Dose Estimates for Nuclear Medicine Scans

This document contains radiation dose estimates for a number of radiopharmaceuticals commonly used in nuclear medicine. This resource provides effective dose and organ doses for adults, and in some cases children, and can be used to estimate the radiation dosimetry information required for JRSC or RDRC approval for use of radiopharmaceuticals in research involving human subjects.

PET/CT Doses

For PET/CT it is important that the investigator include effective dose and organ dose estimates for both the radiopharmaceutical and the CT component of the examination. Effective dose for the radiopharmaceutical is provided by selecting the appropriate radiopharmaceutical from the tables provided later in this document. Organ and effective dose estimates for the CT component of PET are given below. These estimates are based on typical scenarios of common use clinically. ***In unusual circumstances these dose estimates may not be appropriate. It is the principal investigator's responsibility to provide reasonable estimates of all radiation doses a patient may incur.***

Estimate of CT Component of PET/CT at CUMC

Combined PET/CT - CT dose is approximately 20% less than the standard clinical CT dose. In some instances physicians may use a standard CT in addition to this combined PET/CT or adjust the CT dose to improve image quality.

Scan type	CTDIvol (mGy)	DLP (mGy-cm)	Effective dose (mrem)
Male Whole Body	11.2	1285	1175
Female Whole Body	11.2	1225	1255
Brain	64.37	1526	
Babies (3 scan increments)	3.89	218	
Pediatrics (4 scan increments)	5.33	351	

PET with only attenuation CT - This technique considerably reduces dose by lowering mAs by generating an attenuation map from poorer quality CTs which are not suitable for clinical diagnostic reading. This option is infrequently used at CU PET center.

Scan type	CTDIvol (mGy)	DLP (mGy-cm)	Effective dose (mrem)

Male Whole Body	3.7	428	392
Female Whole Body	3.7	408	418
Brain	64.37	1526	
Babies (3 scan increments)	3.89	218	
Pediatrics (4 scan increments)	5.33	351	

Whole body PET/CT Organ Doses

			CT Examination Type	
	Female	**Male**	**Female Attenuation**	**Male Attenuation**
Organ	*Organ Dose (mrad)*	*Organ Dose (mrad)*	*Organ Dose (mrad)*	*Organ Dose (mrad)*
Gonads	1205	1409	402	470
Bone Marrow	1014	908	338	303
Colon	1172	1063	391	354
Lung	1343	1276	448	425
Stomach	1234	1163	411	388
Bladder	1419	1339	473	446
Breast	1070	0	356	0
Liver	1169	1128	390	376
Oesophagus	1268	1229	423	410
Thyroid	2045	2024	682	675
Skin	938	876	313	292
Bone Surface	2211	1932	737	644
Brain	1024	851	341	284
Adrenals	1261	1166	420	389
Small Intestine	1110	1031	370	344
Kidney	1293	1229	431	410
Pancreas	1227	1123	409	374
Spleen	1237	1126	412	375
Thymus	1529	1430	510	477
Uterus	1355	0	452	0
Eye lenses	1731	1396	577	465

Adult and Pediatric Dose Estimates from ICRP 106

The most up-to-date resource for radiation dosimetry of radiopharmaceuticals is ICRP 106, Annex C, which provides dose tables for adults, 1-, 5-, 10-, and 15- year olds for a number of radiopharmaceuticals. Please note that absorbed dose per unit activity administered is provided in mGy/MBq. The list below provides the dose table for each radiopharmaceutical found in this reference:

- [1-^{11}C]-acetate (p. 53)
- C-11 labeled amino acids (p. 59)
- C-11 labeled brain receptor substances (p. 65)
- L-[Methyl-C-11]-methionine (p. 69)
- Other C-11 labeled substances - realistic maximum dose (p. 72)
- O-15 H_2O (p. 75)
- F-18 labeled amino acids (p. 79)
- F-18 labeled brain receptor substances (p. 84)
- F-18 FDG (p. 87)
- F-18 L-DOPA (p. 91)
- Se-75 labeled amino acids (p. 96)
- Tc-99m apcitide (p. 98)
- Tc-99m ethylenedicysteine (EC) w/ normal renal function (p. 101)
- Tc-99m ethylenedicysteine (EC) w/ abnormal renal function (p. 102)
- Tc-99m ethylenedicysteine (EC) w/ acute unilateral renal blockage (p. 103)
- Tc-99m ECD (p. 107)
- Tc-99m furifosmin (Q12) - resting (p.112)
- Tc-99m furifosmin (Q12) - exercise (p.113)
- Tc-99m labeled monoclonal antibodies - intact antibody (p. 118)
- Tc-99m labeled monoclonal antibodies - F(ab')$_2$ fragments (p. 119)
- Tc-99m labeled monoclonal antibodies - F(ab') fragments (p. 120)

- Tc-99m labeled small colloids - intratumoral injection (p.122)
- Tc-99m tetrofosmin - resting (p. 125)
- Tc-99m tetrofosmin - resting (p. 126)
- In-111 labeled monoclonalantibodies - intact antibody (p. 129)
- In-111 labeled monoclonalantibodies - $F(ab')_2$ fragments (p. 130)
- In-111 labeled monoclonalantibodies - F(ab') fragments (p. 131)
- In-111 octreotide (p.135)
- In-111 labeled fatty acid (BMIPP) (p.141)
- In-111 labeled fatty acid (IPPA) (p.142)
- I-123 labeled brain receptor substances (p. 146)
- I-123 labeled monoclonal antibodies - intact antibody (p. 149)
- I-123 labeled monoclonal antibodies - $F(ab')_2$ fragments (p. 150)
- I-123 labeled monoclonal antibodies - F(ab') fragments (p. 151)
- I-131 labeled monoclonal antibodies - intact antibody (p. 155)
- I-131 labeled monoclonal antibodies - $F(ab')_2$ fragments (p. 156)
- I-131 labeled monoclonal antibodies - F(ab') fragments (p. 157)
- Tl-201 (p. 162)

ICRP Publication 106, Annex C Biokinetic models and dose tables. *Ann. ICRP* **38**(1-2):51-162, 2008.

Additional Adult Dose Estimates

These useful, credible and free estimates are maintained by the Radiation Internal Dose Information Center (RIDIC) and by CDE, Inc. Dosimetry Services.

Effective dose equivalent and organ doses to adults for the following radiopharmaceuticals are available:

H-3 Water
H-3 Inulin
C-11 Monoxide - 20 s breathhold
C-11 Monoxide - continuous inhalation (1 hr)
N-13 Ammonia
C-14 Inulin
O-15 O_2
F-18 Sodium Fluoride
Tc-99m Pyrophosphate
Tc-99m Red Blood Cells - In vitro Labeling
Tc-99m Red Blood Cells - In vivo Labeling
Tc-99m Sulfur Colloid (Normal Patients)
Tc-99m Sulfur Colloid (Intermediate-to-Advanced Diffuse Parenchymal Liver Disease)
Tc-99m Teboroxime
Tc-99m White Blood Cells
In-111 DTPA

Cr-51 Erythrocytes (RBCs)
Co-57 Vitamin B-12 (Cyanocobalamin)
Co-58 Vitamin B-12 (Cyanocobalamin)
Fe-59 Citrate
Co-60 Vitamin B-12 (Cyanocobalamin)
Ga-67 Citrate
Ga-68 Citrate
Se-75 Selenomethionine
Kr-81m Inhalation
Kr-81m Injections
Oral Administration of Kr-81m
Rb-82
Sr-85 Nitrate
Tc-99m Albumin Microspheres
Tc-99m Disofenin, Lidofenin and Mebrofenin
Tc-99m DMSA
Tc-99m DTPA (injection)
Tc-99m DTPA (aerosol)
Tc-99m Exametazime (HMPAO)
Tc-99m Glucoheptonate
Tc-99m HEDP
Tc-99m HMDP
Tc-99m HSA
Tc-99m MAA
Tc-99m MAG3
Tc-99m MDP
Tc-99m Sestamibi*
Tc-99m Oral Administrations
Tc-99m Pertechnetate
In-111 Platelets
In-111 Red Blood Cells
In-111 White Blood Cells
I-123 Hippuran
I-123 IMP
I-123 mIBG
I-123 Sodium Iodide
I-124 Sodium Iodide
I-125 Fibrinogen
I-125 IMP
I-125 mIBG
I-125 Sodium Iodide
I-126 Sodium Iodide
I-130 Sodium Iodide
I-131 Hippuran
I-131 HSA
I-131 MAA
I-131 mIBG
I-131 Rose Bengal
I-131 Sodium Iodide
Xe-127 (Breathhold)
Xe-127 (5 minute rebreathing)
Xe-127 (10 minute rebreathing)
Xe-133 (Breathhold)
Xe-133 (5 minute rebreathing)
Xe-133 (10 minute rebreathing)
Xe-133 Injections
Hg-197 Chlormerodrin
Au-198 Colloid

Additional Pediatric Dose Estimates

The links below again are free estimates maintained by the Radiation Internal Dose Information Center (RIDIC) and by CDE, Inc. Dosimetry Services. Effective dose equivalent and organ doses for newborn, 1-, 5-, 10-, and 15- year olds for a variety of nuclear medicine studies are provided.

- Ga-67 Citrate

- Kr-81m in Solution-Oral Administration
- Tc-99m DISIDA
- Tc-99m HEDP
- Tc-99m HMDP
- Tc-99m Pertechnetate
- Tc-99m PPi
- Tc-99m Labeled red blood cells (in-vivo labeling)
- Tc-99m Labeled heat denatured red blood cells
- Tc-99m Sulfur Colloid - Normal Patients
- Tc-99m Sulfur Colloid - Intermediate-to-Advanced Diffuse Parenchymal Liver Disease
- Tc-99m Sulfur Colloid - Oral Administration
- Tc-99m Labeled white blood cells
- In-111 Labeled red blood cells
- In 111 Labeled WBC's
- In-114m/In-114 Platelets
- In-114m/In-114 Labeled red blood cells
- In-114m/In-114 Labeled WBC's
- Xe-133 in Injections - for right heart studies

Age-dependent Committed Effective Dose Coefficients

ICRP Publication 72, states that doses can be estimated by applying age-specific dose coefficients to the age ranges as given in the table below:

Age-Specific Dose Coefficient	Age Range
3 months	from 0 to 1 year of age
1 year	from 1 year to 2 years
5 years	more than 2 years to 7 years
10 years	more than 7 years to 12 years
15 years	more than 12 years to 17 years
Adult	more than 17 y

The information above provides age-specific dose information for a variety of radiopharmaceuticals. For radionuclides not covered in the above material, the dose ratio relative to an adult can be calculated by using the tables provided in ICRP 72. Please consult the radiation safety office or a qualified medical physicist for further advise.

ICRP Publication 72. Age-dependent Doses to the Members of the Public from Intake of Radionuclides - Part 5 Compilation of Ingestion and Inhalation Coeffiicients. *Ann. ICRP* **26**(1):1-91, 1995.

Example Using F-18 FDG

As an example, consider a patient injected with 10 mCi of F-18 FDG in a single study. Assume that the patient will also receive an abdominal CT examination as a part of the study.

First, the radiation dosimetry for the radiopharmaceutical only is calculated.

Dose to Critical Organ

The first two rows in the **Radiation Dosimetry of Radiopharmaceutical** table below involve calculating the committed equivalent dose for potential critical organs. Organ doses can be obtained from the tables linked above, particularly ICRP 106. The critical organ is the organ most susceptible to radiation damage resulting from the specific exposure conditions under consideration, taking into account the dose the various parts of the body receive under the exposure conditions. In the case of two radiopharmaceuticals, determination of the critical organ can be more complex. To determine the critical organ, we ask that investigators consider the organ dose to what would be the critical organ from each radiopharmaceutical for ***both*** radiopharmaceuticals. If, for example, a study involved one radiopharmaceutical whose critical organ is the bladder and another whose critical organ is the spleen, we ask that investigators consider the dose to both the bladder and spleen for both radiopharmaceuticals in order to determine the critical organ. The organ that receives the highest dose from all radiopharmaceuticals combined is likely the critical organ. If there is uncertainty in determining the critical organ, please consult the radiation safety office or a qualified medical physicist for further advise.

- From ICRP 106 (see link above) for an adult receiving F-18 FDG the highest organ radiation dose (1.3×10^{-1} mGy/MBq) is to the bladder. The Critical Organ for this radionuclide is the bladder.
- 1 mGy = 100 mrad and 1 mCi = 37 MBq. So, (1.3×10^{-1} mGy/MBq) x (100 mrad/mGy) x (37 MBq/mCi) = 481 mrad/mCi. This is recorded in the next column (Radiation Absorbed Dose/Unit Activity).
- Clinically, the Activity per Administration is known. In this example it is 10 mCi.
- The Absorbed Dose per Administration is the product of 481 mrad/mCi x 10 mCi/administration = 4810 mrad.

- The Number of Administrations per Study is 1 in this example.
- The Committed Effective Dose would be the Radiation Absorbed Dose per Administration times the Number of Administrations per Study
- Since there is only one radiopharmaceutical, the row "Critical Organ Dose (for second radionuclide)" is not necessary. If there were a second radiopharmaceutical with a different critical organ, the dose to the bladder from this second radiopharmaceutical would be added to the calculation above, and the dose to the other potential critical organ would be estimated.
- The fifth column, all but the last row should be blank, and that last row should be the same as the box immediately to its left (i.e., the same as the whole body committed equivalent dose)

Whole Body Dose

- From ICRP 106 for an adult receiving F-18 FDG the effective dose is 1.9 x 10^{-2} mSv/MBq.
- 1 mSv = 100 mrem and 1 mCi = 37 MBq. So, (1.9 x 10^{-2} mSv/MBq) x (100 mrem/mSv) x (37 MBq/mCi) = 70.3 mrem/mCi. This is recorded in the next column (Radiation Absorbed Dose/Unit Activity).
- Clinically, the Activity per Administration is known. In this example it is 10 mCi.
- The Absorbed Dose per Administration is the product of 70.3 mrem/mSv x 10 mCi/administration = 703 mrem.
- The Number of Administrations per Study is 1 in this example.
- The Committed Effective Dose would be the Radiation Absorbed Dose per Administration times the Number of Administrations per Study
- The fifth column, all but the last row should be blank, and that last row should be the same as the box immediately to its left (i.e., the same as the whole body committed equivalent dose)

Radiation Dosimetry of Radiopharmaceutical (RDRC Form 5a, page 4)

	Critical Organ Name	Radiation Absorbed Dose/Unit Activity	Activity per Administration (mCi)	Radiation Absorbed Dose per Administration	Total No. of Administrations per Study/Year	Dose for Study	
						Committed Equivalent Dose from this Study (mrem)	Committed Effective Dose (mrem)
Critical Organ Dose (for first radionuclide)	bladder	481 (mrad/mCi)	10	4810 mrad	1	4810	
Critical Organ Dose	n/a	n/a	n/a	n/a (mrad)	n/a	n/a	

(for second radionuclide)		(mrad/mCi)					
Whole Body Dose		70.3 (mrem/mCi)	10	703 mrem	1		703 mrem

These results would then be copied into the **Summary Dose Table** (below). In the example, the patients in the study also receive an abdominal CT examination as a part of the study. The radiation dose from CT examination needs to be added to the radiopharmaceutical dose. A separate page provides information for CT dose estimates. Since the CT scanner is not specified, we would use the Average CT scanner dose information. For an abdominal CT the effective dose would be ~.5 rem (525 mrem)

Summary Dose Table (RDRC Form 5a, page 6)

	Critical Organ1	Total Critical Organ 1 Dose per Study (mrad)	Critical Organ2 (if necessary)	Total Critical Organ 2 Dose per Study (mrad) (if necessary)	Committed Equivalent Dose (rem)	Total Body Committed Effective Dose (rem)
Study: (specify) F-18 FDG	Bladder	4810	n/a	n/a	4.81	0.7
Study: (specify) abdominal CT	Bladder	negligible	n/a	n/a	negligible	0.5
Total from all studies	Bladder	4810	n/a	n/a	4.8	1.2
Total **annual** from all studies	Bladder	4810	n/a	n/a	4.8	1.2