionuclides in the food stuffs were identified as inadvertent ingestion of soil and sludge by grazing animals and photosynthetic uptake of carbon-14 following release of carbon-14 from the degrading sludges calculated from the atmospheric concentration of carbon-14 in air around the plant stems and leaves (sub canopy atmosphere). Rate constants for both of these parameters must be derived.

Inadvertent ingestion rate of soil and sludge by animals

A3.13 Soil is inadvertently consumed by grazing animals. The transfer rate arising from inadvertent ingestion rate of soil by sheep and cows (FIRs) (y^{-1}) can be calculated as follows:

$$FIRs = AIIs/MIs$$

Where:

AIIs = The annual inadvertent ingestion of soil and sludge ($kg/(m^2\ y)$)
MIs = Mass of soil available for inadvertent ingestion (kg/m^2)

A3.14 Soil that is inadvertently ingestion by cows and sheep will be the surface layer. In this assessment it has been assumed that the top 1 cm of soil is available for ingestion by cows and sheep, and that the applied sludge becomes mixed into the top few cm of the soil. Cows ingest 0.52 kg of soil for every 13 kg of grass consumed, whilst sheep ingest 0.3 kg of soil per 1.5 kg of grass [Ref A3.6]. For a sustainable biomass (pasture grass) production rate of 1 $kg/(m^2\ y)$, the associated inadvertent soil intake rate (AIIs) by cows are and sheep are 0.04 $kg/(m^2\ y)$ and 0.2 $kg/(m^2\ y)$ respectively.

A3.15 Assuming that the soil available for inadvertent ingestion is the top 1 cm of the soil profile, the mass equivalent available for ingestion by animals (MIs) per unit area (1 m^2) of soil is 15 kg.

A3.16 The fraction of the top 1cm made up of fast degrading sludge was calculated from:

$$F_{fastsls} = f1 * sl_{app} * ffast_{surface}/MI$$
$$F_{slowsls} = f2 * sl_{app} * fslow_{surface}/MI$$

Where:

$F_{fastsls}$ = Fraction of fast degrading sludge in the surface (1 cm) soil layer
$F_{slowsls}$ = Fraction of slow degrading sludge in the surface (1 cm) soil layer
f1 = Fraction of sludge that is fast degrading (0.25)
f2 = Fraction of sludge that is slow degrading (0.75)
sl_{app} = Sludge application rate (kg/m^2)
$ffast_{surface}$ = fraction of fast degrading sludge applied retained in the surface layer
$fslow_{surface}$ = fraction of slow degrading sludge applied retained in the surface layer

A3.17 The amount of sludge in the surface soil were calculated allowing for degradation rates of the applied sludges. Sludges were assumed applied at a rate of 1.5 $kg//(m^2\ y)$. It was assumed that the sludges released all their radionuclides into the soil in the year following the application and therefore in subsequent years inadvertent ingestion of historic sludges did not contribute to the uptake of radionuclides by cows and sheep. The applied sludges were assumed to degrade at 2 rates, 25% by mass being 'fast' and 75% being 'slow'. It was assumed that the fast degrading component was mixed into the top 1 cm of the soil by animal trampling (100% retained in the surface layer) and that the slow degrading component was mixed down to 5cm (20% retained in the surface layer). The fraction of fast and slow degrading sludge in the surface (1 cm) soil layer of soil are 0.025 and 0.015 respectively.

A3.18 The inadvertent ingestion rate of fast and slow degrading sludge applied to soil by sheep and cows ($F_{fastirs}$) and ($F_{slowirs}$) (y^{-1}) can be calculated as follows:

$$F_{fastirs} = FIRs * F_{fastsls}$$
$$F_{slowirs} = FIRs * F_{slowsls}$$

A3.19 The inadvertent ingestion rates of fast and slow degrading sludge in soil by sheep are 0.005 and 0.003 y^{-1} respectively. The inadvertent ingestion rates of fast and slow degrading sludge in soil by cows are 0.001 and 0.0006 y^{-1} respectively.

Rephotosynthesis of carbon-14

A3.20 The concentration of carbon-14 in the 'below canopy atmosphere' arising from releases from sludge may be important, because of photosynthetic uptake of the released carbon-14 by plants. The 'below canopy atmospheric' concentration of carbon-14 is controlled primarily by the transfer rate between the 'below canopy atmosphere' and the 'above canopy atmosphere'. In the area around Cardiff, the mean annual wind velocity at 10 m is 5 m/s. In general, the velocity of air travelling horizontally near ground level above short grass approximately 3 times lower than air at 10 m. The air in the below canopy atmosphere will be subject to mixing and moving in both horizontal and vertical direction (by turbulence).

A3.21 An exchange rate was calculated by assuming that wind from the above canopy atmosphere enters one side of the below canopy atmosphere and travels horizontally through the canopy at below canopy level. It was assumed that the air in the below canopy atmosphere moves at 10% of the air velocity at 10 m (0.5 m/s) and that it travels horizontally through the canopy for 10 m before being lost into the above canopy atmosphere. The average residence time for air in the below canopy atmosphere will be 20 seconds (reasonable for fairly short pasture grass) giving an exchange frequency of 1.58 E+6 y^{-1}.

A3.22 The predicted concentrations of radionuclides using the new model and the using the key parameters defined above in animal products per unit concentration in sludge and at current and proposed discharge limits allowing for processes at the sewage works are shown in Table A3.6.

Habit Data

A3.23 The main dose pathways are intakes of foods produced on land treated with sludges. External dose from the radionuclides discharged from Amersham is a less important dose pathway because the radionuclides do not emit significant gamma radiation. It was assumed that a number of farms will receive sewage sludge and spread it on their land. It is not known which farms will receive the sludges as the plant is not yet operational. Therefore it has been assumed that a farm raising a dairy herd, producing milk, raising a beef herd and sheep flock. Candidate critical groups comprising families living on the farms and consuming foods (beef, mutton and milk) from the farm. The candidate critical group at the farm is assumed to eat two foods giving the highest doses at critical consumption rates and the other foods at mean consumption rates. No specific habit data for families associated with farms receiving sewage sludge are available, therefore UK wide generic data has been used (from Reference A3.7). It is assumed that the animal products are also sold via local outlets to the public who are mean consumers of these foods.

A3.24 Habit data (food intakes) for the candidate critical group and mean consumers are given in Table A3.7.

Calculation of Doses

A3.25 The doses to the candidate critical group for discharges at current and proposed limits were calculated from the concentrations of radionuclides in food, the intake rates of foods (Table A3.7) and the dose coefficients [Ref A3.8].

Assessed Doses

A3.26 The doses predicted using the Agency R&D and the new model are shown in Tables A3.8 and A3.9. The combined results for the new model and Agency R&D (Table A3.9) were selected as the final results. The results are broken down by pathway for the infant member of the group in Table A3.10.

References

A3.1 A Venter, G Smith and R Walden-Bevan (2001). Modelling the Radiological Impact of C-14 and Tritium in Sewage Sludge From Cardiff Waste Water Treatment Works. Assessment of Exposure via the Foodchain. NYCO6239B TN1 (Version 3.1), 30 July 2001.

A3.2 BRC, Water UK and ADAS (2001). The Safe Sludge Matrix. Guidelines for the Application of Sewage Sludge to Agricultural Land. April 2001.

A3.3 J G Titley, A D Carey, G M Crockett, G J Ham, M P Harvey, S F Mobbs, C Tournette, J S S Penfold & B T Wilkins (2000). Investigation of the Sources and Fate of Radioactive Discharges to Public Sewers. Environment Agency R&D Technical Report P288.

A3.4 Crockett GM. Calculation of doses arising from disposal of sewage sludge to land (NRPB in Preparation)

A3.5 J Stansby and M C Thorne (2001). Modelling the Radiological Impacts of ^{3}H and ^{14}C in Sewage Sludge Applied to Land (in publication).

A3.6 C A Attwood, J G Titley, J R Simmonds and C A Robinson (1998). Revised Generalised Derived Limits for Radioisotopes of Strontium, Ruthenium, Iodine, Caesium, Plutonium, Americium and Curium. Documents of the NRPB Volume 9 No 1.

A3.7 Robinson CA (1996). Generalised Habit Data for Radiological Assessments. NRPB-M636.

A3.8 Council Directive 96/29 Euratom of 13 May 1996, Laying Down Basic Safety Standards for the Protection of the Health of Workers and the General Public Against the Dangers Arising from Ionising Radiation. Official Journal of the European Communities, L159, Volume 39, 29 June 1996.

A3.9 WRc (2001). Partitioning of Tritium and Carbon-14 Labelled Compounds in Sewage Treatment Using Porous Pots to Model a Sequencing Batch Reactor. Contract Report UC 3763, January 2001.

A3.10 Nycomed Amersham Cardiff Laboratories (2001). Summary of Doses Resulting from Liquid Discharges. RSA93/CL/RFI/004. June 2001. Issue 1.

Table A3.1 Partitioning of Radionuclides into Sewage Sludge

Radionuclide	Percentage Transfer to Sewage Sludge			
	Porous Pot Experiments by WRc [Ref A3.9]	Activated Sludge Best Estimate [Ref A3.3]	Percolating Filters Best Estimate [Ref A3.3]	Assumed in this assessment
Tritiated water	-	10%	10%	10%
Mixture of tritiated water and OBT	Average 12% (9% to 22%)	-	-	10%[a]
Carbon-14	Average 12% (6% to 20%)	30%	30%	30%
Phosphorus-32/33	-	85%	75%	80%
Iodine-125	-	10%	10%	10%
Others[b]	-	-	-	0%

[a] It is assumed that this percentage transfer to sludge can be applied to OBT. The transfer of OBT to sewage sludge (even at 100% transfer) will be dominated by the incorporation of tritiated water into sewage sludge, most likely in an organic form. It is thus important to assume that some OBT could still be discharged to the Severn Estuary in the treated effluent.

[b] Assumed to be selenium-75 as the most radiologically significant radionuclide in this category [Ref A3.10]. However, no data is available for transfer to sludge. Selenium-75 has a half-life of 120 days, therefore sludge to land pathway is unlikely to be significant compared to other discharged radionuclides (eg C-14).

Table A3.2 Annual Transfer of Radionuclides to Sewage Sludge Pellets (TBq/y)

Radionuclide	Current Limits	Agency Proposed Limits
Tritiated water and OBT	90	9.9
Carbon-14	0.6	0.273
Phosphorus-32/33	0.008	0.000068
Iodine-125	0.005	0.00003
Others[a]	0	0

[a] Assumed to be selenium-75. No transfer data is available for this radionuclide, but dose will be insignificant compared to other radionuclides such as carbon-14.

Table A3.3 Predicted Average Concentration of Radionuclides in Sewage Sludge Pellets (Bq/kg)

Radionuclide	Current Limits	Agency Proposed Limits
Tritiated water and OBT	5.48E+06	6.03E+5
Carbon-14	3.65E+04	1.66E+04
Phosphorus-32/33	487	4.14
Iodine-125	304	1.83
Others[a]	0	0

[a]Assumed to be selenium-75. No transfer data is available for this radionuclide, but dose will be insignificant compared to other radionuclides such as carbon-14.

Table A3.4 Application Rates of Radionuclides to Farmland in Sewage Sludge Pellets ($Bq/m^2/y$)

Radionuclide	Current Limits	Agency Proposed Limits
Tritiated water and OBT	8.22E+6	9.04E+5
Carbon-14	5.48E+4	2.49E+4
Phosphorus-32/33	731	6.21
Iodine-125	457	2.74
Others[a]	0	0

[a] Assumed to be selenium-75.

Table A3.5 Predicted 50th Year Concentrations of Radionuclides in Animal Products Following Application of Sewage Sludge Pellets to Pasture at 1.5 kg m^{-2} y^{-1} (Agency R&D Model)

Radionuclide	Cow Meat	Cow Liver	Milk	Sheep Meat	Sheep Liver
Concentration per unit concentration in sludge (Bq/kg per Bq/kg)					
Total tritium	1.17E-03	1.17E-03	1.36E-03	1.78E-03	1.78E-03
Carbon-14	7.56E-03	7.43E-03	3.72E-03	1.88E-02	1.25E-02
Phosphorus-32/33	5.85E-03	5.82E-03	6.89E-03	1.14E-02	4.56E-03
Iodine-125	1.11E-04	1.11E-04	1.82E-04	3.53E-04	3.53E-04
Concentration arising from discharges to sewers at current limits (Bq/kg)					
Total tritium	6.43E+03	6.43E+03	7.43E+03	9.74E+03	9.74E+03
Carbon-14	2.76E+02	2.71E+02	1.36E+02	6.84E+02	4.58E+02
Phosphorus-32/33	2.85	2.83	3.35	5.56	2.22
Iodine-125	3.36E-02	3.36E-02	5.52E-02	1.07E-01	1.07E-01
Concentration arising from discharges to sewers at proposed limits (Bq/kg)					
Total tritium	7.07E+02	7.07E+02	8.18E+02	1.07E+03	1.07E+03
Carbon-14	1.26E+02	1.23E+02	6.18E+01	3.11E+02	2.08E+02
Phosphoruse-32/33	2.42E-02	2.41E-02	2.85E-02	4.72E-02	1.89E-02
Iodine-125	2.02E-04	2.02E-04	3.31E-04	6.43E-04	6.43E-04

Table A3.6 Predicted 50th Year Concentrations of Tritium and Carbon-14 in Animal Products following Application of Sewage Sludge Pellets to Pasture at 1.5 kg m^{-2} y^{-1} (New Model)

Radionuclide	Cow Meat	Cow Liver	Milk	Milk products	Sheep Meat	Sheep Liver
Concentration per unit concentration in sludge (Bq/kg per Bq/kg)						
Total tritium	5.85E-03	5.85E-03	1.56E-03	1.56E-03	1.47E-02	1.47E-02
Carbon-14	1.74E-04	1.74E-04	6.13E-04	6.74E-03	6.80E-04	6.80E-04
Concentration arising from discharges to sewers at current limits (Bq/kg)						
Total tritium	3.20E+04	3.20E+04	8.52E+03	8.52E+03	8.07E+04	8.07E+04
Carbon-14	6.37E+00	6.37E+00	2.24E+01	2.46E+02	2.48E+01	2.48E+01
Concentration arising from discharges to sewers at proposed limits (Bq/kg)						
Total tritium	3.52E+03	3.52E+03	9.37E+02	9.37E+02	8.87E+03	8.87E+03
Carbon-14	2.90E+00	2.90E+00	1.02E+01	1.12E+02	1.13E+01	1.13E+01

Table A3.7 Critical and Mean Food Consumption and Occupancy rates at Farm Receiving Sludge Pellets for Conditioning Land

Food types	Consumption Rate (kg/y)					
	Infant		Child		Adult	
	Critical[a]	Mean[b]	Critical[a]	Mean[b]	Critical[a]	Mean[b]
Milk	320	130	240	110	240	95
Milk products	0	0	0	0	0	0
Beef	3	3	15	15	15	15
Beef offal	0.5	0.5	1.5	1.5	2.75	2.75
Mutton	3	0.8	10	4	25	8
Sheep offal	0.5	0.5	1.5	1.5	2.75	2.75

[a] Two foods giving highest doses are assumed consumed at critical rates, remainder at mean
[b] Mean consumers

Table A3.8 Doses to Candidate Critical Group of Consumers of Foods from Treated Land at Current and Proposed Limits (μSv/y) from Agency R&D

Radionuclide	Current Limits			Proposed Limits		
	Infant	Child	Adult	Infant	Child	Adult
Total tritium	2.92E+02	1.14E+02	9.11E+01	3.22E+01	1.26E+01	1.00E+01
Carbon-14	7.48E+01	3.58E+01	3.24E+01	3.40E+01	1.63E+01	1.47E+01
Phosphorus-32	2.09E+01	4.82E+00	2.40E+00	1.78E-01	4.10E-02	2.04E-02
Iodine-125	1.04E+00	4.66E-01	2.52E-01	6.21E-03	2.80E-03	1.51E-03
Others Selenium-75	0	0	0	0	0	0
Total	**389**	**155**	**126**	**66.4**	**28.9**	**24.8**

Table A3.9 Doses to Candidate Critical Group of Consumers of Foods from Treated Land at Current and Proposed Limits (μSv/y) from New Model and Agency R&D

Radionuclide	Current Limits			Proposed Limits		
	Infant	Child	Adult	Infant	Child	Adult
Total tritium[a]	3.74E+02	2.00E+02	2.04E+02	4.12E+01	2.19E+01	2.24E+01
Carbon-14[a]	1.16E+01	4.61E+00	3.58E+00	5.29E+00	2.10E+00	1.63E+00
Phosphorus-32[b]	2.09E+01	4.82E+00	2.40E+00	1.78E-01	4.10E-02	2.04E-02
Iodine-125[b]	1.04E+00	4.66E-01	2.52E-01	6.21E-03	2.80E-03	1.51E-03
Others Selenium-75[b]	0	0	0	0	0	0
Total	**408**	**209**	**210**	**46.7**	**24.1**	**24.1**

[a] From new model
[b] From Agency R&D

Table A3.10 Doses to Infant members of the Candidate Critical Group of Consumers of Foods from Treated Land at Proposed Limits (μSv/y) from New Model and Agency R&D.

Radionuclide	Cow Meat	Cow Liver	Milk	Sheep Meat	Sheep Liver	Total
Total tritium[a]	1.27E+00	2.11E-01	3.60E+01	3.19E+00	5.32E-01	4.12E+01
Carbon-14[a]	1.39E-02	2.32E-03	5.22E+00	5.42E-02	9.04E-03	5.29E+00
Phosphorus-32[b]	1.38E-03	2.29E-04	1.73E-01	2.69E-03	1.79E-04	1.78E-01
Iodine-125[b]	3.45E-05	5.75E-06	6.04E-03	1.10E-04	1.83E-05	6.21E-03
Others[b]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	**1.28E+00**	**2.14E-01**	**4.14E+01**	**3.25E+00**	**5.42E-01**	**4.67E+01**

[a] From new model
[b] From Agency R&D

APPENDIX 4 – RADIOLOGICAL ASSESSMENT FOR LIQUID DISCHARGES AT SEWAGE TREATMENT WORKS

Discharges Arriving at the Works

A4.1 The current radionuclide limits and future radionuclide limits proposed by the Agency for discharges to sewer from the Cardiff site are detailed in Table 2.

A4.2 Currently, discharges to the sewer are mixed with other sewage from the Cardiff area and the resultant effluent is discharged into the Severn Estuary. However, a sewage treatment works is under construction to treat this sewage, prior to discharge of the treated effluent to the Severn Estuary. This sewage treatment works is due to commence operation in early 2002. When the sewage works comes into operation, incoming effluent will be treated to remove suspended solids matter and dissolved carbon compounds by settlement and by biological digestion.

Concentrations of Radionuclides in Raw Sewage, Sewage Sludge and Air

A4.3 The concentration of radionuclides in the raw sewage may be derived from the annual disposal of radionuclides to sewer and the annual arising of raw sewage which will be treated by the works. The sludge production rate has been estimated to be 45 te/day with a solids content of about 94% [Ref A4.1]. The typical solids content of raw effluent is 0.05% [Ref A4.2]. Thus, the annual mass rate of raw sewage to be treated by the sewage works is 3.1 10^{10} kg/y. Concentrations of radionuclides in raw sewage arriving at the works are shown in Table A4.1 for current and proposed limits.

A4.4 Radionuclides entering the works in raw effluent may partition between the liquid and solids. The pellet solids contain a very low water content giving a high activity concentration on the pellets compared to the raw sewage. The partitioning factors and concentrations of radionuclides in treated sludge pellets are described and provided in Appendix 3.

A4.5 Studies on the sewage treatment process to come into operation at Cardiff have shown that about 1% of tritiated water and up to 40% of carbon-14 is released to the gaseous phase [Ref A4.3] by biological processes during treatment. At current limits the release rate to air of tritium and carbon-14 are 2.8 10^5 Bq/s and 2.5 10^4 Bq/s respectively, whilst at at proposed limits the release rates are 2.4 10^4 Bq/s and 1.2 10^4 Bq/s. Assuming the release occurs from treatment tanks at ground level, a dispersion coefficient of 5.8 10^{-5} Bq/m^3 per Bq/s (65%D weather, ground level release, exposure location of 100m) has been used to calculate air concentrations.

Calculation of Doses to Sewage Workers

A4.6 Workers at the sewage works may be exposed to external irradiation from radionuclides in the raw sewage and the dry sludge pellets produced by the works. Also, effluent or sludge containing radionuclides may be inhaled or inadvertently ingested. Finally, carbon-14 and tritium may be released in gaseous form and inhaled.

A4.7 External irradiation doses, inhalation doses and inadvertent ingestion doses have been calculated for both exposure to the raw sewage and dry sludge pellets. Inhalation doses have been calculated for gaseous releases of tritium and carbon-14. Occupancy data assumed in the assessment is shown in Table A4.2.

A4.8 External irradiation doses have been assessed for the radionuclide concentrations in raw sewage and sludge pellets, occupancy data and external dose per unit radionuclide concentration factors [Ref A4.2].

A4.9 Doses from inhalation of sewage sludge have been derived from the radionuclide concentrations in raw sewage and sludge pellets, concentration of sewage matter in air (dusts from sludge pellets and raw sewage aerosol) due to resuspension (10^{-7} kg/m^3, Ref A4.2), worker breathing rate (1.2 m^3/h, Ref A4.4), occupancy data and inhalation dose coefficients [Ref A4.5].

A4.10 Doses from inhalation of gaseous tritium and carbon-14 have been derived from the radionuclide concentrations in air, worker breathing rate (1.2 m^3/h, Ref A4.4), occupancy data and inhalation dose coefficients [Ref A4.5].

A4.11 Inadvertent ingestion doses for sewage sludge have been derived from the radionuclide concentrations in raw sewage and sludge pellets, inadvertent ingestion rates (5 10^{-6} kg/h, Ref A4.2), occupancy data and ingestion dose coefficients [Ref A4.5].

Assessed Doses to Sewage Workers

A4.12 The doses to a sewage worker from discharges to sewer at current limits and proposed limits are shown in Tables A4.3 and A4.4 respectively for each radionuclide.

References

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A4.3 WRc (2001). Partitioning of Tritium and Carbon-14 Labelled Compounds in Sewage Treatment Using Porous Pots to Model a Sequencing Batch Reactor. Contract Report UC 3763, January 2001.

A4.4 ICRP (1975). ICRP Publication 23. Report of the Task Group on Reference Man.

A4.5 Council Directive 96/29 Euratom of 13 May 1996, Laying Down Basic Safety Standards for the Protection of the Health of Workers and the General Public Against

the Dangers Arising from Ionising Radiation. Official Journal of the European Communities, L159, Volume 39, 29 June 1996.

Table A4.1 Radionuclide Concentrations in Raw Sewage (Bq/kg)

Radionuclide	Discharges at Current Limits	Discharges at Proposed Limits
Total tritium	$2.9\ 10^{4}$	$3.2\ 10^{3}$
^{3}H water	$2.8\ 10^{4}$	$2.4\ 10^{3}$
OBT	$7.7\ 10^{2}$	$7.7\ 10^{2}$
^{14}C	$6.5\ 10^{1}$	$2.9\ 10^{1}$
^{32}P	$3.2\ 10^{-1}$	$2.7\ 10^{-3}$
^{125}I	$1.6\ 10^{0}$	$9.7\ 10^{-3}$
Others[a]	$1.6\ 10^{-2}$	$3.9\ 10^{-3}$

[a] Assumed to be selenium-75.

Table A4.2 Occupancy Data for Exposure to Raw Sewage, Sewage Sludge and Gaseous Emissions (Bq/kg)

Sewage works media	Occupancy (h/y)	Comment
Sewage sludge pellets	200	Realistic estimate of time spent in close proximity to pellet production and storage
Raw sewage	1800	Remainder of working year spent around sewage works
Gaseous emissions of tritium and carbon-14	2000	Working year at sewage works

Table A4.3 Dose to Sewage Worker for Current Limits (μSv/y)

Nuclide	External Dose		Inhalation			Inadvertent Ingestion		Total
	Raw Sewage	Sludge Pellets	Raw Sewage	Sludge Pellets	Gases	Raw Sewage	Sludge Pellets	
^{3}H water	0.0E+00	0.0E+00	2.8E-04	5.8E-03	7.0E-01	4.6E-03	9.6E-02	8.0E-01
OBT	0.0E+00	0.0E+00	7.5E-06	1.6E-04	-	2.9E-04	6.1E-03	6.6E-03
^{14}C	0.0E+00	0.0E+00	2.8E-05	1.8E-03	2.3E-02	3.4E-04	2.1E-02	4.6E-02
^{32}P	0.0E+00	0.0E+00	2.4E-07	4.0E-05	-	7.0E-06	1.2E-03	1.2E-03
^{125}I	5.0E-03	1.0E-01	1.8E-06	3.7E-05	-	2.2E-04	4.6E-03	1.1E-01
^{75}Se	0.0E+00	0.0E+00	3.5E-09	0.0E+00	-	3.8E-07	0.0E+00	3.8E-07
Total	**5.0E-03**	**1.0E-01**	**3.1E-04**	**7.7E-03**	**7.2E-01**	**5.4E-03**	**1.3E-01**	**9.7E-01**

Table A4.4 Dose to Sewage Worker for Proposed Limits (μSv/y)

Nuclide	External Dose		Inhalation			Inadvertent Ingestion		Total
	Raw Sewage	Sludge Pellets	Raw Sewage	Sludge Pellets	Gases	Raw Sewage	Sludge Pellets	
^{3}H	0.0E+00	0.0E+00	2.4E-05	4.9E-04	6.0E-02	3.9E-04	8.2E-03	6.9E-02
OBT	0.0E+00	0.0E+00	7.5E-06	1.6E-04	-	2.9E-04	6.1E-03	6.6E-03
^{14}C	0.0E+00	0.0E+00	1.3E-05	8.0E-04	1.0E-02	1.5E-04	9.6E-03	2.1E-02
^{32}P	0.0E+00	0.0E+00	2.0E-09	3.4E-07	-	5.9E-08	9.9E-06	1.0E-05
^{125}I	3.0E-05	6.2E-04	1.1E-08	2.2E-07	-	1.3E-06	2.7E-05	6.8E-04
^{75}Se	0.0E+00	0.0E+00	8.4E-10	0.0E+00	-	9.1E-08	0.0E+00	9.2E-08
Total	**3.0E-05**	**6.2E-04**	**4.4E-05**	**1.4E-03**	**7.0E-02**	**8.4E-04**	**2.4E-02**	**9.7E-02**

APPENDIX 5 – RADIOLOGICAL ASSESSMENT FOR LIQUID DISCHARGES OVERFLOWING TO WHITCHURCH BROOK

Discharges to Whitchurch Brook

A5.1 Currently, discharges from the site are made to the Ystradyfodwg and Pontypridd (Y&P) trunk sewer. In the sewer the discharges become mixed with other sewage from the Cardiff area and the effluent is discharged into the Severn Estuary. The sewage system is fitted with a storm overflow chamber at Aberporth Rd. It is fitted with a 4mm automatically raked bar screen for screening and is situated about 4km downstream of the Amersham plc site at Cardiff. The overflow discharges to the Whitchurch Brook and then into the River Taff. The Whitchurch Brook is carried in an underground culvert from the overflow point to the River Taff.

A5.2 Data has been collected on the typical volume of water spilled from the sewage system at this overflow chamber, compared to the annual sewage flow [Ref A5.1]. The annual spill volume is 1.93 10^6 m^3/y and the annual sewage flow is 1.73 10^7 m^3/y, giving a percentage spill volume of 11.1%.

A5.3 If Amersham plc made continuous discharges, then it could be assumed that about 11% of the discharges overflow to the Whitchurch Brook. However, Amersham plc make batch discharges, typically discharging one tank per day for a period of 3-4 hours. Thus discharges may not occur during an overflow event, since discharges only occupy 17% of a 24 hour period. Therefore the resulting percentage of Amersham plc's discharges which are currently likely to overflow into the Brook is 1.9%.

A5.4 A sewerage overflow improvement scheme is expected to significantly reduce the number of overflow events to the Whitchurch Brook from the 50 to 60 per year that occurred recently, to a few per year. This equates to a reduction in the overflow to around 5% or less of the overflow volumes reported recently, or around 0.5% of the annual sewer flow. Once the overflow improvement has been completed, the percentage of discharges from Amersham plc's Cardiff site which overflow to the Whitchurch Brook will be less than 0.1%.

A5.5 The discharges to the Whitchurch Brook and River Taff based on current and proposed discharges from Amersham plc to sewer, for the two scenarios of current overflow scheme and future improved overflow scheme are shown in Table A5.1.

Modelling of Environmental Concentrations

A5.6 The average activity concentrations of radionuclides in water in the Whitchurch Brook and the River Taff have been derived by dividing the annual activity discharged by the following annual volumetric flows:

- Whitchurch Brook 3.16 10^7 m^3 / y (based on an assumed flow of 1 m^3/s from inspection of flow from the culvert)

- River Taff — $7.29\ 10^8\ m^3$ / y (based on 23.1 m^3/s average flow from 1990-2000 [Ref A5.2]. Average flow in 2000 was 30.4 m^3/s compared to 22.4 m^3/s for previous 10 years)

A5.7 The activity concentration of radionuclides within sediment have been calculated from the calculated water activity concentrations and partition coefficients (K_d) (see Table A5.2) expressed in terms of activity concentration in sediment per unit activity concentration in water (Bq/kg per Bq/l).

A5.8 The activity concentration of radionuclides within freshwater fish has been assessed using the calculated water activity concentrations and equilibrium concentration factors (CFs) (see Table A5.2) expressed in terms of activity concentration in fish per unit activity concentration in water (Bq/kg per Bq/l). Concentration factors (CFs) are not available for OBT in for freshwater fish and there are insufficient data to enable calculation from observed concentrations in the River Taff. However concentration factors for OBT for saltwater fish have been derived, and concentration factors for carbon in saltwater and freshwater fish are available. Therefore, for this assessment concentration factors for OBT in freshwater fish have been derived assuming that the ratio between the CFs for OBT and carbon-14 in freshwater fish would be the same as the ratio between the CFs for OBT and carbon in salt water fish.

A5.9 In Appendix 2, an OBT concentration factor of 14 000 Bq/kg per Bq/l has been derived for saltwater fish from monitoring and modelling data. The carbon-14 concentration factors for saltwater fish is 20 000 Bq/kg per Bq/l, therefore the ratio between the OBT CF and C-14 CF is 0.7. The CF for C-14 in freshwater fish is 50 000 Bq/kg per Bq/l, implying an OBT concentration factor for freshwater fish of 35 000 Bq/kg per Bq/l.

Method for Assessment of Doses

A5.10 The exposure pathways likely for the overflow of sewage are consumption of fish caught from the River Taff and inadvertent ingestion of sediments and waters and inhalation of resuspended material from the river banks. It is assumed that adult and children spend time on the banks of the river at the confluence with the Whitchurch Brook and stand in the river angling. Drinking water is not abstracted from Whitchurch Brook or the River Taff.

A5.11 Inadvertent consumption rate data for freshwater from rivers and lakes are not available. Inadvertent ingestion rates for seawater range from 0.2l/y (average) to 0.5 l/y (higher than average) for adults and children (Reference A5.3). Freshwater inadvertent ingestion rates may however, be higher than seawater inadvertent intakes. Therefore for this assessment an inadvertent consumption rate of freshwater of 5 litre/y has been assumed for both adults and children, (i.e. ten times higher than seawater value). Doses have been calculated from the activity concentrations of radionuclides in the water, the ingestion rates and ingestion dose coefficients (Sv Bq^{-1}) published in the Euratom Basic Safety Standards Directive [Ref A5.4].

A5.12 Inhalation of resuspended sediment is a potential exposure pathway during recreational activities around the River Taff and at the confluence of Whitchurch Brook with the river. Doses have been derived using the predicted radionuclide concentrations in sediment, concentration of sediment in air due to resuspension (assumed to be equivalent to ambient dust in air of 10^{-7} kg/m^3, Ref A5.5), breathing rates for adults and children (1.2 m^3/h and 0.78 m^3/h respectively Ref A5.6), river bank occupancy (500 h/y, Ref A5.3) and inhalation dose coefficients [Ref A5.4].

A5.13 Inadvertent ingestion of sediment is also possible during recreational activities around Whitchurch Brook and the River Taff. Inadvertent ingestion doses for sediment have been derived from the radionuclide concentrations in sediment, sediment inadvertent ingestion rates (soil and sand values of 5 10^{-6} kg/h for adults and 1 10^{-5} kg/h for children, Ref A5.3), river bank occupancy (500 h/y, Ref A5.3) and ingestion dose coefficients for the radionuclides in the sediments [Ref A5.4].

A5.14 Anglers catch and consume fish from the River Taff. Consumption rates for freshwater fish of 20 kg/y and 5 kg/y have been assumed for adults and children respectively [Ref A5.3]. Doses have been calculated from the predicted radionuclide concentrations in fish, the fish consumption rate and ingestion dose coefficients [Ref A5.4]. Whitchurch Brook is considered to be too small to support fish which could be caught and consumed.

Assessed Doses Arising from Discharges to Whitchurch Brook

A5.15 The annual dose for members of the public exposed to discharges into the Whitchurch Brook through to the River Taff have been assessed from a unit discharge of 1 TBq/y to the brook (see Table A5.3). The results have been scaled by the expected activity reaching the Brook at the current and proposed discharge limits and overflow scheme as follows:

- Discharges at current limits, current overflow scheme — Table A5.4
- Discharges at current limits, improved overflow scheme — Table A5.5
- Discharges at proposed limits, current overflow scheme — Table A5.6
- Discharges at proposed limits, improved overflow scheme — Table A5.7

The doses to a child at proposed limits with the improved overflow scheme, showing the main pathways are given in Table A5.8.

References

A5.1 A Marshall (2000). Aberport Road Spill Duration Calculation. File Note AE11a. Environment Agency.

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A5.7 IAEA (1994). Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments. IAEA Technical Report Series No 364.

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A5.9 NCRP (1996). Screening Models for Release of Radionuclides to Atmosphere, Surface Water and Ground. NCRP Report 123 I.

A5.10 Mapson R P, Laporte J-M, Andres S, Factors controlling the Bioaccumulation of Mercury, Methylmercury, Arsenic, Selenium, and Cadmium by Freshwater Invertebrates and Fish. Arch. Environ. Contam. Toxicol. Vol 38, 283-297, 2000.

Table A5.1 Discharges to Whitchurch Brook and River Taff Used in the Assessment

Radionuclide	Current Limits (TBq/y)		Agency Proposed Limits (TBq/y)	
	Current Overflow Scheme	Improved Overflow Scheme	Current Overflow Scheme	Improved Overflow Scheme
Total tritium	17.1	0.855	1.88	0.094
Tritiated water	16.6	0.815	1.43	0.070
Organically bound tritium	0.46	0.022	0.46	0.022
Carbon-14	0.038	0.0019	0.017	0.00085
Phosphorus-32/33	0.00019	$9.3\ 10^{-6}$	$1.6\ 10^{-6}$	$7.9\ 10^{-8}$
Iodine-125	0.00095	$4.7\ 10^{-5}$	$5.7\ 10^{-6}$	$2.8\ 10^{-7}$
Others[a]	$9.5\ 10^{-6}$	$4.7\ 10^{-7}$	$2.3\ 10^{-6}$	$1.1\ 10^{-7}$

[a] Assumed to be selenium-75.

Table A5.2 Environmental Transfer Factors

Environmental Transfer Factors	Tritium	OBT	Carbon-14	Phosphorus -32/33	Iodine-125	Selenium-75
Sediment partition coefficient (Bq/kg per Bq/l) [Ref A5.5]	0.03	2000	2000	2000[a]	300	1000[b]
Fish concentration factor (Bq/kg per Bq/l) [Ref A5.7]	1	35 000[c]	50 000	50 000	40	1500[d]

[a] Assumed to be the same as carbon-14.
[b] Large range of K_d values for selenium (0-10000 Bq/kg per Bq/l, Ref A5.8). Value at upper end of range selected.
[c] OBT derived from scaling of OBT for saltwater fish based on difference in carbon-14 CF for saltwater and freshwater fish.
[d] CF for selenium 200 Bq/kg per Bq/l [Ref A5.9] and 1000 - 2000 Bq/kg per Bq/l [Ref A5.10]. Average of higher range selected.

Table A5.3 Dose per Unit Release from Sewer Overflow (Assuming 100% Overflow) (μSv/y/TBq/y)

Radionuclide	Whitchurch Brook		River Taff	
	Child	Adult	Child	Adult
Tritiated water	3.6E-03	2.9E-03	3.2E-04	6.2E-04
Organically bound tritium	2.7E-02	1.3E-02	1.4E+01	4.0E+01
Carbon-14	3.9E-01	1.9E-01	2.7E+02	8.0E+02
Phosphorus-32/33	2.5E+00	7.7E-01	1.8E+03	3.3E+03
Iodine-125	6.4E+00	2.7E+00	8.8E+00	1.7E+01
Others[a]	1.9E+00	6.2E-01	6.2E+01	1.1E+02

[a] Assumed to be selenium-75.

Table A5.4 Doses from Sewer Overflow at Current Limits with Current Overflow Scheme (μSv/y)

Radionuclide	Whitchurch Brook		River Taff	
	Child	Adult	Child	Adult
Tritiated water	6.1E-02	4.8E-02	5.3E-03	1.0E-02
Organically bound tritium	1.2E-02	6.2E-03	6.2E+00	1.8E+01
Carbon-14	1.5E-02	7.3E-03	1.0E+01	3.0E+01
Phosphorus-32/33	4.8E-04	1.5E-04	3.5E-01	6.3E-01
Iodine-125	6.1E-03	2.6E-03	8.3E-03	1.6E-02
Others[a]	1.8E-05	5.9E-06	5.9E-04	1.0E-03
Total	**9.4E-02**	**6.4E-02**	**1.7E+01**	**4.9E+01**

[a] Assumed to be selenium-75.

Table A5.5 Doses from Sewer Overflow at Current Limits with Improved Overflow Scheme (μSv/y)

Radionuclide	Whitchurch Brook		River Taff	
	Child	Adult	Child	Adult
Tritiated water	3.0E-03	2.3E-03	2.6E-04	5.0E-04
Organically bound tritium	6.1E-04	3.0E-04	3.1E-01	9.0E-01
Carbon-14	7.2E-04	3.6E-04	5.1E-01	1.5E+00
Phosphorus-32/33	2.4E-05	7.2E-06	1.7E-02	3.1E-02
Iodine-125	3.0E-04	1.3E-04	4.1E-04	7.7E-04
Others[a]	8.9E-07	2.9E-07	2.9E-05	5.0E-05
Total	**4.6E-03**	**3.1E-03**	**8.3E-01**	**2.4E+00**

[a] Assumed to be selenium-75.

Table A5.6 Doses from Sewer Overflow at Proposed Limits with Current Overflow Scheme (μSv/y)

Radionuclide	Whitchurch Brook		River Taff	
	Child	Adult	Child	Adult
Tritiated water	5.2E-03	4.1E-03	4.5E-04	8.8E-04
Organically bound tritium	1.2E-02	6.2E-03	6.2E+00	1.8E+01
Carbon-14	6.7E-03	3.3E-03	4.7E+00	1.4E+01
Phosphorus-32/33	4.1E-06	1.2E-06	2.9E-03	5.3E-03
Iodine-125	3.6E-05	1.6E-05	5.0E-05	9.5E-05
Others[a]	4.3E-06	1.4E-06	1.4E-04	2.4E-04
Total	**2.4E-02**	**1.4E-02**	**1.1E+01**	**3.2E+01**

[a] Assumed to be selenium-75.

Table A5.7 Doses from Sewer Overflow at Proposed Limits with Improved Overflow Scheme (μSv/y)

Radionuclide	Whitchurch Brook		River Taff	
	Child	Adult	Child	Adult
Tritiated water	2.5E-04	2.0E-04	2.2E-05	4.3E-05
Organically bound tritium	6.1E-04	3.0E-04	3.1E-01	9.0E-01
Carbon-14	3.3E-04	1.6E-04	2.3E-01	6.7E-01
Phosphorus-32/33	2.0E-07	6.1E-08	1.4E-04	2.6E-04
Iodine-125	1.8E-06	7.6E-07	2.5E-06	4.6E-06
Others[a]	2.1E-07	6.9E-08	6.9E-06	1.2E-05
Total	**1.2E-03**	**6.6E-04**	**5.4E-01**	**1.6E+00**

[a] Assumed to be selenium-75.

Table A5.8 Doses to a Child from Sewer Overflow at Proposed Limits with Improved Overflow Scheme (μSv/y) showing main pathways

Radionuclide	River Taff					Whitchurch Brook			
		Inadvertent consumption		Inhalation	Total	Inadvertent consumption		Inhalation	Total
	Fish	Water	Sediment	Sediment		Water	Sediment	Sediment	
Tritiated water	1.10E-05	1.10E-05	3.30E-10	9.33E-12	2.20E-05	2.54E-04	7.63E-09	2.15E-10	2.54E-04
OBT	3.06E-01	8.73E-06	1.75E-05	1.99E-07	3.06E-01	2.02E-04	4.03E-04	4.60E-06	6.10E-04
Carbon-14	2.32E-01	4.65E-06	9.30E-06	2.58E-07	2.32E-01	1.07E-04	2.15E-04	5.95E-06	3.28E-04
Phosphorus-32	1.44E-04	2.88E-09	5.75E-09	4.56E-11	1.44E-04	6.64E-08	1.33E-07	1.05E-09	2.01E-07
Iodine-125	2.37E-06	5.94E-08	1.78E-08	5.01E-11	2.45E-06	1.37E-06	4.11E-07	1.16E-09	1.78E-06
Others[a]	6.89E-06	4.60E-09	4.60E-09	1.52E-11	6.90E-06	1.06E-07	1.06E-07	3.50E-10	2.13E-07
Total	**5.38E-01**	**2.45E-05**	**2.68E-05**	**4.57E-07**	**5.38E-01**	**4.26E-04**	**2.27E-04**	**1.02E-05**	**1.19E-03**

[a] Assumed to be selenium-75.

APPENDIX 6 – METHODOLOGY FOR RADIOLOGICAL ASSESSMENT FOR SHORT TERM RELEASES TO ATMOSPHERE

Short Term Discharges to Atmosphere

A6.1 The current daily radionuclide limits and future daily radionuclide limits proposed by the Agency for discharges to atmosphere from the Cardiff site are detailed in Table 3.

A6.2 The categories for the limits include soluble tritium, insoluble tritium and 'others'. The soluble tritium will be largely tritiated water, insoluble tritium will be tritium gas and the 'others' category can be assumed to be sulphur-35 as the most radiologically significant radionuclide in this category (see Appendix 1). For the purpose of the radiological assessment, it has been assumed that up to 10% of the tritium gas is converted to tritiated water which is then available for take up into plants (see Appendix 1).

A6.3 For the short term release assessment it is assumed that there could be a single release in a day of all radionuclides at the daily limits. It is possible for a series of short term releases (over a number of days) to be made such that the full annual radionuclide limits are utilised. This would take between 8 and 44 short term releases at the daily limits. However, given that this release scenario could occur over a period of up to 44 days, it is unreasonable to assume that the wind would always be blowing in the same direction over 44 days. It is more likely that the wind direction would vary and the releases would travel in different directions and not always travel in the direction of a particular residence or farm. The windrose data for the Cardiff site (see Table A6.1) shows that the prevailing wind direction is from the west (270°). The percentage of time that wind blows in the general direction (ie within a 90° sector) of Radyr and the closest farm are 9.5% and 4.2% respectively. These wind frequency data and the annual limit on discharges can be used to provide an estimate of the maximum radionuclide discharges made as a series of daily discharges that could affect the receptor points at Radyr and the nearest farm.

A6.4 The quantity of each radionuclide discharges as a short term release used in the assessment was based on the maximum of either the daily limit or an estimate of the maximum discharges from a series of releases at the daily limit allowing for wind direction frequency (as described above). The short duration discharges assumed to affect each receptor point at current limits and Agency proposed limits are shown in Tables A6.2 and A6.3 respectively. By utilising this derivation of the source term, allowance has been made for the possibility of a number of short duration releases, but also that the wind could blow the plume in different directions.

A6.5 It is was assumed that all discharges are made though the RP1 stack which has a height of 50 m (as the continuous release assessment). A release duration of 30 minutes has been cautiously assumed.

Calculation of Environmental Concentrations

A6.6 The receptor points are Radyr and the closest farm as for the continuous release assessment (see Appendix 1). Effective stack heights in relation to these receptor points are the same as those described in Appendix 1.

A6.7 A short term release could occur at any time of the year and thus the most common weather conditions (ie Category D) have been used for the assessment. The time integrated air activity concentrations (Bq s m^{-3} per Bq) for the different effective stack heights and distances are shown in Table A6.4 as derived from Reference A6.1. This assumes that the receptor points are on the plume centre line in all cases.

A6.8 Dry deposited activity (Bq m^{-2}) has been assessed from the time integrated air activity concentrations (Bq s m^{-3}) and the following deposition velocities [Ref A6.2]:

- All particulates 10^{-4} to 10^{-3} m s^{-1} 10^{-3} m s^{-1} used
- Reactive iodine (ie gaseous) 10^{-3} to 10^{-2} m s^{-1} 10^{-2} m s^{-1} used

A6.9 For carbon-14 a notional deposition velocity of 10^{-3} m s^{-1} was used (which is likely to be an overestimate). Integrated activity concentrations of radionuclides in food allowing for deposition events occurring over a 50 years were calculated from the radionuclide deposited activity (Bq m^{-2}) and the time integrated activity concentration of radionuclides in foodstuffs (integrated to 50 years) per unit deposit (ie Bq y kg^{-1} per Bq m^{-2}) (Table A6.5) [Ref A6.3, pers comm NRPB].

Calculation of Doses to Candidate Critical Groups

A6.10 The candidate critical groups and exposure pathways considered were the same as those assumed for the continuous release (Appendix 1). The exposure pathways considered were inhalation of radionuclides from the plume, beta and gamma radiation from the plume, beta and gamma radiation from radionuclides deposited on the ground, inhalation of radionuclides resuspended from the ground following deposition, and ingestion of foods produced on land affected by radionuclides in the plume.

A6.11 Inhalation doses were calculated based on time integrated air activity (Bq s m^{-3}) concentration, the breathing rate (m^3 s^{-1}) [Ref A6.4] and the inhalation dose factors (Sv Bq^{-1}) published in the Euratom Basic Safety Standards Directive [Ref A6.5].

A6.12 External doses from the plume were assessed from the calculated time integrated air activity concentrations (Bq s m^{-3}) and the factors of dose per unit time integrated air activity concentration (Sv per Bq s m^{-3}) [Ref A6.8]. No indoor shielding factor has been applied since the releases is assumed to last only 30 minutes and members of the candidate critical group could be outside for all of the release.

A6.13 External doses from deposition on the ground were assessed from the calculated deposited activity (Bq m^{-2}) and external dose factors (Sv per Bq m^{-2}) integrated over the period of occupancy in the first year following the deposition. Allowance for indoor and outdoor occupancy and shielding have been made over the year following the release in a similar manner to the continuous release (see Appendix 1).

A6.14 Ingestion doses from consuming radionuclides incorporated into local food were assessed from the calculated time integrated activity concentrations in food following deposition. Consumption rates for the different food types were the same as those used for the continuous release assessment (see Appendix 1) and ingestion dose factors published in the Euratom Basic Safety Standards Directive [Ref A6.5].

Assessed Doses to Candidate Critical Groups

A6.15 The dose per unit short term release for the allotment holders at Radyr and the farming family at the closest farm are shown in Tables A6.6 and A6.7 respectively.

A6.16 The dose to allotment holders at Radyr for a short term release over one year at the current and proposed limits are shown in Table A6.8. The dose to a farming family at the nearest farm for a short term release over one year at the current and proposed limits are shown in Table A6.9.

References

A6.1 R H Clarke (1979). The First Report of a Working Group on Atmospheric Dispersion: A Model for Short and Medium Range Dispersion of Radionuclides Released to the Atmosphere. NRPB-R91.

A6.2 J R Simmonds, G Lawson & A Mayall (1995). Radiation Protection 72. Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment. EUR 15760.

A6.3 RMC (2001). Nycomed Amersham. Dose Assessment for Atmospheric Releases from Cardiff Laboratories. TN/J3457.4/DA-PR.

A6.4 ICRP (1975). ICRP Publication 23. Report of the Task Group on Reference Man.

A6.5 Council Directive 96/29 Euratom of 13 May 1996, Laying Down Basic Safety Standards for the Protection of the Health of Workers and the General Public Against the Dangers Arising from Ionising Radiation. Official Journal of the European Communities, L159, Volume 39, 29 June 1996.

A6.6 Nycomed Amersham Cardiff Laboratories (2001). Atmospheric Dispersion Modelling for Routine Atmospheric Discharges at Cardiff Laboratories. RSA93/CL/RFI/0024. June 2001. Issue 1.

A6.7 Nycomed Amersham Cardiff Laboratories (2001). Critical Group Dose Assessment for Routine Atmospheric Discharges from Cardiff Laboratories. RSA93/CL/RFI/0021. June 2001. Issue 1.

A6.8 FGR12 EPA (1993). External Exposure to Radionuclides in Air, Water, and Soil. Federal Guidance Report No. 12, EPA-402-R-93-081 (Oak Ridge National Laboratory, Oak Ridge, TN; U.S. Environmental Protection Agency, Washington, DC).

Table A6.1 Windrose Data for Cardiff Site (1988-1997) [Ref A6.6]

Sector (mid Point) Wind Blowing from	Frequency (Percent)	Comment	
270°	20.9%	-	
300°	13.5%	-	
330°	4.3%	-	Average over three sectors is 4.2%
0°	2.5%	Closest Farm	
30°	5.9%	-	
60°	16.0%	-	Average over three sectors is 9.5%
90°	6.3%	Radyr	
120°	6.3%	-	
150°	3.1%	-	
180°	3.1%	-	
210°	6.1%	-	
240°	12.3%	-	

Table A6.2 Short duration radionuclide discharges used in assessment (Current Limits)

Radionuclide	Current Daily Limits (TBq/day)	9.5% of Current Annual Limits[d] (TBq/y)	Discharge Used for Radyr Assessment[e] (TBq in one year)	4.2% of Current Annual Limits[f] (TBq/y)	Discharge Used for Closest Farm Assessment[e] (TBq in one year)
Soluble tritium[a]	9	38	**38**	17	**17**
Insoluble tritium[b]	50	95	**95**	42	**50**
Carbon-14	0.18	0.57	**0.57**	0.25	**0.25**
Phosphorus-32/33	-	1.9E-05	**1.9E-05**	8.4E-06	**8.4E-06**
Iodine-125	-	4.8E-05	**4.8E-05**	2.1E-05	**2.1E-05**
Other activity[c]	0.005	0.0038	**0.005**	0.0017	**0.005**

[a] Assumed to be tritiated water.
[b] Assumed to be tritium gas of which 10% is converted to tritiated water and becomes available for uptake into plants.
[c] Assumed to be sulphur-35 as the most radiologically significant radionuclide in this category [Ref A6.7].
[d] Maximum fraction of annual limit which could be blown towards Radyr in one year.
[e] Maximum of daily limit and fraction of annual limit.
[f] Maximum fraction of annual limit which could be blown towards closest farm in one year.

Table A6.3 Short duration radionuclide discharges used in assessment (Proposed Limits)

Radionuclide	Proposed Daily Limits (TBq/day)	9.5% of Proposed Annual Limits[d] (TBq/y)	Discharge Used for Radyr Assessment[e] (TBq in one year)	4.2% of Proposed Annual Limits[f] (TBq/y)	Discharge Used for Closest Farm Assessment[e] (TBq in one year)
Soluble tritium[a]	6.75	15	**15**	6.6	**6.75**
Insoluble tritium[b]	37.5	57	**57**	25	**37.5**
Carbon-14	0.135	0.23	**0.23**	0.10	**0.135**
Phosphorus-32/33	-	4.8E-07	**4.8E-07**	2.1E-07	**2.1E-07**
Iodine-125	-	1.7E-05	**1.7E-05**	7.6E-06	**7.6E-06**
Other activity[c]	2.5E-05	9.5E-05	**9.5E-05**	4.2E-05	**4.2E-05**

[a] Assumed to be tritiated water.
[b] Assumed to be tritium gas of which 10% is converted to tritiated water and becomes available for uptake into plants.
[c] Assumed to be sulphur-35 as the most radiologically significant radionuclide in this category [Ref A6.7].
[d] Maximum fraction of annual limit which could be blown towards Radyr in one year.
[e] Maximum of daily limit and fraction of annual limit.
[f] Maximum fraction of annual limit which could be blown towards closest farm in one year.

Table A6.4 Unit Air Activity Concentrations (Category D, Plume Centre-line, 30 minute Release)

Distance / m	Stack Height / m	Air Activity Concentration / Bq s m^{-3} per Bq
400	20	5.0×10^{-5}
1900	15	5.4×10^{-6}

Table A6.5 Concentration in foods per unit deposit Bq/kg per Bq/m^2

Radionuclide	Green vegetables	Potatoes and root vegetables	Cow meat	Cow liver	Sheep meat	Sheep liver	Milk	Fruit
Tritium	1.95E-03	1.95E-03	7.82E-04	7.82E-04	1.19E-03	1.19E-03	9.05E-04	1.95E-03
Carbon-14	4.63E-03	1.04E-02	7.15E-03	7.15E-03	1.08E-02	1.08E-02	2.15E-03	1.04E-02
Sulphur-35	1.37E-02	4.07E-04	2.25E-01	2.24E-01	4.74E-01	1.89E-01	3.47E-02	1.37E-02
Phosphorus-32	1.90E-03	5.50E-05	1.30E-02	1.30E-02	3.30E-02	3.30E-02	1.60E-02	1.90E-03
Iodine-125	2.95E-03	1.62E-03	2.64E-03	2.64E-03	5.45E-03	5.45E-03	4.35E-03	2.95E-03

Concentrations in foods for notional deposition rates of carbon-14 were derived using the ratio of activity concentrations of carbon-14 and tritium in air and in plant matter and animal product for equilibrium situation and concentrations of tritium in plant matter and animal product per unit deposit of tritium.

Table A6.6 Dose per Unit Short Term Release at Radyr (μSv/TBq)

Radionuclide	Infant	Child	Adult
Soluble tritium	1.26E+00	1.14E+00	1.02E+00
Insoluble tritium	1.26E-01	1.14E-01	1.02E-01
Carbon-14	9.20E+01	9.21E+01	9.56E+01
Sulphur-35	2.03E+02	1.14E+02	9.96E+01
Phosphorus-32	1.39E+02	9.33E+01	7.61E+01
Iodine-125	6.35E+03	6.38E+03	5.07E+03

Table A6.7 Dose per Unit Short Term Release at Closest Farm (μSv/TBq)

Radionuclide	Infant	Child	Adult
Soluble tritium	1.94E-01	1.39E-01	1.15E-01
Insoluble tritium	1.94E-02	1.39E-02	1.15E-02
Carbon-14	1.35E+01	1.10E+01	1.03E+01
Sulphur-35	3.68E+02	1.29E+02	7.42E+01
Phosphorus-32	5.42E+02	1.28E+02	6.33E+01
Iodine-125	4.69E+03	2.29E+03	1.24E+03

Table A6.8 Dose to Allotment Holders at Radyr from Short Term Releases (μSv/y)

Radionuclide	Current Limits			Proposed Limits		
	Infant	Child	Adult	Infant	Child	Adult
Soluble tritium	4.77E+01	4.34E+01	3.87E+01	1.86E+01	1.69E+01	1.51E+01
Insoluble tritium	1.19E+01	1.09E+01	9.67E+00	7.15E+00	6.51E+00	5.80E+00
Carbon-14	5.24E+01	5.25E+01	5.45E+01	2.08E+01	2.08E+01	2.16E+01
Sulphur-35	1.01E+00	5.70E-01	4.98E-01	1.93E-02	1.08E-02	9.46E-03
Phosphorus-32	2.63E-03	1.77E-03	1.45E-03	6.58E-05	4.43E-05	3.62E-05
Iodine-125	3.02E-01	3.03E-01	2.41E-01	1.09E-01	1.09E-01	8.67E-02
Total	**1.13E+02**	**1.08E+02**	**1.04E+02**	**4.67E+01**	**4.44E+01**	**4.26E+01**

Table A6.9 Dose for Farming Family at Closest Farm from Short Term Releases (μSv/y)

Radionuclide	Current Limits			Proposed Limits		
	Infant	Child	Adult	Infant	Child	Adult
Soluble tritium	3.25E+00	2.34E+00	1.93E+00	1.31E+00	9.41E-01	7.74E-01
Insoluble tritium	9.68E-01	6.97E-01	5.74E-01	7.26E-01	5.23E-01	4.30E-01
Carbon-14	3.40E+00	2.76E+00	2.59E+00	1.82E+00	1.48E+00	1.39E+00
Sulphur-35	1.84E+00	6.43E-01	3.71E-01	1.54E-02	5.40E-03	3.12E-03
Phosphorus-32	4.56E-03	1.08E-03	5.32E-04	1.14E-04	2.69E-05	1.33E-05
Iodine-125	9.86E-02	4.80E-02	2.61E-02	3.55E-02	1.73E-02	9.38E-03
Total	**9.56E+00**	**6.49E+00**	**5.48E+00**	**3.90E+00**	**2.97E+00**	**2.60E+00**

Table A6.10 Dose to Infant in Allotment Holding Family from Short Term Releases at Proposed Limits (μSv/y)

Radionuclide	Inhalation	Cloud gamma + beta	Deposited gamma	Green vegetables	Root vegetables	Fruit	Total
Soluble tritium	1.20E+01	0.00E+00	0.00E+00	1.04E+00	3.13E+00	2.43E+00	1.86E+01
Insoluble tritium	4.62E+00	0.00E+00	0.00E+00	4.01E-01	1.20E+00	9.35E-01	7.15E+00
Carbon-14	4.48E+00	2.94E-05	0.00E+00	1.26E+00	8.47E+00	6.59E+00	2.08E+01
Sulphur-35	1.28E-03	1.48E-08	0.00E+00	5.25E-03	4.70E-04	1.23E-02	1.93E-02
Phosphorus-32	2.14E-05	1.27E-08	4.52E-07	1.29E-05	1.12E-06	3.00E-05	6.58E-05
Iodine-125	1.18E-03	3.19E-07	6.00E-05	2.16E-02	3.55E-02	5.03E-02	1.09E-01
Total	**2.11E+01**	**2.97E-05**	**6.04E-05**	**2.73E+00**	**1.28E+01**	**1.00E+01**	**4.67E+01**

APPENDIX 7 - COLLECTIVE DOSES

Discharges to Atmosphere and Sewer

A7.1 Collective doses will arise from discharges of radionuclides from the site to atmosphere, and to sewer. Radionuclides discharged to sewer will be carried to the Severn Estuary and in future a new sewage treatment works will intercept radionuclides in sewage sludge and then applied to land. Collective doses were therefore calculated for discharges to atmosphere, discharges to sewer reaching the Severn Estuary and discharges to sewer which are incorporated into sludge and applied to land.

A7.2 The radionuclides discharges to atmosphere at current and proposed limits are provided in Table 1. It is assumed that the discharges of insoluble tritium will be converted to a soluble form (tritiated water) over the first few months after release.

A7.3 The radionuclides discharged to the Severn Estuary at current and proposed limits for the scenarios of no sewage treatment and sewage treatment are provided in Appendix 2. It was assumed that tritium released as OBT was converted to tritiated water during the first year before circulating globally.

A7.4 The concentration of radionuclides in sludge after the new sewage works starts up and the quantities of radionuclides that will be applied to land at current and proposed limits is provided in Appendix 3. Radionuclides incorporated into sludge and applied to land may be subsequently released to atmosphere as the applied sludge is broken down by bacterial action. In the calculation it was assumed that all the tritium and carbon-14 applied to land in sludge will be released to atmosphere within one year of application.

Calculation of Collective Doses

A7.5 Collective doses per unit discharge to atmosphere and the Severn Estuary from the Amersham plc at Cardiff have been calculated by NRPB [Ref A7.1] (see Tables A7.1 and A7.2). Collective doses per unit activity concentration in sewage sludge and unit production rate of sewage sludge were taken from an Agency R&D report [Ref A7.2] (see Table A7.3). Radionuclides in sewage sludge may be released to atmosphere once the sludges degrade. Collective doses from atmospheric releases from land treated with sludges have been included (see Table A7.3).

A7.6 Collective doses were calculated for the UK, European and World populations, truncated at 500 years in accordance with guidance from DEFRA [Ref A7.3].

A7.7 The NRPB report on collective doses [Ref A7.1], provides world collective doses for globally circulating radionuclides, I-129, H-3, Kr-85 and C-14. Other less mobile radionuclides will remain disperse less or will undergo significant radioactive decay before they can disperse widely. Thus collective doses from these radionuclides will be restricted to the UK and European population only. Thus, the world collective dose has been calculated as the sum of the European collective dose and the world collective dose for globally circulating radionuclides.

A7.8 For sewage sludge, the sludge production rate for the new sewage treatment works of 45 te/day (1.64 10^7 kg/y) (see Appendix 3) and an application rate of 1.5 kg/m^2 has been used in the assessment.

A7.9 Per caput doses (ie average individual doses) have been calculated for the UK, European and World populations, using the collective doses and UK, European and World populations of 55 million people, 700 million people and 10 000 million people respectively [Ref A7.1].

Assessed Collective Doses

A7.10The collective doses for discharges to atmosphere, discharges to the Severn Estuary (no sewage treatment), discharges to the Severn Estuary (with sewage treatment) and spreading of sludge to land are shown in Tables A7.4, A7.5, A7.6 and A7.7 respectively.

A7.11The per caput doses for the UK, European and World doses are shown in Table A7.8.

References

A7.1 Bexon A (1999). Radiological impact of routine discharges from UK civil nuclear sites in the mid 1990s. National Radiological Protection Board, Chilton NRPB-R312.

A7.2 J G Titley, A D Carey, G M Crockett, G J Ham, M P Harvey, S F Mobbs, C Tournette, J S S Penfold & B T Wilkins (2000). Investigation of the Sources and Fate of Radioactive Discharges to Public Sewers. Environment Agency R&D Technical Report P288.

A7.3 The Environment Agency and the Regulation of Radioactive Discharges into the Environment from Nuclear Licensed Sites. Incorporating: Part I Statutory Guidance to the Environment Agency Made Under Section 4 of the Environment Act 1995. Part II Explanatory Document Accompanying the Statutory Guidance.

Table A7.1 Collective Dose per Unit Discharge to Atmosphere Truncated to 500 years (manSv/Bq)

Radionuclide	UK	Europe	World - Globally Circulating
Soluble tritium	1.50E-15	3.92E-15	3.27E-16
Insoluble tritium	1.50E-15	3.92E-15	3.27E-16
Carbon-14	3.45E-13	3.10E-12	1.72E-11
Phosphorus-32/33	9.00E-13	9.00E-13	-
Iodine-125	3.00E-12	7.50E-12	-
Other activity[a]	3.60E-13*	1.30E-12*	-

[a] Assumed to be sulphur-35.
* Collective dose data for Amersham plc at Amersham.

Table A7.2 Collective Dose per Unit Discharge to Severn Estuary Truncated to 500 years (manSv/Bq)

Radionuclide	UK	Europe	World - Globally Circulating
Tritiated Water	2.70E-19	3.20E-18	4.30E-17
OBT	2.70E-19	3.20E-18	4.30E-17
Carbon-14	1.10E-13	1.10E-12	1.10E-11
Phosphorus-32/33	7.30E-15	2.20E-14	-
Iodine-125	7.90E-17	3.10E-16	-
Others[a]	2.00E-16	9.20E-16	-

[a] Assumed to be cobalt-57 for collective dose assessment (as a worst case radionuclide).

Table A7.3 Collective Dose for Spreading of Sewage Sludge to Land per Unit Activity Concentration and Unit Sludge Production Rate and Released to Atmosphere Truncated at 500 years

	From sludge manSv per Bq/kg per kg/y	Atmospheric releases from degraded sludge on treated land (manSv/Bq)		
Radionuclide	UK	UK	Europe	World global circulation
Tritiated Water	2.6E-14	1.50E-15	3.92E-15	3.27E-16
OBT	2.6E-14	1.50E-15	3.92E-15	3.27E-16
Carbon-14	3.9E-12	3.45E-13	3.10E-12	1.72E-11
Phosphorus-32/33	1.3E-12	0	0	0
Iodine-125	2.5E-13	0	0	0
Others[a]	-	0	0	0

[a] Has been assumed to be selenium-75 for individual dose assessment with no transfer to sludge.

Table A7.4 Collective Dose for Discharges to Atmosphere Truncated to 500 years (manSv)

Radionuclide	Current Limits			Proposed Limits		
	UK	Europe	World[a]	UK	Europe	World[a]
Soluble tritium	6.00E-01	1.57E+00	1.70E+00	2.34E-01	6.12E-01	6.63E-01
Insoluble tritium	1.50E+00	3.92E+00	4.25E+00	9.00E-01	2.35E+00	2.55E+00
Carbon-14	2.07E+00	1.86E+01	1.22E+02	8.21E-01	7.38E+00	4.83E+01
Phosphorus-32/33	1.80E-04	1.80E-04	1.80E-04	4.50E-06	4.50E-06	4.50E-06
Iodine-125	1.50E-03	3.75E-03	3.75E-03	5.40E-04	1.35E-03	1.35E-03
Other activity[b]	1.44E-02	5.20E-02	5.20E-02	3.60E-04	1.30E-03	1.30E-03
Total	**4.19E+00**	**2.41E+01**	**1.28E+02**	**1.96E+00**	**1.03E+01**	**5.15E+01**

[a] Calculated from sum of European collective dose and world collective dose for globally circulating radionuclides H-3 and C-14.
[b] Assumed to be sulphur-35.

Table A7.5 Collective Dose for Discharges to Severn Estuary with no Sewage Treatment Truncated to 500 years (manSv)

Radionuclide	Current Limits			Proposed Limits		
	UK	Europe	World[a]	UK	Europe	World[a]
Tritiated Water	2.37E-04	2.80E-03	4.05E-02	2.03E-05	2.40E-04	3.47E-03
OBT	6.48E-06	7.68E-05	1.11E-03	6.48E-06	7.68E-05	1.11E-03
Carbon-14	2.20E-01	2.20E+00	2.42E+01	1.00E-01	1.00E+00	1.10E+01
Phosphorus-32/33	7.30E-05	2.20E-04	2.20E-04	6.21E-07	1.87E-06	1.87E-06
Iodine-125	3.95E-06	1.55E-05	1.55E-05	2.37E-08	9.30E-08	9.30E-08
Others[b]	1.00E-07	4.60E-07	4.60E-07	2.40E-08	1.10E-07	1.10E-07
Total	**2.20E-01**	**2.20E+00**	**2.42E+01**	**1.00E-01**	**1.00E+00**	**1.10E+01**

[a] Calculated from sum of European collective dose and World collective dose for globally circulating radionuclides tritium and carbon-14.
[b] Assumed to be cobalt-57 for collective dose assessment (as a worst case radionuclide).

Table A7.6 Collective Dose for Discharges to Severn Estuary with Sewage Treatment Truncated to 500 years (manSv)

Radionuclide	Current Limits			Proposed Limits		
	UK	Europe	World[a]	UK	Europe	World[a]
Tritiated Water	2.18E-04	2.59E-03	3.74E-02	2.38E-05	2.82E-04	4.07E-03
OBT[b]	2.92E-07	3.46E-06	4.99E-05	2.92E-07	3.46E-06	4.99E-05
Carbon-14	1.54E-01	1.54E+00	1.69E+01	7.01E-02	7.01E-01	7.71E+00
Phosphorus-32/33	1.46E-05	4.40E-05	4.40E-05	1.24E-07	3.74E-07	3.74E-07
Iodine-125	3.56E-06	1.40E-05	1.40E-05	2.13E-08	8.37E-08	8.37E-08
Others[b]	1.00E-07	4.60E-07	4.60E-07	2.40E-08	1.10E-07	1.10E-07
Total	**1.54E-01**	**1.54E+00**	**1.70E+01**	**7.01E-02**	**7.01E-01**	**7.71E+00**

[a] Calculated from sum of European collective dose and World collective dose for globally circulating radionuclides tritium and carbon-14.
[b] Assumed to be converted to tritiated water as tritium as OBT is unlikely to become widely distributed
[c] Assumed to be cobalt-57 for collective dose assessment (as a worst case radionuclide).

Table A7.7 Collective Dose for Spreading Sludge to Land Truncated to 500 years (manSv)

Radionuclide	Current Limits				Proposed Limits			
	Sludge UK	Atmospheric release from sludge			Sludge UK	Atmospheric releases from sludge		
		UK	Europe	World[a]		UK	Europe	World[a]
Tritiated Water & OBT[b]	4.39E-01	1.35E-01	3.53E-01	3.82E-01	4.83E-02	1.49E-02	3.88E-02	4.21E-02
Carbon-14	4.39E-01	2.07E-01	1.86E+00	1.22E+01	2.00E-01	9.41E-02	8.45E-01	5.53E+00
Phosphorus-32/33	1.95E-03	0.00E+00	0.00E+00	0.00E+00	1.66E-05	0.00E+00	0.00E+00	0.00E+00
Iodine-125	2.34E-04	0.00E+00	0.00E+00	0.00E+00	1.41E-06	0.00E+00	0.00E+00	0.00E+00
Others	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	**8.80E-01**	**3.42E-01**	**2.21E+00**	**1.26E+01**	**2.48E-01**	**1.09E-01**	**8.84E-01**	**5.58E+00**

[a] Calculated from sum of European collective dose and World collective dose for globally circulating radionuclides H-3 and C-14.
[b] OBT assumed to be converted to tritiated water before release to atmosphere

Table A7.8 Per Caput Doses Truncated to 500 years (μSv/y)

Disposal Route	Current Limits			Proposed Limits		
	UK	Europe	World	UK	Europe	World
Discharges to Atmosphere	7.61E-02	3.45E-02	1.28E-02	3.56E-02	1.48E-02	5.15E-03
Discharges to Severn Estuary (no sewage treatment)	4.01E-03	3.15E-03	2.42E-03	1.82E-03	1.43E-03	1.10E-03
Discharges to Severn Estuary (sewage treatment)	2.80E-03	2.20E-03	1.70E-03	1.27E-03	1.00E-03	7.71E-04
Spreading of sludge to land	2.22E-02	3.16E-03	1.26E-03	6.49E-03	1.26E-03	5.58E-04

APPENDIX 8 - SENSITIVITY STUDY

Method for Sensitivity Study

A8.1 The uncertainty and variability in the assumptions made in the radiological assessment have been examined in a sensitivity study for the candidate critical groups which are predicted to receive a dose of more than about 10 μSv/y. These candidate critical groups are as follows:

- Allotment holder at Radyr.
- Fisherman in the Severn Estuary.
- Farming family close to new sewage treatment works.
- Anglers on the River Taff.

A8.2 The key assumptions in the dose assessments for each of these groups has been identified and the extent to which this assumption may have led to an underestimate or and overestimate of the dose has been examined and described. The results are provided in Tables A8.1, A8.2, A8.3 and A8.4 for each of the above groups.

A8.3 For each group, the sensitivity study has been based on the predicted doses for discharges at proposed limits with all sewer improvement schemes completed. The results of the study cannot be directly translated to doses assessed for other scenarios, since assumptions with a relatively large uncertainty may be attributable to that particular scenario (eg impact of sewer improvement schemes).

A8.4 For each key assumption, a conclusion has been reached on the likely impact on the total dose in terms of the numerical factor the total dose may be higher or lower, taking into account the contribution made by the particular radionuclides involved. These factors have been combined together using a statistical propagation technique for errors (ie square root of sum of the squares of the factors). This gives the overall likely underestimate and overestimate of the total dose. The overall likely caution applied in the assessment has been derived from the likely overestimate of the dose divided by the likely underestimate.

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Table A8.1 Discharges to Atmosphere - Uncertainty and Variability in Assessment and Impact on Doses Likely to be Received

Stage in Assessment	Key assumptions	Possible underestimate of dose	Possible overestimate of dose
Source Term	Discharge assumed to occur at limits for all radionuclides	N/A	Discharges are likely to be 70% of the proposed limit for the radonuclides contributing the majority of the dose, tritium and carbon-14. ***Impact on total dose: Factor of 1.4 lower than predicted***
	Soluble tritium assumed to be in the form of tritiated water	There is the potential for a small proportion of this category, perhaps 1%, to be soluble OBT. This is considered later under environmental transfer and dose coefficients.	-
	Insoluble tritium assumed to be tritium gas on release. Assumed that 10% of the insoluble tritium is converted to tritiated water in the vicinity of the release. The remainder assumed to disperse before conversion to tritiated water over time further from the site.	There is the potential for a small proportion of insoluble tritium perhaps 1%, to be OBT. The potential effect of this is considered later under environmental transfer and dose coefficients.	Doses from insoluble tritium are lower than those from soluble tritium, because insoluble tritium as tritium gas is unlikely to be taken up into plants. Insoluble tritium contributes only 13% of the total dose from total discharge of tritium. The research evidence suggests that only about 7.2% of tritium gas will be converted to tritiated water over a period of one year (see Appendix 1). Given that the tritium gas will be dispersed quickly away from the chosen receptor points over a matter of minutes, it is in fact unlikely that more than about 1% of the tritium gas will have been converted to tritiated water. ***Impact on total dose: Factor of 1.1 lower than predicted***
	Other category assumed to be sulphur-35.	N/A.	This is the worst case nuclide from a radiological impact point of view. However, the discharges in this category are small and the consequent dose is a small percentage of the total dose. ***Impact on total dose: Negligible***

Stage in Assessment	**Key assumptions**	**Possible underestimate of dose**	**Possible overestimate of dose**
Environmental concentrations	Gaussian plume model in PC Cream used to undertake assessments.	Under-prediction of dose unlikely. The modelling approach used is likely to overestimate air concentrations at the receptor point locations	Annual average air concentrations of pollutants assessed by modelling codes are generally within a factor of two or three of monitoring measurements. The gaussian plume model tends to overestimate air concentrations compared to other validated modelling codes (eg ADMS) for annual average assessments. An overall comparison of the air concentrations predicted by Gaussian plume model and ADMS are given below.

Table A8.1 Discharges to Atmosphere - Uncertainty and Variability in Assessment and Impact on Doses Likely to be Received (Cont)

Stage in Assessment	Key assumptions	Possible underestimate of dose	Possible overestimate of dose
Environmental concentrations (cont)	Effective release height based on difference in height of the stack above ODN and height of receptor location above ODN.	Downwash of the plume could occur under certain conditions, reducing the stack height by about three times the diameter of the stack (2 m) [Ref A8.1]. Resultant effective stack height could be 6 m lower. This would increase the air activity concentrations by about 20%. ***Impact on total dose: Factor of 1.2 higher than predicted***	Plume rise from the stack could increase the effective stack height under certain weather conditions. Amersham plc have investigated this using the ADMS code and have concluded that for a minimal stack exit velocity the maximum ground level air concentration will be a factor of about 1.3 lower than that assuming a normal operational stack exit velocity. The local topography will create more dispersion than that assumed from this modified effective stack height approach over flat terrain. Both these factors are included in an overall comparison of the air concentrations predicted by gaussian plume models compared to AMDS are given below.
	Location and distance to chosen receptor points	The location at Radyr is predicted to be at the point of highest air concentration for the chosen stack height. Modelling by Amersham plc using ADMS with site meteorological weather data and topography has confirmed that the highest stack concentrations are on the edge of Raydr.	N/A
	Weather (65%D stability category and uniform wind rose assumed)	Ground level air concentrations at receptor points upwind (to the East) of the site are likely to be >5 times lower than those at because the receptor points. This is because the relative stack height is higher for receptors to the east of the site and the ground level air concentration under uniform wind conditions is 10 times lower to the east than at Radyr.	The average stability conditions of 65%D have been confirmed by site meteorological data. However, the assumption of a uniform windrose for the two receptor locations is an overestimate, since the prevailing wind direction is away from these locations. The dispersion coefficient calculated for Radyr in this assessment is 2.5 10^{-6} s/m^3. The highest dispersion coefficient calculated by Amersham plc using ADMS modelling for the Radyr area was 4.2 10^{-7} s/m^3. ***Impact on total dose: Factor of 6 lower than predicted***

Table A8.1 Discharges to Atmosphere - Uncertainty and Variability in Assessment and Impact on Doses Likely to be Received (Cont)

Stage in Assessment	Key assumptions	Possible underestimate of dose	Possible overestimate of dose
Environmental Concentrations (cont)	Deposition velocity of 10^{-3} m/s assumed for particulate radionuclides, 10^{-2} m/s for iodine and zero for noble gases	There is a reasonable range on deposition velocities and the values could be factor of ten higher for particulates [Ref A8.2]. However, unlikely to be higher for iodine. Tritium and carbon-14 concentrations in food modelled without use of deposition and these provide largest contribution to dose. ***Impact on total dose: Negligible***	Deposition velocities could be a factor of ten lower [Ref A8.2], but since this only apply to radionuclides which are have low discharges and therefore have a small effect on the total dose. ***Impact on total dose: Negligible***
	Transfer factors and models in PC Cream used for assessing concentrations of tritium in food.	Tritium concentrations in food crops are assessed assuming that tritium is in the form of tritiated water and that the activity concentration of tritiated water in plants is the same as that in air. These transfer factors are based on a concentration of water in air of 8 g/m^3 and 80-90% water content for fruit and vegetables. The transfer factors can be no more than a factor of two higher. Tritium contributes about 50% of the total dose. ***Impact on total dose: Factor of up to 1.5 higher than predicted***	The transfer factors are probably no more than a factor of two lower. Tritium contributes about 50% of the total dose. This transfer model is likely to be an over-estimate for the transfer of OBT, since it essentially assumes direct uptake of all the tritium into the plant from the air. This route is unlikely for OBT. Thus, although there concentrations of OBT in plants compared to the soil may be enhanced, only a small percentage of the OBT (about 0.1%) would be deposited on the soil. ***Impact on total dose: Factor of 1.5 lower than predicted***
	Transfer factors and models in PC Cream used for assessing concentrations of carbon-14 in food	Carbon-14 concentrations in food crops are assessed assuming that carbon is in the form of carbon dioxide and that the activity concentration of carbon-14 in plants is the same as that in air. These transfer factors are based on a concentration of carbon in air of 0.15 g/m^3 and 4-8% carbon content for fruit and vegetables. The transfer factors are probably no more than a factor of five higher. Carbon-14 contributes about 50% of the total dose. ***Impact on total dose: Factor of 3 higher than predicted***	The transfer factors are probably no more than a factor of two lower for carbon than those used. Carbon-14 contributes about 50% of the total dose. ***Impact on total dose: Factor of 1.5 lower than predicted***

Table A8.1 Discharges to Atmosphere - Uncertainty and Variability in Assessment and Impact on Doses Likely to be Received (Cont)

Stage in Assessment	Key assumptions	Possible underestimate of dose	Possible overestimate of dose
Environmental Concentrations (cont)	Concentration factors and models in PC Cream used for assessing concentrations of other radionuclides in food	There is some considerable variability in concentration factors for food. However, the other radionuclides make little contribution to the overall dose. ***Impact on total dose: Negligible***	There is some considerable variability in concentration factors for food. However, the other radionuclides make little contribution to the overall dose. ***Impact on total dose: Negligible***
Habit data	At Radyr all green vegetables, root vegetable and fruit consumed by this group are assumed to be grown at that location. Similarly, at the nearest farm all vegetables, fruit, beef, lamb, offal and milk eaten is assumed to be produced at this location.	There is the potential for other foods to be produced at Radyr (eg goat's milk, goat's cheese, eggs). These could increase the dose by a few microsievert per year. However, it is fairly unlikely that all these foods would be produced locally and consumed by the same group of people. Similarly, other foods could be produced at the nearest farm (eg milk products, pork, eggs, grain etc), but it is extremely unlikely that all foods would consumed by a farming family would be produced on the farm. ***Impact on total dose: Negligible***	It is fairly likely that allotment holders in Radyr and the nearest farming family would in fact source some food from elsewhere. It is probable that no more than 50% of the annual food intakes would be sourced from a local farm or allotments. In particular, fruit and vegetables from abroad may be bought in supermarkets. If 50% of the foods were sourced from the allotment or the local farm then the dose would be about 50% lower (see Appendix 1). The nearest farm does currently appear to have dairy production, being used mainly for horses. The dose actually received could thus be considerably lower. ***Impact on total dose: Factor of 2 lower than predicted***
	Critical consumption rates assumed for two foods and the remainder at average rates	The variability within critical group consumption rates is typically a factor of three (ie a factor of 1.75 about the mean). ***Impact on total dose: Factor of up to 1.7 higher than predicted***	The variability within critical group consumption rates is typically a factor of three (ie a factor of 1.75 about the mean). ***Impact on total dose: Factor of up to 1.7 lower than predicted***
	90% occupancy at the locations are assumed (allowing time to be away shopping, visiting friends and relatives or on holiday). At Radyr, a large proportion of the time is assumed to be spent indoors. At the farm, the adult is assumed to be outdoors for 4000 hours.	Greater occupancy outdoors might occur at Radyr for adults, but unlikely at nearest farm. The dose pathways for which occupancy is important (inhalation, groundshine and cloudshine) contribute little to the total dose and thus the impact is small. ***Impact on total dose: Negligible***	N/A

Table A8.1 Discharges to Atmosphere - Uncertainty and Variability in Assessment and Impact on Doses Likely to be Received (Cont)

Stage in Assessment	Key assumptions	Possible underestimate of dose	Possible overestimate of dose
Dose coefficients	Dose coefficients within PC Cream used for the assessment. These are based on current international advice. OBT dose coefficient has been used for tritium.	Recent evidence has suggested that the dose factor for OBT could be a factor of two higher [Ref A8.3]. If all the ingested tritium were as OBT, then the dose from tritium could be doubled. Tritium contributes about half the total dose. ***Impact on total dose: Factor of 1.5 higher than predicted***	It is stated in ICRP Publication 60 that some caution is taken into account in the derivation of dose coefficients. OBT dose coefficient has been used which could over-estimate the dose from OBT by a factor of about two, given that the majority of the tritium in foods is likely to be in the form of tritiated water rather than OBT. Tritium contributes about half the total dose. ***Impact on total dose: Factor of 1.5 lower than predicted***
Additional doses from discharges to Severn Estuary and disposals of sewage sludge to land	No contribution from discharges to sewer have been included in the assessment of doses from atmospheric releases	The candidate critical groups around the site could also consume sea foods from the Severn Estuary and duck caught in the Severn Estuary. If foods were caught in the Severn and consumed at average rates by these groups, after the sewer improvement schemes have been implemented, the mean doses would at proposed limits would be 4 - 8 μSv/y (see Appendix 2), representing about 30% of the dose to allotment holders at Radyr. Contribution of atmospheric doses to disposal of sewage sludge to land is considered in the sensitivity assessment for this disposal route. ***Impact on total dose: Factor of 1.3 higher than predicted***	N/A
Overall underestimate or overestimate of dose		Total dose could be a factor of ***4.4 higher than predicted***	Total dose could be a factor of ***7.3 lower than predicted***
		Overall total dose may be a factor of ***1.7 lower than predicted***	

Table A8.2 Discharges to Severn Estuary - Uncertainty and Variability in Assessment and Impact on Doses Likely to be Received by Fisherman for Discharges at Proposed Limits and with Operational Sewage Treatment Works

Stage in Assessment	Key assumptions	Possible underestimate of dose	Possible overestimate of dose
Source Term	Discharge assumed to occur at limits for all radionuclides	N/A	Discharges are likely to be 70% of the proposed limit for the radonuclide contributing the majority of the dose, carbon-14. ***Impact on total dose: Factor of 1.4 lower than predicted***
	Estimated that 24 GBq/y of tritium is in an OBT form (representing 24% of proposed limits). Based on 95% confidence level of effluent monitoring.	Amersham plc state that [Ref A8.4] up to 80% of the discharges of tritium in 1999 could be in an OBT form. OBT contributes 15% of the total dose. ***Impact on total dose: Factor of 1.5 higher than predicted***	The independent monitoring of effluent by the Agency indicates a lower average proportion of OBT in the effluent, being about 6 TBq/y of OBT. This represents 6% of the proposed limit. OBT contributes 15% of the total dose. ***Impact on total dose: Factor of 1.1 lower than predicted***
	Losses from effluent to sludge taken into account for the scenario of operational sewage treatment works. For the key radionuclides, carbon-14 and tritium as tritiated water and as OBT, percentage reamining in effluent of 70% and 90% respectively have been used. In addition is has been assumed that 95% of OBT is converted to tritiated water in the sewage works.	Measurements of the retention of carbon-14 and tritium in sewage effluent during treatment indicate that 80-94% of carbon-14 and 78-91% of tritium remain in the effluent [Ref A8.5]. Other studies have shown transfers of 25-75% carbon-14 remaining in effluent [Ref A8.6]. Carbon-14 contributes the highest doses and thus the assessed doses could be about 1.3 times higher. Doses were also assessed assuming no sewage works scenario, and these are likely to represent the upper limit. ***Impact on total dose: Factor of 1.3 higher than predicted***	Based on experimental studies, removal from effluent of radionuclides during treatment could be up to a factor of 2.0 more than those assumed. ***Impact on total dose: Factor of 2.0 lower than predicted***

Table A8.2 Discharges to Severn Estuary - Uncertainty and Variability in Assessment and Impact on Doses Likely to be Received by Fisherman for Discharges at Proposed Limits and with Operational Sewage Treatment Works (cont)

Stage in Assessment	Key assumptions	Possible underestimate of dose	Possible overestimate of dose
Environmental concentrations	Dispersion of radionuclides in seawater based on PC Cream compartment model and parameter values for local box selected from other studies or derived from monitoring data.	A key parameter in the dispersion calculation is the volumetric exchange with the regional box. This was derived from monitoring data for tritium in seawater (see Appendix 2) and a value of 10^{10} m^3/y selected. An NRPB study derived a lower volumetric exchange rate of 5 10^9 m^3/y based on changes in average height of the estuary water. ***Impact on total dose: Factor of 2 higher than predicted***	Volumetric exchange as derived will be subject to an uncertainty of up to about 20% (exchange is based on observed tritium concentrations in seawater). ***Impact on total dose: Factor of 1.2 lower than predicted***
	Concentration factors for OBT based on measurements of total tritium in fish compared to model predictions of OBT in seawater.	The derived concentration factor for OBT in fish is 14 000 Bq/kg per Bq/l. The best estimate CF for carbon is 20 000 Bq/kg per Bq/l and it is possible that this value may be more appropriate for OBT. OBT in fish contributes about 15% of the total dose. ***Impact on total dose: Factor of 1.1 higher than predicted***	Concentration factors of about 1000 or less are derived from a comparison of the total tritium concentrations in fish and seawater (see Appendix 2). OBT in fish contributes about 15% of the total dose. ***Impact on total dose: Factor of 2 lower than predicted***
	Concentration factors for other radionuclides, including carbon-14, are PC Cream defaults	The IAEA suggests a CF for fish of 50 000 Bq/kg per Bq/l, 2.5 times higher than the value of 20 000 Bq/kg per Bq/l used. 85% of the total dose is from carbon-14 in fish. ***Impact on total dose: Factor of 2.3 higher than predicted***	NCRP suggest a CF of 2000 Bq/kg per Bq/l for carbon-14 in fish, ten times lower than the value of 20 000 Bq/kg per Bq/l used. 85% of the total dose is from carbon-14 in fish. ***Impact on total dose: Factor of 4.3 lower than predicted***
Habit Data	All fish and shellfish consumed by the fisherman is assumed to be caught in an area 2 km x 2 km centred around the discharge point	N/A	It is probable that a fisherman would catch some fish and shellfish from other localities in the Severn further from the outfall. Perhaps up to half of the fish could be caught from outside the immediate vicinity of the outfall. ***Impact on total dose: Factor of 2 lower than predicted***
	Critical group consumption rates selected from the MAFF/FSA habit surveys	The variability within critical group consumption rates is typically a factor of three (ie a factor of 1.75 about the mean). ***Impact on total dose: Factor of 1.7 higher than predicted***	The variability within critical group consumption rates is typically a factor of three (ie a factor of 1.75 about the mean). ***Impact on total dose: Factor of 1.7 higher than predicted***

Table A8.2 Discharges to Severn Estuary - Uncertainty and Variability in Assessment and Impact on Doses Likely to be Received by Fisherman for Discharges at Proposed Limits and with Operational Sewage Treatment Works (cont)

Stage in Assessment	Key assumptions	Possible underestimate of dose	Possible overestimate of dose
Dose coefficients	Dose coefficients within PC Cream used for the assessment. These are based on current international advice.	Recent evidence has suggested that the dose factor for OBT could be a factor of two higher [Ref A8.3]. OBT contributes about 15% of the total dose. ***Impact on total dose: Factor of 1.2 higher than predicted***	It is stated in ICRP Publication 60 that some caution is taken into account in the derivation of dose coefficients.
Additional doses from discharges to air	No contribution to the total dose from discharges to atmosphere have been included in the assessment.	In the unlikely event that all other foods consumed, (in addition to seafoods) are from the farm nearest to the site, the additional to an adult would be 1.8 μSv/y (see Appendix 1), representing about 11% of the dose to fishermen. ***Impact on total dose: Factor of 1.1 higher than predicted***	N/A
Overall underestimate or overestimate of dose		Total dose could be a factor of ***4.5 higher than predicted***	Total dose could be a factor of ***6.1 lower than predicted***
		Overall total dose may be a factor of ***1.4 lower than predicted***	

Table A8.3 Disposal of Sewage Sludge to Land - Uncertainty and Variability in Assessment and Impact on Doses Likely to be Received

Stage in Assessment	**Key assumptions**	**Possible underestimate of dose**	**Possible overestimate of dose**
Source Term	Discharge assumed to occur at limits for all radionuclides	N/A	Discharges are likely to be 90% of the proposed limit for the radionuclides contributing the majority of the dose, tritium. ***Impact on total dose: Factor of 1.1 lower than predicted***
	For the key radionuclides, tritium and carbon-14, percentage transfer to sludge of 10% and 30% respectively have been used.	Measurements on the retention of carbon-14 and tritium in Amersham plc effluent indicate that 6-20% of carbon-14 and 9-22% of tritium are transferred to sludge [Ref A8.5]. Other studies have shown transfers of 25-75% carbon-14 to sludge [Ref A8.6]. Thus the transfer to sludge could be 2.5 times greater. Tritium contributes about 90% of the total dose and carbon-14 the remainder. ***Impact on total dose: Factor of 2.2 higher than predicted***	Using the lower end of the range of transfers of tritium and carbon-14 to sludge would have little effect on the dose assessment. ***Impact on total dose: Negligible***
	A sludge production rate of 45 te/y has been assumed in the assessment based on information supplied by Welsh Water. There is no information to assess the reliability of this production rate. Production rate of sludge is probably equally likely to be either greater or lower.	N/A	N/A

Table A8.3 Disposal of Sewage Sludge to Land - Uncertainty and Variability in Assessment and Impact on Doses Likely to be Received (cont)

Stage in Assessment	Key assumptions	Possible underestimate of dose	Possible overestimate of dose
Environmental concentrations	A sludge application rate of 1.5 kg/m^2/y has been assumed	For the sludge pellets likely to be produced (94% dry), the application rate assumed is unlikely to be exceeded.	For the sludge pellets likely to be produced (94% dry), the UK average application rate is 0.8 kg/m^2/y, with a lower application rate of around 0.4 kg/m^2/y. ***Impact on total dose: Factor of 4 lower than predicted***
	Dynamic models have been used for carbon-14 and tritium, equilibrium models have been used for other radionuclides. Best estimate assumptions have been made for parameter values in the dynamic models.	Parameter values for the dynamic models generally span a range of about a factor of ten [Ref A8.7]. The values could be a factor of about 3.1 higher or lower. ***Impact on total dose: Factor of 3.1 higher than predicted***	Parameter values for the dynamic models generally span a range of about a factor of ten [Ref A8.7]. The values could be a factor of about 3.1 higher or lower ***Impact on total dose: Factor of 3.1 lower than predicted***

Table A8.3 Disposal of Sewage Sludge to Land - Uncertainty and Variability in Assessment and Impact on Doses Likely to be Received (cont)

Stage in Assessment	Key assumptions	Possible underestimate of dose	Possible overestimate of dose
Habit data	Consumption of milk, beef, lamb and offal only assumed.	These are the foods which could be produced on pasture which has been surface spread with sludge pellets which will lead to the highest concentrations in the soil surface/root zone. Fruit and vegetables cannot be cropped until 10 months after applying sludge [Ref 7]. After this time much of the tritium and Carbon-14 applied is likely to have been lost from the soil-plant system. Also, sludge would be mixed into the top 10-30 cm of the soil diluting the activity concentration. Milk products could be produced and consumed. Dose from milk is up to 88% of the total, consumption of milk products is around 15% of milk intakes, radionuclides are concentrated by up to a factor of 11 in milk products relative to milk ***Impact on total dose: Doses could be 1.4 times higher***	It is fairly unlikely that one farm would provide for the annual requirements of the critical groups for all these families. 50% of food consumption is a reasonable assumption for the critical group. ***Impact on total dose: Factor of 2 lower than predicted***
	Critical consumption rates assumed for milk and lamb and the remainder at average rates	The variability within critical group consumption rates is typically a factor of three (ie a factor of 1.75 about the mean). ***Impact on total dose: Factor of 1.7 higher than predicted***	The variability within critical group consumption rates is typically a factor of three (ie a factor of 1.75 about the mean). ***Impact on total dose: Factor of 1.7 higher than predicted***
Dose coefficients	Dose coefficients from the BSS Directive used from the assessment	Recent evidence has suggested that the dose factor for OBT could be a factor of two higher [Ref A8.3]. OBT contributes about 95% of the total dose. ***Impact on total dose: Factor of 2 higher than predicted***	It is stated in ICRP Publication 60 that some caution is taken into account in the derivation of dose coefficients.
Additional doses from discharges to air	No contribution to the total dose from discharges to atmosphere have been included in the assessment.	The farm nearest to the site may also condition its land with sewage sludge pellets. The additional doses from atmospheric discharges were assessed as between 3.8 - 7.1 µSv/y (an addition of up to 16% to the dose). ***Impact on total dose: Factor of 1.2 higher than predicted***	N/A
Overall underestimate or overestimate of dose		Total dose could be a factor of ***5.0 higher than predicted***	Total dose could be a factor of ***5.8 lower than predicted***
		Overall total dose may be a factor of ***1.1 lower than predicted***	

Table A8.4 Overflow Discharges to River Taff - Uncertainty and Variability in Assessment and Impact on Doses Likely to be Received by Anglers after Completion of the Sewer Improvement Scheme

Stage in Assessment	Key assumptions	Possible underestimate of dose	Possible overestimate of dose
Source Term	Discharge assumed to occur at limits for all radionuclides	N/A	Discharges are likely to be 90% of the proposed limit for tritium and carbon-14 which between them contribute the majority of the total dose. ***Impact on total dose: Factor of 1.1 lower than predicted***
	Estimated that 24 GBq/y of tritium is in an OBT form (representing 24% of proposed limits). Based on 95% confidence level of effluent monitoring.	Amersham plc state that [Ref A8.4] up to 80 TBq of the discharges of tritium in 1999 could be in an OBT form rather than 24 TBq/y. OBT contributes about 60% of the dose. ***Impact on total dose: Factor of 2.4 higher than predicted***	The independent monitoring of effluent by the Agency indicates a lower average proportion of OBT in the effluent, being about 6 TBq/y of OBT rather than 24 TBq/y assumed in the assessment. OBT contributes about 60% of the dose. ***Impact on total dose: Factor of 1.8 lower than predicted***
	Proportion of radionuclides overflowing from sewer and reaching River Taff once the sewer overflow improvement scheme has been implemented is based on a few overflows per year compared to the current 50-60 overflows per year and the percentage of time discharges occur and could thus coincide with overflows.	The proportion of sewage overflowing once the sewer improvement scheme has been implemented is probably no more than a factor of two greater than that assumed. Occasionally two tank discharges may be made per day rather than one, no more than once per week. The percentage of time for the release would thus be about 114% of that assumed. ***Impact on total dose: Factor of 2.3 higher than predicted***	The proportion of sewage overflowing may be around a factor of 2 less. Occasionally no tank discharges may be made in a day, but this is unlikely to occur more than once per week. The percentage of time for the release would thus be about 86% of that assumed. ***Impact on total dose: Factor of 2.3 lower than predicted***

Table A8.4 Overflow Discharges to River Taff - Uncertainty and Variability in Assessment and Impact on Doses Likely to be Received by Anglers after Completion of the Sewer Improvement Scheme (cont)

Stage in Assessment	Key assumptions	Possible underestimate of dose	Possible overestimate of dose
Environmental concentrations	Dispersion of radionuclides in River Taff is based on simple equilibrium model and not a dynamic model which takes account of the short term releases from the overflow.	Once the sewer improvement scheme has been completed there are only expected to be a few (say three) overflows per year. The equilibrium model assumes that the release is continuous. Thus, activity concentrations in the river water during the day of the actual overflows could be about 120 times higher than the average daily concentrations assumed. However equilibrium is unlikely and the actual uptake during the overflow day may be a factor of 2 or more lower than equilibrium uptake. In addition a small proportion of the anglers annual catch of fish are likely to be caught on the days of the overflows. A single 1 kg fish caught on one of the days that an overflow occurs, represents 5% of the annual fish catch. ***Impact on total dose: Factor of 3 higher than predicted***	A full dynamic model would include the rate of uptake of carbon and OBT in fish and its subsequent loss. This is likely to lead to lower concentrations in fish in one day than if the equilibrium CF is applied. Use of a dynamic model is thus likely to lead to doses less than those assessed by perhaps a factor of 2 or more for a day long overflow. **Impact on total dose: Factor of 2 lower than predicted**
	Dispersion model relies on water volumetric flow rate.	Lowest 95% confidence limit for the annual river flow in the Taff is about 50% of the mean. ***Impact on total dose: Factor of 2 higher than predicted***	Highest 95% confidence limit for the annual river flow in the Taff is about 50% higher than the mean. Overflow from the sewer would be most likely during periods of high river flow. However, the relationship between river flow and sewer overflow events has not been quantified. ***Impact on total dose: Factor of 1.5 higher than predicted***
	Concentration factors for OBT in freshwater fish based on scaling CF for OBT in marine fish by CF for carbon-14 in both fish types. OBT factor assumed is 35 000 Bq/kg per Bq/l.	The best estimate CF for carbon is 50 000 Bq/kg per Bq/l for freshwater fish and it is possible that this value may be more appropriate for OBT than 35000 Bq/kg per Bq/l. OBT in fish contributes about 60% of the total dose. ***Impact on total dose: Factor of 1.3 higher than predicted***	Concentration factors of 1000 Bq/kg per Bq/l or less are derived from a comparison of the total tritium concentrations in marine fish compared to total tritium in seawater (see Appendix 2). Assuming the increase in OBT CF for freshwater fish is the same as that for marine fish as carbon-14, implies a CF of 2500 Bq/kg per Bq/l rather than 35000 Bq/kg per Bq/l. OBT in fish contributes about 60% of the total dose. ***Impact on total dose: Factor of 2.3 lower than predicted***

Table A8.4 Overflow Discharges to River Taff - Uncertainty and Variability in Assessment and Impact on Doses Likely to be Received by Anglers after Completion of the Sewer Improvement Scheme (cont)

Stage in Assessment	Key assumptions	Possible underestimate of dose	Possible overestimate of dose
Environmental concentrations (cont)	Concentration factor for carbon-14 is selected from an IAEA report (50 000 Bq/kg per Bq/l). All other radionuclides contribute little to the dose.	The selected value for the CF for freshwater fish is at the top end of the range.	The lowest CF for carbon in freshwater fish is 5000 Bq/kg per Bq/l. Carbon-14 in fish contributes 40% of the total dose. ***Impact on total dose: Factor of 1.6 lower than predicted***
Habit Data	All fish consumed by the angler is assumed to be caught in the vicinity of the point where the Whitchurch Brook enters the River Taff.	N/A	Perhaps up to half of the fish consumed could be caught from outside the immediate vicinity of the point where the Whitchurch Brook enters the River Taff. ***Impact on total dose: Factor of 2 lower than predicted***
	Critical group consumption rates selected from the NRPB generic data. Freshwater fish consumption rate of 20 kg/y.	The variability within critical group consumption rates is typically a factor of three (ie a factor of 1.75 about the mean). ***Impact on total dose: Factor of 1.7 higher than predicted***	The variability within critical group consumption rates is typically a factor of three (ie a factor of 1.75 about the mean). ***Impact on total dose: Factor of 1.7 higher than predicted***
Dose coefficients	Dose coefficients from the BSS Directive used from the assessment	Recent evidence has suggested that the dose factor for OBT could be a factor of two higher than the value used [Ref A8.3]. OBT contributes about 60% of the total dose. ***Impact on total dose: Factor of 1.6 higher than predicted***	It is stated in ICRP Publication 60 that some caution is taken into account in the derivation of dose coefficients.

Table A8.4 Overflow Discharges to River Taff - Uncertainty and Variability in Assessment and Impact on Doses Likely to be Received by Anglers after Completion of the Sewer Improvement Scheme (cont)

Stage in Assessment	Key assumptions	Possible underestimate of dose	Possible overestimate of dose
Additional doses from discharges to air deposited into the catchment and washed into the river Taff.	No account taken of deposition of atmospheric discharges in River Taff catchment	Amersham plc have pessimistically assessed the percentage of tritium and carbon-14 which could be deposited in the River Taff catchment as 3.8%. This is an overestimate for carbon-14 which is taken up by photosynthesis. It will then be converted to organic carbon compounds, most of which will remain in soil or be released back to atmosphere. Tritiated water may also be deposited, but the deposition velocity assumed is an overestimate by a factor of ten. 50% of the activity transferred into the terrestrial environment may be outside the catchment of the River Taff. Hence a more realistic percentage deposition for tritiated water is 0.19%. At the proposed limits this equates to a discharge of soluble tritium (tritiated water) of about 0.3 TBq/y at proposed limits, a factor of 3.2 higher than the discharge via the overflow. However, tritiated water only contributes 0.003% of the total dose from the Taff. ***Impact on total dose: Negligible***	N/A
Overall underestimate or overestimate of dose		Total dose could be a factor of ***5.6 higher than predicted***	Total dose could be a factor of **5.5** ***lower than predicted***
		Overall total dose allowing for uncertainty is about the same as that predicted (factor of ***1.0)***	