Health Concerns Related to Radiation Exposure

of the Female Nuclear Medicine Patient

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Abbreviations:
ED: Effective Dose
EDE: Effective Dose Equivalent
ICRP: International Commission on Radiological Protection
RIDIC: Radiation Internal Dose Information Center
USNRC: United States Nuclear Regulatory Commission

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The figures cited in the text of this document are not included in the version that can be downloaded from the RIDIC web page.

ABSTRACT

The female nuclear medicine patient brings special concerns to the evaluation of radiation dose and risk in nuclear medicine. In general, her overall body size and organ sizes are smaller than those of her male counterpart (thus her radiation doses will be higher, given the same amounts of administered activity and similar biokinetics); her gonads are inside of her body instead of outside, and are located nearer to several organs often important as source organs in internal dosimetry (urinary bladder, liver, kidneys, intestines); her risk of breast cancer is significantly higher than that of her male counterpart; and in the case of pregnancy, exposure of the embryo/fetus and of the nursing infant bring special concerns to the analysis. In this study, all of these concerns are addressed through a comparative study of radiation doses for males and females over a large number (~60) of nuclear medicine studies, and through a study of what is known about radiation dosimetry in pregnancy and breast feeding. It was found that women's critical organ doses and effective doses (as defined in ICRP 60) are about 25% higher than for men, across all of these studies. Women's gonad doses, however, may be as much as factors of 10-30 higher than in men, although differences of a factor of 2-3 are common. Many radiopharmaceuticals are administered to women of childbearing age, however, very little is known about how much activity may cross the placenta, and the subsequent biokinetics in the fetus. Nonetheless, dose estimates are provided at four stages of pregnancy (early, 3 months', 6 months' and 9 months' gestation) for a large number of radiopharmaceuticals, whether or not quantitative estimates of placental crossover can be made. Many radiopharmaceuticals are also excreted in the breast milk of nursing mothers; through an analysis of the observed kinetics of these pharmaceuticals and an assumed dose limit of 1 mSv (effective dose equivalent) to the infant, breast feeding interruption schedules are suggested.

INTRODUCTION

The risk/benefit analysis for patients in nuclear medicine necessarily employs calculated estimates of the radiation dose (absorbed dose, dose equivalent, effective dose, etc.) for the exposed person. The analysis is somewhat different than in other situations, as the person receiving the radiation dose usually is also the one who directly receives the benefit of the exposure. However, the female nuclear medicine patient brings special concerns to the evaluation of radiation dose and risk in nuclear medicine. In general, her overall body size and organ sizes are smaller than that of her male counterpart (thus her radiation doses will be higher, given the same amounts of administered activity and similar biokinetics); her gonads are inside of her body instead of outside, and are located nearer to several organs often important as source organs in internal dosimetry (urinary bladder, liver, kidneys, intestines); her risk of breast cancer is significantly higher than that of her male counterpart; and in the case of pregnancy, exposure of the embryo/fetus and of the nursing infant bring special concerns to the analysis. In this study, analysis of the difference in organ doses, effective doses (as defined in ICRP 60 (*1*)), and gonad doses between the male and female nuclear medicine patient is provided. Radiation dose estimates for many nuclear medicine procedures, involving a wide variety of radionuclides and pharmaceuticals (even some which are no longer in common use, in order to broaden the spectrum of observed results), were developed for the standard adult male (70 kg) and female (57 kg), and differences in organ, gonad, and effective doses were studied. Results from some previous studies on radiation dosimetry in pregnancy and lactation were included to provide a more complete discussion of women's health concerns in nuclear medicine.

This work provides only estimates of radiation dose for the adult female from nuclear medicine procedures. The information contained here may be employed in performing an analysis of the risks that women might incur from these procedures and how these risks might be different from those incurred by men; such an analysis is outside the scope of this work. Additional information needed to complete such an analysis would include the amount of activity administered per study, the number of studies performed per year, and an estimate of the risk incurred per unit of dose received. This information changes frequently, and should be obtained at the time that any risk/benefit analysis is performed; thus no attempt was made to include it in this work.

METHODS

A wide variety of nuclear medicine studies (~60) were chosen for the comparative study of the organ, gonad, and effective doses between men and women. Standard biokinetic models were taken from ICRP Publication 53 (*2*), or, in some cases, from internal files at the Radiation Internal Dose Information Center (RIDIC) in Oak Ridge, TN (this Center is funded to maintain an up-to-date knowledge of the kinetics and dosimetry of radiopharmaceuticals, and, in addition to being aware of material in the open literature, often has access to information on biokinetics or dosimetry of these agents due to its support role to the nuclear medicine community). From the standard biokinetic models, estimates of the residence times (*3*) for all significant source organs were established, and entered into the MIRDOSE 3.1 software (*4*), employing the standard adult male (70 kg) and adult female (57 kg) phantoms (*5,6*). Radiation doses per unit administered activity to the critical organ (single organ receiving the highest radiation dose), the gonads, and the breast were noted and compared. In these phantoms, the "breast" tissue represents the female

breast tissue; in this case no comparisons were made with the dose to the male breast tissue, as the latter is not easily evaluated. Only the female breast dose was thus calculated, and simply tabulated for information. Effective doses for males and females were also reported and compared.

Results from two recent studies recently performed by RIDIC were also included in this study - one on radiation dosimetry for the embryo/fetus for the pregnant nuclear medicine patient, and one on the dose to the nursing infant for the breast-feeding mother who receives a radiopharmaceutical. Extensive detail on the methods in these two studies are published elsewhere (*7,8*), but a brief summary will be provided here. For the embryo/fetal doses, first, an informal survey of a number of nuclear medicine institutions was performed to determine what radiopharmaceuticals are commonly administered to women of childbearing age, as well as what procedures may be in place to prevent the inadvertent administration of radiopharmaceuticals to pregnant women. Then, the literature was studied to find as many sources of information about the placental crossover of radiopharmaceuticals as possible. Much of the available information came from animal studies. In any case, where possible, a model of the placental crossover of different radiopharmaceuticals as a function of gestation was developed. Then, residence times for the activity in the maternal organs (as used in the comparative studies of organ and gonad doses, above) were combined with estimated residence times for the placenta and fetus, and used with the four phantoms in the MIRDOSE 3.1 software, representing the adult female in early pregnancy, and at 3 months', 6 months' and 9 months' gestation (*4,6*). There are many

radiopharmaceuticals which may be administered to women of childbearing age for which no information could be found in the literature regarding placental crossover. In these cases, radiation dose estimates to the fetus were developed using only an estimate of the residence times in the mother's organs. It was not thought prudent to just assume values of placental crossover (e.g. 0.5%, 1%, 5%) with no literature support. These radiation doses are thus acknowledged to possibly underestimate the fetal doses in cases in which significant placental crossover occurs, but at present they represent the best estimates of fetal dose available. The dose to the embryo/fetus is thus reported for many radiopharmaceuticals at these four assumed stages of pregnancy. In the study on breast-feeding, literature-reported values of the excretion of many radiopharmaceuticals in the breast milk of nursing mothers who received nuclear medicine studies were used in a standard model for nursing which assumed that the infant consumed 1000 ml/day of milk, feeding at 3 hr intervals, starting either immediately (3 hr) after the administration of the pharmaceutical, or with fixed interruption times (6 hr, 12 hr, 24 hr, etc.). From this analysis, an estimate of the activity ingested by the infant was obtained; the activity ingested was assumed to quickly and instantaneously be taken up into the bloodstream, and thereafter to have biokinetics in the infant similar to that in the adult. Organ residence times were thus assigned, and organ doses and effective dose equivalents (as defined in ICRP Publication 30 (*9*)) were calculated. The effective dose equivalent (*9*), instead of the effective dose (*1*), was used in this study, because the study was commissioned by the United States Nuclear Regulatory Commission (USNRC), which still uses the effective dose equivalent as its regulatory basis (the numerical difference between the effective dose equivalent and the effective dose in nuclear medicine doses is usually very small (*10*)). The USNRC assigned an acceptable dose level of 1 mSv effective dose equivalent to the

infant. If the worst case dose to the infant did not exceed this amount, no interruption of breast feeding was indicated; otherwise the time period for which breast feeding needed to be stopped to ensure a dose below this level was calculated.

RESULTS

Table 1 shows the actual critical organ doses, gonad doses, and effective doses for the radiopharmaceuticals studied in this report. Table 2 shows the ratios of these quantities for the reference adult female/reference adult male. Table 3 shows the breast doses estimated for the adult female for the radiopharmaceuticals studied in this report. Figures 1-3 show plots of these results, in histogram format. Figure 4 shows a plot of the breast doses, also in histogram format. The x axes in Figures 1 and 3 are linear, and in Figures 2 and 4 are logarithmic.

Table 4 shows a summary of absorbed doses to the fetus from administration of radiopharmaceuticals to pregnant women, taken from (*7*). These doses are expressed as absorbed dose to the embryo/fetus per unit activity administered to the mother. Shaded rows in the table indicate that some information was available on the placental crossover, and was used in the estimates. Table 5 gives a summary of the recommendations for possible interruption of breast feeding in the nursing mother given a radiopharmaceutical, given the 1 mSv infant dose criterion. Further details on the dosimetry are given in (*8*).

DISCUSSION

As seen in Table 2, and in Figures 1 and 3, the ratio of the standard female's critical organ doses

and effective doses, over a wide range of studies, is about 1.25, with a relatively small standard deviation (less than 10%). This is reasonable, based simply on the ratio of body weights (57 kg vs. 70 kg), which represents about a 20% difference. Individual organ differences vary, but these differences basically represent the effect of the smaller mass. The gonad doses, however, have a mean ratio of about 3.5, with a very wide standard deviation. If a few of the highest gonad dose ratios are omitted (4 entries, with ratios >10), the mean and standard deviation are 2.6 and 1.67, respectively. Thus, it appears that the gonad dose ratio is typically a factor of 2-3, but that it can vary widely. Thus, the woman will carry a somewhat higher radiation burden than her male counterpart, given the same amount of activity administered per study. Now, if the activity given were scaled based on individual body mass, at least the critical organ and effective dose differences would be eliminated. This is not routine in nuclear medicine practice. The amount of activity administered is often scaled by body mass in pediatric studies, but in adults, generally the same amount of activity is given, based on a number of criteria, and so the differences reported here should generally be realized in practice. Breast doses (Table 3, Figure 4) vary widely between procedures, from a few Gy per MBq, to a few 10's of mGy per MBq.

Fetal doses, when expressed on the basis of dose to the fetus per unit activity given to the mother, for most radiopharmaceuticals tend to decrease throughout gestation. As the baby grows, the absorbed fractions for the fetus absorbing radiation from maternal organs will increase, but the baby's increase in mass generally offsets this increase (recall that absorbed dose is energy absorbed per unit mass). Exceptions to this occur for cases in which there is a considerable increase in the placental crossover of the radiopharmaceutical as pregnancy progresses, thus increasing fetal self-

dose. Some exceptions also occur for certain organs in the mother's body for which the specific absorbed fraction increases throughout gestation, notably the liver, lungs, and spleen (*6*). The doses shown in this report give only the average absorbed dose to the whole fetus; current models do not permit adequate modeling of the dose to individual organs within the fetus, although this may be quite important in many circumstances. Some authors (*11, 12*) have attempted on an individual basis to make such individual organ dose estimates. The most notable of these inquiries is that of Watson, who demonstrated clearly the importance of the dose to the fetal thyroid for iodine (especially I-131) administrations to the woman after the 10th week of gestation.

The dose estimate analysis for the nursing infant reveals that, for many radiopharmaceuticals, no interruption of breast feeding is indicated, even given the relatively low effective dose equivalent criterion of 1 mSv EDE and a use of the "worst case" literature reported values of breast milk concentration and elimination half-time. Many radiopharmaceuticals have short physical half-lives, and so decay away quickly after administration. Also, most of these nuclides, because of their short half-lives and their radiation spectrum, give a fairly low dose per unit intake. A few of the Tc-99m compounds, and one I-123 compound, required short interruption periods to not exceed the 1 mSv effective dose equivalent value. A difference was seen between in-vivo and in-vitro labeled Tc-99m red blood cells, as the former have a higher assumed fraction of free pertechnetate in the injectate - Tc-99m pertechnetate required a 24 hour interruption to satisfy the dose criterion. The most important compounds in the analysis were I-131 NaI, Ga-67 citrate, and Tl-201 chloride. Due to either their long physical or biological half-times, or their high radiation dose per unit intake values, or both, these compounds present the potential for relatively high

infant doses, and if these studies are to be employed, cessation of breast feeding is probably indicated.

In overview, it is clear that there are special concerns that the female nuclear medicine patient brings to the risk/benefit analysis. The most important concerns arise when the woman is either pregnant or breast-feeding, but the slightly higher organ and gonad radiation burden that she carries in general are also of interest. In the latter consideration, a logical extension of this work would be to apply the amount of activity administered per study and the number of nuclear medicine studies performed on men and women, for each type of study, and look at the population doses realized in routine nuclear medicine practice. Such information was not available at the time of this writing. But this study does provide the information that will be needed for this analysis should it be undertaken.

REFERENCES

1) International Commission on Radiological Protection. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60, Pergamon Press, New York, 1991.

2) International Commission on Radiological Protection. Radiation Dose to Patients from Radiopharmaceuticals. ICRP Publication 53, Pergamon Press, New York, 1988.

3) Loevinger R, Budinger T, Watson E: MIRD Primer for Absorbed Dose Calculations, Society of Nuclear Medicine, 1988.

4) Stabin M. MIRDOSE - the personal computer software for use in internal dose assessment in nuclear medicine. J Nucl Med, 37:538-546, (1996).

5) Cristy M, Eckerman K. Specific absorbed fractions of energy at various ages from internal photons sources. ORNL/TM-8381 V1-V7. Oak Ridge National Laboratory, Oak Ridge, TN, 1987.

6) Stabin M, Watson E, Cristy M, Ryman J, Eckerman K, Davis J,

Marshall D, Gehlen K. Mathematical models and specific absorbed fractions of photon energy in the nonpregnant adult female and at the end of each trimester of pregnancy. ORNL Report ORNL/TM-12907, 1995.

7) Russell JR, Stabin MG, Sparks RB, Watson EE. Radiation absorbed dose to the embryo/fetus from radiopharmaceuticals. Health Physics 73(5):756-769, 1997.

8) United States Nuclear Regulatory Commission. Regulatory Analysis on Criteria for the Release of Patients Administered Radioactive Material. NUREG-1492, USNRC, Office of Nuclear Regulatory Research, Washington, D.C., 1997.

9) International Commission on Radiological Protection. Limits for Intakes of Radionuclides by Workers. ICRP Publication 30, Pergamon Press, New York, 1979.

10) Toohey RE, Stabin MG. Effective dose and effective dose equivalent in nuclear medicine. In: Proceedings of the Sixth International Radiopharmaceutical Dosimetry Symposium. Oak Ridge, TN: Oak Ridge Associated Universities, 1999; 532-551.

11) Watson EE. Radiation Absorbed Dose to the Human Fetal Thyroid. In: Fifth International Radiopharmaceutical Dosimetry Symposium. Oak Ridge, Tennessee: Oak Ridge Associated Universities, 1992: 179-187.

12) Stabin MG, Stubbs JB, Russell JR. Review of the fetal radiation doses received from ^{59}Fe studies at Vanderbilt University in the 1940's. Health Phys 72(5):1-7, 1997.

List of Figures

Table 1. Critical Organ, Gonad, and Effective Doses for Females and Males for the Pharmaceuticals Studied in This Report

	CRITICAL ORGAN DOSES (mGy/MBq)		GONAD DOSES (mGy/MBq)			EFFECTIVE DOSES (mSv/MBq)	
Pharmaceutical	FEMALES	MALES	ORGAN	FEMALES	MALES	FEMALES	MALES
Au-198 colloid	12.9	10.6	spleen	0.12	0.042	1.16e+00	9.14e-01
C-11 Tryptophane	0.0267	0.0245	kidneys	0.004	0.0028	5.03e-03	4.32e-03
C-11 Iomazenil	0.127	0.099	UBC	0.00437	0.0022	1.39e-02	1.06e-02
Co-57 B-12, Nor/flsh	30	23	liver	1.1	0.46	2.90e+00	2.25e+00
Co-57 B-12, PA/flsh	3.8	3	liver	0.3	0.068	5.99e-01	4.90e-01
Co-58 B-12, Nor/flsh	44	35	liver	2.65	1	5.45e+00	4.35e+00
Co-58 B-12, PA/flsh	5.8	4.7	liver	1.53	0.22	1.59e+00	1.30e+00
Co-60 B-12, Nor/flsh	680	550	liver	37	16	8.01e+01	6.39e+01
Co-60 B-12, PA/flsh	88	71	liver	7.44	2.2	1.24e+01	1.00e+01
F-18 FDG	0.26	0.19	UBC	0.019	0.013	3.10e-02	2.41e-02
F-18 NaF	0.35	0.25	UBC	0.014	0.0078	3.10e-02	2.31e-02
Ga-67 Citrate	0.33	0.32	BS	0.1	0.055	1.20e-01	1.00e-01
Hg-197 Chlormerodrin	2.4	2.2	kidneys	0.0105	0.006	1.13e-01	9.66e-02
I-123 Hippuran	0.44	0.3	UBC	0.013	0.007	2.90e-02	2.01e-02
I-123 IMP	0.082	0.057	UBC	0.017	0.01	2.34e-02	1.82e-02
I-123 mIBG	0.14	0.094	UBC	0.012	0.0069	2.21e-02	1.66e-02
I-123 NaI	4.1	3.4	thyroid	0.015	0.0051	2.43e-01	2.00e-01
I-125 HSA	1.58	1.22	heart wall	0.249	0.167	2.91e-01	2.29e-01
I-125 mIBG	0.3	0.22	liver	0.02	0.013	4.86e-02	3.63e-02
I-125 NaI	250	210	thyroid	0.0145	0.0065	1.35e+01	1.13e+01
I-131 Hippuran	2.0	1.4	UBC	0.031	0.017	1.17e-01	8.58e-02
I-131 HSA	3.5	3	heart wall	0.52	0.35	9.35e-01	7.43e-01
I-131 MAA	2.9	2.3	lungs	0.0565	0.027	6.06e-01	4.72e-01
I-131 mIBG	1	0.78	liver	0.093	0.058	1.95e-01	1.49e-01
I-131 NaI	420	340	thyroid	0.06	0.028	2.24e+01	1.84e+01
I-131 Rose Bengal	9	8.4	LLI	0.5	0.037	1.33e+00	1.21e+00
In-111 DTPA	0.64	0.43	UBC	0.032	0.019	5.02e-02	3.56e-02

Table 1 (cont'd). Critical Organ, Gonad, and Effective Doses for Females and Males for the Pharmaceuticals Studied in This Report

	CRITICAL ORGAN DOSES (mGy/MBq)		GONAD DOSES (mGy/MBq)			EFFECTIVE DOSES (mSv/MBq)	
Pharmaceutical	FEMALES	MALES	ORGAN	FEMALES	MALES	FEMALES	MALES
In-111 Platelets	6.2	5.2	spleen	0.17	0.09	3.95e-01	3.26e-01
In-111 RBC's	0.91	0.76	spleen	0.23	0.14	2.24e-01	1.85e-01
In-111 WBC's	7.0	5.9	spleen	0.16	0.03	4.88e-01	4.09e-01
In-111 Pentetreotide	0.73	0.67	kidneys	0.06	0.026	1.03e-01	8.14e-02
Kr-81m	0.00025	0.0002	lungs	1.70e-07	1.00e-08	3.39e-05	2.65e-05
N-13 NH3	0.0091	0.0069	UBC	0.0022	0.0014	2.56e-03	2.01e-03
P-32 Na2PO4	10	10	BS	0.98	0.76	2.29e+00	1.80e+00
Tc-99m Albmn Mcrsph	0.074	0.058	lungs	0.003	0.0015	1.77e-02	1.45e-02
Tc-99m DISIDA	0.12	0.11	GB	0.024	0.0017	2.15e-02	1.78e-02
Tc-99m DMSA	0.21	0.19	kidneys	0.0045	0.0018	1.07e-02	9.12e-03
Tc-99m DTPA - iv	0.11	0.077	UBC	0.0068	0.0038	9.66e-03	7.09e-03
Tc-99m DTPA Aersl	0.046	0.032	UBC	0.0041	0.0017	7.50e-03	5.76e-03
Tc-99m glucoheptonate	0.11	0.074	UBC	0.0069	0.0037	1.00e-02	7.42e-03
Tc-99m HDP	0.051	0.052	BS	0.0052	0.0023	6.07e-03	4.80e-03
Tc-99m HEDP	0.058	0.041	UBC	0.0047	0.0026	6.55e-03	4.96e-03
Tc-99m HMPAO	0.058	0.051	GB	0.0051	0.0023	1.29e-02	1.09e-02
Tc-99m HSA	0.025	0.021	heart wall	0.0051	0.0029	7.54e-03	6.21e-03
Tc-99m MAA	0.085	0.067	lungs	0.0022	0.0011	1.54e-02	1.20e-02
Tc-99m MAG3	0.2	0.14	UBC	0.0085	0.0046	1.40e-02	9.99e-03
Tc-99m MDP	0.035	0.035	BS	0.0041	0.0023	6.19e-03	4.75e-03
Tc-99m MIBI/stress	0.047	0.04	ULI	0.014	0.0031	1.31e-02	1.07e-02
Tc-99m MIBI/rest	0.058	0.05	ULI	0.018	0.0035	1.63e-02	1.33e-02
Tc-99m Pertechnetate	0.034	0.036	UBC	0.01	0.0033	1.40e-02	1.14e-02
Tc-99m PYP	0.039	0.038	BS	0.0047	0.0026	6.31e-03	4.95e-03
Tc-99m RBC's/in vitro	0.03	0.021	UBC	0.0057	0.0033	7.83e-03	6.11e-03
Tc-99m RBC's/in vivo	0.019	0.016	heart wall	0.0058	0.0033	7.59e-03	5.99e-03
Tc-99m RBC's/heat	0.78	0.65	spleen	0.00208	0.00047	2.66e-02	2.24e-02

Table 1 (cont'd). Critical Organ, Gonad, and Effective Doses for Females and Males for the Pharmaceuticals Studied in This Report

	CRITICAL ORGAN DOSES (mGy/MBq)		GONAD DOSES (mGy/MBq)			EFFECTIVE DOSES (mSv/MBq)	
Pharmaceutical	FEMALES	MALES	ORGAN	FEMALES	MALES	FEMALES	MALES
Tc-99m Slfr Cld/Nrml	0.11	0.086	liver	0.0022	0.00022	1.03e-02	8.04e-03
Tc-99m Slfr Cld/Dis	0.26	0.22	spleen	0.004	0.00083	1.59e-02	1.32e-02
Tc-99m Slfr Cld/Oral	0.13	0.12	ULI	0.03	0.00125	2.88e-02	2.68e-02
Tc-99m Teboroxime	0.042	0.036	ULI	0.012	0.0019	1.23e-02	1.00e-02
Tc-99m WBC's	0.22	0.18	spleen	0.0048	0.00084	1.54e-02	1.29e-02
Tl-201 Chloride	0.66	0.62	thyroid	0.12	0.2	1.65e-01	2.74e-01
Xe-127, 5 min rebreath	0.00063	0.00049	lungs	0.00026	0.00016	2.92e-04	2.36e-04
Xe-133, 5 min rebreath	0.0014	0.0011	lungs	0.00025	0.00018	3.86e-04	3.04e-04

Abbrveviations: BS = Bone Surfaces, UBC = Urinary Bladder Contents, ULI = Upper Large Intestine, LLI = Lower Large Intestine, GB = Gallbladder

Table 2. Ratios of Critical Organ, Gonad, and Effective Doses for Females/Males for the Pharmaceuticals Studied in This Report.

Pharmaceutical	RATIOS CRITICAL ORGAN	GONAD	ED
Au-198 colloid	1.22	2.86	1.27
C-11 Tryptophane	1.09	1.43	1.16
C-11 Iomazenil	1.28	1.99	1.31
Co-57 B-12, Nor/flsh	1.30	2.39	1.29
Co-57 B-12, PA/flsh	1.27	4.41	1.22
Co-58 B-12, Nor/flsh	1.26	2.65	1.25
Co-58 B-12, PA/flsh	1.23	6.95	1.22
Co-60 B-12, Nor/flsh	1.24	2.31	1.25
Co-60 B-12, PA/flsh	1.24	3.38	1.24
F-18 FDG	1.37	1.46	1.29
F-18 NaF	1.40	1.79	1.34
Ga-67 Citrate	1.03	1.82	1.20
Hg-197 Chlormerodrin	1.09	1.75	1.17
I-123 Hippuran	1.47	1.86	1.44
I-123 IMP	1.44	1.70	1.29
I-123 mIBG	1.49	1.74	1.33
I-123 NaI	1.21	2.94	1.22
I-125 HSA	1.30	1.49	1.27
I-125 mIBG	1.36	1.54	1.34
I-125 NaI	1.19	2.23	1.19
I-131 Hippuran	1.43	1.82	1.36
I-131 HSA	1.17	1.49	1.26
I-131 MAA	1.26	2.09	1.28
I-131 mIBG	1.28	1.60	1.31
I-131 NaI	1.24	2.14	1.22
I-131 Rose Bengal	1.07	13.51	1.10
In-111 DTPA	1.49	1.68	1.41
In-111 Platelets	1.19	1.89	1.21
In-111 RBC's	1.20	1.64	1.21
In-111 WBC's	1.19	5.33	1.19
In-111 Pentetreotide	1.09	2.31	1.27
Kr-81m	1.25	17.00	1.28
N-13 NH3	1.32	1.57	1.27
P-32 Na2PO4	1.00	1.29	1.27
Tc-99m Albmn Mcrsph	1.28	2.00	1.22
Tc-99m DISIDA	1.09	14.12	1.21
Tc-99m DMSA	1.11	2.50	1.17
Tc-99m DTPA - iv	1.43	1.79	1.36
Tc-99m DTPA Aersl	1.44	2.41	1.30
Tc-99m glucoheptonate	1.49	1.86	1.35
Tc-99m HDP	0.98	2.26	1.26
Tc-99m HEDP	1.41	1.81	1.32
Tc-99m HMPAO	1.14	2.22	1.18
Tc-99m HSA	1.19	1.76	1.21
Tc-99m MAA	1.27	2.00	1.28
Tc-99m MAG3	1.43	1.85	1.40
Tc-99m MDP	1.00	1.78	1.30
Tc-99m MIBI/stress	1.18	4.52	1.22
Tc-99m MIBI/rest	1.16	5.14	1.23
Tc-99m Pertechnetate	0.94	3.03	1.23
Tc-99m PYP	1.03	1.81	1.27
Tc-99m RBC's/in vitro	1.43	1.73	1.28
Tc-99m RBC's/in vivo	1.19	1.76	1.27
Tc-99m RBC's/heat	1.20	4.43	1.19
Tc-99m Slfr Cld/Nrml	1.28	10.00	1.28
Tc-99m Slfr Cld/Dis	1.18	4.82	1.20
Tc-99m Slfr Cld/Oral	1.08	24.00	1.07
Tc-99m Teboroxime	1.17	6.32	1.23
Tc-99m WBC's	1.22	5.71	1.19
Tl-201 Chloride	1.06	0.60	0.60
Xe-127, 5 min rebreath	1.29	1.63	1.24
Xe-133, 5 min rebreath	1.27	1.39	1.27
Means:	1.23	3.54	1.25
Standard Deviations:	0.14	4.09	0.11

Table 3. Breast Doses Estimated for the Radiopharmaceuticals Studied in This Report.

Pharmaceutical	Breast Dose (mGy/MBq)	Pharmaceutical	Breast Dose (mGy/MBq)
Au-198 colloid	0.124	Kr-81m	4.60e-06
Co-57 B-12, Nor/flsh	0.986	N-13 NH3	0.00163
Co-57 B-12, PA/flsh	0.126	P-32 Na2PO4	0.98
Co-58 B-12, Nor/flsh	2.47	Tc-99m Albmn Mcrsph	0.00516
Co-58 B-12, PA/flsh	0.327	Tc-99m DMSA	0.00173
Co-60 B-12, Nor/flsh	39.7	Tc-99m DTPA - iv	0.00137
Co-60 B-12, PA/flsh	5.08	Tc-99m DTPA Aersl	0.00162
F-18 FDG	0.0117	Tc-99m glucoheptonate	0.00141
F-18 NaF	0.00337	Tc-99m HDP	0.00163
Ga-67 Citrate	0.0592	Tc-99m HEDP	0.00133
Hg-197 Chlormerodrin	0.00501	Tc-99m HMPAO	0.0023
I-123 Hippuran	0.000236	Tc-99m HSA	0.00457
I-123 IMP	0.011	Tc-99m MAA	0.00551
I-123 mIBG	0.00515	Tc-99m MAG3	0.000142
I-123 NaI	0.0039	Tc-99m MDP	0.00121
I-125 HSA	0.207	Tc-99m MIBI/stress	0.00212
I-125 mIBG	0.0156	Tc-99m Pertechnetate	0.00207
I-125 NaI	0.00889	Tc-99m PYP	0.00192
I-131 Hippuran	0.000935	Tc-99m RBC's/in vitro	0.00382
I-131 HSA	0.509	Tc-99m RBC's/in vivo	0.00414
I-131 MAA	0.0988	Tc-99m RBC's/heat	0.00185
I-131 mIBG	0.0665	Tc-99m Slfr Cld/Nrml	0.00268
I-131 NaI	0.0556	Tc-99m Slfr Cld/Dis	0.00236
I-131 Rose Bengal	0.00694	Tc-99m Slfr Cld/Oral	0.000491
In-111 DTPA	0.00447	Tc-99m Teboroxime	0.0026
In-111 Platelets	0.113	Tc-99m WBC's	0.00224
In-111 RBC's	0.137	Tl-201 Chloride	0.0407
In-111 WBC's	0.0802	Xe-127, 5 min rebreath	0.000182
In-111 Pentetreotide	0.0155	Xe-133, 5 min rebreath	0.00023

Table 4. Absorbed Dose Estimates to the Embryo/Fetus Per Unit Activity of Radiopharmaceutical Administered to the Mother (shading indicates maternal and fetal self dose contributions) (from (7)).

Radiopharmaceutical	Early mGy/MBq	3 Month mGy/MBq	6 Month mGy/MBq	9 Month mGy/MBq
Co-57 Vitamin B-1, Normal-Flushing	1.0E+00	6.8E-01	8.4E-01	8.8E-01
Co-57 Vitamin B-12, Normal-No Flushing	1.5E+00	1.0E+00	1.2E+00	1.3E+00
Co-57 Vitamin B-12, PA- Flushing	2.1E-01	1.7E-01	1.7E-01	1.5E-01
Co-57 Vitamin B-12, PA- No Flushing	2.8E-01	2.1E-01	2.2E-01	2.0E-01
Co-58 Vitamin B-12, Normal-Flushing	2.5E+00	1.9E+00	2.1E+00	2.1E+00
Co-58 Vitamin B-12, Normal-No Flushing	3.7E+00	2.8E+00	3.1E+00	3.1E+00
Co-58 Vitamin B-12, PA-Flushing	8.3E-01	7.4E-01	6.4E-01	4.8E-01
Co-58 Vitamin B-12, PA-No Flushing	9.8E-01	8.5E-01	7.6E-01	6.0E-01
Co-60 Vitamin B-12, Normal-Flushing	3.7E+01	2.8E+01	3.1E+01	3.2E+01
Co-60 Vitamin B-12, Normal-No Flushing	5.5E+01	4.2E+01	4.7E+01	4.7E+01
Co-60 Vitamin B-12, PA-Flushing	5.9E+00	4.7E+00	4.8E+00	4.5E+00
Co-60 Vitamin B-12, PA-No Flushing	8.3E+00	6.5E+00	6.8E+00	6.5E+00
F-18 FDG	2.7E-02	1.7E-02	9.4E-03	8.1E-03
F-18 Sodium Fluoride	2.2E-02	1.7E-02	7.5E-03	6.8E-03
Ga-67 Citrate	9.3E-02	2.0E-01	1.8E-01	1.3E-01
I-123 Hippuran	3.1E-02	2.4E-02	8.4E-03	7.9E-03
I-123 IMP	1.9E-02	1.1E-02	7.1E-03	5.9E-03
I-123 MIBG	1.8E-02	1.2E-02	6.8E-03	6.2E-03
I-123 Sodium Iodide	2.0E-02	1.4E-02	1.1E-02	9.8E-03
I-124 Sodium Iodide	1.4E-01	1.0E-01	5.9E-02	4.6E-02
I-125 HSA	2.5E-01	7.8E-02	3.8E-02	2.6E-02
I-125 IMP	3.2E-02	1.3E-02	4.8E-03	3.6E-03

Radiopharmaceutical	Early mGy/MBq	3 Month mGy/MBq	6 Month mGy/MBq	9 Month mGy/MBq
I-125 MIBG	2.6E-02	1.1E-02	4.1E-03	3.4E-03
I-125 Sodium Iodide	1.8E-02	9.5E-03	3.5E-03	2.3E-03
I-126 Sodium Iodide	7.8E-02	5.1E-02	3.2E-02	2.6E-02
I-130 Sodium Iodide	1.8E-01	1.3E-01	7.6E-02	5.7E-02
I-131 Hippuran	6.4E-02	5.0E-02	1.9E-02	1.8E-02
I-131 HSA	5.2E-01	1.8E-01	1.6E-01	1.3E-01
I-131 MAA	6.7E-02	4.2E-02	4.0E-02	4.2E-02
I-131 MIBG	1.1E-01	5.4E-02	3.8E-02	3.5E-02
I-131 Sodium Iodide	7.2E-02	6.8E-02	2.3E-01	2.7E-01
I-131 Rose Bengal	2.2E-01	2.2E-01	1.6E-01	9.0E-02
In-111 DTPA	6.5E-02	4.8E-02	2.0E-02	1.8E-02
In-111 Pentetreotide	8.2E-02	6.0E-02	3.5E-02	3.1E-02
In-111 Platelets	1.7E-01	1.1E-01	9.9E-02	8.9E-02
In-111 Red Blood Cells	2.2E-01	1.3E-01	1.1E-01	8.6E-02
In-111 White Blood Cells	1.3E-01	9.6E-02	9.6E-02	9.4E-02
Tc-99m Albumin Microspheres	4.1E-03	3.0E-03	2.5E-03	2.1E-03
Tc-99m Disofenin	1.7E-02	1.5E-02	1.2E-02	6.7E-03
Tc-99m DMSA	5.1E-03	4.7E-03	4.0E-03	3.4E-03
Tc-99m DTPA	1.2E-02	8.7E-03	4.1E-03	4.7E-03
Tc-99m DTPA Aerosol	5.8E-03	4.3E-03	2.3E-03	3.0E-03
Tc-99m Glucoheptonate	1.2E-02	1.1E-02	5.3E-03	4.6E-03
Tc-99m HDP	5.2E-03	5.4E-03	3.0E-03	2.5E-03
Tc-99m HEDP	7.2E-03	5.2E-03	2.7E-03	2.4E-03
Tc-99m HMPAO	8.7E-03	6.7E-03	4.8E-03	3.6E-03
Tc-99m Human Serum Albumin	5.1E-03	3.0E-03	2.6E-03	2.2E-03
Tc-99m MAA	2.8E-03	4.0E-03	5.0E-03	4.0E-03
Tc-99m MAG3	1.8E-02	1.4E-02	5.5E-03	5.2E-03
Tc-99m MDP	6.1E-03	5.4E-03	2.7E-03	2.4E-03
Tc-99m MIBI-rest	1.5E-02	1.2E-02	8.4E-03	5.4E-03

Radiopharmaceutical	Early mGy/MBq	3 Month mGy/MBq	6 Month mGy/MBq	9 Month mGy/MBq
Tc-99m MIBI-stress	1.2E-02	9.5E-03	6.9E-03	4.4E-03
Tc-99m Pertechnetate	1.1E-02	2.2E-02	1.4E-02	9.3E-03
Tc-99m PYP	6.0E-03	6.6E-03	3.6E-03	2.9E-03
Tc-99m RBC-Heat Treated	1.7E-03	1.6E-03	2.1E-03	2.2E-03
Tc-99m RBC-in vitro	6.8E-03	4.7E-03	3.4E-03	2.8E-03
Tc-99m RBC-in vivo	6.4E-03	4.3E-03	3.3E-03	2.7E-03
Tc-99m Sulfur Colloid-normal	1.8E-03	2.1E-03	3.2E-03	3.7E-03
Tc-99m Sulfur Colloid-Liver Disease	3.2E-03	2.5E-03	2.8E-03	2.8E-03
Tc-99m Teboroxime	8.9E-03	7.1E-03	5.8E-03	3.7E-03
Tc-99m White Blood Cells	3.8E-03	2.8E-03	2.9E-03	2.8E-03
Tl-201 Chloride	9.7E-02	5.8E-02	4.7E-02	2.7E-02
Xe-127, 5 minute rebreathing, 5 liter spirometer volume	4.3E-04	2.4E-04	1.9E-04	1.5E-04
Xe-127, 5 minute rebreathing, 7.5 liter spirometer volume	2.3E-04	1.3E-04	1.0E-04	8.4E-05
Xe-127, 5 minute rebreathing, 10 liter spirometer volume	2.3E-04	1.4E-04	1.1E-04	9.2E-05
Xe-133, 5 minute rebreathing, 5 liter spirometer volume	4.1E-04	4.8E-05	3.5E-05	2.6E-05
Xe-133, 5 minute rebreathing, 7.5 liter spirometer volume	2.2E-04	2.6E-05	1.9E-05	1.5E-05
Xe-133, 5 minute rebreathing, 10 liter spirometer volume	2.5E-04	2.9E-05	2.1E-05	1.6E-05
Xe-133, injection	4.9E-06	1.0E-06	1.4E-06	1.6E-06

Table 5. Summary of Recommendations for Radiopharmaceuticals Excreted in the Breast Milk (from (8)).

Pharmaceutical	Administered Activity, MBq (mCi)	Counseling Needed?	Advisory	Comments
Ga-67 Citrate	185 (5.0)	Yes	Cessation	
Tc-99m DTPA	740 (20)	No		
Tc-99m MAA	148 (4)	Yes	12 hr	
Tc-99m Pertechnetate	1110 (30)	Yes	24 hr	
I-131 NaI	5550 (150)	Yes	Cessation	
Cr-51 EDTA	1.85 (0.05)	No		
Tc-99m DISIDA	300 (8)	No		
Tc-99m glucoheptonate	740 (20)	No		
Tc-99m HAM	300 (8)	No		
Tc-99m MIBI	1110 (30)	No		
Tc-99m MDP	740 (20)	No		
Tc-99m PYP	740 (20)	No		
Tc-99m RBC's in vivo labeling	740 (20)	Yes	12 hr	
Tc-99m RBC's in vitro labeling	740 (20)	No		
Tc-99m Sulfur Colloid	444 (12)	Yes	12 hr	
In-111 WBC's	18.5 (0.5)	Yes	12 hr	
I-123 NaI	14.8 (0.4)	No		
I-123 OIH	74 (2)	No		No consideration of free iodide
I-123 mIBG	370 (10)	Yes	24 hr	No consideration of free iodide
I-125 OIH	0.37 (0.01)	No		No consideration of free iodide
I-131 OIH	11.1 (0.3)	No		No consideration of free iodide
Tl-201	111 (3)	Yes	168 hr	

Tc-99m DTPA Aerosol	37 (1)	No		
Tc-99m WBC's	185 (5)	Yes	24 hr	Treated as Tc-99m pertechnetate
Tc-99m MAG3	370 (10)	No		Treated as Tc-99m DTPA
Xe-133 gas		No		