ICRP 53 - Addendum 5, 6 and 7

Radiation Dose to Patients from Radiopharmaceuticals

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RADIATION PROTECTION

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Radiation Dose to Patients from Radiopharmaceuticals

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Radiation Dose to Patients from Radiopharmaceuticals

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C F Se
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Amino acids

^{11}C-, ^{18}F- or ^{75}Se- labelled amino acids (Generic models)

^{11}C, ^{18}F, ^{75}Se

Biokinetic model

The methionine analogue [^{75}Se]-selenomethionine has been used in nuclear medicine for many years (ICRP, 1987), and more recently a number of other amino acids labelled with ^{11}C or ^{18}F have been utilised, or proposed, for clinical applications. For example, L-[Methyl-^{11}C]-methionine (Deloar et al., 1998); L-[2-^{18}F]-fluorotyrosine (Coenen et al., 1972; Cottrall et al., 1973; Taylor and Cottrall, 1973); [^{18}F]-*p*-fluorophenylalanine (Cottrall et al., 1973); 6-[^{18}F]-fluorotryptophan (Atkins et al., 1972; Taylor and Cottrall, 1973); *cis*-4-[^{18}F]-fluoroproline and *trans*-4-[^{18}F]-fluoroproline (Wester et al. (1999a, b); L-3-[^{18}F]-fluoro-α-methyl tyrosine (Inoue et al. 1998). ICRP has published biokinetic models only for [^{75}Se]-selenomethionine (ICRP, 1987) and for L-[Methyl-^{11}C]-methionine (ICRP, 2001). Taylor (2000) developed the generic biokinetic model described below for use in the assessment of the internal dose received by human subjects injected intravenously with amino acids labelled with ^{11}C, ^{18}F or ^{75}Se. Comparison of the radiation doses to adults calculated using this generic model with those calculated using compound-specific models for [^{11}C]-labelled and [^{18}F]-labelled amino acids and for [^{75}Se]-selenomethionine indicated that in general the effective doses, as well as the organ and tissue doses, calculated using the generic model agreed within a factor of 2 or less, with those calculated using compound-specific models. It was further noted that the generic model tended to over-, rather than under-estimate the organ and tissue doses. It was concluded that for [^{11}C]-, [^{18}F]- and [^{75}Se]-labelled amino acids or their analogues, that the generic biokinetic model could be applied for general radiation protection purposes.

The generic model assumes that, following entry of a labelled amino acid into the bloodstream, the radiopharmaceutical is taken up instantaneously by the organs and tissues. This is followed by a phase of rapid elimination of that fraction of the injected material which goes directly into the excretory pathways or is excreted following early metabolism, a second phase which represents loss due to metabolic breakdown of labelled proteins, and other compounds with relatively rapid turnover times, and a final phase representing elimination of the small fraction of the radionuclide which had been incorporated into structural proteins, or other body components with very slow turnover. In the model the elimination of the radionuclide from the various organs and tissues is assumed to approximate to a three component exponential relationship with biological half-times of 0.5, 50 and 5000 d. The long biological half-time assigned to the small final component of the model reflects the evidence that ^{14}C incorporated into structural tissues such as bone is retained with a very long-half-time (Stenhouse and Baxter, 1977, Stenström et al, 1996).

The generic model assumes that 20% of the administered activity is directly excreted from the blood to the urinary bladder with biological half-times of 0.2 hours (0.25) and 6 hours (0.75) in the blood. It has further been assumed, that 3% of the injected activity is excreted into the small intestine, half with a biological half-time of 6 hours and half with a biological half-time of 12 hours. Since labelled amino acids are potentially important for studies of protein synthesis in brain (Bergmann et al., 1995; Schmidt, 1997; Shoup et al., 1998), it was assumed that 1.5% of the injected activity deposits in brain from where it is released back to the

circulation with biological half-times of 50 d (70%) and 5000 d (30%). The parameters of this generic model are shown in the biokinetic data table.

Taylor (2000) pointed out that the biokinetic data from humans or animals that were used to derive both the compound specific and the generic models are subject to quite large uncertainties (coefficients of variation ranging from about 20 to about 80 %), therefore when comparing doses calculated by the generic and compound-specific biokinetic models differences in individual tissue or organ doses by a factor of two, or even three, should be regarded as good agreement.

This agreement appears to be close enough for the single generic biokinetic model to be used for normal prospective radiation dosimetry and for general assessments of the risk from the use of amino acids labelled with ^{11}C, ^{14}C, ^{18}F or ^{75}Se. In situations where compound-specific retrospective dosimetry is necessary, e.g. in case of accidental intake of a large amount of a radionuclide compound, it might reasonably be expected that some subject- and compound-specific biokinetic information would be available, upon which a more accurate person-specific dose assessment could be based.

This model is not appropriate for the interpretation of bioassay data following intakes of ^{14}C-labelled amino acids.

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Biokinetic data for ^{11}C-, ^{18}F- or ^{75}Se-labelled amino acids

Organ *(S)*	F_s	*T (hours)*	*a*	$\tilde{A}_s/A_0$ *(hours)* ^{11}C	^{18}F	^{75}Se
Brain	0.015	1200	0.70	0.0074	0.040	31
		120000	0.30			
Thyroid	0.0007	1200	0.70	0.00034	0.0019	1.4
		120000	0.30			
Lungs	0.02	12	0.10	0.0098	0.052	25
		1200	0.85			
		120000	0.05			
Kidneys	0.02	12	0.15	0.0098	0.052	24
		1200	0.80			
		120000	0.05			
Kidney transit	0.20			0.0030	0.0066	0.017
Liver	0.08	12	0.40	0.039	0.20	71
		1200	0.55			
		120000	0.05			
Pancreas	0.03	12	0.85	0.014	0.070	5.9
		1200	0.15			
Spleen	0.004	12	0.33	0.0019	0.010	3.3
		1200	0.67			
Small intestine	0.03	6	0.50	0.014	0.065	0.39
		12	0.50			
Ovaries	0.0002	1200	0.70	0.000098	0.00053	0.41
		120000	0.30			
Testes	0.00092	1200	0.70	0.00045	0.0024	1.9
		120000	0.30			
Muscle	0.24	12	0.15	0.12	0.62	520
		1200	0.45			
		120000	0.40			
Other organs and tissues	0.359	12	0.15	0.18	0.93	780
		1200	0.45			
		120000	0.40			
Urinary bladder	0.20					
Adults and 15 years				0.016	0.13	0.44
10 years				0.016	0.12	0.037
5 years and 1 year				0.016	0.086	0.024
Blood	0.20	0.2	0.25	0.079	0.32	1.3
		6	0.75			

For [^{75}Se]-selenomethionine, the compound specific data (ICRP, 1987) should be used.
For L-[Methyl-^{11}C]-methionine, the compound specific data (ICRP, 2001) should be used.

Absorbed doses: ^{11}C-labelled amino acids

^{11}C 20.38 min

	Absorbed dose per unit activity administered (mGy/MBq)				
Organ	Adult	15 years	10 years	5 years	1 year
Adrenals	4.5E-03	5.4E-03	8.4E-03	1.3E-02	2.4E-02
Bladder	1.3E-02	1.6E-02	2.5E-02	3.8E-02	7.1E-02
Bone surfaces	3.0E-03	3.4E-03	5.1E-03	8.0E-03	1.5E-02
Brain	2.3E-03	2.4E-03	2.9E-03	3.7E-03	5.9E-03
Breasts	2.3E-03	2.6E-03	4.0E-03	6.2E-03	1.2E-02
Gall bladder	4.1E-03	4.6E-03	7.2E-03	1.1E-02	2.0E-02
GI-tract					
Stomach	3.4E-03	3.9E-03	5.9E-03	8.9E-03	1.7E-02
SI	5.4E-03	7.0E-03	1.2E-02	2.0E-02	3.8E-02
Colon	3.3E-03	3.6E-03	5.7E-03	8.8E-03	1.6E-02
(ULI	3.4E-03	3.8E-03	6.0E-03	9.3E-03	1.7E-02)
(LLI	3.1E-03	3.4E-03	5.3E-03	8.1E-03	1.5E-02)
Heart	6.0E-03	7.4E-03	1.1E-02	1.8E-02	3.3E-02
Kidneys	1.4E-02	1.7E-02	2.5E-02	3.8E-02	6.9E-02
Liver	9.0E-03	1.2E-02	1.8E-02	2.7E-02	5.2E-02
Lungs	6.3E-03	8.6E-03	1.3E-02	2.1E-02	4.1E-02
Muscles	2.3E-03	3.4E-03	6.5E-03	1.7E-02	2.9E-02
Oesophagus	2.8E-03	3.2E-03	4.8E-03	7.3E-03	1.4E-02
Ovaries	4.5E-03	4.6E-03	1.1E-02	1.9E-02	4.1E-02
Pancreas	4.1E-02	5.8E-02	1.2E-01	1.5E-01	3.4E-01
Red marrow	3.2E-03	3.7E-03	5.5E-03	8.5E-03	1.7E-02
Skin	2.1E-03	2.3E-03	3.6E-03	5.5E-03	1.1E-02
Spleen	6.4E-03	8.6E-03	1.3E-02	2.1E-02	4.0E-02
Testes	3.9E-03	8.4E-03	5.8E-02	6.7E-02	9.2E-02
Thymus	2.8E-03	3.2E-03	4.8E-03	7.3E-03	1.4E-02
Thyroid	5.7E-03	8.8E-03	1.4E-02	2.9E-02	5.5E-02
Uterus	3.5E-03	4.0E-03	6.3E-03	9.7E-03	1.8E-02
Remaining organs	2.5E-03	3.7E-03	6.7E-03	1.3E-02	2.2E-02
Effective dose (mSv/MBq)	**5.5E-03**	**7.4E-03**	**1.7E-02**	**2.4E-02**	**4.4E-02**

For L-[Methyl-^{11}C]-methionine, the compound specific data (ICRP, 2001) should be used.

Absorbed doses: ^{18}F-labelled amino acids

^{18}F 1.83 h

	Absorbed dose per unit activity administered (mGy/MBq)				
Organ	Adult	15 years	10 years	5 years	1 year
Adrenals	1.9E-02	2.2E-02	3.4E-02	5.2E-02	9.4E-02
Bladder	7.2E-02	9.1E-02	1.2E-01	1.5E-01	2.7E-01
Bone surfaces	1.2E-02	1.4E-02	2.1E-02	3.2E-02	6.2E-02
Brain	9.6E-03	1.0E-02	1.2E-02	1.5E-02	2.4E-02
Breasts	9.5E-03	1.1E-02	1.6E-02	2.5E-02	4.9E-02
Gall bladder	1.8E-02	2.1E-02	3.2E-02	4.7E-02	8.7E-02
GI-tract					
Stomach	1.5E-02	1.7E-02	2.6E-02	3.9E-02	7.2E-02
SI	2.0E-02	2.6E-02	4.4E-02	7.1E-02	1.3E-01
Colon	1.5E-02	1.7E-02	2.5E-02	3.8E-02	7.0E-02
(ULI	1.5E-02	1.7E-02	2.6E-02	4.0E-02	7.4E-02)
(LLI	1.4E-02	1.6E-02	2.4E-02	3.5E-02	6.4E-02)
Heart	2.2E-02	2.7E-02	4.1E-02	6.2E-02	1.1E-01
Kidneys	4.9E-02	5.9E-02	8.5E-02	1.3E-01	2.3E-01
Liver	3.5E-02	4.6E-02	6.9E-02	1.0E-01	1.9E-01
Lungs	2.3E-02	3.1E-02	4.6E-02	7.2E-02	1.4E-01
Muscles	1.0E-02	1.5E-02	2.7E-02	6.4E-02	1.1E-01
Oesophagus	1.2E-02	1.4E-02	2.0E-02	3.1E-02	5.9E-02
Ovaries	2.0E-02	2.1E-02	4.5E-02	7.5E-02	1.6E-01
Pancreas	1.4E-01	2.0E-01	4.1E-01	5.2E-01	1.1E+00
Red marrow	1.3E-02	1.5E-02	2.2E-02	3.3E-02	6.3E-02
Skin	8.4E-03	9.3E-03	1.4E-02	2.2E-02	4.4E-02
Spleen	2.5E-02	3.3E-02	5.1E-02	8.0E-02	1.5E-01
Testes	1.7E-02	3.3E-02	2.1E-01	2.5E-01	3.4E-01
Thymus	1.2E-02	1.4E-02	2.0E-02	3.1E-02	5.9E-02
Thyroid	2.2E-02	3.3E-02	5.2E-02	1.1E-01	2.0E-01
Uterus	1.7E-02	2.0E-02	3.0E-02	4.4E-02	8.0E-02
Remaining organs	1.1E-02	1.5E-02	2.7E-02	5.0E-02	8.2E-02
Effective dose (mSv/MBq)	**2.3E-02**	**3.0E-02**	**6.5E-02**	**8.9E-02**	**1.6E-01**

Absorbed doses: ^{75}Se-labelled amino acids

^{75}Se 119.80 days

	Absorbed dose per unit activity administered (mGy/MBq)				
Organ	Adult	15 years	10 years	5 years	1 year
Adrenals	2.6E+00	3.1E+00	4.6E+00	6.7E+00	1.2E+01
Bladder	2.0E+00	2.6E+00	3.6E+00	5.3E+00	9.0E+00
Bone surfaces	2.9E+00	3.3E+00	4.7E+00	6.8E+00	1.2E+01
Brain	1.7E+00	1.7E+00	2.0E+00	2.7E+00	3.9E+00
Breasts	1.3E+00	1.6E+00	2.2E+00	3.4E+00	6.4E+00
Gall bladder	2.7E+00	3.3E+00	5.2E+00	7.4E+00	1.0E+01
GI-tract					
Stomach	2.3E+00	2.8E+00	4.2E+00	5.9E+00	1.0E+01
SI	2.0E+00	2.4E+00	3.6E+00	5.5E+00	9.5E+00
Colon	2.1E+00	2.6E+00	3.9E+00	6.0E+00	1.0E+01
(ULI	2.1E+00	2.6E+00	3.7E+00	6.1E+00	9.8E+00)
(LLI	2.2E+00	2.6E+00	4.1E+00	5.9E+00	1.1E+01)
Heart	2.3E+00	2.8E+00	4.0E+00	5.7E+00	1.0E+01
Kidneys	3.8E+00	4.6E+00	6.3E+00	9.3E+00	1.6E+01
Liver	3.0E+00	3.8E+00	5.6E+00	7.7E+00	1.4E+01
Lungs	2.1E+00	2.8E+00	3.9E+00	5.7E+00	1.0E+01
Muscles	1.7E+00	2.3E+00	3.6E+00	6.6E+00	1.2E+01
Oesophagus	2.0E+00	2.4E+00	3.5E+00	5.2E+00	9.4E+00
Ovaries	2.7E+00	3.0E+00	5.4E+00	8.8E+00	1.7E+01
Pancreas	3.6E+00	4.7E+00	7.8E+00	1.1E+01	2.0E+01
Red marrow	1.9E+00	2.2E+00	3.2E+00	4.5E+00	7.6E+00
Skin	1.2E+00	1.3E+00	2.0E+00	3.1E+00	5.7E+00
Spleen	2.2E+00	2.9E+00	4.3E+00	6.4E+00	1.1E+01
Testes	2.3E+00	3.9E+00	1.7E+01	2.0E+01	2.8E+01
Thymus	2.0E+00	2.4E+00	3.5E+00	5.2E+00	9.4E+00
Thyroid	2.8E+00	4.0E+00	6.1E+00	1.1E+01	2.1E+01
Uterus	2.3E+00	2.7E+00	4.2E+00	6.5E+00	1.1E+01
Remaining organs	1.8E+00	2.3E+00	3.4E+00	5.3E+00	8.8E+00
Effective dose (mSv/MBq)	**2.2E+00**	**2.9E+00**	**5.3E+00**	**7.6E+00**	**1.3E+01**

For [^{75}Se]-selenomethionine, the compound specific data (ICRP, 1987) should be used.

Technetium-labelled small colloids (intratumoral injection)

^{99m}Tc

Biokinetic model

The typical procedure is to inject about 20 MBq ^{99m}Tc-colloid immediately adjacent to the breast tumour that is later to be removed. The patient is investigated with a gamma camera 4 hours after injection and then operated on for the removal of the tumour very shortly afterwards. If no uptake of ^{99m}Tc in the lymph nodes is seen on the scan, the tumour, plus the site(s) of injection of the radioactivity, is removed surgically. If lymph node uptake of activity is found, a more radical operation is performed. In either situation the injected ^{99m}Tc-colloid is removed in its entirety by about 6 hours after injection (this may be extended to 18 hours in some circumstances). The only significant radiation absorbed dose is that to surrounding tissues, mainly lung, as a result of irradiation from the local deposit of radionuclide in the breast during the few hours of exposure. This dose is considered to be generally very small.

Current ICRP dosimetric models do not permit calculations of dose from breast as a source organ, and because the doses are likely to be very small the TG does not consider it necessary to develop a new dosimetric model in which breast is treated as a source organ.

Leakage of radionuclide from the injection site into the systemic circulation is not considered likely; anyhow, such leakage would be covered by the existing ^{99m}Tc-colloid model.

Biokinetic data for ^{99m}Tc-labelled small colloids (intratumoral injection)

Organ *(S)*	F_s	*T (hours)*	*a*	$\tilde{A}_s/A_0$ *(hours)*
Time to removal: 6 hours				
Breast	1.0			4.3
Time to removal: 18 hours				
Breast	1.0			7.6

Absorbed doses: ^{99m}Tc-labelled small colloids (intratumoral injection)

^{99m}Tc 6.02 h

	Absorbed dose per unit activity administered (mGy/MBq)			
	6 hours to removal		*18 hours to removal*	
Organ	Adult	15 years	Adult	15 years
Adrenals	7.9E-04	9.3E-04	1.4E-03	1.6E-03
Bladder	2.1E-05	3.9E-05	3.6E-05	6.8E-05
Bone surfaces	1.2E-03	1.5E-03	2.1E-03	2.6E-03
Brain	4.9E-05	5.8E-05	8.7E-05	1.0E-04
Breast (remaining*)	3.6E-03	3.9E-03	6.4E-03	6.9E-03
Gall bladder	5.3E-04	7.2E-04	9.3E-04	1.3E-03
GI-tract				
Stomach	9.2E-04	1.3E-03	1.6E-03	2.3E-03
SI	1.1E-04	1.5E-04	2.0E-04	2.7E-04
Colon	8.3E-05	1.9E-04	1.4E-04	3.3E-04
(ULI	1.2E-04	2.8E-04	2.0E-04	4.9E-04
(LLI	3.8E-05	7.0E-05	6.6E-05	1.2E-04
Heart	4.1E-03	5.2E-03	7.1E-03	9.1E-03
Kidneys	3.1E-04	4.2E-04	5.4E-04	7.3E-04
Liver	1.1E-03	1.4E-03	1.9E-03	2.4E-03
Lungs	3.6E-03	3.9E-03	6.4E-03	6.9E-03
Muscles	6.6E-04	8.3E-04	1.2E-03	1.5E-03
Oesophagus	3.6E-03	5.0E-03	6.2E-03	8.7E-03
Ovaries	4.1E-05	4.8E-05	7.1E-05	8.3E-05
Pancreas	9.7E-04	1.1E-03	1.7E-03	2.0E-03
Red marrow	8.6E-04	9.2E-04	1.5E-03	1.6E-03
Skin	1.2E-03	1.4E-03	2.1E-03	2.4E-03
Spleen	6.8E-04	8.3E-04	1.2E-03	1.5E-03
Thymus	3.6E-03	5.0E-03	6.2E-03	8.7E-03
Thyroid	4.7E-04	6.2E-04	8.2E-04	1.1E-03
Uterus	4.1E-05	6.4E-05	7.1E-05	1.1E-04
Remaining organs	6.6E-04	8.3E-04	1.2E-03	1.5E-03
Effective dose (mSv/MBq)	**1.2E-03**	**1.4E-03**	**2.0E-03**	**2.4E-03**

In the model it is assumed that no leakage of the activity occurs.
*Dose to the remaining breast has been assumed to be equal to the dose to the lungs

Errata to ICRP Publication 80

$H_2{}^{15}O$

It has been pointed out that there is a disagreement between the dose data in ICRP 80 and data in one of the reports on which it was based. Due to a software error, the dose to the GI-tract for adults had been calculated with all the activity in the content of the intestine instead of the wall. This resulted in a 20 % lower effective dose than if it had been placed in the gut wall – a localisation, which the TG has assumed. The error has now been corrected and the revised dose table is attached.

^{201}Tl

A question has been raised to the TG concerning the great difference in dose to the ovaries from ^{201}Tl-ion that can be seen between ICRP 53 and 80 (0.12 compared to 0.73 mGy/MBq). The biokinetic data table as presented in ICRP 53 gives an uptake in the ovaries of 0.003, which should have been 0.0003. The error was detected just before ICRP 53 went to the printer and the Scientific Secretary of the ICRP was notified. The dose table in ICRP 53 was corrected, but not the biokinetic data table. The incorrect uptake figure was unfortunately used when recalculating the doses for ICRP 80. This resulted in a value for the ovaries that is six times too high. The TG regrets these mistakes and a correct dose table is attached.

^{99m}Tc-labelled denatured erythrocytes

There is a printing error in the effective dose table in ICRP Publication 80 (page 116). The correct figure is: E = 1.9E-02 (i.e. 0.019) mSv/MBq, which is the same as was reported in ICRP Publication 62 (page 27).

Absorbed doses: ^{15}O-labelled water

^{15}O 2.04 min

	Absorbed dose per unit activity administered (mGy/MBq)				
Organ	Adult	15 years	10 years	5 years	1 year
Adrenals	1.4E-03	2.2E-03	3.1E-03	4.3E-03	6.6E-03
Bladder	2.6E-04	3.1E-04	5.0E-04	8.4E-04	1.5E-03
Bone surfaces	6.3E-04	8.0E-04	1.3E-03	2.3E-03	5.5E-03
Brain	1.3E-03	1.3E-03	1.4E-03	1.6E-03	2.2E-03
Breasts	2.8E-04	3.5E-04	6.0E-04	9.9E-04	2.0E-03
Gall bladder	4.5E-04	5.5E-04	8.6E-04	1.4E-03	2.7E-03
GI-tract					
Stomach	1.7E-03	2.2E-03	3.1E-03	5.3E-03	1.2E-02
SI	1.3E-03	1.7E-03	3.0E-03	5.0E-03	9.9E-03
Colon	1.6E-03	2.1E-03	3.7E-03	6.2E-03	1.2E-02
(ULI	1.6E-03	2.1E-03	3.7E-03	6.2E-03	1.2E-02)
(LLI	1.6E-03	2.1E-03	3.7E-03	6.2E-03	1.2E-02)
Heart	1.9E-03	2.4E-03	3.8E-03	6.0E-03	1.1E-02
Kidneys	1.7E-03	2.1E-03	3.0E-03	4.5E-03	8.1E-03
Liver	1.6E-03	2.1E-03	3.2E-03	4.8E-03	9.3E-03
Lungs	1.6E-03	2.4E-03	3.4E-03	5.2E-03	1.0E-02
Muscles	2.9E-04	3.7E-04	6.1E-04	1.0E-03	2.0E-03
Oesophagus	3.3E-04	4.2E-04	6.7E-04	1.1E-03	2.1E-03
Ovaries	8.5E-04	1.1E-03	1.8E-03	2.8E-03	5.8E-03
Pancreas	1.4E-03	2.0E-03	4.2E-03	5.4E-03	1.2E-02
Red marrow	8.9E-04	9.7E-04	1.6E-03	3.0E-03	6.1E-03
Skin	2.5E-04	3.1E-04	5.2E-04	8.8E-04	1.8E-03
Spleen	1.6E-03	2.3E-03	3.7E-03	5.8E-03	1.1E-02
Testes	7.4E-04	9.3E-04	1.5E-03	2.6E-03	5.1E-03
Thymus	3.3E-04	4.2E-04	6.7E-04	1.1E-03	2.1E-03
Thyroid	1.5E-03	2.5E-03	3.8E-03	8.5E-03	1.6E-02
Uterus	3.5E-04	4.4E-04	7.2E-04	1.2E-03	2.3E-03
Remaining organs	4.0E-04	5.6E-04	9.4E-04	1.7E-03	2.9E-03
Effective dose (mSv/MBq)	**1.1E-03**	**1.4E-03**	**2.3E-03**	**3.8E-03**	**7.7E-03**

Absorbed doses: ^{201}Tl-ion

^{201}Tl 3.05 days

	Absorbed dose per unit activity administered (mGy/MBq)				
Organ	Adult	15 years	10 years	5 years	1 year
Adrenals	5.8E-02	7.1E-02	1.1E-01	1.5E-01	2.7E-01
Bladder	4.1E-02	5.5E-02	8.0E-02	1.2E-01	2.3E-01
Bone surfaces	3.8E-01	3.9E-01	6.9E-01	1.2E+00	1.9E+00
Brain	2.3E-02	2.5E-02	3.8E-02	5.6E-02	1.1E-01
Breasts	2.5E-02	2.8E-02	4.5E-02	6.8E-02	1.3E-01
Gall bladder	6.6E-02	8.2E-02	1.3E-01	1.9E-01	3.1E-01
GI-tract					
Stomach	1.2E-01	1.5E-01	2.2E-01	3.5E-01	7.3E-01
SI	1.4E-01	1.8E-01	3.1E-01	5.0E-01	9.4E-01
Colon	2.5E-01	3.2E-01	5.5E-01	9.2E-01	1.8E+00
(ULI	1.8E-01	2.3E-01	3.9E-01	6.4E-01	1.2E+00)
(LLI	3.4E-01	4.5E-01	7.6E-01	1.3E+00	2.5E+00)
Heart	1.9E-01	2.4E-01	3.8E-01	6.0E-01	1.1E+00
Kidneys	4.8E-01	5.8E-01	8.2E-01	1.2E+00	2.2E+00
Liver	1.5E-01	2.0E-01	3.1E-01	4.5E-01	8.4E-01
Lungs	1.1E-01	1.6E-01	2.3E-01	3.6E-01	6.9E-01
Muscles	5.2E-02	8.2E-02	1.6E-01	4.5E-01	7.6E-01
Oesophagus	3.6E-02	4.3E-02	6.2E-02	9.2E-02	1.7E-01
Ovaries	1.2E-01	1.2E-01	2.9E-01	4.9E-01	1.1E+00
Pancreas	5.8E-02	7.1E-02	1.1E-01	1.6E-01	2.8E-01
Red marrow	1.1E-01	1.3E-01	2.2E-01	4.4E-01	1.0E+00
Skin	2.2E-02	2.5E-02	3.9E-02	6.0E-02	1.1E-01
Spleen	1.2E-01	1.7E-01	2.6E-01	4.1E-01	7.4E-01
Testes	4.5E-01	1.1E+00	8.3E+00	9.6E+00	1.3E+01
Thymus	3.6E-02	4.3E-02	6.2E-02	9.2E-02	1.7E-01
Thyroid	2.2E-01	3.5E-01	5.4E-01	1.2E-00	2.3E-00
Uterus	5.1E-02	6.3E-02	1.0E-01	1.5E-01	2.7E-01
Remaining organs	5.4E-02	8.9E-02	1.6E-01	3.4E-01	5.5E-01
Effective dose (mSv/MBq)	**1.7E-01**	**2.5E-01**	**1.1E+00**	**1.4E+00**	**2.1E-00**

2002-09-16

RADIATION PROTECTION

ADDENDUM 6 TO ICRP PUBLICATION 53

Radiation Dose to Patients from Radiopharmaceuticals

A report of a Task Group of Committees 2 and 3 of the
International Commission on Radiological Protection

PRE-PUBLICATION VERSION

Interim report, October 2002

Radiation Dose to Patients from Radiopharmaceuticals

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Carbon-11-labelled brain receptor substances (Generic model)

^{11}C

Biokinetic model

A large number of radiopharmaceuticals labelled with ^{11}C are being developed for positron emission tomographic studies of different types of receptor in the human brain. For most of these agents the available biokinetic data are insufficient to construct realistic compound-specific biokinetic models for calculating the internal radiation dose delivered to persons undergoing investigation. A generic model for brain receptor substances that predicts the internal dose with sufficient accuracy for general radiation protection purposes has, therefore, been developed. Biokinetic data for 13 ^{11}C-radiopharmaceuticals used clinically for imaging different brain receptors indicate that, despite differences in chemical structure, their uptake and retention in the human brain and other tissues is broadly similar. The proposed model assumes instantaneous deposition of 5 % of the injected activity in the brain, with the remaining activity being rapidly and uniformly distributed throughout all other tissues. Elimination from all tissues is assumed to occur with a half-time of 2 hours. It is further assumed that 75% of the injected ^{11}C is excreted in the urine, and 25% via the gall bladder, with a half-time of 2 hours.

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Table 1: Brain receptor substances — Comparison of ^{11}C retention in brain up to ~90 minutes

Substance	Brain			Other tissues	Reference
	Uptake (%)	*T_{max} (h)*	*T_b (h)*		
Acetylcholine esterase receptor agents					
N-Methylpiperidyl-acetate	5	0.2	0.1-∝	No human information, but some animal data	1, 2, 3
N-Methylpiperidyl-propionate					
Benzodiazepine receptor agents					
Flumazenil	7	0.1	~0.5	No human data for [^{11}C]flumazenil, dosimetry based on data for [^{123}I]flumazenil	4, 5, 6, 7
Dopamine receptor agents					
Raclopride	1.5	0.4	~3	No human data, data from PET imaging in monkeys	8,9
FLB-457	5	0.3	0.5-12	No human data	10, 11
Epidepride	n.a.	n.a.		Data from humans for [^{123}I]epidepride	12
Spiperone	1	0.5	~0.5	Human data for [^{76}Br]spiperone. Mouse data for [^{11}C]methylspiperone	13, 14
Dopamine-transporter agents					
Methylphenidate	9	0.1-0.2	1.25+	No Human data	15
Opiate receptor agents					
Carfentanil	3	0.1	1-2	Human data for plasma clearance of fentanyl	16, 17, 18
Serotonin receptor agents					
OMeWAY-100634	9	0.1	~1	Human plasma clearance data	19, 20, 21
COWAY	3-4	0.1	0.05-3	Human plasma clearance data	22
McN-5652	3	0.2	3+	No human data	23
DASB	8		0.8-1.8	No human data	25

n.a. - not available

Biokinetic data for ^{11}C-labelled brain receptor substances (Generic model)

Organ *(S)*	F_s	*T (hours)*	*a*	$\tilde{A}_s/A_0$ *(hours)*
Brain	0.05	2	1	0.021
Other organs and tissues	0.95	2	0.95	0.34
Urinary bladder	0.75			
Adults and 15 years				0.045
10 years				0.044
5 years and 1 years				0.042
Gall bladder	0.0875			0.0062
Small intestine	0.25			0.010
Upper Large Intestine	0.25			0.0012

Absorbed doses: ^{11}C-labelled brain receptor substances (Generic model)

^{11}C 20.38 min

	Absorbed dose per unit activity administered (mGy/MBq)				
Organ	Adult	15 years	10 years	5 years	1 year
Adrenals	3.0E–03	3.8E–03	6.0E–03	1.0E–02	1.9E–02
Bladder	3.2E–02	4.2E–02	6.3E–02	9.2E–02	1.7E–01
Bone surfaces	2.8E–03	3.6E–03	5.6E–03	8.6E–03	1.6E–02
Brain	5.2E–03	5.3E–03	5.7E–03	7.7E–03	1.5E–02
Breasts	2.2E–03	2.8E–03	4.4E–03	6.9E–03	1.3E–02
Gall bladder	1.7E–02	1.9E–02	2.5E–02	4.6E–02	1.6E–01
GI-tract					
Stomach	2.9E–03	3.6E–03	5.8E–03	9.1E–03	1.7E–02
SI	6.3E–03	8.1E–03	1.4E–02	2.2E–02	4.2E–02
Colon	4.3E–03	5.4E–03	8.8E–03	1.4E–02	2.5E–02
(ULI	4.9E–03	6.1E–03	1.0E–02	1.6E–02	3.0E–02)
(LLI	3.6E–03	4.4E–03	7.1E–03	1.1E–02	1.9E–02)
Heart	2.8E–03	3.5E–03	5.7E–03	8.8E–03	1.6E–02
Kidneys	8.7E–03	1.1E–02	1.5E–02	5.0E–02	9.0E–02
Liver	2.9E–03	3.7E–03	5.8E–03	9.4E–03	1.7E–02
Lungs	2.5E–03	3.2E–03	5.2E–03	7.9E–03	1.5E–03
Muscles	2.7E–03	3.4E–03	5.4E–03	8.4E–03	1.6E–02
Oesophagus	2.6E–03	3.3E–03	5.3E–03	8.0E–03	1.6E–02
Ovaries	3.8E–03	4.8E–03	7.4E–03	1.1E–02	2.1E–02
Pancreas	3.1E–03	4.0E–03	6.5E–03	1.0E–02	1.9E–02
Red marrow	2.8E–03	3.6E–03	5.5E–03	8.2E–03	1.5E–02
Skin	2.1E–02	2.7E–03	4.4E–03	6.9E–03	1.3E–02
Spleen	2.8E–03	3.6E–03	5.7E–03	9.6E–03	1.8E–02
Testes	2.9E–03	3.7E–03	6.1E–03	9.2E–03	1.8E–02
Thymus	2.9E–03	3.7E–03	6.1E–03	9.2E–03	1.8E–02
Thyroid	2.6E–03	3.3E–03	5.4E–03	8.5E–03	1.6E–02
Uterus	4.5E–03	5.6E–03	8.9E–03	1.3E–02	2.4E–02
Remaining organs	3.0E–03	3.8E–03	6.1E–03	1.0E–02	1.9E–02
Effective dose (mSv/MBq)	**4.5E-03**	**5.7E-03**	**9.0E-03**	**1.4E-02**	**2.6E-02**

Errata to ICRP Publication 80

^{111}In -labelled octreotide

The absorbed dose to the colon for the 1 year old, 1.5E-02 mGy/MBq is not correct. It should be 1.5E-01 mGy/MBq (ICRP Publication 80, page 46).

2003-10-03

RADIATION PROTECTION

ADDENDUM 7 TO ICRP PUBLICATION 53

Radiation Dose to Patients from Radiopharmaceuticals

A report of a Task Group of Committees 2 and 3 of the
International Commission on Radiological Protection

PRE-PUBLICATION VERSION

Interim report, October, 2003

Radiation Dose to Patients from Radiopharmaceuticals

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Iodine-labelled fatty acid
^{123}I-BMIPP and ^{123}I-IPPA

^{123}I

Biokinetic models

Free fatty acids are major energy sources for the myocardium, and iodine-labelled free fatty acids are used to study the energy metabolism of the heart. Long-chain fatty acids are rapidly taken up by the heart and metabolised by β-oxidation (Tamaki et al., 2000). The first iodine-labelled free fatty acids that were developed had the disadvantage of too high a release of radioiodide. This was overcome by the introduction of ^{123}I-para-iodophenyl pentadecanoic acid (^{123}I-IPPA), a terminally phenylated straight-chain fatty acid, where the iodine was substituted in the phenyl group (Machulla et al., 1980; Reske et al. 1982; Reske, 1985; Dudzcak, 1986). The rapid clearance of ^{123}I-IPPA from the myocardium is, however, a problem when tomography (SPECT) is performed. This problem has been overcome by the introduction of a methyl group on the 3-carbon of the fatty acid. 3-Methyl-branched fatty acids are metabolised in the peroxisomes by an initial alfa-oxidation followed by peroxisomal beta-oxidation, a process that is slower than the mitochondrial beta-oxidation (Casteels et al., 2003). This principle was first utilised by Knapp et al. (Knapp et al., 1986) by the introduction of beta-methyl-p-(^{123}I)-iodophenylpentadecanoic acid (^{123}I-BMIPP). See also references in (Knapp et al., 1995b).

After an intravenous injection, ^{123}I-IPPA and ^{123}I-BMIPP are rapidly cleared from the blood (biological half-time 2.5 – 3.0 min) (Knapp et al., 1995a) due to a fast uptake in various organs and tissues (Torizuka et al., 1991; Yoshizumi et al., 2000). Whole body pictures shortly after the injection (Sloof et al., 1997; Cavaliers et al., 2003; Torizuka et al., 1991; Yoshizumi et al., 2000) show a concentration of the activity in the liver and the heart and a uniform distribution in the rest of the body.

After the uptake, only a part of ^{123}I-IPPA and ^{123}I-BMIPP will be immediately metabolised to water soluble low molecular weight products. ^{123}I-IPPA is to a large extent metabolised like long chain fatty acids by a rapid mitochondrial beta-oxidation ending up with p-(^{123}I)-iodobenzoic acid, which is excreted in a conjugated form in the urine. The metabolism of ^{123}I-BMIPP is slower than that of ^{123}I-IPPA due to the methyl group on the beta-carbon. The end product is p-(^{123}I)-iodophenyl acetic acid which also is excreted as a conjugate in the urine. In either case no release of free iodine has been detected. The initially unmetabolised part of ^{123}I-IPPA and ^{123}I-BMIPP will become incorporated into the fat stores in the body, which have a slow turnover, thus causing a considerably delayed metabolism of this part.

Time-activity curves for the heart and the liver indicate a biexponential elimination of ^{123}I-BMIPP (Torizuka et al., 1991, De Geeter et al., 1998). Out of these curves we have calculated an initial uptake in the heart of 5.0-5.7 % of the activity administered (excluding blood activity) and 13-14 % in the liver. For ^{123}I-BMIPP, the biological half-time of the fast phase is about 1 hour and for the slow phase it is approximately 2 days. The fast phase corresponds to a fraction of 0.43 of the uptake in the heart. In the liver the fast eliminated fraction is 0.33-

0.36. The final metabolite is excreted via the kidney and urinary bladder. After 16 hours 15 % (Dudczak et al.,1986) and after 24 hours 22.6% is excreted (Torizuka et al., 1991). There are no data for ^{123}I-BMIPP covering longer time periods but from studies on labelled fatty acids (Gunnarsson et al. 2003) one must assume uptake into body fat and consequently a slow turnover of a part of the administered activity.

The biokinetic model for ^{123}I-BMIPP adopted here assumes an initial uptake in the heart of 6 % and in the liver of 14 % of the administered activity. The rest is assumed to be uniformly distributed in the remaining organs and tissues. From the heart 40 % is excreted with a biological half-time of 1 hour and 60 % with a half-time of 48 hours. For the liver the fractions are 30 % and 70 %, respectively. The elimination from the rest of the body is assumed to be biexponential with a fast phase with a half-time of 48 hours and a slow phase with a half-time exceeding 100 hours (Gunnarsson et al., 2003). The faster phase corresponds to the combined fast and slow phases of heart and liver and represents the turnover of a more dynamic fat pool of the body and the slow phase represents the turnover of the rest of the body fat. The size of the latter long-lasting pool is here taken to be 20 % of the administered activity, a high value according to data occurring in the literature (see Gunnarsson et al., 2003).

For ^{123}I-IPPA, data suitable for dose estimations are non-existent. The initial uptake to the heart, liver and other organs and tissues is assumed to be the same as for ^{123}I-BMIPP. The first phase elimination from heart and liver, however, should be much faster since the β-oxidation is not inhibited, and in the model we assume a 5 times shorter half life, i.e. a biological half-time of 10 minutes for the initial fast phase. For the slow phase of the heart and liver and for the elimination from the rest of the body the same figures are used as in the ^{123}I-BMIPP model.

NOTE THAT THE MODELS ARE INTENDED FOR ^{123}I, ONLY.

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Biokinetic data for ^{123}I-BMIPP

Organ *(S)*	F_s	*T (hours)*	*a*	$\tilde{A}_s/A_0$ *(hours)*
Heart wall	0.06	1	0.40	0.57
		48	0.60	
Liver	0.14	1	0.30	1.52
		48	0.70	
Urinary bladder contents	1.0			
Adult and 15 years				0.41
10 years				0.35
5 years and 1 year				0.23
Other organs and tissues	0.80	48	0.75	12.8
		15 000	0.25	

(No free iodide released)

This model is intended for ^{123}I only

Biokinetic data for ^{123}I-IPPA

Organ *(S)*	F_s	*T (hours)*	*a*	$\tilde{A}_s/A_0$ *(hours)*
Heart wall	0.06	0.17	0.40	0.54
		48	0.60	
Liver	0.14	0.17	0.30	1.47
		48	0.70	
Urinary bladder contents	1.0			
Adult and 15 years				0.47
10 years				0.40
5 years and 1 year				0.27
Other organs and tissues	0.80	48	0.75	12.8
		15 000	0.25	

(No free iodide released)

This model is intended for ^{123}I only

Absorbed doses: Iodine-labelled fatty acid, ^{123}I-BMIPP

^{123}I 13.2 hours

	Absorbed dose per unit activity administered (mGy/MBq)				
Organ	Adult	15 years	10 years	5 years	1 year
Adrenals	1.5E-02	1.9E-02	2.9E-02	4.4E-02	8.0E-02
Bladder	3.9E-02	5.1E-02	6.5E-02	7.5E-02	1.4E-01
Bone surfaces	2.0E-02	2.4E-02	3.8E-02	5.8E-02	1.1E-01
Brain	9.7E-03	1.2E-02	2.0E-02	3.3E-02	5.9E-02
Breasts	9.0E-03	1.1E-02	1.7E-02	2.7E-02	5.3E-02
Gall bladder	1.9E-02	2.3E-02	3.5E-02	5.4E-02	8.6E-02
GI-tract					
Stomach	1.3E-02	1.7E-02	2.8E-02	4.2E-02	7.7E-02
SI	1.4E-02	1.7E-02	2.7E-02	4.3E-02	7.8E-02
Colon	1.4E-02	1.8E-02	2.7E-02	4.2E-02	7.6E-02
(ULI	1.4E-02	1.8E-02	2.7E-02	4.4E-02	7.8E-02)
(LLI	1.4E-02	1.7E-02	2.7E-02	4.0E-02	7.4E-02)
Heart	5.3E-02	6.8E-02	1.0E-01	1.6E-01	2.8E-01
Kidneys	1.3E-02	1.7E-02	2.6E-02	4.0E-02	7.2E-02
Liver	3.6E-02	4.6E-02	6.9E-02	9.8E-02	1.8E-01
Lungs	1.3E-02	1.7E-02	2.6E-02	4.0E-02	7.4E-02
Muscles	1.1E-02	1.4E-02	2.1E-02	3.2E-02	6.2E-02
Oesophagus	1.3E-02	1.6E-02	2.4E-02	3.8E-02	6.9E-02
Ovaries	1.4E-02	1.8E-02	2.7E-02	4.2E-02	7.7E-02
Pancreas	1.6E-02	2.0E-02	3.1E-02	4.9E-02	8.7E-02
Red marrow	1.1E-02	1.3E-02	2.0E-02	3.0E-02	5.5E-02
Skin	7.5E-03	9.1E-03	1.4E-02	2.3E-02	4.4E-02
Spleen	1.2E-02	1.5E-02	2.5E-02	3.8E-02	7.0E-02
Testes	1.0E-02	1.3E-02	2.0E-02	3.1E-02	5.8E-02
Thymus	1.3E-02	1.6E-02	2.4E-02	3.8E-02	6.9E-02
Thyroid	1.1E-02	1.4E-02	2.3E-02	3.7E-02	6.9E-02
Uterus	1.6E-02	1.9E-02	3.0E-02	4.4E-02	8.1E-02
Remaining organs	1.1E-02	1.4E-02	2.1E-02	3.4E-02	6.2E-02
Effective dose (mSv/MBq)	1.6E-02	2.0E-02	3.0E-02	4.5E-02	8.3E-02

Absorbed doses: Iodine-labelled fatty acid, ^{123}I-IPPA

^{123}I 13.2 hours

	Absorbed dose per unit activity administered (mGy/MBq)				
Organ	Adult	15 years	10 years	5 years	1 year
Adrenals	1.5E-02	1.9E-02	2.9E-02	4.4E-02	7.9E-02
Bladder	4.4E-02	5.6E-02	7.2E-02	8.3E-02	1.5E-01
Bone surfaces	2.0E-02	2.4E-02	3.8E-02	5.8E-02	1.1E-01
Brain	9.7E-03	1.2E-02	2.0E-02	3.3E-02	5.9E-02
Breasts	8.9E-03	1.1E-02	1.7E-02	2.7E-02	5.2E-02
Gall bladder	1.8E-02	2.3E-02	3.5E-02	5.3E-02	8.5E-02
GI-tract					
Stomach	1.3E-02	1.7E-02	2.7E-02	4.2E-02	7.6E-02
SI	1.4E-02	1.7E-02	2.7E-02	4.3E-02	7.8E-02
Colon	1.4E-02	1.8E-02	2.7E-02	4.2E-02	7.6E-02
(ULI	1.4E-02	1.8E-02	2.7E-02	4.4E-02	7.7E-02)
(LLI	1.4E-02	1.7E-02	2.7E-02	4.0E-02	7.5E-02)
Heart	5.1E-02	6.5E-02	9.8E-02	1.5E-01	2.7E-01
Kidneys	1.3E-02	1.6E-02	2.6E-02	4.0E-02	7.2E-02
Liver	3.5E-02	4.5E-02	6.7E-02	9.6E-02	1.7E-01
Lungs	1.3E-02	1.7E-02	2.6E-02	4.0E-02	7.4E-02
Muscles	1.1E-02	1.4E-02	2.1E-02	3.2E-02	6.2E-02
Oesophagus	1.3E-02	1.6E-02	2.4E-02	3.8E-02	6.9E-02
Ovaries	1.4E-02	1.8E-02	2.7E-02	4.2E-02	7.8E-02
Pancreas	1.6E-02	2.0E-02	3.1E-02	4.8E-02	8.7E-02
Red marrow	1.1E-02	1.3E-02	2.0E-02	3.0E-02	5.5E-02
Skin	7.5E-03	9.1E-03	1.4E-02	2.3E-02	4.4E-02
Spleen	1.2E-02	1.6E-02	2.5E-02	3.8E-02	7.0E-02
Testes	1.1E-02	1.3E-02	2.0E-02	3.1E-02	5.9E-02
Thymus	1.3E-02	1.6E-02	2.4E-02	3.8E-02	6.9E-02
Thyroid	1.1E-02	1.4E-02	2.3E-02	3.7E-02	6.9E-02
Uterus	1.6E-02	2.0E-02	3.1E-02	4.5E-02	8.2E-02
Remaining organs	1.1E-02	1.4E-02	2.1E-02	3.4E-02	6.2E-02
Effective dose (mSv/MBq)	1.6E-02	2.0E-02	3.0E-02	4.5E-02	8.3E-02

Carbon-11-labelled substances (Realistic maximum)

^{11}C

Biokinetic model

It is assumed that 50 % of the decays occurs while the substance passes the bladder and the remaining 50 % of the disintegrations occurs when homogeneously distributed within the total body.

Biokinetic data for ^{11}C-labelled substances (Realistic maximum)

Organ *(S)*	F_s	*T (hours)*	*a*	$\tilde{A}_s/A_0$ *(hours)*
Urinary bladder	0.50			0.25
Other organs and tissues	0.50			0.25

Absorbed doses: ^{11}C-labelled substances (Realistic maximum)

^{11}C 20.38 minutes

	Absorbed dose per unit activity administered (mGy/MBq)				
Organ	Adult	15 years	10 years	5 years	1 year
Adrenals	1.7E-03	2.2E-03	3.5E-03	5.7E-03	1.1E-02
Bladder	1.7E-01	2.1E-01	3.2E-01	5.0E-01	9.5E-01
Bone surfaces	1.9E-03	2.4E-03	3.7E-03	5.8E-03	1.1E-02
Brain	1.3E-03	1.7E-03	2.8E-03	4.6E-03	8.8E-03
Breasts	1.3E-03	1.7E-03	2.6E-03	4.3E-03	8.4E-03
Gall bladder	2.0E-03	2.4E-03	4.0E-03	6.2E-03	1.2E-02
GI-tract					
Stomach	1.8E-03	2.2E-03	3.5E-03	5.7E-03	1.1E-02
SI	3.0E-03	4.0E-03	6.2E-03	9.7E-03	1.8E-02
Colon	3.7E-03	4.7E-03	7.2E-03	1.1E-02	1.8E-02
(ULI	2.7E-03	3.4E-03	5.4E-03	8.7E-03	1.5E-02)
(LLI	5.1E-03	6.4E-03	9.6E-03	1.4E-02	2.3E-02)
Heart	1.6E-03	2.1E-03	3.3E-03	5.3E-03	1.0E-02
Kidneys	1.8E-03	2.2E-03	3.6E-03	5.9E-03	1.1E-02
Liver	1.7E-03	2.1E-03	3.5E-03	5.8E-03	1.1E-02
Lungs	1.5E-03	1.9E-03	3.0E-03	4.8E-03	9.4E-03
Muscles	2.3E-03	2.8E-03	4.5E-03	7.1E-03	1.3E-02
Oesophagus	1.5E-03	1.9E-03	3.1E-03	4.9E-03	9.5E-03
Ovaries	4.9E-03	6.3E-03	9.1E-03	1.4E-02	2.4E-02
Pancreas	1.8E-03	2.3E-03	3.7E-03	6.1E-03	1.2E-02
Red marrow	2.1E-03	2.7E-03	4.0E-03	5.9E-03	1.0E-02
Skin	1.5E-03	1.9E-03	3.0E-03	5.0E-03	9.5E-03
Spleen	1.7E-03	2.2E-03	3.3E-03	5.5E-03	1.1E-02
Testes	3.7E-03	5.3E-03	9.2E-03	1.4E-02	2.6E-02
Thymus	1.5E-03	1.9E-03	3.1E-03	4.9E-03	9.5E-03
Thyroid	1.5E-03	1.9E-03	3.1E-03	5.1E-03	9.8E-03
Uterus	9.2E-03	1.1E-02	1.8E-02	2.7E-02	4.6E-02
Remaining organs	2.3E-03	2.8E-03	4.3E-03	6.4E-03	1.2E-02
Effective dose (mSv/MBq)	1.1E-02	1.4E-02	2.1E-02	3.3E-02	6.1E-02

Bladder wall contibutes to 79 % of the effective dose

Technetium-labelled apcitide

^{99m}Tc

Biokinetic model

Apcitide is a peptide, which binds to the GP IIb/IIIa receptor on the surface of activated platelets, a major component of active thrombus formation. Apcitide is used for the detection and localization of acute venous thrombosis in the lower extremities. A biokinetic model with distribution in circulating blood and with an effective half-time equal to the physical one is assumed.

Reference for ^{99m}Tc-labelled apcitide

Taillefer, R., Edell, S., Innes, G. and Lister-James, J. 2000 Acute thromboscintigraphy with (99m)Tc-apcitide: results of the phase 3 multicenter clinical trial comparing 99mTc-apcitide scintigraphy with contrast venography for imaging acute DVT. Multicenter Trial Investigators. *J. Nucl. Med.* **41**, 1214-1223.

Biokinetic data for ^{99m}Tc-labelled apcitide

Organ *(S)*	F_s	*T (hours)*	*a*	$\tilde{A}_s/A_0$ *(hours)*
Blood	1.0	∞	1.0	8.69

Absorbed doses: ^{99m}Tc-labelled apcitide

^{99m}Tc 6.02 hours

	Absorbed dose per unit activity administered (mGy/MBq)				
Organ	Adult	15 years	10 years	5 years	1 year
Adrenals	1.1E-02	1.3E-02	2.1E-02	3.2E-02	5.9E-02
Bladder	3.2E-03	4.5E-03	6.4E-03	9.5E-03	1.8E-02
Bone surfaces	8.8E-03	1.0E-02	1.7E-02	2.9E-02	4.7E-02
Brain	4.0E-03	5.1E-03	8.3E-03	1.3E-02	2.4E-02
Breasts	3.8E-03	4.5E-03	7.6E-03	1.2E-02	2.1E-02
Gall bladder	7.0E-03	8.6E-03	1.4E-02	2.2E-02	3.1E-02
GI-tract					
Stomach	4.9E-03	6.4E-03	1.0E-02	1.6E-02	2.7E-02
SI	4.1E-03	5.1E-03	8.1E-03	1.3E-02	2.2E-02
Colon	3.9E-03	5.0E-03	7.9E-03	1.3E-02	2.1E-02
(ULI	4.2E-03	5.4E-03	8.5E-03	1.4E-02	2.3E-02)
(LLI	3.5E-03	4.5E-03	7.1E-03	1.1E-02	1.9E-02)
Heart	2.5E-02	3.2E-02	4.8E-02	7.2E-02	1.3E-01
Kidneys	1.3E-02	1.7E-02	2.7E-02	4.3E-02	7.9E-02
Liver	1.5E-02	1.8E-02	2.8E-02	4.3E-02	7.8E-02
Lungs	1.9E-02	2.4E-02	3.9E-02	6.2E-02	1.2E-01
Muscles	3.5E-03	4.3E-03	6.5E-03	1.0E-02	1.9E-02
Oesophagus	6.7E-03	7.8E-03	1.1E-02	1.6E-02	2.6E-02
Ovaries	3.7E-03	5.0E-03	7.2E-03	1.1E-02	2.0E-02
Pancreas	7.0E-03	8.6E-03	1.3E-02	2.1E-02	3.5E-02
Red marrow	6.1E-03	7.6E-03	1.2E-02	2.0E-02	4.0E-02
Skin	2.2E-03	2.6E-03	4.2E-03	6.8E-03	1.3E-02
Spleen	1.5E-02	1.8E-02	3.0E-02	4.7E-02	8.7E-02
Testes	2.4E-03	3.0E-03	4.4E-03	7.1E-03	1.3E-02
Thymus	6.7E-03	7.8E-03	1.1E-02	1.6E-02	2.6E-02
Thyroid	6.2E-03	7.9E-03	1.3E-02	2.1E-02	4.0E-02
Uterus	3.7E-03	4.6E-03	7.1E-03	1.1E-02	2.0E-02
Remaining organs	3.7E-03	4.7E-03	7.6E-03	1.3E-02	2.4E-02
Effective dose (mSv/MBq)	**7.3E-03**	**9.1E-03**	**1.4E-02**	**2.3E-02**	**4.1E-02**