Radiation Dosimetry in Nuclear Medicine

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Introduction

The main purpose of this chapter is to provide an overview of effective radiation doses to patients for all clinical protocols that are presented in part I and II. In almost all cases, the values were taken from the most recent publications of the International Commission on Radiological Protection (ICRP). In cases where ICRP data are not (yet) available, the authors have done their best to present data from the most recent scientific literature. In all cases, dose values are given for adults. In addition, dose values for 1, 5, 10 and 15 y old children are presented when available.

Furthermore, this chapter provides recommendations with regard to several issues that are related to the administration of these radiopharmaceuticals. These include doses to foetuses, infants (from breast milk and/or contact with the mother who has received a radiopharmaceutical), household members (after the patient has returned home), third parties (people in contact with the patient within a short time following the investigation), and pregnant or breast-feeding hospital personnel. This chapter does not cover radiation dosimetry for hospital personnel besides the pregnant or breast-feeding hospital personnel.

In the Netherlands, bone densitometry using Dual Energy X-ray Absorption (DEXA) is often carried out in Nuclear Medicine departments. For this reason, this chapter also contains dosimetric data related to DEXA investigations although these are not associated with the use of radiopharmaceuticals. The same holds for low dose CT scans made in PET/CT or SPECT/CT scanners for the purpose of anatomical localization and attenuation correction.

1. Patients

1.1 Effective dose in patients with normal biokinetics and biodistribution

Table 1 presents dosimetric data for patients with normal biokinetics and biodistribution for all protocols and radiopharmaceuticals that have been described in in part I and II of this book. The patient's effective dose is calculated using models developed by the MIRD (Medical Internal Radiation Dose commission), which were subsequently adopted by the ICRP. In some cases the effective dose is calculated by a more recent model than that provided by the MIRD. Effective doses are calculated using organ or tissue weighting factors which provide the opportunity to represent the radiation-induced risk to patients undergoing different radio-diagnostic procedures by means of a single value. These weighting factors are proportional to the degree of risk to a particular organ, and sum to 1 for all organs together.

Column 1 presents the relevant protocol and page number. Column 2 gives the radiopharmaceutical with the radionuclide indicated in square brackets. Column 3 gives

the activity for adults as recommended in the protocol. Column 4 gives the recommended activity for children, if available in the protocol. In general, it is recommended to use the latest version of the EANM paediatric dosage card (to be downloaded from www.eanm.org). Column 5 gives the route of administration. Column 6 gives the reference in which the data were published (e.g. ICRP publication 53, 62, 80 or 106). Note that effective doses from different publications can be based on different tissue weighting factors. Due to better measurements and/or models, tissue-weighting factors have changed between the IRCP publications 26 (1977), 60 (1990) and 103 (2007), most importantly for the gonads where a decrease from 0,25 to 0,20 to 0,08 was effected over the course of time. Also the weighting factor for the breast has changed: from 0,15 to 0,05 to 0,12. Effective doses in ICRP62 and ICRP80 are based on the tissue weighting factors of ICRP60, whereas those in ICRP53 are based on tissue weighting factors from ICRP26. The updated tissue weighting factors as published in ICRP103 have not yet led to a complete re-evaluation of the effective doses for the radiopharmaceuticals of ICRP80. ICRP106 (2008) lists effective dose values for a limited number of radiopharmaceuticals not yet described in earlier publications using the tissue weighting factors of ICRP103, but does not give an update for all other radiopharmaceuticals published earlier (ICRP80, ICRP62, and ICRP53).

Columns 7-11 give the effective dose per MBq of administered radiopharmaceutical for patients of different ages. It should be mentioned that for several radiopharmaceuticals, the age-dependent doses were taken from ICRP53, whereas effective doses for adults are from ICRP62, ICRP80, or ICRP106. The reason is that for these radiopharmaceuticals, age dependence was not included in the more recent ICRP publications. As mentioned earlier, please note that different tissue weighting factors were used in the different publications. Finally, please note the difference in wording: "effective dose equivalent" (ICRP53) versus "effective dose" (ICRP60), which reflects the different tissue weighting factors (and also the use of different phantoms). The authors of this chapter have striven to present the most recently published dose values for all cases. Finally, column 12 gives the effective doses for adults when administering the recommended amount of activity.

It should be noted that table 1 is restricted to effective doses. Individual organ doses are available for many radiopharmaceuticals (see, e.g. ICRP53, ICRP62, ICRP80, ICRP106). but are not presented here. Furthermore, calculations are based on the assumption that the radiation energy absorbed by the organs is homogenous; micro-dosimetric effects are not taken into account. More information about the calculation methods is given in the references.

A factor which can highly influence doses is the micturition interval used in the models, which is mostly taken as 3,5 h for adults, but is shorter for children (3 h for a 5 y old child, 2 h for a 1 y old child and newborns (ICRP106). In general, good hydration and frequent micturition can reduce radiation dose considerably. The effective doses in individual patients may vary significantly from the values shown in table 1, due to uncertainties of the quantitative description of uptake, distribution and retention of radiopharmaceuticals, and in radiation transport and absorption calculations and phantoms used. ICRP53 states that values can vary by up to a factor of 2.

1.2 Effective dose in patients with deviating biokinetics and biodistribution
Table 2 presents dosimetric data for patients with deviating biokinetics and biodistribution for a selected number of protocols and radiopharmaceuticals.

1.3 Radiopharmaceuticals administered via local routes
The absorbed dose for radiopharmaceuticals administered via other, local routes (that is, other than intravenously or orally) depends largely on their biodistribution and their clearance rate from the region of accumulation. It is not always possible to provide figures for the effective dose given the limited yet widely varying aspects of local accumulation. In general, such examinations involve small amounts of radioactivity, see table 1, resulting in low radiation doses.

1.4 Injection site extravasation
Extravasation of radioactive material at the site of injection results in a high radiation dose to that area. The radiation dose depends on the amount of radioactivity and the volume of fluid containing the radioactivity, but also the rate at which the material is cleared. Massage can help to reduce the radiation dose at the injection site. The effective half-life of extravasated material around the injection site is generally short (approximately 2 h), but may be longer (8-10 h) if the material is extravasated at a site that is poorly vascularised. In order to gain some idea of the clearance time, the half-life can be roughly calculated by measuring the activity at the injection site several times during the first 24 h under standardised circumstances using a gamma camera, a scintillation counter or a radiation monitor. Extravasation of injection fluid may result in the radiopharmaceutical having to be re-injected (at a later stage) for the same investigation.

2. Foetuses
2.1 Dose to foetus in a pregnant woman undergoing administration of a radiopharmaceutical
The absorbed dose to the embryo or foetus has long been an area of concern. The use of pregnant female phantom series has enabled the estimation of absorbed doses for the foetus in early pregnancy and at 3, 6, and 9 months gestation possible. Table 3 shows these doses as calculated by Russell et al for radiopharmaceuticals which might be given, whether intentionally or not, to women of childbearing age. Biokinetic data for these radiopharmaceuticals were gathered from various documents and other resources. The absorbed doses to the embryo and foetus at these different stages of gestation from radiation originating within the mother's organs were then estimated. In addition, information about activity distributed within the placenta and foetus was included where quantitative data were available.

In many cases, bladder activity will comprise a relatively large proportion of the total radiation dose to the foetus. Extra micturition can reduce this dose significantly, and should therefore be advised.

According to the Dutch Health Council, there is no reason to terminate a pregnancy when the foetal dose is lower than 100 mGy. However, doses above 500 mGy can induce considerable damage to the health of the unborn child. Based on the data of table 3,

it is concluded that for most diagnostic administrations, the value of 100 mGy will not be reached. Further details with regard to the effects of radiation on the foetus with a subdivision into stochastic and deterministic effects for several stages of pregnancy, can be found in "Dutch Health Council". When administering radiation to a woman who is over 10-13 weeks gestation. Special attention should be given to the foetal thyroid.

After this period, the foetal thyroid has already been formed, and concentrates iodine that crosses the placenta. Foetal thyroid dose for ^{123}I, ^{124}I, ^{125}I and I ^{131}I administered to the mother at 3-9 months of gestation are presented in Table 4. It should be mentioned that a period of 10-13 weeks of pregnancy will generally not be unnoticed. This implies that a careful trade-off between interruption of pregnancy and necessity of treatment or diagnosis of the pregnant patient can be made. Doses to the foetus from hyperthyroid and athyroid subjects for ^{131}I can be found in, tables 3.9 and 3.10]

When administering therapeutic doses of radiopharmaceuticals to pregnant patient, much care should be taken. Recommendations for pregnant women are given in. The most important advice for ^{131}I therapy being the prevention of pregnancy during the first 4 months after therapy. More details can be found in.

2.2 Dose to foetus in pregnant hospital personnel, dose limit for pregnant hospital personnel

According to section 80, paragraph 1 of the 2012 Radiation Protection Act (RPA), a woman may continue to work with ionizing radiation during her pregnancy as long as the effective dose to the unborn child is as low as reasonably achievable and this dose, calculated as of the date the pregnancy is first reported, does not exceed 1mSv during the rest of the pregnancy. The risk assessment outlined in section 10 of the RPA describes the type of work for which this applies. In addition to the obligatory dosimetry, supplementary dosimetry may be carried out in order to determine whether these requirements can be met. In practice, this must be assessed for each individual situation. For instance, it could be essential to carry an electronic personal dosimeter with direct dose reading instead of a thermoluminescent detector that provides cumulative doses only.

3. Infants

If a radiopharmaceutical is administered to a breastfeeding mother, the child may be exposed to radiation through internal contamination by breast milk or by external irradiation during direct contact. For radionuclide therapy, any breastfeeding is prohibited: *"breast feeding must be stopped before therapy and not be resumed after discharge from the hospital"*. The following considerations hold for diagnostic examinations:

3.1 Internal contamination

If a patient is breast-feeding, it is of interest how long breast-feeding should be interrupted (if at all) to protect the nursing infant. The most recent recommendations are given in table 5 (ICRP106). The radiation dose from internal contamination can be limited by expressing milk with a breast pump and storing it in a refrigerator until the radioactivity has decayed sufficiently. Otherwise, breast-feeding should be temporarily discontinued and replaced by formula feed.

3.2 External radiation

The radiation dose to which infants are exposed due to external radiation depends on the radiopharmaceutical used and its bio-distribution. Highest doses will of course be received from body parts of the mother that are close to the breasts. Not much literature data is available pertaining to this issue. However, references exist for ^{99m}Tc macroaggregates (lung scintigraphy), and for FDG. Both papers conclude that the external radiation dose from breasts and other body part close to the infant is higher than the dose from the ingested milk. This implies that in case of doubt, one could use expressed milk. Depending on the internal dose associated with the ingestion of expressed milk, one could use it to feed the child immediately (e.g. by the father or other person), or store the breast milk in a refrigerator as mentioned in the previous section.

3.3 Internal contamination of breastfeeding hospital personnel

Section 80, paragraph 2, of the RPA states that employers must ensure any staff member who is breastfeeding is exempted from activities which pose a greater than negligible risk of radioactive contamination of the body. In the explanatory notes to the RPA, work with open sources is limited to two sources for which the total activity, and activity concentration, is equal to and no greater than the source strength and concentration, as indicated in the exclusion and exemption levels in table 1 of the RPA. These limits are extremely rigorous and are currently under discussion. The new version of the Dutch Decree on Radiation Protection from January 2014 states a less severe requirement: The employer must ensure that an employee who has mentioned that she is breastfeeding, does not perform work for which, based on risk analysis, a relevant risk is present for radioactive contamination of the body

4. Household members, third parties

Following administration of the radiopharmaceutical, patients become a temporary source of radiation to their environment due to the radiation emitted by the patients themselves and possibly by contamination through radioactive excreta. Contamination through excreta is, however, negligible if good hygiene practices are adhered to. The dose received through direct exposure to the radiation depends on the type and energy of the radiation, the amount of activity administered, and the effective (that is, biological and physical) half-life of the radiopharmaceutical. Precautions for the public are rarely required after diagnostic nuclear medicine procedures, as indicated in ICRP103. Examples of dose rates are given in IRCP68 for bone and liver scintigraphy, and blood pool determination using ^{99m}Tc coupled MDP, colloid and RBC respectively, and myocardial scintigraphy using ^{201}Tl. Absorbed dose rates are around 10 nGy/MBq at a distance of 30 cm from to the patient, and are well below 10 nGy/MBq for distances of 1 m and farther. These numbers hold immediately after administration and for 2 h after administration, and will decrease in time due to physical decay and biological clearance. Given typically administered activities of several hundreds of MBq, dose rates will be several μGy/h at 30 cm and <1 μGy/h at 1 m from the patient. In view of the generally short half-lives of diagnostic radionuclides, the doses to household members and third parties can be neglected compared to the background radiation, which is around 2 mSv/y in the Netherlands.

When using ionizing radiation, the radiation dose to everyone should be kept as low as

reasonably achievable. The Nuclear Energy Act (Decree on Radiation Protection) stipulates a maximum permitted dose such that the risks as a result of exposure to this radiation be negligible. This maximum dose is 1 mSv/y for members of the public. The same limit applies to the unborn child. Given the fact that the radiation dose to which household members and third parties are exposed is negligible compared to background radiation, measures to limit the contact between patient and household members (including pregnant women) are not required.

Please note that this holds for diagnostic examinations. On the contrary, rules are recommended for household members of patients who undergo radionuclide therapy. ICRP94] provides recommendations for the release of patients after radionuclide therapy. These recommendations include that young children and infants, as well as visitors not engaged in direct care or comforting, should be treated as members of the public for radiological protection purposes (i.e., be subject to the public dose limit of 1 mSv/y). For individuals directly involved in comforting and caring, other than young children and infants, a dose constraint of 5 mSv per episode (i.e., for the duration of a given release after therapy) is reasonable. The constraint needs to be used flexibly. For example, higher doses may well be appropriate for parents of very sick children.

Recent developments in diagnostic investigations show the use of longer-lived PET nuclides such as ^{89}Zr and ^{124}I. This led to a discussion on the need to provide rules for household members in these cases. At the time of writing no consensus has been reached.

The cornerstones of release criteria are dose limits for the public and dose constraints for relatives and caregivers. In spite of this, there is wide variation in criteria used to decide whether to release or hospitalise patients. At present, the two general forms of release criteria are those based on individual situations and projected doses to other people, and those based on retained activity (usually following conservative assumptions). It is interesting to note that the ICRP has not provided recommendations on the criteria to follow regarding the release of patients after radionuclide therapy. Instead, the recommendations have been directed at dose limits for occupationally exposed workers in hospitals, dose limits for the public, and dose constraints for caregivers. Thus, the ICRP has not set any retained activity level to require hospitalisation. A patient may be discharged regardless of the magnitude of retained activity provided that the dose limit and dose constraint issues are met.

Specifications of release criteria in the Netherlands for patients after radionuclide therapy can be found in *(Het werken met therapeutische doses radionucliden (VROM, SZW, NVNG))*. ICRP94 provides an overview of recommendations given in several countries and by several national and international organizations.

5. Bone densitometry

Dual energy x-ray absorption (DEXA) using x-ray sources of different energy (e.g. 100 and 140 keVp) is used for bone density measurements. As mentioned before, for historical reasons this kind of equipment is often operated by nuclear medicine departments

instead of radiology departments. The dose to the patient depends on factors including source energy, tube current, scan speed, bundle size, size of scan area and the radiation filters used. Manufacturers of DEXA scanners usually specify skin entrance doses (mGy) for the protocols provided with their scanners. However, in dosimetric considerations, organ doses and effective doses with tissue weighting factors taken into account, should be available. Blake et al have provided organ doses and effective doses for hip, spine and total body DEXA scans. A physical phantom (Rando) was used to obtain depth dose data, which were mapped to the set of mathematical phantoms developed by Christy for adults and children of 5, 10 and 15 years old. Tissue weighting factors were taken from ICRP60. Although these doses were obtained for a specific scanner (Hologic Discovery), it may be assumed that doses obtained using other scanners will be in the same order of magnitude. Without going into all details of, it can be concluded that patient doses associated with DEXA scans are very low, the highest reported effective doses being in the order of 50 μSv, which is 34 times smaller than the yearly, background radiation in the Netherlands (around 2 mSv/y).

6. Low dose CT in PET/CT or SPECT/CT scans

For the purpose of PET or SPECT attenuation correction and for anatomical localization, low dose CT scans are made in conjunction with these nuclear scans. For these scans, CT settings resulting in lower doses than for high quality, diagnostic CT scans can be used.

Most CT scanners have the option to adapt the tube current setting (mA) to the total attenuation encountered in different body parts during the scan. That is, e.g. lungs, head, legs are scanned using lower mA values than e.g. the abdomen, where attenuation is less, thus lowering the total patient dose. Recently, modulation of the kV settings has also become available for several types of CT scanners.

Furthermore, iterative CT reconstruction techniques are available for most modern CT scanners. This allows to further reduce mA and/or kV settings whilst maintaining image quality. At present it is not yet clear as to how far the CT dose in PET/CT and SPECT/CT can be lowered using a combination of all available techniques.

Low dose CT scans contribute to the total effective dose of the multi-modality scan depending on the acquisition protocol being used by the institute which will in general be a locally determined optimum between low-dose and image quality. The effective dose resulting from the low dose CT scan may be calculated using the excel sheets provided by ImPACT. Since the number of different acquisition protocols is usually limited (e.g. low-dose CT for a whole-body PET/CT and low-dose CT for brain PET/CT), the parameters of these low dose CT scanning protocols need to be entered into the excel sheets only once. The dosimetry of stand-alone CT usage of a nuclear/CT camera, such as diagnostic CT, is beyond the scope of these recommendations and are at the time of writing usually performed under responsibility of radiology.

7. References

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- ImPACT CT dosimetry tool: http://www.impactscan.org/ctdosimetry.htm

Table 1. Radiation dose in patients with normal biological behaviour

Protocol, page number	Radiopharmaceutical	Recommended activity for adults [MBq]	
C-14-urea breath test [p.330]	[^{14}C] urea	0,2	
Detection of protein loss through the intestin wall [p.311]	[^{51}Cr] chloride	1,2	
Diagnosis of gastrointestinal protein loss (localisation using ^{99m}Tc HSA) [p.308]	[^{99m}Tc] HSA	500 - 740	
Iodine Total-Body Scintigraphy [p.47]	Sodium [^{131}I] iodide (4)	Pre-ablation scintigram: 40–80	
Iodine Total-Body Scintigraphy [p.47]	Sodium [^{131}I] iodide (4)	Pre-ablation scintigram: 185-370	
Iodine Total-Body Scintigraphy [p.47]	Sodium [^{131}I] iodide (4)	Post ablation follow up: 80–185	
Iodine Total-Body Scintigraphy [p.47]	Sodium [^{131}I] iodide (4)	Post therapy scintigram after ablation: 1100–3700	
Iodine Total-Body Scintigraphy [p.47]	Sodium [^{131}I] iodide (4)	In locoregional metastases or non-radical resection of primary tumour: 3700-7400	
Iodine Total-Body Scintigraphy [p.47]	Sodium [^{131}I] iodide (4)	In remote metastases 5550-7400	
MIBG cardiac sympathetic imaging [p.238]	[^{123}I] MIBG	185	
Erythrocyte and Plasma Volume Measurement [p.161]	[^{125}I] albumin	1,3 kBq/kg body weight.	
Erythrocyte and Plasma Volume Measurement [p.161]	[^{131}I] albumin	1,3 kBq/kg body weight.	
Erythrocyte and Plasma Volume Measurement [p.161]	[^{51}Cr] autologic erythrocytes	5,1 kBq/kg body weight	
Erythrocyte Survival Time [p.167]	[^{51}Cr] autologic erythrocytes	1,2	
Adrenal cortex scintigraphy [p.71]	[^{131}I] cholesterol	20	

	Recommended activity for children [MBq/kg] ****	Route of administration**	P*	Effective dose*** (mSv/MBq)				
				1 yr	5 yr	10 yr	15 yr	Adult
	-	or	80	-	-	-	-	0,031
	-	iv	62	-	-	-	-	0,068
			53	0,55	0,31	0,21	0,14	0,11
	-	iv	80					0,0061
			53	0,042	0,023	0,015	0,0097	0,0079
	-	or/iv (7)	62					24
			53	140	78	36	24	15
	-	or/iv	62					0,22
			53	1,4	0,74	0,35	0,23	0,15
	-	or/iv	62					24
			53	140	78	36	24	15
	-	or/iv	62					24
			53	140	78	36	24	15
	-	or/iv	62					24
			53	140	78	36	24	15
	-	or/iv	62					24
			53	140	78	36	24	15
	--	iv	80					0,013
			62					0,014
			53	0,09	0,05	0,034	0,023	0,018
	-	iv	62					0,22
			53	2,2	1,1	0,68	0,41	0,34
	-	iv	62					0,64
			53	5,4	2,8	1,7	1,1	0,86
	-	iv	62					0,17
			53	1,5	0,8	0,52	0,33	0,26
	-	iv	62					0,17
			53	1,5	0,8	0,52	0,33	0,26
	-	iv	80	18	9,6	4,4	2,9	1,8

Protocol, page number	Radiopharmaceutical	Recommended activity for adults [MBq]	
^{131}I Therapy in primary hyperthyroidism and non-toxic (multi) nodular goiter [p.372]	Sodium [^{131}I] iodide	3,7-11,1 MBq/ml or fixed activities 370 – 740 MBq	
^{131}I Therapy for the treatment of differentiated thyroid carcinoma [p.384]	Sodium [^{131}I] iodide	Ablation: 1100-1850	
^{131}I Therapy for the treatment of differentiated thyroid carcinoma [p.384]	Sodium [^{131}I] iodide	T3-T4 tumours: 3700 – 7400	
^{131}I Therapy for the treatment of differentiated thyroid carcinoma [p.384]	Sodium [^{131}I] iodide	Metastases after ablation: 5550-7400	
MIBG Scintigraphy [p.59]	[^{131}I] MIBG	40–80	
MIBG Scintigraphy [p.59]	[^{131}I] MIBG	post treatmanent scintigraphy: 3700–7400	
MIBG Scintigraphy [p.59]	[^{123}I] MIBG	185 - 370	
Radionuclide Cisternography [p.14]	[^{111} In] DTPA	20 (4 in case of evaluation of drainage system)	
Bile acid malabsorption test [p.314]	[^{75}Se] HCAT	0,04 (faecal excretion test) 0,4 (camera test)	
Liver and spleen scintigraphy [p.323]	[^{99m} Tc] large colloids	80	
Oesophageal scintigraphy [p.288]	[^{99m} Tc] colloid (liquid)	5 x 10	
Gastric emptying study [p.291]	[^{99m} Tc] colloid (solid , in pancake or milk pap)	10	
Cholescintigraphy [p.334]	[^{99m} Tc] Mebrofenin	See protocol, several activities	
Renal cortical scintigraphy/DMSA scan [p.341]	[^{99m} Tc] DMSA	80 - 110	
Scintigraphy of gastrointestinal tract bleeding [p.300]	[^{99m} Tc] erythrocytes	750	
Hepatic hemangioma scintigraphy [p.327]	[^{99m} Tc] autologous erythrocytes	500	
Spleen Scintigraphy Using Denatured Erythrocytes [p.158]	[^{99m} Tc] denatured RBCs	80	
Regional Cerebral Blood Perfusion Scan [p.18]	[^{99m} Tc] exametazine (HMPAO)	500	
Regional Cerebral Blood Perfusion Scan [p.18]	[^{99m} Tc]-ethyl cysteinate dimer (ECD)	500	

	Recommended activity for children [MBq/kg] ****	Route of administration**	P*	Effective dose*** (mSv/MBq)				
				1 yr	5 yr	10 yr	15 yr	Adult
	-	or /iv	62					24
			53	140	78	36	25	15
	-	or /iv	62					24
			53	140	78	36	25	15
	-	or /iv	62					24
			53	140	78	36	25	15
	-	or /iv	62					24
			53	140	78	36	25	15
	-	iv	62					0,14
			53	1,1	0,61	0,4	0,26	0,2
	-	iv	62					0,14
			53	1,1	0,61	0,4	0,26	0,2
	Scaled to body weight according to EANM Paediatric Task Group: 80–400 MBq)	iv	80	0,068	0,037	0,026	0,017	0,013
	-	lumbar injection	53					0,14
		cisternal injection	53					0,12
	-	iv	80	3,9	2,0	1,3	0,86	0,69
	-	iv	80	0,050	0,028	0,018	0,012	0,0094
	--	or	80	0,11	0,062	0,039	0,025	0,019
	--	or	80	0,14 (s) 0,11 (l)	0,076 (s) 0,062 (l)	0,048 (s) 0,039 (l)	0,031 (s) 0,025 (l)	0,024 (s) 0,019 (l)
	See protocol, several activities	iv	80	0,10	0,045	0,029	0,021	0,017
	-	iv	80	0,037	0,021	0,015	0,011	0,0088
	-	iv	80	0,039	0,021	0,014	0,0089	0,0070
	-	iv	80	0,039	0,021	0,014	0,0089	0,0070
	-	iv	62					0,019
			53	0,22	0,13	0,084	0,056	0,041
	-	iv	80	0,049	0,027	0,017	0,011	0,0093
	-	iv	106	0,04	0,022	0,015	0,0099	0,0077

Protocol, page number	Radiopharmaceutical	Recommended activity for adults [MBq]	
Leukocyte scintigraphy [p.171]	[^{99m}Tc] exametazine (HMPAO) labeled leukocytes	370 - 740	
Leukocyte scintigraphy [p.171]	[^{111}In] oxine labeled leucocytes	10 – 18,5	
Salivary gland scintigraphy [p.284]	[^{99m}Tc] sodium pertechnetate	100	
Scintigraphy of ectopic gastric mucosa [p.300]	[^{99m}Tc] sodium pertechnetate	200	
Micturition Cystourethrography using Scintigraphy [p.356]	[^{99m}Tc] DTPA	30	
Micturition Cystourethrography using Scintigraphy [p.356]	[^{99m}Tc] colloid	30	
^{18}F-FDG for inflammation and infection detection [p.187]	[^{18}F]-FDG		
Myocardial perfusion PET/CT with Rubidium-82 [p.222]	[^{82}Rb]	1110 - 1480	
16α-[^{18}F]fluoro-17β-oestradiol ([^{18}F] FES) in oncology [p.90]	[^{18}F]-FES	200	
Nasal Mucociliary Clearance [p.280]	[^{99m}Tc] nanocolloid	2	
Lymphoscintigraphy of the Upper Extremities [p.145]	[^{99m}Tc] nanocolloid	50 MBq per hand	
Parathyroid gland scintigraphy [p.52]	[^{99m}Tc] labeled sestamibi	500 - 700	
Parathyroid gland scintigraphy [p.52]	[^{99m}Tc] labeled tetrofosmin	500 - 700	
Parathyroid gland scintigraphy [p.52]	Dual tracer imaging using sodium [^{99m}Tc] pertechnetate	35-75	
Parathyroid gland scintigraphy [p.52]	Dual tracer imaging using sodium [^{123}I]	7,5 – 22	
Thyroid Gland Scintigraphy [p.35]	[^{99m}Tc] sodium pertechnetate	80-180	
Thyroid Gland Scintigraphy [p.35]	[^{123}I] sodium iodide	10 - 20	
Molecular Breast Imaging (MBI) using breast specific gamma cameras (BSGI) [p.85]	[^{99m}Tc] labeled sestamibi	200 - 600	
Molecular Breast Imaging (MBI) using breast specific gamma cameras (BSGI) [p.85]	[^{99m}Tc] labeled tetrofosmin	200 - 600	

	Recommended activity for children [MBq/kg] ****	Route of administration**	P*	Effective dose*** (mSv/MBq)				
				1 yr	5 yr	10 yr	15 yr	Adult
	-	iv	80	0,062	0,034	0,022	0,014	0,011
	-	iv	62					0,36
			53	3,2	1,8	1,2	0,79	0,59
	-	iv	80	0,079	0,042	0,026	0,017	0,013
	7 - 10	iv	80	0,079	0,042	0,026	0,017	0,013
	-	bladder	[a]					0,0024
			[b]					0,002
	-	bladder	[a]					0,0024
			[b]					0,002
	-	iv	106	0,095	0,056	0,037	0,024	0,019
	-	iv	[c]					0,00126 (8)
			[d]					0,00128 (9)
			62					0,0034
			53	0,033	0,018	0,010	0,0067	0,0048
	-	iv	106	0,16	0,093	0,066	0,031	0,023
	-	Drop deposited in nose	80	0,14	0,076	0,048	0,031	0,024
	-	Subcutaneous injection						0,005
	-	iv	80	0,053	0,028	0,018	0,012	0,009
	-	iv	Ad4	0,046	0,024	0,015	0,01	0,008
	-	iv	80	0,079	0,042	0,026	0,017	0,013
	-	iv	62					0,22
			53	1,4	0,74	0,35	0,23	0,15
	-	iv	80	0,079	0,042	0,026	0,017	0,013
	3 MBq neonates	iv/or	62					0,22
			53	1,4	0,74	0,35	0,23	0,15
	-	iv	80	0,053	0,028	0,018	0,012	0,009
	-	iv	Ad4	0,046	0,024	0,015	0,01	0,008

Protocol, page number	Radiopharmaceutical	Recommended activity for adults [MBq]	
FDG-PET-CT of the brain [p.27]	[^{18}F]-FDG	150 - 250	
Sentinel node localisation in breast cancer patients [p.75]	[^{99m} Tc]-nanocolloid	40 - 80	
P-32 phosphate treatment of myeloproliferative diseases [p.435]	Sodium [^{32}P] phosphate	3,7 (max = 260 MBq)	
Dynamic Renography [p.344]	[^{99m} Tc] Tiatide (MAG3)	70 - 100	
Dynamic Renography [p.344]	[^{99m} Tc] Pentetate (DTPA)	150 – 200	
Dynamic Renography [p.344]	[^{123}I] Sodium iodohippurate (IOH)	75	
Measurement of renal function (GFR) [p.352]	[^{125}I-Iothalamate (IOT)	1,5	
Measurement of renal function (ERPF) [p.352]	[^{131}I]-Sodium-iodohippurate (IOH)	2	
Lacrimal Scintigraphy [p.31]	[^{99m} Tc] sodium pertechnetate	4 per eye	
Measurement of Iodine Uptake by the Thyroid [p.42]	[^{131}I] sodium iodide	2 - 4	
Measurement of Iodine Uptake by the Thyroid [p.42]	[^{123}I] sodium iodide	2 - 4	
^{188}Re HEDP Therapy for Skeletal Metastases [p.400]	[^{188}Re]-HEDP	40 MBq/kg body weight	
Bone scintigraphy [p.249]	[^{99m} Tc] HDP or [^{99m} Tc] PDP	300 – 740 11 – 13 MBq/kg body weight for obese patients	
Myocardial perfusion scintigraphy in rest and stress [p.191]	[^{99m} Tc] labeled sestamibi	increasing from 600 for BMI < 25 to 900 for BMI > 35 (6)	
Myocardial perfusion scintigraphy in rest and stress [p.191]	[^{99m} Tc] labeled tetrofosmin	increasing from 600 for BMI < 25 to 900 for BMI > 35 (6)	
Myocardial perfusion scintigraphy in rest and stress [p.191]	[^{201}Tl] chloride	74 - 111	
Somatostatin-receptor scintigraphy with ^{111} In-pentetreotide [p.65]	[^{111} In] pentetreotide	200	
Equilibrium radionuclide angiography / Multi Gated Acquisition [p.211]	[^{99m} Tc]-labeled erythrocytes	500 - 1050	

	Recommended activity for children [MBq/kg] ****	Route of administration**	P*	Effective dose*** (mSv/MBq)				
				1 yr	5 yr	10 yr	15 yr	Adult
	2 - 4	iv	106	0,095	0,056	0,037	0,024	0,019
	-	Peritumoral, subdermal, or periareolar	[e]					0,005
		iv/or	62					2,4
			53	22	10	5,1	3,0	2,2
	-	iv	80	0,022	0,012	0,012	0,009	0,007
	-	iv	80	0,016	0,009	0,0082	0,0062	0,0049
	-	iv	80	0,034	0,019	0,019	0,015	0,012
	-	iv	62					0,0072
			53	0,057	0,030	0019	0,012	0,0097
	-	iv	80	0,16	0,083	0,086	0,067	0,052
	-	Droplets in eye	80	0,079	0,042	0,026	0,017	0,013
	-	iv/or	62					24
			53	140	78	36	25	15
	-	iv/or	62					0,22
			53	1,4	0,74	0,35	0,23	0,15
	-	iv	[f]					0,07
	EANM dosage calculator, minimum 40 MBq	iv	80	0,027	0,014	0,011	0,007	0,0057
	-	iv	80	0,053 (8)	0,028 (8)	0,018 (8)	0,012 (8)	0,009 (8)
				0,045 (9)	0,023 (9)	0,016 (9)	0,010 (9)	0,0079 (9)
	-	iv	Ad4	0,046 (8)	0,024(8)	0,015(8)	0,01(8)	0,008 (8)
			106	0,039 ((9)	0,021 (9)	0,013 (9)	0,0088 (9)	0,0069 (9)
	-	iv	106	1,3	0,79	0,56	0,2	0,14
	-	iv	80	0,28	0,16	0,10	0,071	0,054
	-	iv	80	0,039	0,021	0,014	0,0089	0,0070

Protocol, page number	Radiopharmaceutical	Recommended activity for adults [MBq]	
Equilibrium radionuclide angiography / Multi Gated Acquisition [p.211]	[^{99m} Tc]-labeled human serum albumin (HSA),	500 - 1050	
Myocardial viability imaging using ^{18}F-FDG PET/CT [p.205]	[^{18}F]-FDG	185 - 400	
FDOPA revisited [p.136]	Fluoro-18-L-Dihydroxyphenylalanine [^{18}F] FDOPA)	Parkinsonism: 200 Neuroendocrine tumours 200 or 1,5 /kg	
^{18}F-choline PET/CT for prostate cancer [p.126]	[^{18}F]-methyl-choline	50 – 400	
[^{223}Ra]-dichloride (Xofigo ®) [p.404]	[^{223}Ra]-dichloride	50 kBq/kg	
I-124-PET(/CT) in thyroid cancer [p.119]	[^{124}I]-sodium iodide	25 - 74	
[^{153} Sm]- EDTMP Therapy for Skeletal Metastases (Quadramet®) [p.407]	[^{153} Sm]- EDTMP	37 MBq/kg	
Sr-89-chloride (Metastron ®) Therapy for Skeletal Metastases [p.411]	[^{89}Sr]-chloride	150	
Sentinel Node Localisation of Melanoma [p.80]	[^{99m} Tc]-nanocolloid	4 x 10 - 20	
Peptide Receptor Radionuclide Therapy using 177Lu-octreotate [p.439]	[^{177}Lu]-[DOTA0,Tyr3]-octreotate	4 x 7400	
Imaging of the dopamine transporter and receptors [p.22]	[^{123}I]-FP-CIT (DaTSCAN)	185	
Imaging of the dopamine transporter and receptors [p.22]	[^{123}I]-IBZM	185	

	Recommended activity for children [MBq/kg] ****	Route of administration**	P*	Effective dose*** (mSv/MBq)				
				1 yr	5 yr	10 yr	15 yr	Adult
	-	iv	80					0,0061
			53	0,042	0,023	0,015	0,0097	0,0079
	-	iv	106	0,095	0,056	0,037	0,024	0,019
	-	iv	106	0,10	0,070	0,049	0,032	0,025
	-	iv	Ad4	0,10	0,057	0,037	0,024	0,02
	-	iv	[g]					23,11
			[h]					
	-	iv/or	80					0,095 (5) 1,5 (4)
			53	0,56 (5) 86 (4)	0,31 (5) 46 (4)	0,20 (5) 21 (4)	0,13 (5) 14 (4)	0,11 (5) 9,1 (4)
	-		[i]					0,307
	-	iv	80					3,1
			53	25	12	6,5	3,8	2,9
	-	intradermal						0,005
	-	iv	[j]					
	-	iv	106	0,32	0,15	0,096	0,061	0,05
	-	iv	106	0,32	0,15	0,096	0,061	0,05

Remarks:

(1) Also doses for iv administration available in ICRP publications. However, only or administration is mentioned in protocol
(2) With flushing
(3) Without flushing
(4) For 35% thyroid uptake
(5) For 0% thyroid uptake
(6) This holds for the 2-day protocol, for one day protocol the activity should be divided into one third for first injection, two third for second injection
(7) Model holds for iv and or administrations (page 259 ICRP 53)
(8) For rest
(9) For stress

* 53, 62, 80, 106, Ad4 refer to ICRP publication number (Ad4 = A fourth addendum to ICRP Publication 53, 2013, revised 2014). Erroneous values for ^{99m}Tc tetrofosmin at rest in ICRP 60 have been corrected in this addendum.

** iv = intravenous, or = oral

*** ICRP 53 uses the term effective dose equivalent and the dosimetry is based on different organ weight factors then later publications. For some radiopharmaceuticals, effective doses for adults were available in more recent publications than ICRP53, whereas doses for children still had to be taken from ICRP53 because they are lacking in more recent publications. In these cases, for completeness, we presented the adult doses from both sources, with the ICRP53 values printed in italics.

**** In general, it is recommended to use the latest version of the EANM paediatric dosage card (to be downloaded from www.eanm.org).

References other than ICRP publications:

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- Liepe, K., J. Kropp, R. Runge, and J. Kotzerke, Therapeutic efficiency of rhenium-188-HEDP in human prostate cancer skeletal metastases. Br J Cancer, 2003. 89(4): p. 625-9.
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- CIS bio international, Summary of product characteristics, 2007
- Kam et al: Eur J Nucl Med Mol Imaging. Feb 2012; 39 (Suppl 1): 103-12.

Table 2. Radiation dose in patients with abnormal biological behaviour

Radiopharmaceutical	Route of administration*	P**	Effective dose*** (mSv/MBq)					
			1 yr	5 yr	10 yr	15 yr	Adult	
[^{14}C] urea	or	80					0,031	
							0,081	
Sodium [^{123}I] iodide	or/iv	62					0,22	
		53	1,4	0,74	0,35	0,23	0,15	
		62					0,011	
		53	0,067	0,037	0,024	0,016	0,013	
[^{99m}Tc] Tiatide (MAG3)	iv	80	0,022	0,012	0,012	0,009	0,007	
			0,0064	0,0064	0,0045	0,0031	0,0025	
			0,0068	0,0039	0,0029	0,0021	0,0017	
			0,019	0,011	0,010	0,0078	0,0061	
			0,038	0,022	0,017	0,012	0,010	
[^{99m}Tc] Pentetate (DTPA)	iv	80	0,016	0,009	0,0082	0,0062	0,0049	
		80	0,014	0,0077	0,0065	0,0048	0,0038	
		80	0,014	0,0079	0,0070	0,0053	0,0041	
		53	0,026	0,015	0,0097	0,0063	0,0053	
[^{123}I] Sodium iodohippurate (IOH)	iv	80	0,034	0,019	0,019	0,015	0,012	
		80	0,019	0,011	0,0083	0,0059	0,0046	
		80	0,019	0,011	0,0099	0,0076	0,0059	
		53	0,067	0,037	0,024	0,016	0,013	
		53	0,27	0,16	0,11	0,075	0,062	
[^{125}I]-Iothalamate (IOT)	iv	62					0,0072	
		53	0,057	0,030	0019	0,012	0,0097	
		53	0,12	0,060	0,037	0,024	0,019	
[^{131}I]-Sodium-iodohippurate (IOH)	iv	80	0,16	0,083	0,086	0,067	0,052	
		80	0,089	0,047	0,036	0,026	0,02	
		80	0,090	0,047	0,045	0,034	0,026	
		53	0,36	0,19	0,12	0,08	0,065	
		53	6,8	3,8	2,6	1,8	1,5	
[^{131}I] sodium iodide	iv/or	62					24	
		53	140	78	36	24	15	
		62					0,061	
		53	0,40	0,21	0,14	0,088	0,072	
[^{99m}Tc] large colloids	iv	80	0,050	0,028	0,018	0,012	0,0094	
		53					0,014	
		53					0,017	

	Biological behaviour
	Normal patient
	Helicobacter positive patient
	35% thyroid uptake
	0% thyroid uptake
	Normal miction
	Bladder emptied 1 hour after administration
	Bladder emptied 0,5 hour after administration
	Abnormal renal function
	Unilateral renal blockage
	Normal miction
	Bladder emptied 1 hour after administration
	Bladder emptied 0,5 hour after administration
	Abnormal renal function
	Normal miction
	Bladder emptied 1 hour after administration:
	Bladder emptied 0,5 hour after administration:
	Abnormal renal function
	Unilateral renal blockage
	Normal function
	Impaired renal function
	Normal miction
	Bladder emptied 1 hour after administration
	Bladder emptied 0,5 hour after administration
	Abnormal renal function
	Unilateral renal blockage
	35% thyroid uptake
	0% thyroid uptake
	Normal patient
	Early to intermediate diffuse parenchymal liver disease
	Intermediate to advanced parenchymal liver disease

* ICRP publication number

** iv = intravenous, or = oral

*** ICRP 53 uses the term "effective dose equivalent" and the dosimetry is based on different organ weight factors and different phantoms as compared to later publications. For some radiopharmaceuticals, both the effective dose equivalent values (from ICRP53) and the effective dose values (from later publications) are presented in the table. This was done when non-adult dose values are available from ICRP53, and not from newer publications. In those cases, the effective dose equivalents are written in italic, smaller font.

TABLE 3.7. Absorbed dose estimates to the embryo/fetus per unit activity of radiopharmaceutical administered to the mother (shading indicates maternal and fetal self dose contributions).

Radiopharmaceutical	Early mGy/MBq[a]	3 Month mGy/MBq	6 Month mGy/MBq	9 Month mGy/MBq
^{57}Co vitamin B-1, normal-flushing	$1,0 \times 10^{0}$	$6,8 \times 10^{-1}$	$8,4 \times 10^{-1}$	$8,8 \times 10^{-1}$
^{57}Co vitamin B-12, normal-no flushing	$1,5 \times 10^{0}$	$1,0 \times 10^{0}$	$1,2 \times 10^{0}$	$1,3 \times 10^{0}$
^{57}Co vitamin B-12, PA-flushing	$2,1 \times 10^{-1}$	$1,7 \times 10^{-1}$	$1,7 \times 10^{-1}$	$1,5 \times 10^{-1}$
^{57}Co vitamin B-12, PA-no flushing	$2,8 \times 10^{-1}$	$2,1 \times 10^{-1}$	$2,2 \times 10^{-1}$	$2,0 \times 10^{-1}$
^{58}Co vitamin B-12, normal-flushing	$2,5 \times 10^{0}$	$1,9 \times 10^{0}$	$2,1 \times 10^{0}$	$2,1 \times 10^{0}$
^{58}Co vitamin B-12, normal-no flushing	$3,7 \times 10^{0}$	$2,8 \times 10^{0}$	$3,1 \times 10^{0}$	$3,1 \times 10^{0}$
^{58}Co vitamin B-12, PA-flushing	$8,3 \times 10^{-1}$	$7,4 \times 10^{-1}$	$6,4 \times 10^{-1}$	$4,8 \times 10^{-1}$
^{58}Co vitamin B-12, PA-no flushing	$9,8 \times 10^{-1}$	$8,5 \times 10^{-1}$	$7,6 \times 10^{-1}$	$6,0 \times 10^{-1}$
^{60}Co vitamin B-12, normal-flushing	$3,7 \times 10^{1}$	$2,8 \times 10^{1}$	$3,1 \times 10^{1}$	$3,2 \times 10^{1}$
^{60}Co vitamin B-12, normal-no flushing	$5,5 \times 10^{1}$	$4,2 \times 10^{1}$	$4,7 \times 10^{1}$	$4,7 \times 10^{1}$
^{60}Co vitamin B-12, PA-flushing	$5,9 \times 10^{0}$	$4,7 \times 10^{0}$	$4,8 \times 10^{0}$	$4,5 \times 10^{0}$
^{60}Co vitamin B-12, PA-no flushing	$8,3 \times 10^{0}$	$6,5 \times 10^{0}$	$6,8 \times 10^{0}$	$6,5 \times 10^{0}$
^{18}F FDG[b]	$2,2 \times 10^{-2}$	$2,2 \times 10^{-2}$	$1,7 \times 10^{-2}$	$1,7 \times 10^{-2}$
^{18}F sodium fluoride	$2,2 \times 10^{-2}$	$1,7 \times 10^{-2}$	$7,5 \times 10^{-3}$	$6,8 \times 10^{-3}$
^{67}Ga citrate	$9,3 \times 10^{-2}$	$2,0 \times 10^{-1}$	$1,8 \times 10^{-1}$	$1,3 \times 10^{-1}$
^{123}I hippuran	$3,1 \times 10^{-2}$	$2,4 \times 10^{-2}$	$8,4 \times 10^{-3}$	$7,9 \times 10^{-3}$
^{123}I IMP	$1,9 \times 10^{-2}$	$1,1 \times 10^{-2}$	$7,1 \times 10^{-3}$	$5,9 \times 10^{-3}$
^{123}I MIBG	$1,8 \times 10^{-2}$	$1,2 \times 10^{-2}$	$6,8 \times 10^{-3}$	$6,2 \times 10^{-3}$
^{123}I sodium iodide	$2,0 \times 10^{-2}$	$1,4 \times 10^{-2}$	$1,1 \times 10^{-1}$	$9,8 \times 10^{-3}$
^{124}I sodium iodide	$1,4 \times 10^{-1}$	$1,0 \times 10^{-1}$	$5,9 \times 10^{-2}$	$4,6 \times 10^{-2}$
^{125}I HSA	$2,5 \times 10^{-1}$	$7,8 \times 10^{-2}$	$3,8 \times 10^{-2}$	$2,6 \times 10^{-2}$
^{125}I IMP	$3,2 \times 10^{-2}$	$1,3 \times 10^{-2}$	$4,8 \times 10^{-3}$	$3,6 \times 10^{-3}$
^{125}I MIBG	$2,6 \times 10^{-2}$	$1,1 \times 10^{-2}$	$4,1 \times 10^{-3}$	$3,4 \times 10^{-3}$
^{125}I sodium iodide	$1,8 \times 10^{-2}$	$9,5 \times 10^{-3}$	$3,5 \times 10^{-3}$	$2,3 \times 10^{-3}$
^{126}I sodium iodide	$7,8 \times 10^{-2}$	$5,1 \times 10^{-2}$	$3,2 \times 10^{-2}$	$2,6 \times 10^{-2}$
^{130}I sodium iodide	$1,8 \times 10^{-1}$	$1,3 \times 10^{-1}$	$7,6 \times 10^{-2}$	$5,7 \times 10^{-2}$
^{131}I hippuran	$6,4 \times 10^{-2}$	$5,0 \times 10^{-2}$	$1,9 \times 10^{-2}$	$1,8 \times 10^{-2}$
^{131}I HSA	$5,2 \times 10^{-1}$	$1,8 \times 10^{-1}$	$1,6 \times 10^{-1}$	$1,3 \times 10^{-1}$
^{131}I MAA	$6,7 \times 10^{-2}$	$4,2 \times 10^{-2}$	$4,0 \times 10^{-2}$	$4,2 \times 10^{-2}$
^{131}I MIBG	$1,1 \times 10^{-1}$	$5,4 \times 10^{-2}$	$3,8 \times 10^{-2}$	$3,5 \times 10^{-2}$
^{131}I sodium iodide	$7,2 \times 10^{-2}$	$6,8 \times 10^{-2}$	$2,3 \times 10^{-1}$	$2,7 \times 10^{-1}$
^{131}I rose bengal	$2,2 \times 10^{-1}$	$2,2 \times 10^{-1}$	$1,6 \times 10^{-1}$	$9,0 \times 10^{-2}$
^{111}In DTPA	$6,5 \times 10^{-2}$	$4,8 \times 10^{-2}$	$2,0 \times 10^{-2}$	$1,8 \times 10^{-2}$
^{111}In pentetreotide	$8,2 \times 10^{-2}$	$6,0 \times 10^{-2}$	$3,5 \times 10^{-2}$	$3,1 \times 10^{-2}$
^{111}In platelets	$1,7 \times 10^{-1}$	$1,1 \times 10^{-1}$	$9,9 \times 10^{-2}$	$8,9 \times 10^{-2}$
^{111}In red blood cells	$2,2 \times 10^{-1}$	$1,3 \times 10^{-1}$	$1,1 \times 10^{-1}$	$8,6 \times 10^{-2}$
^{111}In white blood cells	$1,3 \times 10^{-1}$	$9,6 \times 10^{-2}$	$9,6 \times 10^{-2}$	$9,4 \times 10^{-2}$
^{99m}Tc albumin microspheres	$4,1 \times 10^{-3}$	$3,0 \times 10^{-3}$	$2,5 \times 10^{-3}$	$2,1 \times 10^{-3}$
^{99m}Tc disofenin	$1,7 \times 10^{-2}$	$1,5 \times 10^{-2}$	$1,2 \times 10^{-2}$	$6,7 \times 10^{-3}$
^{99m}Tc DMSA	$5,1 \times 10^{-3}$	$4,7 \times 10^{-3}$	$4,0 \times 10^{-3}$	$3,4 \times 10^{-3}$
^{99m}Tc DTPA	$1,2 \times 10^{-2}$	$8,7 \times 10^{-3}$	$4,1 \times 10^{-3}$	$4,7 \times 10^{-3}$

TABLE 3.7. (Continued)

Radiopharmaceutical	Early mGy/MBq[a]	3 Month mGy/MBq	6 Month mGy/MBq	9 Month mGy/MBq
^{99m}Tc DTPA aerosol	$5,8 \times 10^{-3}$	$4,3 \times 10^{-3}$	$2,3 \times 10^{-3}$	$3,0 \times 10^{-3}$
^{99m}Tc glucoheptonate	$1,2 \times 10^{-2}$	$1,1 \times 10^{-2}$	$5,3 \times 10^{-3}$	$4,6 \times 10^{-3}$
^{99m}Tc HDP	$5,2 \times 10^{-3}$	$5,4 \times 10^{-3}$	$3,0 \times 10^{-3}$	$2,5 \times 10^{-3}$
^{99m}Tc HEDP	$7,2 \times 10^{-3}$	$5,2 \times 10^{-3}$	$2,7 \times 10^{-3}$	$2,4 \times 10^{-3}$
^{99m}Tc HMPAO	$8,7 \times 10^{-3}$	$6,7 \times 10^{-3}$	$4,8 \times 10^{-3}$	$3,6 \times 10^{-3}$
^{99m}Tc human serum albumin	$5,1 \times 10^{-3}$	$3,0 \times 10^{-3}$	$2,6 \times 10^{-3}$	$2,2 \times 10^{-3}$
^{99m}Tc MAA	$2,8 \times 10^{-3}$	$4,0 \times 10^{-3}$	$5,0 \times 10^{-3}$	$4,0 \times 10^{-3}$
^{99m}Tc MAG3	$1,8 \times 10^{-2}$	$1,4 \times 10^{-2}$	$5,5 \times 10^{-3}$	$5,2 \times 10^{-3}$
^{99m}Tc MDP	$6,1 \times 10^{-3}$	$5,4 \times 10^{-3}$	$2,7 \times 10^{-3}$	$2,4 \times 10^{-3}$
^{99m}Tc MIBI-rest	$1,5 \times 10^{-2}$	$1,2 \times 10^{-2}$	$8,4 \times 10^{-3}$	$5,4 \times 10^{-3}$
^{99m}Tc MIBI-stress	$1,2 \times 10^{-2}$	$9,5 \times 10^{-3}$	$6,9 \times 10^{-3}$	$4,4 \times 10^{-3}$
^{99m}Tc pertechnetate	$1,1 \times 10^{-2}$	$2,2 \times 10^{-2}$	$1,4 \times 10^{-2}$	$9,3 \times 10^{-3}$
^{99m}Tc PYP	$6,0 \times 10^{-3}$	$6,6 \times 10^{-3}$	$3,6 \times 10^{-3}$	$2,9 \times 10^{-3}$
^{99m}Tc RBC-heat treated	$1,7 \times 10^{-3}$	$1,6 \times 10^{-3}$	$2,1 \times 10^{-3}$	$2,2 \times 10^{-3}$
^{99m}Tc RBC-in vitro	$6,8 \times 10^{-3}$	$4,7 \times 10^{-3}$	$3,4 \times 10^{-3}$	$2,8 \times 10^{-3}$
^{99m}Tc RBC-in vivo	$6,4 \times 10^{-3}$	$4,3 \times 10^{-3}$	$3,3 \times 10^{-3}$	$2,7 \times 10^{-3}$
^{99m}Tc sulfur colloid-normal	$1,8 \times 10^{-3}$	$2,1 \times 10^{-3}$	$3,2 \times 10^{-3}$	$3,7 \times 10^{-3}$
^{99m}Tc sulfur colloid-liver disease	$3,2 \times 10^{-3}$	$2,5 \times 10^{-3}$	$2,8 \times 10^{-3}$	$2,8 \times 10^{-3}$
^{99m}Tc teboroxime	$8,9 \times 10^{-3}$	$7,1 \times 10^{-3}$	$5,8 \times 10^{-3}$	$3,7 \times 10^{-3}$
^{99m}Tc white blood cells	$3,8 \times 10^{-3}$	$2,8 \times 10^{-3}$	$2,9 \times 10^{-3}$	$2,8 \times 10^{-3}$
^{201}Tl chloride	$9,7 \times 10^{-2}$	$5,8 \times 10^{-2}$	$4,7 \times 10^{-2}$	$2,7 \times 10^{-2}$
^{127}Xe, 5 min rebreathing, 5 liter spirometer volume	$4,3 \times 10^{-4}$	$2,4 \times 10^{-4}$	$1,9 \times 10^{-4}$	$1,5 \times 10^{-4}$
^{127}Xe, 5 min rebreathing, 7,5 liter spirometer volume	$2,3 \times 10^{-4}$	$1,3 \times 10^{-4}$	$1,0 \times 10^{-4}$	$8,4 \times 10^{-5}$
^{127}Xe, 5 min rebreathing, 10 liter spirometer volume	$2,3 \times 10^{-4}$	$1,4 \times 10^{-4}$	$1,1 \times 10^{-4}$	$9,2 \times 10^{-5}$
^{133}Xe, 5 min rebreathing, 5 liter spirometer volume	$4,1 \times 10^{-4}$	$4,8 \times 10^{-5}$	$3,5 \times 10^{-5}$	$2,6 \times 10^{-5}$
^{133}Xe, 5 min rebreathing, 7,5 liter spirometer volume	$2,2 \times 10^{-4}$	$2,6 \times 10^{-5}$	$1,9 \times 10^{-5}$	$1,5 \times 10^{-5}$
^{133}Xe, 5 min rebreathing, 10 liter spirometer volume	$2,5 \times 10^{-4}$	$2,9 \times 10^{-5}$	$2,1 \times 10^{-5}$	$1,6 \times 10^{-5}$
^{133}Xe, injection	$4,9 \times 10^{-6}$	$1,0 \times 10^{-6}$	$1,4 \times 10^{-6}$	$1,6 \times 10^{-6}$

Source: Adapted with permission from Russell JR, Stabin MG, Sparks RB, Watson EE. Radiation absorbed dose to the embryo/fetus from radiopharmaceuticals. Health Phys, 73:756-769. 1997.

[a] mGy/MBq x 3,7 = rad/mCi.

[b] Stabin M. Proposed addendum to previously published fetal dose estimate tables for 18F-FDG. J Nucl Med, 45:634-635, 2004.

TABEL 3.8. Dose to the fetal thyroid (doses are mGy to the fetal thyroid per MBq administered to the mother).

Gestational age (months)	^{123}I	^{124}I	^{125}I	^{131}I
3	2,7	24	290	230
4	2,6	27	240	260
5	6,4	76	280	580
6	6,4	100	210	550
7	4,1	96	160	390
8	4,0	110	150	350
9	2,9	99	120	270

Source: Adapted with permission of ORAU from Watson EE, Radiation absorbed dose to the human fetal thyroid. In: Fifth International Radio-pharmaceutical Dosimetry Symposium. Watson EE, Schlafke-Stelson. eds, Oak Ridge Associated Universities, Oak Ridge, TN, 1992, pp. 179-187.

ANNEX D. RECOMMENDATIONS ON BREAST-FEEDING INTERRUPTIONS

D.1. Introduction

(D1) Since many radiopharmaceuticals are secreted in breast milk, it is safest to assume that, unless there are data to the contrary, some radioactive compound will be found in the breast milk when a radiopharmaceutical is administered to a lactating female. Consideration should be given to postponing the procedure. If the procedure is performed, the child should not be breast fed until the radiopharmaceutical is no longer secreted in an amount estimated to give an effective dose >1 mSv to the child. It is therefore recommended that the following actions should be taken for various radiopharmaceuticals, and that the milk expressed during this interruption period should be discarded.

Radiopharmaceutical	Interruption
^{14}C-labelled	
Triolein	No
Glycocholic acid	No
Urea	No
^{99m}Tc-labelled	
DISDA	No [*,†]
DMSA	No [*,†]
DTPA	No [*,†]
ECD	No [*,†]
Phosphonates (MDP)	No [*,†]
Gluconate	No [*,†]
Glucoheptonate	No [*,†]
HM-PAO	No [*,†]
Sulphur colloids	No [*,†]
MAA	12 h
MAG3	No [*,†]
MIBI	No [*,†]
Microspheres (HAM)	12 h
Pertechnetate	12 h
PYP	No [*,†]
RBC (in vivo)	12 h
RBC (in vitro)	No [*,†]
Technegas	No [*,†]
Tetrofosmin	No [*,†]
WBC	12 h

Radiopharmaceutical	Interruption
I-labelled	
^{123}I-BMIPP	>3 weeks[‡,§]
^{123}I-HSA	>3 weeks[‡,§]
^{123}I-iodo hippurate	12 h
^{123}I-IPPA	>3 weeks[‡,§]
^{123}I-MIBG	>3 weeks[‡,§]
^{123}I-NaI	>3 weeks[‡,§]
^{125}I-HSA	>3 weeks[‡,§]
^{125}I-iodo hippurate	12 h
^{131}I-iodo hippurate	12 h
^{131}I-MIBG	>3 weeks[‡]
^{131}I-NaI	>3 weeks[‡]
Others	
^{11}C-labelled	No[¶]
^{13}N-labelled	No[¶]
^{15}O-labelled	No[¶]
^{18}F-FDG	No
^{22}Na	>3 weeks[‡]
^{51}Cr-EDTA	No
^{67}Ga-citrate	>3 weeks[‡]
^{75}Se-labelled agents	>3 weeks[‡]
^{81m}Kr-gas	No
^{111}In-octreotide	No
^{111}In-WBC	No
^{133}Xe	No
^{201}Tl-chloride	48 h

[*] 'No', interruption not essential

[†] 'No' for most of the ^{99m}Tc-labelled compounds, under the circumstances that no free

[‡] 3 weeks (504 h) at least. However, difficult to maintain the milk supply → cessation.

[§] ^{123}I, all substances labelled with ^{123}I (except iodo-hippurate): >3 weeks due to the risk of

[¶] ^{11}C, ^{13}N and ^{15}O-labelled substances, interruption not essential due to short physical half-life.

D.2. References and further reading for Annex D

Ahlgren, L., Ivarsson, S., Johansson, L., Mattsson, S., Nosslin, B., 1985. Excretion of radionuclides in human breast milk after the administration of radiopharmaceuticals. J. Nucl. Med. 26, 1085-1090.

Castronovo, Jr., F.P., Stone, H., Ulanski, J., 2000. Radioactivity in breast milk following ^{111}In-octreotide. Nucl. Med. Commun. 21, 695-699.