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The pulmonologist's role in caring for pregnant women with regard to the reproductive risks of diagnostic radiological studies or radiation therapy.

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I. Introduction

Almost every practicing physician is aware that the utilization of diagnostic radiological techniques and radiation therapy utilizing ionizing radiation has increased substantially over the past 30 years.[1] In 1980 the USA population received 20% of their exposure to ionizing radiation from medical care. The National Council on Radiation Protection (NCRP) No. 160 (2009) reported that almost 50% of the population's radiation exposure came from medical care. Unfortunately, this increased exposure has been presented in the newspapers, television and internet and in many instances the risks of birth defects, miscarriage and cancer have been exaggerated and the benefits ignored. It is important for physicians to become as knowledgeable about the risks of ionizing radiation as they are about its benefits. Although pulmonologists do not concentrate their practice on pregnant women or women of reproductive age, these patients will be part of their practice. An important concern is that many women will visit their physician and not know they are pregnant, or worse, will become pregnant between the time of the office visit and the appointment for the radiological exam. These situations can be concerning for the patient and the physician. In order for the physician to interpret the various forms of exposure measurement Table 1 lists the various nomenclatures for radiation exposures so that the reader will be able to understand radiation exposures in the terms with which they may be familiar.

Pulmonologists are fortunate with regard to the specific studies they request in order to provide clinical care, since most of the diagnostic tests do not directly expose the uterus (embryo) or ovary. Radiography of the chest, head, neck, dental or extremity exposes the embryo or ovary to miniscule (insignificant) exposures of radiation. In some instances there is no exposure at all.

The pulmonologist may infrequently order diagnostic studies for a patient that exposes the abdomen or pelvis but should be aware of other studies that could have been ordered by other providers. Fortunately, the vast majority of diagnostic studies exposing the abdomen or pelvis expose the embryo or ovary to less than 10 rad (0.1 Gy)

II. The reproductive and developmental risks of exposures of ionizing radiation to pregnant or potentially pregnant women.

The reproductive and developmental risks of in utero exposures to ionizing radiation are listed below (Tables 2 and 3)

1) Birth defects, mental retardation, other neurobehavioral effects, growth retardation and embryonic death (miscarriage) are deterministic effects (Threshold effects). This indicates that these effects have a NOAEL (no adverse effect level). Almost all diagnostic radiological procedures provide exposures that are below the NOAEL for these developmental effects. Diagnostic radiological studies rarely exceed 10 rad (0.1 Gy), while the threshold for congenital malformations or miscarriage is > 20 rad (0.2 Gy). (Table 2).

2) In order for the embryo to be deleteriously affected by ionizing radiation when the mother is exposed to a diagnostic study, the embryo has to be exposed above the NOAEL to increase the risk of deterministic effects. This rarely happens when pregnant women have x-ray studies of the head, neck, chest or extremities.

3) During the pre-implantation and pre-organogenesis stages of embryonic development the embryo is least likely to be malformed by the effects of ionizing radiation because the cells of the very young embryo are omnipotent and can replace adjacent cells that have been deleteriously affected. This early period of development has been designated as "the all or none period."

4) Protraction and fractionation of exposures of ionizing radiation to the embryo decrease the magnitude of the deleterious effects of deterministic effects. The more protracted or fractionated the radiation the lower the risk because the threshold increases.

5) The increased risk of cancer following high level of exposures to ionizing radiation exposure in adult populations has been demonstrated in the survivors of atomic bomb. Radiation-induced carcinogenesis is assumed to be a stochastic effect (nonthreshold effect) so that there is theoretically a risk at low exposures. While there is no question that high-level exposures of ionizing radiation can increase the risk of cancer, the magnitude of the risk of cancer from embryonic exposures following diagnostic radiological procedures is controversial. Recent publications and analyses indicate that the risk is lower for the irradiated embryo than the irradiated child, which surprised many scientists interested in this subject (Tables 4- 6)[2].

III. Evaluating the risks of radiation exposure to the developing embryo

When evaluating the risks of ionizing radiation, the physician is faced with several different clinical situations:

Situation 1

The pulmonologists are very fortunate because the radiological tests that would be ordered for their patients will not expose the embryo directly and therefore the embryo will not receive an exposure that would increase the embryo's risk for birth defects, miscarriage, growth retardation, mental retardation or neural behavioral effects (Table 7). Table 7 lists many frequently used diagnostic radiological and radionuclide tests. Note that none of the tests exceed exposures of 10 rad (0.1 Gy or 100 mGy) except for radiation therapy or extensive fluoroscopy to the abdomen or pelvis.

Although most diagnostic radiological studies of the abdomen or pelvis do not expose the embryo to more than 10 rad (0.10 Gy), the family is upset because they are aware that the embryo was directly exposed. Under these circumstances it may be necessary to request the Health Physicist to calculate the actual exposure in order to be able to allay the family's concern with the actual exposure.

Situation 2

The pregnant patient presents with clinical symptoms that need to be evaluated. What is the appropriate utilization of diagnostic radiological procedures that may expose the embryo or fetus to ionizing radiation?

A pregnant or possibly pregnant woman complaining of chest symptoms that cannot be attributed to pregnancy deserves the appropriate studies to diagnose and treat her clinical problems, including radiological studies. Furthermore, these studies should not be relegated to one portion of the menstrual cycle if she has not yet missed her period. The studies should be performed at the time they are clinically indicated whether or not the woman is in the first or second half of the menstrual cycle. During the 2nd half of the menstrual cycle the pregnancy test may be negative even though the patient is pregnant. This should be explained to the patient and family.

Situation 3

A patient has completed a diagnostic procedure that has exposed her uterus to ionizing radiation. Her pregnancy test result was negative. She believes she was pregnant at the time of the procedure. What is your response to this situation?

Explain that you would have proceeded with the necessary radiological diagnostic test whether the patient was pregnant or not because diagnostic studies that are indicated in the patient have to take priority over the possible risk to her embryo; however, almost 100% of

diagnostic studies do not increase the risks to the embryo (Table 1). Second, she must have been very early in her pregnancy because her pregnancy test result was negative. At this time, obtain the calculated dose to the embryo and determine her stage of pregnancy. If the dose is below 10 rad (0.1 Gy; 0.1 Sv), you can inform the patient that her risks for birth defects and miscarriage have not been increased. In fact, the threshold for these effects is 20 rad (0.2Gy) at the most sensitive stage of embryonic development (Table 2). Of course, you are obligated to tell her that every healthy woman is at risk for the background incidence of birth defects and miscarriage, which is 3% for birth defects and 15% for miscarriage (Table 3).

Situation 4

A woman delivers a baby with serious birth defects. On her first postpartum visit, she recalls that she had a diagnostic X-ray study early in her pregnancy. What is your response when she asks you whether the baby's malformation could be caused by the radiation exposure?

In most instances, the nature of the clinical malformations will rule out radiation teratogenesis (microcephaly, mental retardation and fetal growth retardation). In such a case, a clinical teratologist or radiation embryologist could be of assistance. On the other hand, if the exposure is below 10 rad (0.1 Gy), it would not be scientifically supportable to indicate that the radiation exposure was the cause of the malformation. The threshold for malformations is 20 rad (0.20 Gy) (Table 2). The dose, timing, and nature of the malformation are considered in this analysis.

To appropriately and more completely respond to these questions, the physician should rely on the extensive amount of available information on the effects of radiation on the embryos. In fact, there is no environmental hazard that has been more extensively studied or on which more information is available (Tables 2 and 4).[3-12]

IV. Radiation risks to the embryo

An acute exposure to ionizing radiation more than 50 rad represents a significant risk to the embryo, regardless of the stage of gestation. [6-9, 12, 13] The threshold dose for low energy transfer ionizing radiation that results in an increase in malformations is approximately 20 rad (0.2 Gy) (Table 2). Although congenital malformations are unlikely to be produced by radiation

during the first 14 days of human development, there would be a substantial risk of embryonic loss if the dose is high. From approximately the 18th day to the 40th day postconception, the embryo would be at risk for an increased frequency of anatomic malformations if the radiation exposure exceeds 20-25 rad (0.2-0.25 Gy). Until about the 15th week, the embryo has an increased susceptibility to central nervous system (CNS) effects, major CNS malformations early in gestation and mental retardation in midgestation. Of course, with very high doses, in the hundreds of rads, mental retardation can occur in the later part of gestation. Although it is true that the embryo is vulnerable to the deleterious effects of these midrange exposures of ionizing radiation, the measurable effects fall off rapidly as the exposure approaches the usual levels that the embryo receives from diagnostic radiologic procedures (<10 rad; 0.1 Gy). The threshold of 20 rad (0.2 Gy) at the most vulnerable stage of development (20-25 days post conception) is increased by protraction of the radiation exposure. If a pregnant woman had a series of radiographic analyses over a period of three to four days that totaled 15 rad (0.15 Gy), there would be no increased risk for any of the developmental threshold (deterministic) effects.[6,12,13] The recommendations of most radiation embryologists indicate that exposures in the diagnostic range will not increase the risk of birth defects or miscarriage.[6.8.9.12] Table 4 compares the spontaneous risks facing an embryo at conception and the risks from a low exposure of ionizing radiation (10 rad; 100 mGy 10,000 mrad).

Therefore, the hazards of exposures in the range of diagnostic roentgenology (20-10,000 mrad [0.2mGy-0.1 Gy]) present an extremely low risk to the embryo when compared with the spontaneous mishaps that can befall human embryos (Table 3 and 4). Approximately 30-40 % of human embryos abort spontaneously (many abort before the first missed menstrual period) Table 3. Human infants have a 3 % major malformation rate at term that increases to approximately 6% to 8 % once all minor malformations are recorded. Although doses of 1-3 rad (0.01-0.03 Gy) can

produce cellular effects and the fact that diagnostic radiation exposure during pregnancy has been associated with malignancy in childhood, the maximum theoretical risk to human embryos exposed to doses of 10 rads or less is extremely small. When the data and risks are explained to the patient, the family with a wanted pregnancy invariably continues with the pregnancy.

A frequent difficulty is that the risks from diagnostic radiation are evaluated outside the context of the significant normal risks of pregnancy. Furthermore, many physicians approach the evaluation of diagnostic radiation exposure with either of two extremes: a cavalier attitude or panic. The usual procedures in clinical medicine are ignored, and an opinion based on meager information is given to the patient. Frequently, this attitude reflects the physician's bias about radiation effects or his or her ignorance of radiation biology. We have patient records in our files of scores of patients who were not properly evaluated but were advised to have an abortion following radiation exposure. The following case history is an example.

V. Case report

A 33 year old woman was diagnosed with breast cancer and radiation therapy of the breast was initiated. Four weeks into her therapy it was discovered that she was 11 weeks pregnant. The oncologist, radiation therapist and surgeon all encouraged the future mother and family to abort the pregnancy. She already had received 3800 rads (3.8 Gy) to the breast. The family asked for another opinion and our counseling service was contacted. The health physicist at the consultee institution had calculated that the fetus had received 50 rads over a period of almost 4 weeks. On each day of therapy the fetus had received 0.9 rad. Each week the fetus had 2 days without being exposed. The future mother’s physicians still suggested a therapeutic abortion, but with less certainty. They asked me what I would tell her. I said that “I would not tell her anything. I wanted to talk with her.”

When we were able to talk, she immediately asked what should I do? I responded, "Do you have any questions? She asked, "Could my baby be malformed"? I told her that 3 % of babies are malformed. That is the background incidence, but in her case the fetus's risks for major birth defects were not increased for two reasons. The radiation was initiated in the seventh week after all the organs had formed and more important the dose each day was too low to produce malformations at any stage of pregnancy. Then she asked whether her baby could be severely mentally retarded. I answered her in the negative. But I also had to tell her that one in 200 children is born mentally retarded. She then asked whether the baby could be growth retarded. I responded that 4% of newborns are growth retarded, but that the radiation exposure would not cause significant growth retardation. Finally, she asked, could my baby be normal? I said, "Yes."

The mother decided to keep the pregnancy and she delivered a 6 pound 11 ounce baby boy who was physically normal and has been developing, according to the mother, "very normally."

VI. Evaluating the patient

Case histories are transmitted to our laboratory frequently. In 2008, we had 2,200,000 hits on our pregnancy website of the Health Physics Society, "Ask the Expert". There were 760,000 downloads and 1646 direct consultations. In most instances the dose to the embryo is < 10 rads (0.1 Gy) and frequently is < 1 rad (.01 Gy). Our experience has taught us that there are many variables involved in radiation exposure to a pregnant or potentially pregnant woman. Therefore, there is no routine or predetermined advice that can be given in this situation. However, if the physician takes a systematic approach for the evaluation of the possible effects of radiation exposure, he/she can help the patient make an informed decision about continuing the

pregnancy. This systematic evaluation can begin only when the following information has been obtained:

- Stage of pregnancy at the time of exposure
- Menstrual history
- Previous pregnancy history
- Family history of congenital malformations, miscarriages
- Other potentially harmful environmental factors during the pregnancy
- Ages of the mother and father
- Type of radiation study, dates and number of studies performed
- Calculation of the embryonic exposure by a medical physicist or competent radiologist
- Status of the pregnancy: wanted or unwanted

The evaluation should be concluded, with both patient and counselor arriving at a decision. The physician should place a summary of the following information in the medical record. It should state that the patient has been informed that every pregnancy has a significant risk of problems and that the decision to continue the pregnancy does not mean that the counselor is guaranteeing the outcome of the pregnancy. The use of amniocentesis and ultrasound to evaluate the fetus is an individual decision that would have to be made in each pregnancy.

Each consultation should include the following statement. “If you are healthy, young (under 35) and have no personal or family history of reproductive or fetal developmental problems, then you began this pregnancy with a risk of 3% for birth defects and 15% for miscarriage. These are background risks faced by all pregnant women. Good luck with this pregnancy and keep in touch.”

VII. The Carcinogenic effects of radiation

The carcinogenic risks of in-utero radiation is an important topic that cannot be addressed adequately in this article. In 1956, Stewart et al. (13) published the results of her case control studies indicating the diagnostic radiation from pelvimetry was associated with a 50% increased risk of childhood leukemia (Table 4). That would change the risk of childhood leukemia from 40 cases per million to 60 cases per million in the population of exposed fetuses. This has been a very controversial subject. [12-17 S]A recent publication by Preston et al. (2) presented data from the in utero population of the A-bomb survivors which indicated that the embryo was less vulnerable to the oncogenic effects of ionizing radiation than the child. It appears that the embryo is much less vulnerable to the oncogenic effects of radiation than previous investigators have believed. Patients can be told that the fetal risk is extremely small, so small that we cannot measure the risks because such a large exposed population would be necessary (Tables 3, 4 and 5). Even if one accepts the controversial concept that the embryo is more vulnerable to the carcinogenic effects of radiation than the child, the risk at these low exposures is much, much smaller that the spontaneous risks (1). Furthermore, other studies indicate that Stewart's (13) estimate of the risk involved is exaggerated. [10-11, 15-17]

VIII. Diagnostic or therapeutic abdominal radiation in women of reproductive age

In women of reproductive age, it is important for the patient and physician to be aware of the pregnancy status of the patient before performing any type of X-ray procedure in which the ovaries or uterus will be exposed. If the embryonic exposure will be 10 rad (0.1 Gy) or less, the radiation risks to the embryo are very small when compared with the spontaneous risks (Tables 2-5). Even if the exposure is 10 rad (0.1 Gy), this exposure is far from the threshold or no-effect dose of 20 rad. The patient will accept this information if it is offered as part of the preparation for the radiological studies at a time when both the physician and patient are aware that a

pregnancy exists or may exist. The pregnancy status of the patient should be determined and noted.

Because the risks of 10-rad (0.1 Gy) fetal irradiation are so small, the immediate medical care of the mother should take priority over the risks of diagnostic radiation exposure to the embryo. Radiological studies that are essential for optimal medical care of the mother and evaluation of medical problems that need to be diagnosed or treated should not be postponed. Elective procedures such as employment examinations or follow-up examinations, once a diagnosis has been made, need not be performed on a pregnant woman even though the risk to the embryo is very small. If other procedures (e.g., magnetic resonance imaging or ultrasound) can provide adequate information without exposing the embryo to ionizing radiation, then of course they should be used. Naturally, there is a period when the patient is pregnant but the pregnancy test is negative and the menstrual history is of little use. However, the risks of exposure to 10 rad (0.1 Gy) or less are extremely small during this period of gestation (all or none period,[4] first two weeks). The patient will benefit from knowing that the diagnostic study was indicated and should be performed in spite of the fact that she may be pregnant.

IX. Scheduling the examination

When elective radiological studies need to be scheduled, it is difficult to know whether to schedule them during the first half of the menstrual cycle just before ovulation or during the second half of the menstrual cycle, when most women will not be pregnant. The genetic risk of diagnostic exposures to the oocyte or the embryopathic effects on the preimplanted embryo are extremely small, and there are no data available to compare the relative risk of 10 rad (0.1 Gy) to the oocyte or the preimplanted embryo. If the diagnostic study is performed in the first 14 days of the menstrual cycle, the patient should be advised to defer conception for several months, based

on the assumption that the deleterious effect of radiation to the ovaries decreases with increasing time between radiation exposure and a subsequent ovulation? The physician is in a quandary because he may be warning the patient about a very-low-risk phenomenon. On the other hand, avoiding conception for several months is not an insurmountable hardship. This potential genetic hazard is quite speculative for man, as indicated by the report by the NCRP and BEIR committee report dealing with preconception radiation[1, 6]

> "It is not known whether the interval between irradiation of the gonads and conception has a marked effect on the frequency of genetic changes in human offspring, as has been demonstrated in the female mouse. Nevertheless, it may be advised for patients receiving high doses to the gonads (>25 rads) to wait for several months after such exposures before conceiving additional offspring." [3].

Because the patients exposed during diagnostic radiologic procedures absorb considerably less than 25 rads, the recommendations made here may be unnecessary, but it involves no hardship to the patient. Because both the NCRP and ICRP have previously recommended that elective radiologic examinations of the abdomen and pelvis be performed during the first part of the menstrual cycle (10-day rule, 14-day cycle) to protect the zygote from possible but largely conjectural hazards, the recommendation to avoid fertilization of recently irradiated ova perhaps merits equal attention.

X. Importance of determining pregnancy status of patient

If exposures less than 10 rads (0.1 Gy) do not measurably affect the exposed embryos, and it is recommended that diagnostic procedures should be performed at any time during the menstrual cycle, if necessary, for the medical care of the patient, then the question of expending energy to determine the pregnancy status of the patient arises.

There are several reasons why the physician and patient should share the burden of determining the pregnancy status before performing a radiological or nuclear medicine procedure that exposes the uterus:

1. If the physician is forced to include the possibility of pregnancy in the differential diagnosis, a small percentage of diagnostic studies may no longer be considered necessary. Early symptoms of pregnancy may mimic certain types of gastrointestinal or genitourinary disease.

2. If the physician and patient are both aware that pregnancy is a possibility and the procedure is still performed, it is much less likely that the patient will be upset if she subsequently proves to be pregnant.

3. The careful evaluation of the reproductive status of women undergoing diagnostic procedures will prevent many unnecessary lawsuits. Many lawsuits are stimulated by the factor of surprise. In some instances, the jury is not concerned with cause and effect but with the fact that something was not done properly by the physicians. [18, 19] In this day and age, failure to communicate adequately can be interpreted as less-than-adequate medical care. Both these factors are eliminated if the patient's pregnancy status has been evaluated properly and the situation discussed adequately with the patient. Physicians are going to have to learn that practicing good technical medicine may not be good enough in a litigation-prone society. Even more important, the patient will have more confidence if the decision to continue the pregnancy is made before the medical radiological procedure is performed, because the necessity of performing the procedure would have been determined with the knowledge that the patient was pregnant. In every consultation dealing with the exposure of the embryo to diagnostic studies involving ionizing radiation (radiography, computed tomography, use of radionuclides) in which the reproductive risks or developmental risks for a fetus have not been increased by the radiation exposure, the patient should be informed that every healthy woman with a negative personal and

genetic family reproductive history has background reproductive risks which are 3% for birth defects and 15% for miscarriage. these background risks cannot be changed.

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Table 1

Ionizing radiation Exposure Terminology*

rad (rem)	millirad; millirem	Gray (Gy)	Sievert (Sv)
0.001	1	0.01 mGy	0.01 mSv
0.01	10	0.1 mGy	0.1 mSv
0.1	100	1 mGy	1 mSv
1	1000	0.01 mGy	0.01 Sv
10	10,000	0.1 mGy	0.1 Sv
100	100,000	1 Gy	1 Sv

* The rad and the rem, and the Gray and Sievert are identical for exposures of low energy transfer (LET) radiation, i.e, x-rays, gamma rays, beta rays, and protons. These forms of radiation have a Relative Biological Effectiveness (RBR) rated at one. Exposures to alpha rays and neutrons have a biological effectiveness greater than one. The rem and the Sievcert take into consideration the RBE of the radiation. For clinicians, the RBE is infrequently relevant, because most radiological procedures utilize radiation with an RBE of 1 so the Gray and Sievert exposures will be identical.

Table 2. Radiation effects at different stages of gestation*

Stage, Gestation Weeks	Effect
First and second weeks post last menstrual period.(LMP) (Prior to conception)	First two weeks post first day of the last menstrual period. This is preconception radiation. Mother has not yet ovulated
Third and fourth week of gestation (First two weeks post conception)	Minimum human acute lethal dose (from animal studies). Approximately 0.15-0.20 Gy. Most sensitive period for the induction of embryonic death. No increase risk of malformations in surviving fetuses. "All or none stage"
Fourth to eighth week of gestation (Second to sixth week post conception)	Minimum lethal dose (from animal studies). At 18 day post conception = 0.25 Gy (25 rad). After 50 days post conception >0.50 Gy (50 rad). Embryo is vulnerable to the induction of major malformations. Threshold for malformations > 0.2 Gy to 0.5 Gy, depending on the malformation. Minimum dose for growth retardation. At 18-36 days = 0.20-0.50 Gy (20 rad-50 rad). At 36-110 days = 0.25-0.50 Gy.(25 to 50 rad) But the induced growth retardation during this period is not as severe as during mid-gestation (8-15 wks) from similar exposures and is more recuperable (Rugh, 1962).
Eighth to fifteenth week of gestation	Most sensitive period for irreversible whole body growth retardation, microcephaly and severe mental retardation. Threshold for severe metal retardation is0.35 to 0.50 Gy (35-50 rad). Miller believes the threshold is > 0.5 Gy. Decrease in I.Q can occur at lower exposures.
Sixteenth week to term of gestation	Higher exposures can produce growth retardation and decreased brain size and intellect, although the effects are not as severe as occurs from similar exposures during mid-gestation. No documented risk for major anatomical malformations. Minimum lethal dose threshold for mental retardation (from animal studies) from 15 weeks to term > 1.5 Gy (150 rad) but decrease in I.Q. can occur at lower exposures

*Radiation exposure and risk at different gestational phases. There is no evidence that radiation exposure in the diagnostic ranges (<0. 10 Gy, <10 rad) is associated with measurably increased incidence of congenital malformation, stillbirth, miscarriage, growth retardation or mental retardation.

Table 3 Reproductive risks per million recognized pregnancies

Reproductive Risks	Frequency
Immunologically & clinically diagnosed spontaneous abortions per million conceptions (< 20% has lethal malformations or chromosome abnormalities that cause abortion before the first month of gestation).	350,000
Clinically recognized spontaneous abortions per million clinically recognized pregnancies. Spontaneous abortion after the first missed menstrual period.	150,000
Genetic Diseases per million births	110,000
Multifactoral or polygenic genetic environmental interactions)	90,000
Dominantly inherited disease	10,000
Autosomal and sex-linked genetic disease	1,200
Cytogenetic (chromosomal abnormalities)	5,000
New mutations in the developing ova or sperm prior to conception	3,000
Major malformations (genetic, unknown, environmental)	30,000
Prematurity (Ireland 55,000; United States 124,000	69,000
Fetal growth retardation	30,000
Stillbirths (>20 wk.)	4,000-20,900
Infertility	7% of couples

Brent 1999

Table 4 **Risk of 10 rad (0.1 Gy) to Embryo***		
Risk	Background Incidence	Additional risk of 10 rad (0.1 Gy) exposure
Risk of very early pregnancy loss, before, the first missed period	$350{,}000/10^6$ pregnancies	0
Risk of spontaneous abortion in a known pregnant women	$150{,}000/10^6$ pregnancies	0
Risk of major congenital malformations	$30{,}000/10^6$	0
Risk of severe mental retardation	$5{,}000/10^6$	0
Risk of childhood leukemia/year	$40/10^6$ /year	Very low increased risk, and possibly no measurably identifiable increased risk
Risk of early- or late-onset genetic disease	$100{,}000/10^6$	Very low risk is in next generation
Prematurity	$69{,}000/10^6$ pregnancies	0
Growth retardation	$30{,}000/10^6$ pregnancies	0
Stillbirth	$20\text{-}2000/10^6$ pregnancies	0
Infertility	7% of couples	0

Table 5				
Follow-up of adults with solid cancers in Hiroshima and Nagasaki who were in utero at the time of detonation of the A-bombs in 1945				
Results published in March 2008 (Preston et al 2008)				
Dose in Sv (rads)	No. of patients	No. of Cancers	Person years	% with solid Cancers
<0.005 (<0.5)	1547	54	49,326	3.5
0.005-<0.1 (0.5 to 10)	435	16	14,005	3.7
0.1 to <0.2 (10 to <20)	168	6	5041	3.6
0.2 to <0.5 (20 to <50)	172	8	5496	4.6
0.5 to <1.0 (50 to <100)	92	7	2771	7.6
>1.o	48	3	1404	6.2
Total	2452	94	94	3.5

Table 6				
Follow-up of adults with solid cancers in Hiroshima and Nagasaki who were in children at the time of detonation of the A-bombs in 1945				
Results published in March 2008 (Preston et al 2008)				
Dose in Sv (rads)	No. of patients	No. of Cancers	Person years	% of Cancers
<0.005 (<0.5)	8549	318	247,744	3.7
0.005-<0.1 (0.5 to 10)	4528	173	134,621	3.8
0.1 to <0.2 (10 to <20)	853	38	25,802	4.4
0.2 to <0.5 (20 to <50)	859	51	25,722	5.9
0.5 to <1.0 (50 to <100)	325	21	9522	6.5
>1.0	274	48	7620	17.5
Total	15388	649	451,031	4.2

Table 7. Typical doses for selected medical procedures

Type	Description	Embryo/Fetal Dose Range (mGy)	Gonadal Dose (mGy) (Ovaries, Testes)
x-ray	Skull	<0.01	<0.01, <0.01
x-ray	Chest	<0.01	<0.01, <0.01
x-ray	Thoracic spine	<0.01	<0.01, <0.01
x-ray	Mammography	<0.01	<0.01, <0.01
x-ray	Barium meal	0.1-1.1	
x-ray	Pelvis	0.1-1.1	1.2, 4.6
x-ray	Lumbar spine	1-2	4.3, 0.6
x-ray	Abdomen	1-3	2.2, 0.4
x-ray	Barium enema	7-8	16, 3.4
CT	Chest /CTPA	0.1-1	0.08, <0.01
CT	Abdomen	4-16	8.0, 0.7
CT	Pelvis	10-32	23, 1.7
Chest fluoroscopy	Chest	<0.1 mGy/min	
IR fluoroscopy	Abdominal fluoro	6 mGy/min	
Nuc Med	Lung ventilation	0.1-0.3	0.13-0.5, 0.13-0.5
Nuc Med	Lung perfusion	0.1-0.4	0.06-0.27, 0.04-0.16
Nuc Med	White cell scan	0.7-1.4	
Nuc Med	Renal scan	3-7	1.0-2.0, 0.7-1.4
Nuc Med	Bone scan	4.5-7	2.7-4.0, 1.8-2.7
Nuc Med	Cerebral blood flow	5-10	3.7-7.3, 1.3-2.7
Nuc Med	PET	8-16	5.6-11.1, 4.4-8.8
Nuc Med	Myocardial perfusion	16.7-22.2	9.3-12.4, 2.7-3.6
Nuc Med	Therapy	>50	31, 19