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Radiation Dose Concerns for the Pregnant or Lactating Patient

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This article discusses issues regarding administration of radiopharmaceuticals to pregnant women or nursing mothers. Uncertainties in calculated dose estimates and possible biological effects on the unborn child are presented. Models and dose estimates for pregnant women at several stages of gestation are given; the radionuclide of highest concern is ^{131}I-NaI due to its affinity for the fetal thyroid and the potentially high fetal thyroid doses. The article also reviews the extant literature regarding the expression of radiopharmaceuticals in breast milk, and suggested time periods for interruption of breast feeding after a nursing mother receives a radiopharmaceutical, if needed. Again, ^{131}I-NaI is often the radiopharmaceutical of most concern, for the same reasons in the nursing infant as were shown for the unborn child. Strategies for preventing unwanted administrations of radiopharmaceuticals to these patients are reviewed, with strategies for minimizing radiation doses where possible.
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Introduction

The classic 'law' of Bergonie and Tribondeau can be stated as 'the radiosensitivity of living cells is proportional to their rate of division and inversely related to their degree of specialization[1]. Two classic examples of this principle are dividing progenitor cells in the active marrow and the embryo/fetus. Radiation exposures of pregnant or potentially pregnant medical patients is always an area of acute concern, due to the known radiosensitivity of the unborn child. For diagnostic studies (x-rays, computed tomography, diagnostic nuclear medicine procedures), concerns are real, but overshadowed of course by the concerns related to any therapeutic studies. Patients and physicians are many times needlessly worried about the possible consequences of fetal exposures to radiation from diagnostic studies, as will be discussed below; the risks, if there are any, are very small, and are much lower than the risks of not obtaining important information about the health of the mother. For nuclear medicine studies, significant sources of exposure to the embryo/fetus include photons originating in the mother's body and particulate and photon radiation from any material that may cross the placenta and enter the baby's body. Much is known about placental crossover of radiopharmaceuticals (e.g. Russell et al. 1997[2]), but much remains to be discovered. Much of the available data on this subject was gathered in animals, so implications are that similar rates of crossover may occur in humans, but uncertainties are high. In a few cases (notably ^{131}I as NaI and ^{18}FDG, as will be discussed below), reasonably good data have been obtained in human subjects, but in a limited number of cases. Despite the considerable uncertainties, dose estimates for most pharmaceuticals routinely administered to women of childbearing age have been developed, and a significant amount of data has been published regarding the presence of radiopharmaceuticals appearing in the breast milk of lactating women. A dose estimate with some associated uncertainty is better than no dose estimate at all, when a potential exposure has occurred. The woman and the physicians involved may be dealing with considerable levels of stress, and a reasonable estimate of the radiation doses received is essential to (usually) alleviating concerns that the exposure was dangerous, and in decision making about any actions to be taken in response. In diagnostic exposures, contrary to the feelings of some physicians, who are merely poorly informed, there is no expectation of any short term effects, and long term effects, such as cancer, are of very low probability, and, if they exist at all, they are very small compared to all other risks associated with any pregnancy. For the unborn child or nursing infant, the radionuclide of most concern is ^{131}I, due to its affinity for thyroid tissue, and, as the thyroid is a very small organ (particularly in early

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pregnancy), radiation doses from any uptakes can be very high (as radiation dose is related to energy per unit mass). This article will summarize the current knowledge about radiation effects on the embryo/fetus, provide the most recent dose estimates for the unborn child and nursing infant, and discuss methods for avoiding unwanted exposures to the potentially pregnant patient and nursing infant.

Effects on the Embryo/Fetus

Several excellent summaries of potential radiation effects on the embryo/fetus have been presented by Brent (e.g. Brent's 2009 summary[3]). Much of the information in this section has been extracted from his work. Dr Brent describes four types of threshold effects known to be observed in human populations and one (assumed) nonthreshold effect (assuming that doses are high enough):

1. Pregnancy loss (abortion, stillbirths)
2. Congenital malformations (anatomical defects)
3. Neurobehavioral abnormalities (i.e., mental retardation)
4. Fetal growth retardation (reversible and irreversible)
5. Cancer

The first four effects are 'deterministic', meaning that they will be observed if doses exceed a certain threshold; one may also speak of a 'no-adverse effect level' (NOAEL) of radiation exposure. The fifth, a 'stochastic' effect, is assumed to not have a threshold; however this is a conservative assumption, not a known fact. For doses below a NOAEL, there will be no short term, deterministic, consequences to the exposure. The effects that are possible at different stages of gestation are shown in Table 1.

In early pregnancy, radiation exposures are associated with the 'all or nothing' phenomenon, i.e. embryonic death may occur, or no adverse effects at all will be observed. Malformations, growth retardation and induction of microcephaly and mental retardation (possible loss of 30 IQ points per Gy of dose[4] may be observed during periods when active cell division is occurring for any organ system. The most sensitive period is between 8-15 weeks; particular care should be taken in this time to avoid unwanted radiation exposures to the fetus. However, clear thresholds exist for these effects, and it is difficult to imagine a diagnostic study, even using multiple ionizing radiation modalities (e.g. PET/CT) to approach these levels. The International Commission on Radiological Protection states that[5]:

- Medical professionals using radiation should be familiar with the effects of radiation on the embryo and fetus. At most diagnostic levels this would include risk of childhood cancer, while at doses in excess of 100-200 mGy risks related to nervous system abnormalities, malformations, growth retardation, and fetal death should be considered.
- Termination of pregnancy at fetal doses of less than 100 mGy is not justifed based upon radiation risk.

The stochastic risks, for doses below 100-200 mGy, if they exist at all, are very small compared to other risks of pregnancy[3]. In 2008, Preston[6] presented data on stochastic risks (Table 2) from in-utero exposure and concluded that:

> "Lifetime risks following in utero exposure maybe considerably lower than for early childhood exposure, but further follow-up is needed."

Patients and medical professionals should always bear in mind that all pregnancies in healthy mothers are associated with a 3-4% risk of congenital malformations and a 15% chance of miscarriage.

The Pregnant Patient

When a radiopharmaceutical is administered to a pregnant woman, in general it will be distributed in the mother's body in the same manner as a nonpregnant subject. Radioactivity will move through the circulatory system, concentrate in certain organs and tissues, and gradually be eliminated from the body and will disappear due to radioactive decay. Photons emitted from anywhere in the mother's body may contribute to the radiation exposure of the fetus; particulate and photon radiation from activity that may cross the placenta and enter the fetus may be a much more important source of exposure. Much of our knowledge of the placental crossover of radiopharmaceuticals is based on experiments performed in animals. The few exceptions in which we have data collected in

Table 1 Summary of possible deterministic effects of radiation from in-utero exposures.

Stage of Gestation	Possible Effects of Radiation
3-4 weeks	Embryonic death, 0.10-0.20 Gy threshold
4-8 weeks	— Embryonic death, 0.25 Gy threshold, 0.5 Gy after 50 days (from animal studies) — Growth retardation, 0.20-0.50 Gy at 18-36 days, 0.25-0.50 Gy 36-110 days — Anatomic malformations, threshold 0.2 Gy
8-15 weeks	— Most sensitive period for growth retardation, microcephaly and mental retardation (threshold 0.35-0.50 Gy) — Anatomic malformations, threshold 0.5 Gy
16-40 weeks	— Growth retardation, decreased brain size, mental retardation (threshold 1.5 Gy)

Table 2 Comparison of observed lifetime cancer risks (%) from in-utero and early childhood exposures to radiation.

Dose (Sv)	In-utero	Early childhood
<0.005	3.5	3.7
0.005<0.1	3.7	3.8
0.1<0.2	3.6	4.4
0.2<0.5	4.6	5.9
0.5<1	7.6	6.5
>1	6.2	17.5
Total	3.5	4.2

Table 3 Doses to the fetal thyroid (mGy to the fetal thyroid per MBq administred to the mother)[7]

Gestational Age (mo)	I-123	I-124	I-125	I-131
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

human subjects will be discussed below. Russell et al.[2] performed an extensive literature search to identify data on placental crossover for radiopharmaceuticals typically given to women of childbearing years. Generally, the percent of the activity crossing the placenta was assumed to be the same in animals as in humans. Developmental stages of gestation were matched as closely as possible to the corresponding values in humans. Data were often provided at only one stage of gestation; data in later stages of gestation were usually the highest and was used to provide conservative estimates of crossover at earlier stages. Quantitative estimates of crossover were obtained for:

- ^{99m}Tc-methylene diphosphonate (MDP)
- ^{99m}Tc-macroaggregated albumin (MAA).
- ^{123}I and ^{131}I sodium iodide (NaI)
- ^{67}Ga citrate
- ^{133}Xe
- ^{201}Tl chloride
- ^{99m}Tc diethylenetriaminepentaacetic acid (DTPA)
- ^{99m}Tc DTPA aerosol
- ^{99m}Tc sulfur colloid
- ^{99m}Tc hydroxymethylene diphosphonate (HMDP or HDP)
- ^{99m}Tc pertechnetate
- ^{99m}Tc red blood cells
- ^{99m}Tc pyrophosphate (PYP)
- ^{99m}Tc 2,3 dimercaptosuccinic acid
- ^{99m}Tc glucoheptonate

Russell et al. then used the pregnant female phantoms developed by Stabin et al.[7] to calculate dose to the embryo/fetus at four stages of pregnancy (early, using the dose to the nongravid uterus, and at 3, 6, and 9 months' gestation. Perhaps the best studied radiopharmaceutical regarding placental crossover and fetal dosimetry is ^{131}I sodium iodide. Russell et al. cited six studies that provided data and/or models of the crossover of NaI and its incorporation in fetal tissues, particularly the fetal thyroid. The fetal thyroid may begin to concentrate iodine as early as 10 weeks' gestation. Watson[8] compared these various studies, based on measured uptakes and biological half-times measured in humans. The data were sometimes difficult to merge together, but Watson created a working model for fetal thyroid kinetics throughout gestation, and her dose estimates are still considered the best available. Table 3 summarizes Watson's dose estimates for 4 isotopes of iodine.

Russell et al. reported dose estimates for ^{18}F-flourodeoxyglucose (FDG) with no consideration of placental crossover. Later, Stabin[9] revised the ^{18}FDG fetal doses throughout gestation using measured ^{18}FDG placental crossover in primates. Takalkar et al.[10] reported ^{18}FDG fetal uptakes in five pregnant subjects, using nuclear medicine imaging to quantify the uptakes. Their measured time-activity integrals and estimated doses were reasonably consistent with those of Stabin, but generally lower.

Tables 4 and 5 show dose estimates at all stages of pregnancy, per unit administered activity, and assuming an administered activity, as provided by Russell et al.[11] The rows in bold indicate radiopharmaceuticals for which placental crossover is included in the dose estimate. The dose estimates of Stabin for ^{18}FDG are provided, as they are conservatively higher.

An unusual kinetic picture sometimes arises when conception occurs *after* the iodine has been administered. In this case, the iodine has already started to wash out of the body, and whatever iodine is left will irradiate the embryo. Dose estimates for this situation were given by Sparks and Stabin[12].

The Lactating Patient

Many radiopharmaceuticals are also known to be excreted in breast milk. Measuring activity in a milk sample is easier than quantitative imaging of a pregnant subject, so a number of authors have presented data on measured concentrations at various times after radiopharmaceutical administration to a lactating mother. There are difficulties in assigning doses to the nursing infant, as most radiopharmaceutical dose estimates are based on injected, not ingested compounds. The measurements typically do not account for the chemical form that was in the breast milk (e.g. for ^{99m}Tc-DTPA administered to the mother is activity in the milk ^{99m}Tc-DTPA or free ^{99m}Tc?). Performing dose estimates generally assume that the ingested radioactivity quickly enters the infant's bloodstream and then is distributed and cleared from the body in the same manner as an injection to an adult subject, as this is probably a conservative way to treat the data, and there are simply no data to support any other approach. As with placental crossover, one of the compounds of high concern is ^{131}I-NaI, again because of its propensity for uptake in the very small thyroid of the infant and subsequently high doses per unit

Table 4 Absorbed Dose Estimates to the Embryo/Fetus Per Unit Activity of Radiopharmaceutical Administered to the Mother (bold font indicates maternal and fetal self dose contributions). (From Russell et al.[11]).

Radiopharmaceutical	Early	3 Month	6 Month	9 Month
	mGy/MBq	mGy/MBq	mGy/MBq	mGy/MBq
^{57}Co Vitamin B-1, Normal-Flushing	1.0×10^{0}	6.8×10^{-1}	8.4×10^{-1}	8.8×10^{-1}
^{57}Co Vitamin B-12, Normal-No Flushing	1.5×10^{0}	1.0×10^{0}	1.2×10^{0}	1.3×10^{0}
^{57}Co Vitamin B-12, PA- Flushing	2.1×10^{-1}	1.7×10^{-1}	1.7×10^{-1}	1.5×10^{-1}
^{57}Co Vitamin B-12, PA- No Flushing	2.8×10^{-1}	2.1×10^{-1}	2.2×10^{-1}	2.0×10^{-1}
^{58}Co Vitamin B-12, Normal Flushing	2.5×10^{0}	1.9×10^{0}	2.1×10^{0}	2.1×10^{0}
^{58}Co Vitamin B-12, Normal-No Flushing	3.7×10^{0}	2.8×10^{0}	3.1×10^{0}	3.1×10^{0}
^{58}Co Vitamin B-12, PA-Flushing	8.3×10^{-1}	7.4×10^{-1}	6.4×10^{-1}	4.8×10^{-1}
^{58}Co Vitamin B-12, PA-No Flushing	9.8×10^{-1}	8.5×10^{-1}	7.6×10^{-1}	6.0×10^{-1}
^{60}Co Vitamin B-12, Normal Flushing	3.7×10^{1}	2.8×10^{1}	3.1×10^{1}	3.2×10^{1}
^{60}Co Vitamin B-12, Normal-No Flushing	5.5×10^{1}	4.2×10^{1}	4.7×10^{1}	4.7×10^{1}
^{60}Co Vitamin B-12, PA-Flushing	5.9×10^{0}	4.7×10^{0}	4.8×10^{0}	4.5×10^{0}
^{60}Co Vitamin B-12, PA-No Flushing	8.3×10^{0}	6.5×10^{0}	6.8×10^{0}	6.5×10^{0}
^{18}F FDG	**2.2×10^{-2}**	**2.2×10^{-2}**	**1.7×10^{-2}**	**1.7×10^{-2}**
^{18}F Sodium Fluoride	2.2×10^{-2}	1.7×10^{-2}	7.5×10^{-3}	6.8×10^{-3}
^{67}Ga Citrate	**9.3×10^{-2}**	**2.0×10^{-1}**	**1.8×10^{-1}**	**1.3×10^{-1}**
^{123}I Hippuran	3.1×10^{-2}	2.4×10^{-2}	8.4×10^{-3}	7.9×10^{-3}
^{123}I IMP	1.9×10^{-2}	1.1×10^{-2}	7.1×10^{-3}	5.9×10^{-3}
^{123}I MIBG	1.8×10^{-2}	1.2×10^{-2}	6.8×10^{-3}	6.2×10^{-3}
^{123}I Sodium Iodide	**2.0×10^{-2}**	**1.4×10^{-2}**	**1.1×10^{-2}**	**9.8×10^{-3}**
^{124}I Sodium Iodide	**1.4×10^{-1}**	**1.0×10^{-1}**	**5.9×10^{-2}**	**4.6×10^{-2}**
^{125}I HSA	2.5×10^{-1}	7.8×10^{-2}	3.8×10^{-2}	2.6×10^{-2}
^{125}I IMP	3.2×10^{-2}	1.3×10^{-2}	4.8×10^{-3}	3.6×10^{-3}
^{125}I MIBG	2.6×10^{-2}	1.1×10^{-2}	4.1×10^{-3}	3.4×10^{-3}
^{125}I Sodium Iodide	**1.8×10^{-2}**	**9.5×10^{-3}**	**3.5×10^{-3}**	**2.3×10^{-3}**
^{126}I Sodium Iodide	**7.8×10^{-2}**	**5.1×10^{-2}**	**3.2×10^{-2}**	**2.6×10^{-2}**
^{130}I Sodium Iodide	**1.8×10^{-1}**	**1.3×10^{-1}**	**7.6×10^{-2}**	**5.7×10^{-2}**
^{131}I Hippuran	6.4×10^{-2}	5.0×10^{-2}	1.9×10^{-2}	1.8×10^{-2}
^{131}I HSA	5.2×10^{-1}	1.8×10^{-1}	1.6×10^{-1}	1.3×10^{-1}
^{131}I MAA	6.7×10^{-2}	4.2×10^{-2}	4.0×10^{-2}	4.2×10^{-2}
^{131}I MIBG	1.1×10^{-1}	5.4×10^{-2}	3.8×10^{-2}	3.5×10^{-2}
^{131}I Sodium Iodide	**7.2×10^{-2}**	**6.8×10^{-2}**	**2.3×10^{-1}**	**2.7×10^{-1}**
^{131}I Rose Bengal	2.2×10^{-1}	2.2×10^{-1}	1.6×10^{-1}	9.0×10^{-2}
^{111}In DTPA	6.5×10^{-2}	4.8×10^{-2}	2.0×10^{-2}	1.8×10^{-2}
^{111}In Pentetreotide	8.2×10^{-2}	6.0×10^{-2}	3.5×10^{-2}	3.1×10^{-2}
^{111}In Platelets	1.7×10^{-1}	1.1×10^{-1}	9.9×10^{-2}	8.9×10^{-2}
^{111}In Red Blood Cells	2.2×10^{-1}	1.3×10^{-1}	1.1×10^{-1}	8.6×10^{-2}
^{111}In White Blood Cells	1.3×10^{-1}	9.6×10^{-2}	9.6×10^{-2}	9.4×10^{-2}
^{99m}Tc Albumin Microspheres	4.1×10^{-3}	3.0×10^{-3}	2.5×10^{-3}	2.1×10^{-3}
^{99m}Tc Disofenin	1.7×10^{-2}	1.5×10^{-2}	1.2×10^{-2}	6.7×10^{-3}
^{99m}Tc DMSA	**5.1×10^{-3}**	**4.7×10^{-3}**	**4.0×10^{-3}**	**3.4×10^{-3}**
^{99m}Tc DTPA	**1.2×10^{-2}**	**8.7×10^{-3}**	**4.1×10^{-3}**	**4.7×10^{-3}**
^{99m}Tc DTPA Aerosol	**5.8×10^{-3}**	**4.3×10^{-3}**	**2.3×10^{-3}**	**3.0×10^{-3}**
^{99m}Tc Glucoheptonate	**1.2×10^{-2}**	**1.1×10^{-2}**	**5.3×10^{-3}**	**4.6×10^{-3}**
^{99m}Tc HDP	**5.2×10^{-3}**	**5.4×10^{-3}**	**3.0×10^{-3}**	**2.5×10^{-3}**
^{99m}Tc HEDP	7.2×10^{-3}	5.2×10^{-3}	2.7×10^{-3}	2.4×10^{-3}
^{99m}Tc HMPAO	8.7×10^{-3}	6.7×10^{-3}	4.8×10^{-3}	3.6×10^{-3}
^{99m}Tc Human Serum Albumin	5.1×10^{-3}	3.0×10^{-3}	2.6×10^{-3}	2.2×10^{-3}
^{99m}Tc MAA	2.8×10^{-3}	4.0×10^{-3}	5.0×10^{-3}	4.0×10^{-3}
^{99m}Tc MAG3	1.8×10^{-2}	1.4×10^{-2}	5.5×10^{-3}	5.2×10^{-3}
^{99m}Tc MDP	**6.1×10^{-3}**	**5.4×10^{-3}**	**2.7×10^{-3}**	**2.4×10^{-3}**
^{99m}Tc MIBI-rest	1.5×10^{-2}	1.2×10^{-2}	8.4×10^{-3}	5.4×10^{-3}
^{99m}Tc MIBI-stress	1.2×10^{-2}	9.5×10^{-3}	6.9×10^{-3}	4.4×10^{-3}
^{99m}Tc Pertechnetate	**1.1×10^{-2}**	**2.2×10^{-2}**	**1.4×10^{-2}**	**9.3×10^{-3}**
^{99m}Tc PYP	**6.0×10^{-3}**	**6.6×10^{-3}**	**3.6×10^{-3}**	**2.9×10^{-3}**
^{99m}Tc RBC-Heat Treated	1.7×10^{-3}	1.6×10^{-3}	2.1×10^{-3}	2.2×10^{-3}
^{99m}Tc RBC-in vitro	**6.8×10^{-3}**	**4.7×10^{-3}**	**3.4×10^{-3}**	**2.8×10^{-3}**
^{99m}Tc RBC-in vivo	**6.4×10^{-3}**	**4.3×10^{-3}**	**3.3×10^{-3}**	**2.7×10^{-3}**

Table 4 (*continued*)

Radiopharmaceutical	Early	3 Month	6 Month	9 Month
	mGy/MBq	mGy/MBq	mGy/MBq	mGy/MBq
^{99m}Tc Sulfur Colloid-normal	**1.8×10^{-3}**	**2.1×10^{-3}**	**3.2×10^{-3}**	**3.7×10^{-3}**
^{99m}Tc Sulfur Colloid-Liver Disease	**3.2×10^{-3}**	**2.5×10^{-3}**	**2.8×10^{-3}**	**2.8×10^{-3}**
^{99m}Tc Teboro x ime	8.9×10^{-3}	7.1×10^{-3}	5.8×10^{-3}	3.7×10^{-3}
^{99m}Tc Tetrofosmin	9.6×10^{-3}	7.0×10^{-3}	5.4×10^{-3}	3.6×10^{-3}
^{99m}Tc White Blood Cells	3.8×10^{-3}	2.8×10^{-3}	2.9×10^{-3}	2.8×10^{-3}
^{201}Tl Chloride	9.7×10^{-2}	5.8×10^{-2}	4.7×10^{-2}	2.7×10^{-2}
^{127}Xe, 5 minute rebreathing, 5 liter spirometer volume	4.3×10^{-4}	2.4×10^{-4}	1.9×10^{-4}	1.5×10^{-4}
^{127}Xe, 5 minute rebreathing, 7.5	2.3×10^{-4} liter spirometer volume	1.3×10^{-4}	1.0×10^{-4}	8.4×10^{-5}
^{127}Xe, 5 minute rebreathing, 10 liter spirometer volume	2.3×10^{-4}	1.4×10^{-4}	1.1×10^{-4}	9.2×10^{-5}
^{133}Xe, 5 minute rebreathing, 5 liter spirometer volume	4.1×10^{-4}	4.8×10^{-5}	3.5×10^{-5}	2.6×10^{-5}
^{133}Xe, 5 minute rebreathing, 7.5	2.2×10^{-4} liter spirometer volume	2.6×10^{-5}	1.9×10^{-5}	1.5×10^{-5}
^{133}Xe, 5 minute rebreathing, 10 liter spirometer volume	2.5×10^{-4}	2.9×10^{-5}	2.1×10^{-5}	1.6×10^{-5}
^{133}Xe, injection	4.9×10^{-6}	1.0×10^{-6}	1.4×10^{-6}	1.6×10^{-6}

intake of the activity. ^{131}I-NaI excretion in breast milk can be quite extensive, even competing with urinary excretion in some cases studied[13]. For all radiopharmaceuticals studied, individuals vary greatly in the concentrations excreted, although effective half–times are more similar between subjects. Even in one subject who received two different administrations at different times post partum, the concentrations were quite different[13]. So, if at all possible, obtaining measured data in an individual patient and measuring the concentrations over time is preferable to relying on published data for other subjects. Stabin and Breitz[13] evaluated the pathways by which radiopharmaceuticals enter the breast milk, and, using the assumptions stated above, calculated effective doses to newborns. They calculated interruption times that would limit the effective dose to the infant to 1 mSv. In some cases, no interruption is needed at all, in a few cases, the interruption times are so long as to be impractical to try and express milk, so cessation was recommended, and in other cases, interruption times of a few hours to a few days were suggested. A more recent ICRP publication[14] (ICRP 106) reviewed mostly the same data sets and some data published after 2000, and repeated the exercise, using the same 1 mSv effective dose criterion. People are often surprised by the long interruption times suggested for ^{123}I; this nuclide itself does not give a very high dose to the thyroid. However, uncertainty about the presence of radiocontaminants, which have longer physical half-lives and beta and other emissions, results in caution in establishing the interruption time. The ICRP 106 findings are more recent and include more radiopharmaceuticals; their recommendations are given in Table 6.

Preventing Unwanted Exposures or Minimizing Dose

For diagnostic procedures, a combination of signage and interviewing patients that may be pregnant or breastfeeding will usually suffice to prevent unwanted exposures. In some locations, signage with language such as 'If it is possible that you might be pregnant or breastfeeding, notify the physician or technician before receiving any radioactive material' may need to be presented in more than one language. Interviews should be conducted with someone who is fluent in the patient's language. Discretion may be important for adolescent patients who may have a parent with them. Mossman demonstrated that performing a pregnancy test on every woman of childbearing years who is to receive a medical examination involving ionizing radiation is not cost-effective[15]. For any therapeutic procedure, if the study cannot be postponed until after the pregnancy, performing a pregnancy test is absolutely essential. Because of the propensity of radioactive iodine to cross the placenta and concentrate in the very small fetal thyroid, some sites perform pregnancy tests even when only giving a diagnostic administration of ^{131}I. Even if the administered activity is reduced, it is prudent to follow the recommended 12 hour interruption of breast feeding (Table 6).

If possible, one may consider administering less activity to a pregnant subject, and using longer imaging times. Since one of the organs often delivering a significant portion of the dose to the fetus may be the

Table 5 Fetal Dose Estimates from Various Nuclear Medicine Procedures (bold font indicates maternal and fetal self dose contributions) (From Russell et al.[11])

Radiopharmaceutical	Activity Administered MBq (mCi)	Fetal Dose			
		Early mGy (rad)	3 Month mGy (rad)	6 Month mGy (rad)	9 Month, mGy (rad)
^{57}Co Vitamin B-12	0.04	4.0×10^{-2}	2.7×10^{-2}	3.4×10^{-2}	3.5×10^{-2}
Normal-Flushing	(0.001)	(4.0×10^{-3})	(2.7×10^{-3})	(3.4×10^{-3})	(3.5×10^{-3})
^{57}Co Vitamin B-12	0.04	6.0×10^{-2}	4.0×10^{-2}	4.8×10^{-2}	5.2×10^{-2}
Normal-No Flushing	(0.001)	(6.0×10^{-3})	(4.0×10^{-3})	(4.8×10^{-3})	(5.2×10^{-3})
^{57}Co Vitamin B-12 Pernicious	0.04	8.4×10^{-3}	6.8×10^{-3}	6.8×10^{-3}	6.0×10^{-3}
Anemia-Flushing	(0.001)	(8.4×10^{-4})	(6.8×10^{-4})	(6.8×10^{-4})	(6.0×10^{-4})
^{57}Co Vitamin B-12 Pernicious Anemia-No	0.04	1.1×10^{-2}	8.4×10^{-3}	8.8×10^{-3}	8.0×10^{-3}
Flushing	(0.001)	(1.1×10^{-3})	(8.4×10^{-4})	(8.8×10^{-4})	(8.0×10^{-4})
^{58}Co Vitamin B-12	0.03	7.5×10^{-2}	5.7×10^{-2}	6.3×10^{-2}	6.3×10^{-2}
Normal-Flushing	(0.0008)	(7.5×10^{-3})	(5.7×10^{-3})	(6.3×10^{-3})	(6.3×10^{-3})
^{58}Co Vitamin B-12	0.03	1.1×10^{-1}	8.4×10^{-2}	9.3×10^{-2}	9.3×10^{-2}
Normal-No Flushing	(0.0008)	(1.1×10^{-2})	(8.4×10^{-3})	(9.3×10^{-3})	(9.3×10^{-3})
^{58}Co Vitamin B-12 Pernicious	0.03	2.5×10^{-2}	2.2×10^{-2}	1.9×10^{-2}	1.4×10^{-2}
Anemia-Flushing	(0.0008)	(2.5×10^{-3})	(2.2×10^{-3})	(1.9×10^{-3})	(1.4×10^{-3})
^{58}Co Vitamin B-12 Pernicious Anemia-No	0.03	2.9×10^{-2}	2.6×10^{-2}	2.3×10^{-2}	1.8×10^{-2}
Flushing	(0.0008)	(2.9×10^{-3})	(2.6×10^{-3})	(2.3×10^{-3})	(1.8×10^{-3})
^{18}F FDG	**370**	**8.1×10^{0}**	**8.1×10^{0}**	**6.3×10^{0}**	**6.3×10^{0}**
	(10)	**(8.1×10^{-1})**	**(8.1×10^{-1})**	**(6.3×10^{-1})**	**(6.3×10^{-1})**
^{67}Ga Citrate	**190**	**1.8×10^{1}**	**3.8×10^{1}**	**3.4×10^{1}**	**2.5×10^{1}**
	(5)	**(1.8×10^{0})**	**(3.8×10^{0})**	**(3.4×10^{0})**	**(2.5×10^{0})**
^{197}Hg Chlormerodrin	4	4.4×10^{-2}	3.0×10^{-2}	2.7×10^{-2}	2.8×10^{-2}
	(0.1)	(4.4×10^{-3})	(3.0×10^{-3})	(2.7×10^{-3})	(2.8×10^{-3})
^{123}I Hippuran	75	2.3×10^{0}	1.8×10^{0}	6.3×10^{-1}	5.9×10^{-1}
	(2)	(2.3×10^{-1})	(1.8×10^{-1})	(6.3×10^{-2})	(5.9×10^{-2})
^{123}I IMP	200	3.8×10^{0}	2.2×10^{0}	1.4×10^{0}	1.2×10^{0}
	(5.5)	(3.8×10^{-1})	(2.2×10^{-1})	(1.4×10^{-1})	(1.2×10^{-1})
^{123}I MIBG phaeochromocytoma	350	6.3×10^{0}	4.2×10^{0}	2.4×10^{0}	2.2×10^{0}
	(9.5)	(6.3×10^{-1})	(4.2×10^{-1})	(2.4×10^{-1})	(2.2×10^{-1})
cecholamine tumor	80	1.4×10^{0}	9.6×10^{-1}	5.4×10^{-1}	5.0×10^{-1}
	(2)	(1.4×10^{-1})	(9.6×10^{-2})	(5.4×10^{-2})	(5.0×10^{-2})
^{123}I Sodium Iodide thyroid uptake study	**30**	**6.0×10^{-1}**	**4.2×10^{-1}**	**3.3×10^{-1}**	**2.9×10^{-1}**
	(0.8)	**(6.0×10^{-2})**	**(4.2×10^{-2})**	**(3.3×10^{-2})**	**(2.9×10^{-2})**
thyroid imaging	**15**	**3.0×10^{-1}**	**2.1×10^{-1}**	**1.7×10^{-1}**	**1.4×10^{-2}**
	(0.4)	**(3.0×10^{-2})**	**(2.1×10^{-2})**	**(1.7×10^{-2})**	**(1.4×10^{-3})**
^{125}I HSA	2	5.0×10^{-1}	1.6×10^{-1}	7.6×10^{-2}	5.2×10^{-2}
	(0.05)	(5.0×10^{-2})	(1.6×10^{-2})	(7.6×10^{-3})	(5.2×10^{-3})
^{125}I NaI	1	1.8×10^{-2}	9.5×10^{-3}	3.5×10^{-3}	2.3×10^{-3}
	(0.03)	(1.8×10^{-3})	(9.5×10^{-4})	(3.5×10^{-4})	(2.3×10^{-4})
^{131}I Hippuran renal function	1.3	8.3×10^{-2}	6.5×10^{-2}	2.5×10^{-2}	2.3×10^{-2}
	(0.035)	(8.3×10^{-3})	(6.5×10^{-3})	(2.5×10^{-3})	(2.3×10^{-3})
renal imaging	1.3	8.3×10^{-2}	6.5×10^{-2}	2.5×10^{-2}	2.3×10^{-2}
	(0.035)	(8.3×10^{-3})	(6.5×10^{-3})	(2.5×10^{-3})	(2.3×10^{-3})
^{131}I HSA	0.5	2.6×10^{-1}	9.0×10^{-2}	8.0×10^{-2}	6.5×10^{-2}
	(0.013)	(2.6×10^{-2})	(9.0×10^{-3})	(8.0×10^{-3})	(6.5×10^{-3})
^{131}I MAA	55	3.7×10^{0}	2.3×10^{0}	2.2×10^{0}	2.3×10^{0}
	(1.5)	(3.7×10^{-1})	(2.3×10^{-1})	(2.2×10^{-1})	(2.3×10^{-1})
^{131}I MIBG	20	2.2×10^{0}	1.1×10^{0}	7.6×10^{-1}	7.0×10^{-1}
	(0.5)	(2.2×10^{-1})	(1.1×10^{-1})	(7.6×10^{-2})	(7.0×10^{-2})
^{131}I NaI (Diagnostic) thyroid uptake	**0.55**	**4.0×10^{-2}**	**3.7×10^{-2}**	**1.3×10^{-1}**	**1.5×10^{-1}**
	(0.015)	**(4.0×10^{-3})**	**(3.7×10^{-3})**	**(1.3×10^{-2})**	**(1.5×10^{-2})**
scintiscanning	**4**	**2.9×10^{-1}**	**2.7×10^{-1}**	**9.2×10^{-1}**	**1.1×10^{0}**
	(0.11)	**(2.9×10^{-2})**	**(2.7×10^{-2})**	**(9.2×10^{-2})**	**(1.1×10^{-1})**
localization of e x tra-thyroid metastases	**40**	**2.9×10^{0}**	**2.7×10^{0}**	**9.2×10^{0}**	**1.1×10^{1}**
	(1.1)	**(2.9×10^{-1})**	**(2.7×10^{-1})**	**(9.2×10^{-1})**	**(1.1×10^{0})**
^{131}I NaI (Therapeutic) hyperthyroidism	**350**	**2.5×10^{1}**	**2.3×10^{1}**	**8.1×10^{1}**	**9.5×10^{1}**
	(9.5)	**(2.5×10^{0})**	**(2.3×10^{0})**	**(8.1×10^{0})**	**(9.5×10^{0})**

Table 5 (*continued*)

ablation of normal thyroid tissue	**1900**	**1.4×10^{2}**	**1.3×10^{2}**	**4.4×10^{2}**	**5.1×10^{2}**
	(50)	**(1.4×10^{1})**	**(1.3×10^{1})**	**(4.4×10^{1})**	**(5.1×10^{1})**
^{131}I Rose Bengal	0.04	8.8×10^{-3}	8.8×10^{-3}	6.4×10^{-3}	3.6×10^{-3}
	(0.001)	(8.8×10^{-4})	(8.8×10^{-4})	(6.4×10^{-4})	(3.6×10^{-4})
^{111}In DTPA	20	1.3×10^{0}	9.6×10^{-1}	4.0×10^{-1}	3.6×10^{-1}
	(0.5)	(1.3×10^{-1})	(9.6×10^{-2})	(4.0×10^{-2})	(3.6×10^{-2})
^{111}In Pentetreotide planar imaging	110	9.0×10^{0}	6.6×10^{0}	3.8×10^{0}	3.4×10^{0}
	(3)	(9.0×10^{-1})	(6.6×10^{-1})	(3.8×10^{-1})	(3.4×10^{-1})
SPECT imaging	230	1.9×10^{1}	1.4×10^{1}	8.0×10^{0}	7.0×10^{0}
	(6)	(1.9×10^{0})	(1.4×10^{0})	(8.0×10^{-1})	$7.0 \times 10^{-1})$
^{111}In Platelets	10	1.7×10^{0}	1×10^{0}	9.9×10^{-1}	8.9×10^{-1}
	(0.25)	(1.7×10^{-1})	(1.1×10^{-1})	(9.9×10^{-2})	(8.9×10^{-2})
^{111}In White Blood Cell	20	2.6×10^{0}	1.9×10^{0}	1.9×10^{0}	1.9×10^{0}
	(0.5)	(2.6 x 10-1)	(1.9×10^{-1})	(1.9×10^{-1})	(1.9×10^{-1})
^{81m}Kr Gas	600	1.1×10^{-4}	1.0×10^{-4}	1.6×10^{-4}	2.0×10^{-4}
	(15)	(1.1×10^{-5})	(1.0×10^{-5})	(1.6×10^{-5})	(2.0×10^{-5})
^{99m}Tc Disofenin	350	6.0×10^{0}	5.2×10^{0}	4.2×10^{0}	2.3×10^{0}
	(9.5)	(6.0×10^{-1})	(5.2×10^{-1})	(4.2×10^{-1})	(2.3×10^{-1})
^{99m}Tc DMSA	**220**	**1.1×10^{0}**	**1.0×10^{0}**	**8.8×10^{-1}**	**7.5×10^{-1}**
	(6)	**(1.1×10^{-1})**	**(1.0×10^{-1})**	**(8.8×10^{-2})**	**(7.5×10^{-2})**
^{99m}Tc DTPA kidney imaging & glomular filtration	**750**	**9.0×10^{0}**	**6.5×10^{0}**	**3.1×10^{0}**	**3.5×10^{0}**
	(20)	**(9.0×10^{-1})**	**(6.5×10^{-1})**	**(3.1×10^{-1})**	**(3.5×10^{-1})**
brain imaging & renal perfusion	**750**	**9.0×10^{0}**	**6.5×10^{0}**	**3.1×10^{0}**	**3.5×10^{0}**
	(20)	**(9.0×10^{-1})**	**(6.5×10^{-1})**	**(3.1×10^{-1})**	**(3.5×10^{-1})**
1st pass	**350**	**4.2×10^{0}**	**3.0×10^{0}**	**1.4×10^{0}**	**1.6×10^{0}**
	(9.5)	**(4.2×10^{-1})**	**(3.0×10^{-1})**	**(1.4×10^{-1})**	**(1.6×10^{-1})**
gastric reflu x	**10**	**1.2×10^{-1}**	**8.7×10^{-2}**	**4.1×10^{-2}**	**4.7×10^{-2}**
	(0.27)	**(1.2×10^{-2})**	**(8.7×10^{-3})**	**(4.1×10^{-3})**	**(4.7×10^{-3})**
hypertension	**800**	**9.6×10^{0}**	**7.0×10^{0}**	**3.3×10^{0}**	**3.8×10^{0}**
	(22)	**(9.6×10^{-1})**	**(7.0×10^{-1})**	**(3.3×10^{-1})**	**(3.8×10^{-1})**
residual urine determination	**350**	**4.2×10^{0}**	**3.0×10^{0}**	**1.4×10^{0}**	**1.6×10^{0}**
	(9.5)	**(4.2×10^{-1})**	**(3.0×10^{-1})**	**(1.4×10^{-1})**	**(1.6×10^{-1})**
^{99m}Tc DTPA Aerosol	**40**	**2.3×10^{-1}**	**1.7×10^{-1}**	**9.2×10^{-2}**	**1.2×10^{-1}**
	(1.1)	**(2.3×10^{-2})**	**(1.7×10^{-2})**	**(9.2×10^{-3})**	**(1.2×10^{-2})**
^{99m}Tc Glucoheptonate renal imaging	**750**	**9.0×10^{0}**	**8.2×10^{0}**	**4.0×10^{0}**	**3.4×10^{0}**
	(20)	**(9.0×10^{-1})**	**(8.2×10^{-1})**	**(4.0×10^{-1})**	**(3.4×10^{-1})**
brain imaging	**750**	**9.0×10^{0}**	**8.2×10^{0}**	**4.0×10^{0}**	**3.4×10^{0}**
	(20)	**(9.0×10^{-1})**	**(8.2×10^{-1})**	**(4.0×10^{-1})**	**(3.4×10^{-1})**
^{99m}Tc HDP	**750**	**3.9×10^{0}**	**4.10×10^{0}**	**2.3×10^{0}**	**1.9×10^{0}**
	(20)	**(3.9×10^{-1})**	**(4.0×10^{-1})**	**(2.3×10^{-1})**	**(1.9×10^{-1})**
^{99m}Tc HMPAO	750	6.5×10^{0}	5.0×10^{0}	3.6×10^{0}	2.7×10^{0}
	(20)	(6.5×10^{-1})	(5.0×10^{-1})	(3.6×10^{-1})	(2.7×10^{-1})
^{99m}Tc Human Serum Albumin	200	1.0×10^{0}	6.0×10^{-1}	5.2×10^{-1}	4.4×10^{-1}
	(5.5)	(1.0×10^{-1})	(6.0×10^{-2})	(5.2×10^{-2})	(4.4×10^{-2})
^{99m}Tc MAA hepatic artery perfusion	**150**	**4.2×10^{-1}**	**6.0×10^{-1}**	**7.5×10^{-1}**	**6.0×10^{-1}**
	(4)	**(4.2×10^{-2})**	**(6.0×10^{-2})**	**(7.5×10^{-2})**	**(6.0×10^{-2})**
lung imaging	**200**	**5.6×10^{-1}**	**8.0×10^{-1}**	**1.0×10^{0}**	**8.0×10^{-1}**
	(5.5)	**(5.6×10^{-2})**	**(8.0×10^{-2})**	**(1.0×10^{-1})**	**(8.0×10^{-2})**
isotopic venography	**220**	**6.2×10^{-1}**	**8.8×10^{-1}**	**1.1×10^{0}**	**8.0×10^{-1}**
	(6)	**(6.2×10^{-2})**	**(8.8×10^{-2})**	**$(1.1 \times 10^{-1}$**	**(8.0×10^{-2})**
LeVeen shunt patency	110	3.1×10^{-1}	4.4×10^{-1}	5.5×10^{-1}	4.4×10^{-1}
	(3)	(3.1×10^{-2})	(4.4×10^{-2})	(5.5×10^{-2})	(4.4×10^{-2})
^{99m}Tc MAG3	750	1.4×10^{1}	1.0×10^{1}	4.1×10^{0}	3.9×10^{0}
	(20)	(1.4×10^{0})	(1.0×10^{0})	(4.1×10^{-1})	(3.9×10^{-1})
^{99m}Tc MDP	**750**	**4.6×10^{0}**	**4.0×10^{0}**	**2.0×10^{0}**	**1.8×10^{0}**
	(20)	**(4.6×10^{-1})**	**(4.0×10^{-1})**	**(2.0×10^{-1})**	**(1.8×10^{-1})**
^{99m}Tc MIBI-rest	1100	1.7×10^{1}	1.3×10^{1}	9.2×10^{0}	5.9×10^{0}
	(30)	(1.7×10^{0})	(1.3×10^{0})	(9.2×10^{-1})	(5.9×10^{-1})
^{99m}Tc MIBI-stress	1100	1.3×10^{1}	1.0×10^{1}	7.6×10^{0}	4.8×10^{0}
	(30)	(1.3×10^{0})	(1.0×10^{0})	(7.6×10^{-1})	(4.8×10^{-1})

Table 5 (*continued*)

^{99m}Tc Pertechnetate brain imaging	**1100**	**1.2×10^{1}**	**2.4×10^{1}**	**1.5×10^{1}**	**1.0×10^{1}**
	(30)	**(1.2×10^{0})**	**(2.4×10^{0})**	**(1.5×10^{0})**	**(1.0×10^{0})**
thyroid imaging400	**4.4×10^{0}**	**8.8×10^{0}**	**5.6×10^{0}**	**3.7×10^{0}**	
	(11)	**(4.4×10^{-1})**	**(8.8×10^{-1})**	**(5.6×10^{-1})**	**(3.7×10^{-1})**
salivary gland imaging	**200**	**2.2×10^{0}**	**4.4×10^{0}**	**2.8×10^{0}**	**1.9×10^{0}**
	(5.5)	**(2.2×10^{-1})**	**(4.4×10^{-1})**	**(2.8×10^{-1})**	**(1.9×10^{-1})**
placental localization	**110**	**1.1×10^{0}**	**2.4×10^{0}**	**1.5×10^{0}**	**1.0×10^{0}**
	(3)	**(1.1×10^{-1})**	**(2.4×10^{-1})**	**(1.5×10^{-1})**	**(1.0×10^{-1})**
blood pool imaging	**1100**	**1.1×10^{1}**	**2.4×10^{1}**	**1.4×10^{1}**	**1.0×10^{1}**
	(30)	**(1.1×10^{0})**	**(2.4×10^{0})**	**(1.4×10^{0})**	**(1.0×10^{0})**
cardiovascular shunt detection	**550**	**6.0×10^{0}**	**1.2×10^{1}**	**7.7×10^{0}**	**5.1×10^{0}**
	(15)	**(6.0×10^{-1})**	**(1.2×10^{0})**	**(7.7×10^{-1})**	**(5.1×10^{-1})**
1st pass	**550**	**6.0×10^{0}**	**1.2×10^{1}**	**7.7×10^{0}**	**5.1×10^{0}**
	(15)	**(6.0×10^{-1})**	**(1.2×10^{0})**	**(7.7×10^{-1})**	**(5.1×10^{-1})**
^{99m}Tc PYP skeletal imaging	**550**	**3.3×10^{0}**	**3.6×10^{0}**	**2.0×10^{0}**	**1.6×10^{0}**
	(15)	**(3.3×10^{-1})**	**(3.6×10^{-1})**	**(2.0×10^{-1})**	**(1.6×10^{-1})**
cardiac imaging	**700**	**4.2×10^{0}**	**4.6×10^{0}**	**2.5×10^{0}**	**2.0×10^{0}**
	(19)	**4.2×10^{0}**	**4.6×10^{0}**	**2.5×10^{0}**	**2.0×10^{0}**
	(19)	**(4.2×10^{-1})**	**(4.6×10^{-1})**	**(2.5×10^{-1})**	**(2.0×10^{-1})**
^{99m}Tc RBC - in?vitro labeling	**930**	**6.3×10^{0}**	**4.4×10^{0}**	**3.2×10^{0}**	**2.6×10^{0}**
	(25)	**(6.3×10^{-1})**	**(4.4×10^{-1})**	**(3.2×10^{-1})**	**(2.6×10^{-1})**
^{99m}Tc RBC - in?vivo labeling rest	**550**	**3.5×10^{0}**	**2.4×10^{0}**	**1.8×10^{0}**	**1.5×10^{0}**
	(15)	**(3.5×10^{-1})**	**(2.4×10^{-1})**	**(1.8×10^{-1})**	**(1.5×10^{-1})**
exercise	**930**	**6.0×10^{0}**	**4.0×10^{0}**	**3.1×10^{0}**	**2.5×10^{0}**
	(25)	**(6.0×10^{-1})**	**(4.0×10^{-1})**	**(3.1×10^{-1})**	**(2.5×10^{-1})**
lower GI bleeding	**930**	**6.0×10^{0}**	**4.0×10^{0}**	**3.1×10^{0}**	**2.5×10^{0}**
	(25)	**(6.0×10^{-1})**	**(4.0×10^{-1})**	**(3.1×10^{-1})**	**(2.5×10^{-1})**
^{99m}Tc Sulfur Colloid-normal liver-spleen imaging	**300**	**5.4×10^{-1}**	**6.3×10^{-1}**	**9.6×10^{-1}**	**1.1×10^{0}**
	(8)	**(5.4×10^{-2})**	**(6.3×10^{-2})**	**(9.6×10^{-2})**	**(1.1×10^{-1})**
bone marrow imaging	**450**	**8.1×10^{-1}**	**9.5×10^{-1}**	**1.4×10^{0}**	**1.7×10^{0}**
	(12)	**(8.1×10^{-2})**	**(9.5×10^{-2})**	**(1.4×10^{-1})**	**(1.7×10^{-1})**
pulmonary aspiration	**20**	**3.6×10^{-2}**	**4.2×10^{-2}**	**6.4×10^{-2}**	**7.4×10^{-2}**
	(0.5)	**(3.6×10^{-3})**	**(4.2×10^{-3})**	**(6.4×10^{-3})**	**(7.4×10^{-3})**
LeVeen shunt patency	**110**	**2.0×10^{-1}**	**2.3×10^{-1}**	**3.5×10^{-1}**	**4.1×10^{-1}**
	(3)	**(2.0×10^{-2})**	**(2.3×10^{-2})**	**(3.5×10^{-2})**	**(4.1×10^{-2})**
^{99m}Tc Tetrofosmin	370	3.5×10^{0}	2.6×10^{-0}	2.0×10^{0}	1.3×10^{0}
	(10)	(3.5×10^{-1})	(2.6×10^{-1})	(2.0×10^{-1})	(1.3×10^{-1})
^{99m}Tc White Blood Cells	200	7.6×10^{-1}	5.6×10^{-1}	5.8×10^{-1}	5.6×10^{-1}
	(5.4)	(7.6×10^{-2})	(5.6×10^{-2})	(5.8×10^{-2})	(5.6×10^{-2})
^{201}Tl Chloride planar imaging	150	1.5×10^{1}	8.7×10^{0}	7.0×10^{0}	4.0×10^{0}
	(4)	(1.5×10^{0})	(8.7×10^{-1})	(7.0×10^{-1})	(4.0×10^{-1})
SPECT imaging	110	1.1×10^{1}	6.4×10^{0}	5.2×10^{0}	3.0×10^{0}
	(3)	(1.1×10^{0})	(6.4×10^{-1})	(5.2×10^{-1})	(3.0×10^{-1})
myocardial perfusion	55	5.3×10^{0}	3.2×10^{0}	2.6×10^{0}	1.5×10^{0}
	(1.5)	(5.3×10^{-1})	(3.2×10^{-1})	(2.6×10^{-1})	(1.5×10^{-1}
thyroid imaging	80	7.8×10^{0}	4.6×10^{0}	3.8×10^{0}	2.2×10^{0}
	(2.2)	(7.8×10^{-1})	(4.6×10^{-1})	(3.8×10^{-1})	(2.2×10^{-1})
^{133}Xe, injection muscle blood flow	20	9.8×10^{-5}	2.0×10^{-5}	2.8×10^{-5}	3.2×10^{-5}
	(0.5)	(9.8×10^{-6})	(2.0×10^{-6})	(2.8×10^{-6})	(3.2×10^{-6})
pulmonary function with imaging	1100	5.4×10^{-3}	1.1×10^{-3}	1.5×10^{-3}	1.8×10^{-3}
	(30)	(5.4×10^{-4})	(1.1×10^{-4})	(1.5×10^{-4})	(1.8×10^{-4})

urinary bladder, encouraging subjects to maintain a high hydration state and void their bladders frequently can reduce fetal dose. Lung scans are frequently used in pregnant and breast feeding women, as pulmonary embolism is the leading cause of mortality during maternity[16]. For a lung ventilation study, one may consider using ^{133}Xe gas instead of ^{99m}Tc-DTPA aerosol, as the latter is absorbed and some activity is excreted via the urinary pathway, while the former gives a very small dose to the fetus. If administering ^{99m}Tc-MAA, reducing the administered activity, by as much as one half, is advocated by some.

Table 6 Recommended breastfeeding interruption times for various radiopharmaceuticals[14]. ('No' means 'no interruption recommended. '>3 weeks' likely indicates cessation)

Radiopharmaceutical	Recommendation	Radiopharmaceutical	Recommendation
^{14}C-labelled		**Iodine-labeled**	
Triolein	No	^{123}I-BMIPP	>3 weeks
Glycocholic acid	No	^{123}I-HSA	>3 weeks
Urea	No	^{123}I-iodo hippurate	12 h
^{99m}Tc-labelled		^{123}I-IPPA	>3 weeks
DISDA	No	^{123}I-MIBG	>3 weeks
DMSA	No	^{123}I-NaI	>3 weeks
DTPA	No	^{125}I-HSA	>3 weeks
ECD	No	^{125}I-iodo hippurate	12 h
Phosphonates (MDP)	No	^{131}I-iodo hippurate	12 h
Gluconate	No	^{131}I-MIBG	>3 weeks
Glucoheptonate	No	^{131}I-NaI	>3 weeks
HM-PAO	No	**Others**	
Sulphur colloids	No	^{11}C-labelled	No
MAA	12 h	^{13}N-labelled	No
MAG3	No	^{15}O-labelled	No
MIBI	No	^{18}F-FDG	No
Microspheres (HAM)	12 h	^{22}Na	>3 weeks
Pertechnetate	12 h	^{51}Cr-EDTA	No
PYP	No	^{67}Ga-citrate	>3 weeks
RBC (in vivo)	12 h	^{75}Se-labelled agents	>3 weeks
RBC (in vitro)	No	^{81}mKr-gas	No
Technegas	No	^{111}In-octreotide	No
Tetrofosmin	No	^{111}In-WBC	No
WBC	12 h	^{133}Xe	No
		^{201}Tl-chloride	48 h

Summary

Due to the high radiosensitivity of the embryo/fetus, particular care is needed to avoid unwanted radiation exposures from any imaging modality. Radiopharmaceuticals carry the additional concern of radioactive compounds crossing the placenta and irradiating the fetus internally, as compared to external radiation sources such as x-rays. A combination of signage and questioning of women of childbearing years is usually adequate for diagnostic studies. In almost all cases, even involving multiple imaging studies with exposure of the abdomen (e.g. a CT scan and a ^{99m}Tc bone scan), doses from diagnostic studies will not result in doses above the known thresholds for causing deleterious effects in the fetus. For any kind of therapy administration, however, pregnancy testing is obligatory. The radionuclide of most concern is ^{131}I, due to its affinity for the thyroid, which is a small organ. Giving a therapeutic level of ^{131}I as NaI to a pregnant woman will likely result in the complete ablation of the fetal thyroid. Even if only using ^{131}I for a thyroid uptake scan, many institutions will ask for a pregnancy test. Many radiopharmaceuticals are also excreted in breast milk, and protection of the nursing infant is important. Again, the nuclide of highest concern is ^{131}I, but there are several other radiopharmaceuticals for which cessation of breast feeding is indicated, using a 1 mSv effective dose limit for exposure of the nursing infant. Relatively simple methods exist for avoiding unwanted radiation exposures, or minimizing dose to the embryo/fetus or nursing infant when a study must be performed on a pregnant or lactating woman.

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