



DRAFT REGULATORY GUIDE DG-8011
RADIATION DOSE TO THE EMBRYO/FETUS

A. INTRODUCTION

Section 20.1208 of 10 CFR Part 20, "Standards for Protection Against Radiation," requires that each licensee ensure that the dose to an embryo/fetus during the entire pregnancy, from occupational exposure of a declared pregnant woman, does not exceed 0.5 rem (5 mSv). Paragraph 20.1208(b) requires the licensee to make efforts to avoid substantial variation above a uniform monthly exposure rate to a declared pregnant woman that would satisfy the 0.5 rem limit. The dose to the embryo/fetus is to be the sum of (1) the deep-dose equivalent to the declared pregnant woman (10 CFR 20.1208(c)(1)) and (2) the dose to the embryo/fetus from radionuclides in the embryo/fetus and radionuclides in the declared pregnant woman (10 CFR 20.1208(c)(2)).

This guide is being developed to provide guidance on calculating the radiation dose to the embryo/fetus.

Any information collection activities mentioned in this draft regulatory guide are contained as requirements in 10 CFR Part 20, which provides the regulatory basis for this guide. The information collection requirements in 10 CFR Part 20 have been cleared under OMB Clearance No. 3150-0014.

B. DISCUSSION

Revision 2 of Regulatory Guide 8.13, "Instruction Concerning Prenatal Radiation Exposure," provides instructions concerning prenatal radiation exposure. Its main purpose is to ensure that workers are informed of the increased

This regulatory guide is being issued in draft form to involve the public in the early stages of the development of a regulatory position in this area. It has not received complete staff review and does not represent an official NRC staff position.

Public comments are being solicited on the draft guide (including any implementation schedule) and its associated regulatory analysis or value/impact statement. Comments should be accompanied by appropriate supporting data. Written comments may be submitted to the Regulatory Publications Branch, DFIPS, Office of Administration, U.S. Nuclear Regulatory Commission, Washington, DC 20555. Copies of comments received may be examined at the NRC Public Document Room, 2120 L Street NW., Washington, DC. Comments will be most helpful if received by May 4, 1992.

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radiosensitivity of the embryo/fetus. The mammalian embryo/fetus is more susceptible to radiation injury than is the adult. The stage of gestation at exposure and the rate at which radiation is delivered affect the nature and severity of the induced effects. In the first 8 to 15 weeks of pregnancy, the fetus is most sensitive to radiation. The primary effects from radiation during this period are seen in the central nervous system. This stage includes the time period in which a woman might be unaware of her pregnancy.

The 1987 report by the National Council on Radiation Protection and Measurements (NCRP), "Recommendations on Limits for Exposure to Ionizing Radiation" (Ref. 1), recommends a total dose equivalent limit of 0.5 rem for the embryo/fetus, with a further limitation of 0.05 rem per month once the pregnancy becomes known. The 1987 Federal radiation protection guidance for occupational exposure (Ref. 2) specifies a dose equivalent limit of 0.5 rem to the unborn child during the entire gestation period if the pregnancy has been declared by the mother. The Federal guidance also recommends that substantial variations in the monthly rate of exposure be avoided. The limits in 10 CFR 20.1208 adopt both the recommended dose equivalent limit and the guidance on variations in the monthly rate of exposure.

Calculating the radiation dose to the embryo/fetus from internally deposited radionuclides requires quantitative information about maternal radionuclide intake, placental transfer and kinetics, and resulting embryo/fetus radionuclide concentrations. Intakes of radioactive material occurring prior to the pregnancy may also be important if these materials remain in the pregnant woman during all or part of the gestation period. Transfer kinetics from the mother to the embryo/fetus are modelled as a function of stage of pregnancy, route of intake by the pregnant woman, and time after intake. The stage of gestation (or fetal development) is an important parameter in estimating radionuclide concentrations in the embryo/fetus. The geometry of the embryo/fetus (i.e., organ size and weight) affects the radionuclide dosimetry.

It is recognized that calculation of prenatal radiation doses from internally deposited radionuclides has many associated difficulties, including a lack of quantitative information about prenatal radionuclide concentrations and transfer across the placenta. The International Commission on Radiological Protection (ICRP) in Publication 56 (Ref. 3) stated that, for most radionuclides, preliminary estimates from dosimetric and biokinetic models indicate that the dose to the embryo can be approximated by the dose to the uterus.

The dose to the fetus is dependent upon the activity present in both fetal and maternal tissues. ICRP Publication 56 (Ref. 3) also states that, for most radionuclides, the dose to fetal tissue will be similar to or less than the dose to the corresponding maternal tissues.

The current methods available for assessing the radiation dose to the human embryo/fetus from internally deposited radioactive materials in the pregnant woman are subject to a number of uncertainties. NUREG/CR-5631, "Contribution of Maternal Radionuclide Burdens to Prenatal Radiation Dose - Interim Recommendations" (Ref. 4), provides recommendations and methods for estimating the radiation doses to the embryo/fetus from internal radionuclides. In NUREG/CR-5631, a number of radionuclides were evaluated. To expedite efforts, the initial evaluation was directed to those radionuclides that were expected to be of greatest significance for prenatal exposure in the work environment. The radionuclides that were identified and included were ^3H , ^{14}C , ^{57}Co , ^{58}Co , ^{60}Co , ^{89}Sr , ^{90}Sr , ^{106}Ru , ^{125}I , ^{131}I , ^{132}I , ^{133}I , ^{134}I , ^{135}I , ^{134}Cs , ^{137}Cs , ^{233}U , ^{234}U , ^{235}U , ^{238}U , ^{238}Pu , ^{239}Pu , and ^{241}Am . The methods of NUREG/CR-5631 are considered interim as efforts continue to further develop the bases and calculational methods for estimating prenatal radiation doses. The details of the data and bases for determining the dosimetric features used in NUREG/CR-5631 can be found in Reference 4.

It is expected that the embryo/fetus dose assessment methods will evolve over the next several years as more research is conducted in this area. As additional research is conducted, better estimates of actual embryo/fetus doses resulting from the exposure of the declared pregnant woman will be possible. For internal doses, research that categorizes the degree of placental transfer, the resulting embryo/fetus/placenta concentrations, and the potential radiation exposures of the embryo/fetus from radionuclides in their more usual chemical forms should simplify assessment of the dose to the embryo/fetus based on the maternal exposure. The ICRP is considering the formulation of dose assessment methods specific for the embryo/fetus. Because of the developing scientific information, the NRC staff seeks detailed technical comments on the utility or difficulty of the methodologies presented in this guide on determination of the dose to the embryo/fetus.

This regulatory guide provides a means for licensees to determine when the dose to the embryo/fetus needs to be evaluated. For internal exposure, a simplified approach and a more detailed methodology are presented for conducting dose evaluation. This guide provides guidance on threshold criteria for

when the dose to the embryo/fetus needs to be determined in Regulatory Position 1. Regulatory Position 2 presents a simplified approach for estimating the dose to the embryo/fetus from intakes by the declared pregnant woman. Regulatory Position 3 provides an alternative, more detailed methodology for a limited number of radionuclides, utilizing the gestation time-dependent dosimetric data from NUREG/CR-5631 (Ref. 4). A graded approach to determining when to evaluate, with both a simple and more detailed dose assessment methodology, is provided. It is recognized that some licensees will only need to demonstrate that the dose to the embryo/fetus is not likely to exceed the monitoring threshold of 10 CFR 20.1502, while other licensees may need to determine an embryo/fetus dose for demonstrating compliance with the dose limit of 10 CFR 20.1208 and the recordkeeping requirements of 10 CFR 20.2106(e).

The total radiation dose to the embryo/fetus is limited by placing more stringent restrictions on the exposure of the declared pregnant woman than on other members of the occupational work force. As specified in 10 CFR 20.1208(a), the dose to the embryo/fetus from occupational exposure of the declared pregnant woman must not exceed 0.5 rem. In addition, the licensee is required to make efforts such that the maximum dose rate does not vary markedly from a uniform monthly rate throughout the period of gestation. If the dose to the embryo/fetus is found to have exceeded 0.5 rem, or is within 0.05 rem of this dose, by the time the woman declares the pregnancy to the licensee, the licensee is required to limit the additional dose to the embryo/fetus to 0.05 rem during the remainder of the pregnancy.

Guidance on monitoring requirements and methods for summation of internal and external occupational doses needed for demonstrating compliance with the dose limits of 10 CFR 20.1208 is being developed in a separate regulatory guide.

C. REGULATORY POSITION

1. CRITERIA FOR DETERMINING DOSE TO THE EMBRYO/FETUS

1.1 Monitoring

The dose equivalent to the embryo/fetus should be determined based on the monitoring of the declared pregnant woman as required by 10 CFR 20.1502. This

dose determination is not required when monitoring of the declared pregnant woman is not required.

External monitoring of the declared pregnant woman should be performed for determining the external dose to the embryo/fetus if the declared pregnant woman is likely to receive a deep-dose equivalent in excess of 0.05 rem for the entire gestation period.

Monitoring the intake of radionuclides by the declared pregnant woman should be performed for determining an internal dose to the embryo/fetus if the intakes by the declared pregnant woman are likely to exceed 1% of the stochastic ALIs during the gestation period. According to 10 CFR 20.1502(b)(2), the licensee must monitor the occupational intakes of radioactive material for the declared pregnant woman if her intake is likely to exceed, in 1 year, a committed effective dose equivalent in excess of 0.05 rem (0.5 Msv). The position that the dose to the embryo/fetus be determined if the intake exceeds 1% of ALI is based on this same threshold. This threshold will ensure that any potentially significant exposures to the embryo/fetus are evaluated and, as appropriate, doses are determined.

1.2 Evaluation of Dose to the Embryo/Fetus

The dose to the embryo/fetus should be evaluated by determining the embryo/fetus dose equivalent for the duration of the pregnancy. An assessment of the 50-year committed dose is not required. Also, it is not appropriate to use effective dose equivalent or committed effective dose equivalent. (Note: the committed dose equivalent to the uterus may be applied to the embryo/fetus under certain conditions as a simplified approach as specified in Regulatory Position 2.)

1.3 External Dose to the Embryo/Fetus

As specified in 10 CFR 20.1208(c)(1), the external dose to the embryo/fetus is to be taken to be equal to the deep dose equivalent to the declared pregnant woman. The external dose should consider all occupational exposures of the declared pregnant woman since the estimated date of conception. The deep-dose equivalent that should be assigned is that dose that would be most representative of the exposure of the embryo/fetus (e.g., in the lower torso region). If multiple measurements have been made, assignment of the highest

deep-dose equivalent for the declared pregnant woman to the embryo/fetus is not required unless that dose is also the most representative deep-dose equivalent for the region of the embryo/fetus.

1.4 Internal Dose to the Embryo/Fetus

The internal dose to the embryo/fetus should consider the exposure to the embryo/fetus from radionuclides in the declared pregnant woman and in the embryo/fetus. The intake for the declared pregnant woman should be determined using the air sample data, bioassay data, or a combination of the two. Guidance on bioassay measurements used to quantify intake is being developed and has been issued for public comment as Draft Regulatory Guide DG-8009, "Interpretation of Bioassay Measurements." As appropriate, multiple bioassay measurements should be taken to ensure a better estimate of intake. Air sample data may be used to determine the intake. Specific guidance on workplace air sampling is being developed and has been issued for public comment as DG-8003, "Air Sampling in the Workplace."

1.5 Evaluating Continuous Exposure

For continuous or near continuous exposure to radioactive material that may be inhaled or ingested, the cumulative intake should be quantified at least every 30 days. If significant variation in the exposure levels may have occurred, the time interval for quantifying the intake should be reduced. A more frequent evaluation should also be performed if the potential dose to the embryo/fetus exceeds 25 mrem per 30-day period. If continued over a 9-month gestation period, 25 mrem in a 30-day period would approach 1/2 of the total gestation dose limit from internal exposure alone. The methods presented in Regulatory Positions 2 or 3 should be used for evaluating this potential dose.

1.6 Existing Maternal Body Burdens

Maternal body burdens resulting from internal exposures prior to conception should be included in determining the embryo/fetus dose. The contribution to the embryo/fetus dose from a maternal burden existing at the time of conception should be evaluated if the maternal burden at the time of pregnancy exceeds 1% of the radionuclide's stochastic ALI value for the appropriate mode

of intake and class (for inhalation intakes). Only body burdens existing at the time of conception need to be considered in evaluating this threshold; radioactive material already eliminated from the body should not be included.

This threshold of 1% ALI provides a simplified approach for determining when pre-existing body burdens should be evaluated. At this threshold, it is unlikely that any resultant dose to the embryo/fetus would be significant (i.e., greater than 10% of the 0.5 rem limit). As an alternative, the dose assessment methods presented in Regulatory Position 3 of this guide may be used for determining whether a pre-existing body burden represents a potentially significant dose (i.e., greater than 0.05 rem). Any dose greater than 0.05 rem should be included in the determination of the total dose to the embryo/fetus.

2. SIMPLIFIED METHOD FOR DETERMINING EMBRYO/FETUS DOSE FROM MATERNAL INTAKES

The determination of the dose to the embryo/fetus from the intake of radioactive material by the pregnant woman should be based on the best available scientific data. For most radionuclides, the dose to the fetal tissue will be similar to or less than the dose to the corresponding maternal tissue (Ref. 3). However, the data in NUREG/CR-5631 (Ref. 4) indicate that the embryo/fetus dose may be significantly different for some radionuclides, either greater than or less than the dose to the uterus.

Based on these premises (uterus dose similar to fetal dose and the NUREG/CR-5631 data), a set of dose factors have been developed for use in calculating an embryo/fetus dose. Except for those radionuclides addressed in NUREG/CR-5631 (Ref. 4), the dose factors presented in Appendix A to this guide represent the committed dose equivalent to the uterus per introduction of unit activity into the first transfer compartment (i.e., blood) of the woman.¹ For the radionuclides in NUREG/CR-5631, the dose factors in Appendix A represent the maximum dose equivalent to the embryo/fetus for the gestation period

¹The uterus committed dose equivalent factors presented in Appendix A were calculated based on the modeling employed during the development of the ICRP 30 (Ref. 5) data. It is recognized that the metabolism of the pregnant woman may not be adequately represented by the standard metabolic model. However, partly because of the lack of more definitive data, this modeling has been used for determining the uterine dose commitment factors that may be used for evaluating compliance with the embryo/fetus dose limit.

from the introduction of unit activity into the first transfer compartment of the woman at any time during the gestation period.

The dose limit for the embryo/fetus is expressed as a 9-month gestation dose equivalent. Particularly for certain radionuclides with both long radiological half-lives and long-term biological retention, the committed dose equivalent to the uterus may be significantly different than a 9-month gestation dose equivalent to the embryo/fetus. Several radionuclides of this type have been evaluated in NUREG/CR-5631 (Ref. 4), and data have been developed for calculating an embryo/fetus gestation dose instead of using the committed dose equivalent to the uterus. The methodology of NUREG/CR-5631 may be used for evaluating other radionuclides with long radiological half-lives and long-term biological retention.

For demonstrating compliance with the dose limits of 10 CFR 20.1208, the dose factors in Appendix A may be used for approximating the embryo/fetus dose equivalent for the entire gestation period.

The steps for determining the embryo/fetus dose, using the simplified method, are as follows.

2.1 The calculation of the embryo/fetus dose should include the intakes by the declared pregnant woman at any time during the gestation period.

2.2 For ingested radionuclides, determine the activity uptake by the first transfer compartment (blood) by multiplying the intake by the appropriate uptake factor (f_1) from Appendix B (adapted from Federal Guidance Report No. 11, Table 3 (Ref. 6)). The uptake factor, f_1 , is the fraction of an ingested compound of a radionuclide that is transferred into the first transfer compartment (i.e., blood uptake fraction).

2.3 For inhaled radionuclides, determining the fraction of initial intake that is transferred to the blood involves an evaluation of the deposition in the three compartments of the lung and the subsequent time-dependent transfer to the body fluids and to the GI tract. Unless it is known otherwise, it should be assumed that the transfer from the lung to body fluids and from lung to GI tract to body fluids follows the ICRP 30 (Ref. 5) modeling (which is the basis for this guide).

2.4 The total uptake into the blood from the maternal intake is assumed to be instantaneous. For radionuclides with lung clearance class of W (10- to 100-day half-life clearance) or Y (greater than 100-day half-life clearance), the actual translocation from the lung and uptake in the blood may occur over a time period that exceeds the gestation period. Clearance from the lung may take up to several years. All the initially deposited material is not immediately available for uptake by the first transfer compartment (blood). For simplicity and conservatism in the modeling, an instantaneous transfer should be assumed for use with the dose factor data in Appendix A. However, an incremental transfer from the lung to the blood may be assessed based on the lung model as described in ICRP Publications 30 and 19 (Refs. 5 and 7).²

The following Table 1, adapted from the data in Figure 5.2 of ICRP 30 (Ref. 5), may be used for determining the total transfer from the lung to the first transfer compartment (i.e., blood).

Table 1	
Fractional Transfer of Inhaled Activity to First Transfer Compartment	
Class	Transfer Fraction
D	$0.48 + 0.15 f_1$
W	$0.12 + 0.51 f_1$
Y	$0.05 + 0.58 f_1$

2.5 For pre-existing body burdens, the total burden determined to exist at time of pregnancy should be assumed to be available for uptake in the blood of the woman. Transfer should be assumed to occur during the first month of pregnancy.

This method provides a simplified approach for evaluating the significance of pre-existing conditions. If the embryo/fetus is likely to receive a

²As modeled in ICRP Publications 19 and 30, the clearance from the different lung compartments is assumed to follow first-order kinetics. This approach is complex, involving interlinking differential equations, and is considered outside the scope of a routine operational health physics program.

dose in excess of 25% of the limit from pre-existing burdens (i.e., greater than 125 mrem), more detailed modeling should be considered.³

2.6 Based on the determination of the maternal intake, the dose to the embryo/fetus for the entire gestation period should be calculated using the following equations:

$$DE = \sum A_i \times f_{1,i} \times DF_i \quad \text{INGESTION INTAKES} \quad \text{Equation 1}$$

$$DE = \sum A_i \times FT_i \times DF_i \quad \text{INHALATION INTAKES} \quad \text{Equation 2}$$

where:

- DE = dose equivalent to the embryo/fetus for the entire gestation period from the acute intakes of all radionuclides during the gestation period (rems)
- A_i = intake of radionuclide i by the declared pregnant woman at any time during the gestation period (μCi)
- DF_i = dose factor for use in approximating the dose equivalent to the embryo/fetus for the entire gestation period from the introduction of unit activity (1 μCi) into the maternal blood at any time during the gestation period, from tabular data presented in Appendix A to this guide (rem/μCi in maternal blood)
- f_{1,i} = the fraction of radionuclide i reaching the body fluids following ingestion (i.e., the fraction of ingested activity of radionuclide i that enters the blood), from data presented in Appendix B to this guide

³The inaccuracy of the above simplified approaches for evaluating pre-existing body burdens is recognized. The methods are presented as simplified approaches with reasonable assurance that actual dose to the embryo/fetus from existing body burdens will not be significantly underestimated. More detailed evaluations may be needed for very unusual circumstances where pre-existing body burdens may present a significant source of exposure to the embryo/fetus. Such a situation is thought to be unlikely, although not impossible. An evaluation of this nature should be conducted by individuals knowledgeable in the area of internal dosimetry. Such a detailed evaluation could consider the element retention functions as presented in ICRP Publications 30 and 54 (Refs. 5 and 8). Also, an application of the modeling presented in NUREG/CR-5631 (Ref. 4) could be applied. The details of this type of an evaluation are beyond the types of analyses that are considered routinely required and, as such, are outside the scope of this guide.

FT_i = fractional transfer of inhaled activity to the first transfer compartment (i.e., the fraction of inhaled activity of radionuclide i that enters the blood, see Table 1 of this guide).

2.7 Doses from multiple nuclides or multiple intakes should be evaluated on a frequency corresponding to the determination of intake (i.e., at least once every 30 days). Multiple dose determinations should be added to determine the total dose. Doses may need to be reevaluated if better estimates of intakes are provided by follow-up bioassay measurements.

3. DETERMINING TIME-DEPENDENT EMBRYO/FETUS DOSE USING NUREG/CR-5631 METHODS

As an alternative to the simplified methods presented above, a time-dependent dose to the embryo/fetus may be calculated for the radionuclides addressed in NUREG/CR-5631 (Ref. 4). NUREG/CR-5631 presents dosimetric methods for calculating the dose to the embryo/fetus following the instantaneous introduction of unit activity into the first transfer compartment (blood) of the pregnant woman at successive stages of gestation. These methods include the contribution to the embryo/fetus dose from the resultant body burdens of the declared pregnant woman and from activity in the embryo/fetus resulting from transfer across the placenta. Refer to NUREG/CR-5631 (Ref. 4) for a detailed description of the modeling.

The methods and data of NUREG/CR-5631 (Ref. 4) may be used for determining the dose to the embryo/fetus from maternal intakes at successive stages of gestation for the radionuclides ^3H , ^{14}C , ^{57}Co , ^{58}Co , ^{60}Co , ^{89}Sr , ^{90}Sr , ^{106}Ru , ^{125}I , ^{131}I , ^{132}I , ^{133}I , ^{134}I , ^{135}I , ^{134}Cs , ^{137}Cs , ^{233}U , ^{234}U , ^{235}U , ^{238}U , ^{238}Pu , ^{239}Pu , and ^{241}Am .

The steps for determining the embryo/fetus dose using NUREG/CR-5631 (Ref. 4) methods are as follows.

3.1 The methods presented in Regulatory Positions 2.1 through 2.5 should be used for determining the uptake in the first transfer compartment (blood) of the declared pregnant woman.

3.2 Equations 1 and 2 of Regulatory Position 2.6 may be used for determining the embryo/fetus dose with the following clarifications:

3.2.1 For Equations 1 and 2, the dose factor parameter, DF_i , should be taken from Appendix C of this guide for the time period representing the time of intake relative to stage of gestation. For using the tabular dose data in calculating the embryo/fetus dose, it may be assumed that all intakes occurring within any of the 30-day periods of gestation occur at the beginning of that period.⁴ The cumulated dose column should be used in order to determine the total dose for the remainder of the gestation period.

3.2.2 The dose factor data in Appendix C of this guide are for an absorbed dose (in rads) from introduction of 1 μ Ci of the radionuclide into the first transfer compartment (blood) of the woman at the beginning of the specified month of gestation. To convert from an absorbed dose (rad) to a dose equivalent (rem), the data in Appendix C should be multiplied by the appropriate quality factor from Table 1004(b).1 of 10 CFR Part 20. For ^3H , ^{14}C , ^{57}Co , ^{58}Co , ^{60}Co , ^{89}Sr , ^{90}Sr , ^{106}Ru , ^{125}I , ^{131}I , ^{132}I , ^{133}I , ^{134}I , ^{135}I , ^{134}Cs and ^{137}Cs , a quality factor of 1 should be applied. For ^{233}U , ^{234}U , ^{235}U , ^{238}U , ^{238}Pu , ^{239}Pu , and ^{241}Am , a quality factor of 20 should be applied, recognizing that most of the embryo/fetus dose results from the alpha activity.

3.2.3 For existing body burdens, the uptake in the blood should be considered to occur during the first month of pregnancy for the purpose of evaluating the dose to the embryo/fetus. Alternatively, time-dependent release kinetics may be used for calculating that fraction of the body burden that is translocated to the blood through the duration of the pregnancy. The time-dependent release is described in ICRP Publications 30 and 54 (Refs. 5 and 8). This approach is complex, involving interlinking differential equations, and is considered outside the scope of a routine health physics program.

3.3 Doses from multiple nuclides and multiple intakes should be evaluated with a frequency corresponding to the intake (i.e., at least once every 30 days). Multiple dose determinations should be added to determine the total

⁴The correlation of intake to actual stage of gestation can only be roughly estimated. For this reason, it is believed that the correlation should be limited to the best estimate of the month of gestation.

dose. Doses may need to be reevaluated if better estimates of intakes are provided by follow-up bioassay measurements.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide.

This draft guide has been released to encourage public participation in its development. Except in those cases in which the applicant or licensee proposes an acceptable alternative method of complying with specified portions of the Commission's regulations, the method to be described in the active guide reflecting public comments will be used in the evaluation of applications for new licenses or license renewals and for evaluating compliance with 10 CFR §§20.1001-20.2401.

REFERENCES

1. National Council on Radiation Protection and Measurements, "Recommendations on Limits for Exposure to Ionizing Radiation," Report No. 91, 1987.
2. "Radiation Protection Guidance to Federal Agencies for Occupational Exposure," Federal Register, page 2822 (52 FR 2822), January 27, 1987.
3. International Commission on Radiological Protection, "Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 1," ICRP No. 56, Pergamon Press Inc., 1989.
4. M. R. Sikov, R. J. Traub, and H. K. Mezmarich, "Contribution of Maternal Radionuclide Burdens to Prenatal Radiation Dose—Interim Recommendations," NUREG/CR-5631 (PNL-7445), U.S. Nuclear Regulatory Commission, (in press).
5. International Commission on Radiological Protection, "Limits for Intakes of Radionuclides by Workers," ICRP No. 30, Parts 1 through 4, including supplements, Annals of the ICRP, Volume 2, No. 3/4, Pergamon Press Inc., 1979.
6. K. F. Eckerman, A. B. Wolbarst, and A. C. B. Richardson, "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion," Environmental Protection Agency, Federal Guidance Report No. 11 (EPA-520/1-88-020), September 1988.
7. International Commission on Radiological Protection, "The Metabolism of Compounds of Plutonium and other Actinides," ICRP No. 19, Pergamon Press Inc., May 1972.
8. International Commission on Radiological Protection, "Individual Monitoring for Intake of Radionuclides by Workers: Design and Interpretation," ICRP No. 54, Annals of the ICRP, Volume 19, No.1-3, Pergamon Press Inc., 1988.

APPENDIX A

DOSE EQUIVALENT FACTORS FOR USE IN APPROXIMATING THE EMBRYO/FETUS DOSE FROM RADIONUCLIDES IN MATERNAL BLOOD

Except as noted, the dose factors (DF_i) presented in Table A-1 represent the committed dose equivalent to the uterus per introduction of unit activity into the first transfer compartment (i.e., blood) of the woman. These entries were calculated from tabulated values of uterine committed dose equivalent per unit intake and fractional absorption (f_1) from the gastrointestinal tract using ICRP-30 (Ref. A1) methodology. The DF_i dose factors were derived by dividing the committed dose equivalent per unit intake by the fractional absorption factor (f_1). These dose factors are based on unit activity in the blood. The most conservative f_1 (i.e., largest fraction) for each radionuclide has been used for deriving the data in Table A-1.

For the radionuclides ^3H , ^{14}C , ^{57}Co , ^{58}Co , ^{60}Co , ^{89}Sr , ^{90}Sr , ^{106}Ru , ^{125}I , ^{131}I , ^{132}I , ^{133}I , ^{134}I , ^{135}I , ^{134}Cs , ^{137}Cs , ^{233}U , ^{234}U , ^{235}U , ^{238}U , ^{238}Pu , ^{239}Pu , and ^{241}Am , the dose factors in Table A-1 represent the maximum dose equivalent to the embryo/ fetus for the gestation period from the introduction of unit activity into the first transfer compartment of the woman at any time during the gestation period. These entries are based on the modeling of NUREG/CR-5631 (Ref. A2) and are derived from the data tables presented in Appendix C to this guide. The maximum calculated embryo/fetus dose (as presented in the Appendix C tables) from intake by the declared pregnant woman during the gestation period has been used for inclusion in Table A-1.

The dose factor data presented in NUREG/CR-5631 (Ref. A2) are for an absorbed dose expressed in units of rads. To adapt this data as presented in Appendix C of this guide for inclusion in Table A-1, appropriate quality factors have been applied to convert from rads to dose equivalent, expressed in units of rems. For beta and gamma emitting radionuclides, a quality factor of 1 has been applied. For ^{233}U , ^{234}U , ^{235}U , ^{238}U , ^{238}Pu , ^{239}Pu , and ^{241}Am , a quality factor of 20 has been applied, recognizing that most of the embryo/fetus dose results from the alpha activity.

TABLE A-1

DOSE EQUIVALENT FACTORS FOR USE IN APPROXIMATING THE EMBRYO/FETUS DOSE FROM RADIONUCLIDES IN MATERNAL BLOOD

Nuclide	DF _i (rem/μCi)	Nuclide	DF _i (rem/μCi)	Nuclide	DF _i (rem/μCi)
H-3	5.87E-05*	Cr-51	6.96E-04	Ga-68	5.66E-02
Be-7	1.67E-02	Mn-51	3.65E-04	Ga-70	8.99E-05
Be-10	1.79E-02	Mn-52	4.70E-02	Ga-72	1.53E+00
C-11	1.21E-05	Mn-52M	2.80E-04	Ga-73	9.36E-02
C-14	1.29E-03*	Mn-53	5.77E-05	Ge-66	1.42E-04
F-18	1.32E-05	Mn-54	1.86E-02	Ge-67	1.11E-05
Na-22	1.06E-02	Mn-56	2.18E-03	Ge-68	8.81E-04
Na-24	1.21E-03	Fe-52	1.30E-02	Ge-69	3.02E-04
Mg-28	3.83E-03	Fe-55	3.88E-03	Ge-71	6.99E-06
Al-26	5.33E-01	Fe-59	4.63E-02	Ge-75	1.61E-05
Si-31	3.85E-05	Fe-60	1.47E+00	Ge-77	3.40E-04
Si-32	4.33E-02	Co-55	4.01E-03	Ge-78	1.08E-04
P-32	3.03E-03	Co-56	3.43E-02	As-69	2.46E-05
P-33	4.33E-04	Co-57	2.12E-03*	As-70	2.90E-04
S-35	3.53E-04	Co-58	9.17E-03*	As-71	1.21E-03
Cl-36	2.96E-03	Co-58M	5.17E-05	As-72	2.70E-03
Cl-38	3.17E-05	Co-60	3.80E-02*	As-73	3.02E-04
Cl-39	3.89E-05	Co-60M	4.12E-07	As-74	2.90E-03
K-40	1.84E-02	Co-61	4.50E-05	As-76	1.11E-03
K-42	7.73E-04	Co-62M	5.33E-05	As-77	1.88E-04
K-43	7.10E-04	Ni-56	5.39E-02	As-78	1.85E-04
K-44	1.94E-05	Ni-57	3.60E-02	Se-70	1.61E-04
K-45	1.21E-05	Ni-59	2.71E-03	Se-73	3.66E-04
Ca-41	3.21E-05	Ni-63	6.29E-03	Se-73M	3.21E-05
Ca-45	6.61E-04	Ni-65	1.43E-03	Se-75	8.79E-03
Ca-47	5.18E-03	Ni-66	2.81E-03	Se-79	4.19E-03
Sc-43	2.48E+00	Cu-60	9.32E-05	Se-81	1.00E-06
Sc-44	4.59E+00	Cu-61	2.69E-04	Se-81M	1.46E-05
Sc-44M	2.56E+01	Cu-64	2.09E-04	Se-83	3.62E-05
Sc-46	3.15E+01	Cu-67	6.50E-04	Br-74	3.33E-05
Sc-47	1.86E+00	Zn-62	1.38E-03	Br-74M	6.18E-05
Sc-48	3.52E+01	Zn-63	5.92E-05	Br-75	6.07E-05
Sc-49	4.18E-04	Zn-65	3.49E-02	Br-76	1.20E-03
Ti-44	1.36E+00	Zn-69	3.09E-06	Br-77	3.27E-04
Ti-45	1.54E-02	Zn-69M	5.54E-04	Br-80	3.01E-06
V-47	2.29E-03	Zn-71M	5.75E-04	Br-80M	1.46E-04
V-48	4.37E-01	Zn-72	5.28E-03	Br-82	1.87E-03
V-49	8.36E-05	Ga-65	9.18E-03	Br-83	2.72E-05
Cr-48	5.77E-03	Ga-66	9.95E-01	Br-84	2.56E-05
Cr-49	3.51E-04	Ga-67	2.50E-01	Rb-79	1.15E-05

*Dose equivalent factor based on data presented in NUREG/CR-5631 (Ref. A2). All other factors represent the committed dose equivalent to the uterus.

TABLE A-1 (Con't)

<u>Nuclide</u>	<u>DF_i</u> <u>(rem/μCi)</u>	<u>Nuclide</u>	<u>DF_i</u> <u>(rem/μCi)</u>	<u>Nuclide</u>	<u>DF_i</u> <u>(rem/μCi)</u>
Rb-81	8.18E-05	Nb-90	2.39E-01	Rh-105	1.93E-03
Rb-81M	1.08E-05	Nb-93M	9.29E-04	Rh-106M	6.86E-03
Rb-82M	3.49E-04	Nb-94	3.04E-01	Rh-107	8.51E-05
Rb-83	7.07E-03	Nb-95	1.24E-01	Pd-100	3.94E-01
Rb-84	1.05E-02	Nb-95M	1.27E-02	Pd-101	3.33E-02
Rb-86	8.14E-03	Nb-96	2.03E-01	Pd-103	1.39E-03
Rb-87	4.22E-03	Nb-97	4.11E-03	Pd-107	7.33E-06
Rb-88	1.02E-05	Nb-98	9.66E-03	Pd-109	1.27E-03
Rb-89	1.20E-05	Mo-90	7.77E-04	Ag-102	3.76E-04
Sr-80	3.96E-04	Mo-93	4.36E-04	Ag-103	8.58E-04
Sr-81	1.22E-04	Mo-93M	4.76E-04	Ag-104	3.05E-03
Sr-82	1.25E-02	Mo-99	9.39E-04	Ag-104M	1.09E-03
Sr-83	2.31E-03	Mo-101	1.48E-05	Ag-105	1.94E-02
Sr-85	4.03E-03	Tc-93	1.33E-04	Ag-106	2.12E-04
Sr-85M	4.81E-05	Tc-93M	4.67E-05	Ag-106M	8.21E-02
Sr-87M	1.62E-04	Tc-94	4.56E-04	Ag-108M	6.59E-02
Sr-89	1.84E-02*	Tc-94M	7.08E-05	Ag-110M	1.04E-01
Sr-90	5.22E-02*	Tc-95	3.86E-04	Ag-111	1.41E-03
Sr-91	1.49E-03	Tc-95M	1.23E-03	Ag-112	2.18E-03
Sr-92	7.79E-04	Tc-96	2.62E-03	Ag-115	1.98E-04
Y-86	2.18E+01	Tc-96M	2.29E-05	Cd-104	3.30E-03
Y-86M	1.26E+00	Tc-97	4.67E-05	Cd-107	1.95E-04
Y-87	1.01E+01	Tc-97M	2.42E-04	Cd-109	2.12E-02
Y-88	3.96E+01	Tc-98	2.97E-03	Cd-113	2.77E-01
Y-90	4.66E-04	Tc-99	2.79E-04	Cd-113M	2.55E-01
Y-90M	1.21E+00	Tc-99M	3.32E-05	Cd-115	9.47E-03
Y-91	6.03E-02	Tc-101	2.96E-06	Cd-115M	1.27E-02
Y-91M	2.13E-01	Tc-104	2.07E-05	Cd-117	4.23E-03
Y-92	4.81E-01	Ru-94	2.32E-03	Cd-117M	9.62E-03
Y-93	4.18E-01	Ru-97	6.89E-03	In-109	7.95E-03
Y-94	1.10E-01	Ru-103	1.97E-02	In-110	4.01E-02
Y-95	3.56E-02	Ru-105	4.09E-03	In-110	4.50E-03
Zr-86	8.62E-01	Ru-106	1.12E-01	In-111	3.05E-02
Zr-88	3.87E-01	Rh-99	2.19E-02	In-112	9.47E-05
Zr-89	7.31E-01	Rh-99M	3.51E-03	In-113M	1.24E-03
Zr-93	8.79E-05	Rh-100	3.86E-02	In-114M	3.05E-02
Zr-95	6.16E-01	Rh-101	3.33E-02	In-115	8.99E-01
Zr-97	5.24E-01	Rh-101M	9.40E-03	In-115M	2.16E-03
Nb-88	1.17E-03	Rh-102	1.93E-01	In-116M	4.92E-03
Nb-89	1.83E-02	Rh-102M	3.48E-02	In-117	1.22E-03
Nb-89	1.30E-02	Rh-103M	1.18E-06	In-117M	2.61E-03

*Dose equivalent factor based on data presented in NUREG/CR-5631 (Ref. A2). All other factors represent the committed dose equivalent to the uterus.

TABLE A-1 (Con't)

Nuclide	DF _i (rem/μCi)	Nuclide	DF _i (rem/μCi)	Nuclide	DF _i (rem/μCi)
In-119M	1.39E-05	Te-127M	1.82E-03	Ba-131M	1.32E-05
Sn-110	2.11E-02	Te-129	2.35E-05	Ba-133	1.27E-02
Sn-111	8.81E-04	Te-129M	3.39E-03	Ba-133M	8.77E-04
Sn-113	2.63E-02	Te-131	2.18E-04	Ba-135M	7.03E-04
Sn-117M	1.57E-02	Te-131M	6.64E-03	Ba-139	4.55E-05
Sn-119M	2.29E-03	Te-132	8.57E-03	Ba-140	1.54E-02
Sn-121	3.70E-05	Te-133	3.26E-05	Ba-141	9.47E-05
Sn-121M	5.70E-03	Te-133M	5.48E-04	Ba-142	2.74E-04
Sn-123	6.35E-03	Te-134	3.98E-04	La-131	3.77E-02
Sn-123M	2.48E-04	I-120	9.36E-05	La-132	5.07E-01
Sn-125	2.37E-02	I-120M	8.73E-05	La-135	3.43E-02
Sn-126	2.35E-01	I-121	1.79E-05	La-137	7.55E-02
Sn-127	1.14E-02	I-123	2.27E-05	La-138	2.84E+00
Sn-128	7.14E-03	I-124	2.16E-04	La-140	2.32E+00
Sb-115	2.00E-04	I-125	1.38E-03*	La-141	9.43E-03
Sb-116	1.59E-04	I-126	2.23E-04	La-142	1.91E-01
Sb-116M	1.49E-03	I-128	5.25E-06	La-143	2.85E-03
Sb-117	3.34E-04	I-129	5.11E-04	Ce-134	3.13E+00
Sb-118M	6.59E-03	I-130	2.29E-04	Ce-135	4.44E+00
Sb-119	2.08E-04	I-131	3.64E-03*	Ce-137	7.13E-02
Sb-120	3.70E-05	I-132	1.56E-04*	Ce-137M	3.31E-01
Sb-120	3.42E-02	I-132M	6.14E-05	Ce-139	1.15E+00
Sb-122	5.85E-03	I-133	9.04E-04*	Ce-141	5.56E-01
Sb-124	2.98E-02	I-134	4.83E-05*	Ce-143	1.05E+00
Sb-124M	4.88E-05	I-135	3.72E-04*	Ce-144	3.79E-01
Sb-125	8.51E-03	Cs-125	1.33E-05	Pr-136	4.12E-02
Sb-126	4.37E-02	Cs-127	5.96E-05	Pr-137	1.26E-01
Sb-126M	1.69E-04	Cs-129	2.13E-04	Pr-138M	9.61E-01
Sb-127	9.66E-03	Cs-130	6.99E-06	Pr-139	1.16E-01
Sb-128	1.33E-04	Cs-131	2.27E-04	Pr-142	1.36E-01
Sb-128	8.73E-03	Cs-132	2.10E-03	Pr-142M	1.73E-03
Sb-129	3.36E-03	Cs-134	1.11E-01*	Pr-143	4.53E-08
Sb-130	9.40E-04	Cs-134M	2.66E-05	Pr-144	8.44E-04
Sb-131	3.36E-04	Cs-135	7.07E-03	Pr-145	1.41E-02
Te-116	1.45E-03	Cs-135M	2.42E-05	Pr-147	1.95E-02
Te-121	4.87E-03	Cs-136	1.42E-02	Nd-136	3.59E-01
Te-121M	7.90E-03	Cs-137	5.94E-02*	Nd-138	8.26E-01
Te-123	3.09E-05	Cs-138	2.95E-05	Nd-139	4.11E-02
Te-123M	2.94E-03	Ba-126	1.14E-03	Nd-139M	1.74E+00
Te-125M	9.75E-04	Ba-128	1.17E-02	Nd-141	4.33E-02
Te-127	6.31E-05	Ba-131	7.40E-03	Nd-147	8.45E-01

*Dose equivalent factor based on data presented in NUREG/CR-5631 (Ref. A2). All other factors represent the committed dose equivalent to the uterus.

TABLE A-1 (Con't)

Nuclide	DF _i (rem/μCi)	Nuclide	DF _i (rem/μCi)	Nuclide	DF _i (rem/μCi)
Nd-149	1.37E-01	Gd-149	2.47E+00	Tm-166	2.37E+00
Nd-151	2.53E-02	Gd-151	4.99E-01	Tm-167	1.03E+00
Pm-141	3.63E-02	Gd-152	0.00E-01	Tm-170	5.38E-02
Pm-143	1.79E+00	Gd-153	8.92E-01	Tm-171	8.13E-03
Pm-144	8.68E+00	Gd-159	1.52E-01	Tm-172	1.89E+00
Pm-145	2.58E-01	Tb-147	6.76E-01	Tm-173	5.88E-01
Pm-146	4.34E+00	Tb-149	1.27E+00	Tm-175	2.70E-02
Pm-147	3.49E-05	Tb-150	1.01E+00	Yb-162	8.97E-02
Pm-148	2.60E+00	Tb-151	2.33E+00	Yb-166	6.08E+00
Pm-148M	1.08E+01	Tb-153	1.16E+00	Yb-167	1.23E-02
Pm-149	4.70E-02	Tb-154	5.65E+00	Yb-169	2.47E+00
Pm-150	6.86E-01	Tb-155	9.52E-01	Yb-175	2.10E-01
Pm-151	1.11E+00	Tb-156	8.65E+00	Yb-177	6.98E-02
Sm-141	4.11E-02	Tb-156M	9.32E-01	Yb-178	4.11E-02
Sm-141M	1.42E-01	Tb-156M	2.89E-01	Lu-169	3.60E+00
Sm-142	2.11E-01	Tb-157	2.39E-02	Lu-170	8.42E+00
Sm-145	5.56E-01	Tb-158	4.79E+00	Lu-171	3.72E+00
Sm-146	0.00E-01	Tb-160	6.08E+00	Lu-172	9.20E+00
Sm-147	0.00E-01	Tb-161	2.64E-01	Lu-173	1.10E+00
Sm-151	1.26E-05	Dy-155	1.08E+00	Lu-174	8.93E-01
Sm-153	3.54E-01	Dy-157	5.81E-01	Lu-174M	5.54E-01
Sm-155	5.65E-03	Dy-159	4.19E-01	Lu-176	3.45E+00
Sm-156	3.55E-01	Dy-165	1.38E-02	Lu-176M	1.53E-02
Eu-145	2.00E+00	Dy-166	3.56E-01	Lu-177	2.24E-01
Eu-146	3.38E+00	Ho-155	1.41E-01	Lu-177M	6.80E+00
Eu-147	8.51E-01	Ho-157	2.57E-02	Lu-178	8.18E-03
Eu-148	3.53E+00	Ho-159	3.47E-02	Lu-178M	5.54E-02
Eu-149	1.40E-01	Ho-161	4.70E-02	Lu-179	3.03E-02
Eu-150	2.92E-02	Ho-162	4.66E-03	Hf-170	4.74E-01
Eu-150	3.02E+00	Ho-162M	1.43E-01	Hf-172	4.63E-01
Eu-152	2.20E+00	Ho-164	3.10E-03	Hf-173	2.26E-01
Eu-152M	1.38E-01	Ho-164M	1.32E-02	Hf-175	3.70E-01
Eu-154	2.28E+00	Ho-166	1.04E-01	Hf-177M	5.22E-02
Eu-155	1.60E-01	Ho-166M	1.07E+01	Hf-178M	2.94E+00
Eu-156	1.90E+00	Ho-167	2.38E-01	Hf-179M	8.51E-01
Eu-157	2.01E-01	Er-161	6.29E-01	Hf-180M	1.71E-01
Eu-158	3.56E-02	Er-165	1.12E-01	Hf-181	4.96E-01
Gd-145	1.09E-01	Er-169	1.34E-04	Hf-182	1.16E+00
Gd-146	4.11E+00	Er-171	5.88E-01	Hf-182M	2.61E-02
Gd-147	4.91E+00	Er-172	2.59E+00	Hf-183	2.33E-02
Gd-148	0.00E-01	Tm-162	6.87E-02	Hf-184	1.94E-01

*Dose equivalent factor based on data presented in NUREG/CR-5631 (Ref. A2). All other factors represent the committed dose equivalent to the uterus.

TABLE A-1 (Con't)

Nuclide	DF _i (rem/μCi)	Nuclide	DF _i (rem/μCi)	Nuclide	DF _i (rem/μCi)
Ta-172	4.07E-02	Os-189M	5.11E-06	Hg-193M	3.23E-04
Ta-173	1.94E-01	Os-191	1.99E-02	Hg-194	1.81E-01
Ta-174	4.25E-02	Os-191M	1.12E-03	Hg-195	7.47E-05
Ta-175	4.96E-01	Os-193	8.55E-03	Hg-195M	5.48E-04
Ta-176	8.25E-01	Os-194	8.69E-02	Hg-197	2.38E-04
Ta-177	1.30E-01	Ir-182	2.23E-03	Hg-197M	2.97E-04
Ta-178	1.47E-01	Ir-184	3.24E-02	Hg-199M	7.55E-06
Ta-179	9.40E-02	Ir-185	3.85E-02	Hg-203	5.33E-03
Ta-180	1.16E+00	Ir-186	1.12E-01	Tl-194	6.44E-06
Ta-180M	3.47E-02	Ir-187	2.08E-02	Tl-194M	2.16E-05
Ta-182	2.15E+00	Ir-188	1.60E-01	Tl-195	3.49E-05
Ta-182M	2.65E-03	Ir-189	1.96E-02	Tl-197	3.85E-05
Ta-183	5.44E-01	Ir-190	2.52E-01	Tl-198	1.94E-04
Ta-184	7.40E-01	Ir-190M	1.01E-03	Tl-198M	8.36E-05
Ta-185	9.25E-03	Ir-192	1.63E-01	Tl-199	5.55E-05
Ta-186	7.03E-03	Ir-192M	8.99E-02	Tl-200	6.55E-04
W-176	6.55E-04	Ir-194	7.55E-03	Tl-201	2.48E-04
W-177	3.66E-04	Ir-194M	4.55E-01	Tl-202	1.38E-03
W-178	6.43E-04	Ir-195	1.24E-03	Tl-204	2.43E-03
W-179	8.12E-06	Ir-195M	1.03E-02	Pb-195M	1.65E-04
W-181	2.80E-04	Pt-186	2.06E-02	Pb-198	3.92E-04
W-185	3.51E-07	Pt-188	1.21E-01	Pb-199	6.51E-04
W-187	1.04E-03	Pt-189	2.08E-02	Pb-200	3.37E-03
W-188	1.68E-04	Pt-191	4.88E-02	Pb-201	1.78E-03
Re-177	1.49E-05	Pt-193	1.07E-04	Pb-202	6.77E-02
Re-178	8.37E-06	Pt-193M	2.71E-03	Pb-202M	1.91E-03
Re-181	4.61E-04	Pt-195M	1.58E-02	Pb-203	2.02E-03
Re-182	4.56E-04	Pt-197	2.64E-03	Pb-205	3.63E-04
Re-182	1.92E-03	Pt-197M	1.12E-03	Pb-209	9.93E-06
Re-184	1.64E-03	Pt-199	5.40E-04	Pb-210	2.31E+00
Re-184M	1.31E-03	Pt-200	2.04E-02	Pb-211	3.63E-04
Re-186	4.53E-04	Au-193	1.63E-03	Pb-212	3.29E-02
Re-186M	9.43E-04	Au-194	1.10E-02	Pb-214	5.64E-04
Re-187	1.82E-06	Au-195	2.35E-03	Bi-200	1.66E-03
Re-188	3.73E-04	Au-198	5.66E-03	Bi-201	4.07E-03
Re-188M	8.19E-06	Au-198M	1.05E-02	Bi-202	4.83E-03
Re-189	2.46E-04	Au-199	1.68E-03	Bi-203	2.54E-02
Os-180	1.78E-03	Au-200	1.01E-04	Bi-205	4.82E-02
Os-181	1.75E-02	Au-200M	1.61E-02	Bi-206	9.03E-02
Os-182	1.07E-01	Au-201	1.15E-05	Bi-207	4.88E-02
Os-185	1.33E-01	Hg-193	4.88E-05	Bi-210	1.46E-03

*Dose equivalent factor based on data presented in NUREG/CR-5631 (Ref. A2). All other factors represent the committed dose equivalent to the uterus.

TABLE A-1 (Con't)

Nuclide	DF _i (rem/μCi)	Nuclide	DF _i (rem/μCi)	Nuclide	DF _i (rem/μCi)
Bi-210M	8.66E-02	U-233	2.92E-02*	Am-245	2.68E-04
Bi-212	1.70E-03	U-234	2.92E-02*	Am-246M	1.51E-02
Bi-213	4.36E-04	U-235	2.67E-02*	Am-246	2.03E-02
Bi-214	3.52E-04	U-236	1.81E-01	Cm-238	1.31E-01
Po-203	1.07E-03	U-237	5.42E-03	Cm-240	3.50E-02
Po-205	1.64E-03	U-238	2.55E-02*	Cm-241	8.69E-01
Po-207	4.03E-03	U-239	5.52E-05	Cm-242	3.30E-02
Po-210	3.05E+00	U-240	4.17E-03	Cm-243	3.74E-01
At-207	8.32E-04	Np-232	8.69E-03	Cm-244	3.19E-02
At-211	3.92E-02	Np-233	2.85E-03	Cm-245	3.11E-01
Fr-222	2.13E-03	Np-234	1.45E+00	Cm-246	1.27E-01
Fr-223	8.58E-03	Np-235	2.99E-03	Cm-247	9.51E-01
Ra-223	7.84E-01	Np-236	4.29E-01	Cm-248	3.49E+01
Ra-224	3.85E-01	Np-236	5.25E-02	Cm-249	1.07E-03
Ra-225	6.23E-01	Np-237	3.59E-01	Cm-250	2.76E+02
Ra-226	1.69E+00	Np-238	6.07E-01	Bk-245	4.11E-01
Ra-227	6.10E-05	Np-239	2.55E-01	Bk-246	1.04E+00
Ra-228	2.90E+00	Np-240	7.07E-02	Bk-247	2.83E-01
Ac-224	9.47E-02	Pu-234	1.24E-01	Bk-249	8.40E-04
Ac-225	3.68E-01	Pu-235	1.72E-03	Bk-250	1.54E-01
Ac-226	1.66E-01	Pu-236	6.81E-02	Cf-244	9.25E-05
Ac-227	2.60E-01	Pu-237	1.07E-01	Cf-246	2.88E-02
Ac-228	3.12E-01	Pu-238	5.56E-02*	Cf-248	4.18E-02
Th-226	3.02E-03	Pu-239	5.22E-02*	Cf-249	9.80E-01
Th-227	3.52E+00	Pu-240	2.80E-02	Cf-250	3.30E-01
Th-228	4.40E+01	Pu-241	2.96E-04	Cf-251	4.26E-01
Th-229	8.51E+01	Pu-242	2.81E-02	Cf-252	1.15E+01
Th-230	1.26E+01	Pu-243	9.62E-03	Cf-253	8.55E-04
Th-231	8.97E-02	Pu-244	1.07E+00	Cf-254	3.70E+02
Th-232	2.26E+01	Pu-245	2.22E-01	Es-250	4.77E-02
Th-234	2.33E-01	Pu-246	1.34E+00	Es-251	1.24E-01
Pa-227	2.42E-03	Am-237	2.60E-02	Es-253	3.58E-02
Pa-228	9.58E-01	Am-238	7.81E-02	Es-254M	5.22E-01
Pa-230	1.04E+00	Am-239	1.63E-01	Es-254	1.33E+00
Pa-231	2.25E-01	Am-240	1.16E+00	Fm-252	2.61E-02
Pa-232	8.95E-01	Am-241	1.11E-02*	Fm-253	1.38E-01
Pa-233	3.81E-01	Am-242M	3.64E-02	Fm-254	6.11E-03
Pa-234	6.77E-01	Am-242	1.32E-02	Fm-255	2.85E-02
U-230	6.13E-01	Am-243	4.74E-01	Fm-257	2.60E-01
U-231	2.63E-03	Am-244M	1.05E-05	Md-257	3.69E-02
U-232	6.02E-01	Am-244	3.92E-01	Md-258	5.96E-02

*Dose equivalent factor based on data presented in NUREG/CR-5631 (Ref. A2). All other factors represent the committed dose equivalent to the uterus.

REFERENCES

- A1. International Commission on Radiological Protection, "Limits for Intakes of Radionuclides by Workers," ICRP No. 30, Parts 1 through 4, including supplements, Annals of the ICRP, Volume 2, No. 3/4, Pergamon Press Inc., 1979.
- A2. M. R. Sikov, R. J. Traub, and H. K. Meznarich, "Contribution of Maternal Radionuclide Burdens to Prenatal Radiation Dose—Interim Recommendations," NUREG/CR-5631 (PNL-7445), U.S. Nuclear Regulatory Commission, (in press).

APPENDIX B

BLOOD UPTAKE FRACTIONS FOR INGESTED ACTIVITY

<u>Element</u>	<u>f₁</u>	<u>Element</u>	<u>f₁</u>
Actinium (Ac)	1E-3	Cerium (Ce)	3E-4
Aluminum (Al)	1E-2	Cesium (Cs)	1E0
Americium (Am)	1E-3	Chlorine (Cl)	1E0
Antimony (Sb)	1E-1	Chromium (Cr)	1E-1
Arsenic (As)	5E-1	Cobalt (Co)	3E-01
Astatine (At)	1E0	Copper (Cu)	5E-1
Barium (Ba)	1E-1	Curium (Cm)	1E-3
Berkelium (Bk)	1E-3	Dysprosium (Dy)	3E-4
Beryllium (Be)	5E-3	Einsteinium (Es)	1E-3
Bismuth (Bi)	5E-2	Erbium (Er)	3E-4
Bromine (Br)	1E0	Europium (Eu)	1E-3
Cadmium (Cd)	5E-2	Fermium (Fm)	1E-3
Calcium (Ca)	3E-1	Fluorine (F)	1E0
Californium (Cf)	1E-3	Francium (Fr)	1E0
Carbon (C)	1E0	Gadolinium (Gd)	3E-4

Blood Uptake Fractions for Ingested Activity (con't)

<u>Element</u>	<u>f₁</u>	<u>Element</u>	<u>f₁</u>
Gallium (Ga)	1E-3	(Md)	
Germanium (Ge)	1E0	Mercury (Hg)	1E0
Gold (Au)	1E-1	Molybdenum (Mo)	8E-1
Hafnium (Hf)	2E-3	Neodymium (Nd)	3E-4
Holmium (Ho)	3E-4	Neptunium (Np)	1E-3
Hydrogen (H)	1E0	Nickel (Ni)	5E-2
Indium (In)	2E-2	Niobium (Nb)	1E-2
Iodine (I)	1E0	Osmium (Os)	1E-2
Iridium (Ir)	1E-2	Palladium (Pd)	5E-3
Iron (Fe)	1E-1	Phosphorus (P)	8E-1
Lanthanum (La)	1E-3	Platinum (Pt)	1E-2
Lead (Pb)	2E-1	Plutonium (Pu)	1E-3
Lutetium (Lu)	3E-4	Polonium (Po)	1E-1
Magnesium (Mg)	5E-1	Potassium (K)	1E0
Manganese (Mn)	1E-1	Praseodymium (Pr)	3E-4
Mendelevium	1E-3		

Blood Uptake Fractions for Ingested Activity (con't)

<u>Element</u>	<u>f₁</u>	<u>Element</u>	<u>f₁</u>
Promethium (Pm)	3E-4	Technetium (Tc)	8E-1
Protactinium (Pa)	1E-3	Tellurium (Te)	2E-1
Radium (Ra)	2E-1	Terbium (Tb)	3E-4
Rhenium (Re)	8E-1	Thallium (Tl)	1E0
Rhodium (Rh)	5E-2	Thorium (Th)	2E-4
Rubidium (Rb)	1E0	Thulium (Tm)	3E-4
Ruthenium (Ru)	5E-2	Tin (Sn)	2E-2
Samarium (Sm)	3E-4	Titanium (Ti)	1E-2
Scandium (Sc)	1E-4	Tungsten (W)	3E-1
Selenium (Se)	8E-1	Uranium (U)	5E-2
Silicon (Si)	1E-2	Vanadium (V)	1E-2
Silver (Ag)	5E-2	Ytterbium (Yb)	3E-4
Sodium (Na)	1E0	Yttrium (Y)	1E-4
Strontium (Sr)	3E-1	Zinc (Zn)	5E-1
Sulfur (S)	8E-1	Zirconium (Zr)	2E-3
Tantalum (Ta)	1E-3		

APPENDIX C

RADIATION ABSORBED DOSE TO THE EMBRYO/FETUS FOLLOWING INTRODUCTION OF SPECIFIED RADIONUCLIDES AND CHEMICAL FORMS INTO THE MATERNAL TRANSFER COMPARTMENT (BLOOD)

The entries for selected radionuclides and chemical forms in the tables in this appendix have been calculated from the modeling presented in NUREG/CR-5631 (Ref. C1). It has been assumed that 1 μCi of activity is introduced into the maternal transfer compartment (blood). Pregnancy is assumed to begin at the time of fertilization, roughly 2 weeks after menses, and gestation is considered to consist of nine 30-day months.

Radiation dose rates were calculated from the initial fraction that was present after a single administration at the start of each of these months or on the assumed final day (day 270) of gestation. Monthly doses were determined by integrating under the curve relating the fraction of the activity in the embryo/fetus at the start of each month after administration and the fraction at the beginning of the subsequent month of gestation. Monthly doses are shown for the inclusive periods, expressed in days. Doses to the embryo/fetus from radionuclides in maternal organs were calculated; when appropriate, these are included to provide total radiation absorbed doses. The tabulated values of cumulated doses were determined as the sum of the monthly doses.

As was noted in NUREG/CR-5631 (Ref. C1), ICRP Publication 30 (Ref. C2) employs a metabolic model in which a fraction of activity in the first transfer compartment (blood) often is assumed to go immediately to excretion. Because of the minuscule mass of the embryo/fetus immediately following fertilization, for some materials the biokinetic model thus predicts that there would be negligible initial activity in the embryo after administration at that time, and that there would be minimal activity at later times. As a consequence, the dose rate and doses also would be negligible, which is indicated by N in the table. For these nuclides, an approximation of the cumulative dose for an intake occurring during the first 30 days should be made based on a time-weighted average of the 30-day intake data. The cumulative dose from an intake in the first 30 days of pregnancy may be estimated by multiplying the ratio of remaining days at time of intake to the 30-day period by the cumulative dose for an intake occurring at day 30. For example, assuming a maternal intake of ^{14}C resulting in a 1 μCi blood uptake on the 20th day of the pregnancy, the gestation dose should be determined by multiplying the cumulative dose from an intake at day 30 (i.e., Table C3, Cumulated Dose column, 1.89E-04 rads) by the ratio of 20 days to 30 days.

Table C1. Radiation Doses to the Embryo/Fetus from 1 μCi of ^3H , as Tritiated Water, Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	9.03E-06	3.96E-11	7.67E-14	2.00E-15	5.31E-17	2.63E-18	1.72E-19	1.34E-20	1.18E-21	9.03E-06
30		1.77E-05	2.64E-08	7.50E-10	1.94E-11	9.70E-13	6.30E-14	4.94E-15	4.33E-16	1.77E-05
60			3.93E-05	8.96E-07	2.47E-08	1.21E-09	7.91E-11	6.17E-12	5.41E-13	4.02E-05
90				3.82E-05	1.06E-06	5.19E-08	3.39E-09	2.64E-10	2.32E-11	3.93E-05
120					4.50E-05	2.14E-06	1.41E-07	1.10E-08	9.63E-10	4.73E-05
150						4.98E-05	3.22E-06	2.53E-07	2.21E-08	5.33E-05
180							5.28E-05	4.08E-06	3.57E-07	5.72E-05
210								5.40E-05	4.70E-06	5.87E-05
240									5.28E-05	5.28E-05

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Table C2. Radiation Doses to the Embryo/Fetus from 1 μCi of ^3H , as a Hexose or Amino Acid, Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	N*	N	N	N	N	N	N	N	N	N
30		2.21E-05	2.14E-07	4.68E-08	1.04E-08	4.37E-09	2.35E-09	1.50E-09	1.06E-09	2.24E-05
60			6.00E-05	7.27E-06	1.67E-06	6.81E-07	3.68E-07	2.34E-07	1.66E-07	7.04E-05
90				5.82E-05	9.25E-06	3.69E-06	1.97E-06	1.26E-06	8.92E-07	7.53E-05
120					7.24E-05	1.97E-05	1.03E-05	6.50E-06	4.62E-06	1.14E-04
150						8.29E-05	3.05E-05	1.89E-05	1.33E-05	1.46E-04
180							8.96E-05	3.93E-05	2.72E-05	1.56E-04
210								9.31E-05	4.58E-05	1.39E-04
240									1.05E-04	1.05E-04

*N indicates that the metabolic pattern is such that the dose rates and doses would be negligible throughout gestation when activity is administered immediately after fertilization. Approximations of doses resulting from administration during the first month are described on page C-1.

Table C3. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{14}C , as a Bicarbonate, Hexose, Amino Acid, Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	N*	N	N	N	N	N	N	N	N	N
30		1.87E-04	1.72E-06	4.12E-07	9.18E-08	3.88E-08	2.09E-08	1.34E-08	9.56E-09	1.89E-04
60			4.96E-04	5.83E-05	1.46E-05	6.02E-06	3.26E-06	2.09E-06	1.49E-06	5.82E-04
90				4.81E-04	7.48E-05	3.24E-05	1.74E-05	1.11E-05	7.95E-06	6.25E-04
120					5.96E-04	1.59E-04	9.09E-05	5.74E-05	4.11E-05	9.44E-04
150						6.80E-04	2.47E-04	1.66E-04	1.17E-04	1.21E-03
180							7.33E-04	3.19E-04	2.39E-04	1.29E-03
210								7.61E-04	3.70E-04	1.13E-03
240									8.88E-04	8.88E-04

*N indicates that the metabolic pattern is such that the dose rates and doses would be negligible throughout gestation when activity is administered immediately after fertilization. Approximations of doses resulting from administration during the first month are described on page C-1.

Table C4. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{57}Co , Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	7.30E-04	2.76E-04	2.36E-04	1.97E-04	1.75E-04	1.56E-04	1.39E-04	1.23E-04	1.09E-04	2.14E-03
30		8.66E-04	2.74E-04	2.45E-04	2.07E-04	1.82E-04	1.60E-04	1.41E-04	1.24E-04	2.20E-03
60			8.71E-04	2.82E-04	2.56E-04	2.15E-04	1.88E-04	1.63E-04	1.42E-04	2.12E-03
90				8.96E-04	2.96E-04	2.67E-04	2.22E-04	1.91E-04	1.64E-04	2.04E-03
120					9.37E-04	3.08E-04	2.75E-04	2.25E-04	1.92E-04	1.94E-03
150						9.78E-04	3.18E-04	2.79E-04	2.27E-04	1.80E-03
180							1.01E-03	3.22E-04	2.83E-04	1.61E-03
210								1.03E-03	3.19E-04	1.35E-03
240									1.04E-03	1.04E-03

Table C5. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{58}Co , Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	4.81E-03	1.27E-03	9.03E-04	6.03E-04	4.25E-04	3.00E-04	2.13E-04	1.52E-04	1.09E-04	8.79E-03
30		5.12E-03	1.30E-03	9.30E-04	6.24E-04	4.37E-04	3.06E-04	2.15E-04	1.53E-04	9.08E-03
60			5.26E-03	1.34E-03	9.62E-04	6.41E-04	4.45E-04	3.09E-04	2.17E-04	9.17E-03
90				5.39E-03	1.38E-03	9.88E-04	6.54E-04	4.49E-04	3.11E-04	9.17E-03
120					5.59E-03	1.42E-03	1.01E-03	6.59E-04	4.53E-04	9.13E-03
150						5.75E-03	1.45E-03	1.02E-03	6.64E-04	8.88E-03
180							5.87E-03	1.46E-03	1.03E-03	8.36E-03
210								5.95E-03	1.45E-03	7.40E-03
240									6.00E-03	6.00E-03

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Table C6. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{60}Co , Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	1.28E-02	4.73E-03	4.37E-03	3.79E-03	3.60E-03	3.40E-03	3.22E-03	3.05E-03	2.88E-03	4.18E-02
30		1.38E-02	4.73E-03	4.40E-03	3.98E-03	3.73E-03	3.48E-03	3.26E-03	3.06E-03	4.04E-02
60			1.39E-02	4.76E-03	4.62E-03	4.12E-03	3.81E-03	3.52E-03	3.27E-03	3.80E-02
90				1.40E-02	4.99E-03	4.79E-03	4.22E-03	3.86E-03	3.54E-03	3.54E-02
120					1.46E-02	5.17E-03	4.90E-03	4.27E-03	3.88E-03	3.28E-02
150						1.52E-02	5.29E-03	4.96E-03	4.29E-03	2.97E-02
180							1.56E-02	5.35E-03	5.01E-03	2.60E-02
210								1.59E-02	5.29E-03	2.12E-02
240									1.60E-02	1.60E-02

Table C7. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{57}Co , as Vitamin B-12, Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	1.47E-03	1.11E-03	7.18E-04	4.88E-04	3.34E-04	2.28E-04	1.54E-04	1.02E-04	6.74E-05	4.67E-03
30		1.67E-03	1.10E-03	7.44E-04	5.10E-04	3.48E-04	2.35E-04	1.56E-04	1.03E-04	4.87E-03
60			1.68E-03	1.14E-03	7.80E-04	5.31E-04	3.59E-04	2.38E-04	1.57E-04	4.89E-03
90				1.74E-03	1.19E-03	8.13E-04	5.49E-04	3.64E-04	2.40E-04	4.90E-03
120					1.82E-03	1.24E-03	8.38E-04	5.56E-04	3.67E-04	4.82E-03
150						1.89E-03	1.28E-03	8.48E-04	5.60E-04	4.58E-03
180							1.95E-03	1.30E-03	8.55E-04	4.10E-03
210								1.98E-03	1.31E-03	3.29E-03
240									1.99E-03	1.99E-03

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Table C8. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{60}Co , as Vitamin B-12, Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	2.54E-02	1.90E-02	1.33E-02	9.38E-03	6.88E-03	4.98E-03	3.56E-03	2.52E-03	1.77E-03	8.68E-02
30		2.71E-02	1.90E-02	1.34E-02	9.82E-03	7.10E-03	5.09E-03	3.61E-03	2.53E-03	8.76E-02
60			2.70E-02	1.91E-02	1.40E-02	1.02E-02	7.28E-03	5.16E-03	3.62E-03	8.64E-02
120				2.74E-02	2.00E-02	1.45E-02	1.04E-02	7.38E-03	5.18E-03	8.49E-02
150					2.86E-02	2.08E-02	1.49E-02	1.05E-02	7.41E-03	8.22E-02
180						2.97E-02	2.13E-02	1.51E-02	1.06E-02	7.67E-02
210							3.04E-02	2.15E-02	1.51E-02	6.70E-02
240								3.08E-02	2.16E-02	5.24E-02
270									3.10E-02	3.10E-02

Table C9. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{89}Sr Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	4.09E-03	5.66E-04	2.92E-04	1.37E-04	6.64E-05	3.59E-05	2.10E-05	1.23E-05	7.01E-06	5.23E-03
30		5.35E-03	5.74E-04	2.95E-04	1.36E-04	6.57E-05	3.53E-05	2.05E-05	1.20E-05	6.49E-03
60			9.01E-03	1.20E-03	3.84E-04	1.63E-04	7.45E-05	3.86E-05	2.18E-05	1.09E-02
90				9.09E-03	1.36E-03	5.06E-04	2.12E-04	9.67E-05	4.93E-05	1.13E-02
120					1.07E-02	2.24E-03	8.99E-04	3.90E-04	1.84E-04	1.44E-02
150						1.19E-02	3.15E-03	1.40E-03	6.55E-04	1.71E-02
180							1.26E-02	3.87E-03	1.89E-03	1.84E-02
210								1.29E-02	4.38E-03	1.73E-02
240									1.31E-02	1.31E-02

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Table C10. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{90}Sr (in Equilibrium with ^{90}Y) Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	9.07E-03	2.01E-03	1.57E-03	1.10E-03	8.07E-04	6.58E-04	5.81E-04	5.15E-04	4.43E-04	1.68E-02
30		1.13E-02	2.04E-03	1.57E-03	1.09E-03	7.99E-04	6.49E-04	5.69E-04	5.00E-04	1.85E-02
60			2.03E-02	3.60E-03	1.72E-03	1.33E-03	8.94E-04	7.10E-04	6.04E-04	2.92E-02
90				1.50E-02	3.31E-03	2.80E-03	1.67E-03	1.17E-03	8.98E-04	2.48E-02
120					1.90E-02	7.93E-03	4.71E-03	3.11E-03	2.22E-03	3.70E-02
150						2.69E-02	1.10E-02	7.41E-03	5.23E-03	5.05E-02
180							2.86E-02	1.36E-02	1.00E-02	5.22E-02
210								2.95E-02	1.54E-02	4.49E-02
240									2.93E-02	2.93E-02

Table C11. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{106}Ru (in Equilibrium with ^{106}Rh) Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	1.56E-03	1.00E-03	9.36E-04	7.68E-04	6.67E-04	5.94E-04	5.35E-04	4.85E-04	4.41E-04	6.99E-03
30		2.02E-03	1.21E-03	9.48E-04	7.77E-04	6.72E-04	5.94E-04	5.32E-04	4.80E-04	7.23E-03
60			2.42E-03	1.23E-03	9.56E-04	7.80E-04	6.70E-04	5.90E-04	5.27E-04	7.17E-03
90				2.50E-03	1.24E-03	9.68E-04	7.84E-04	6.68E-04	5.85E-04	6.74E-03
120					2.53E-03	1.25E-03	9.63E-04	7.77E-04	6.62E-04	6.18E-03
150						2.55E-03	1.26E-03	9.59E-04	7.69E-04	5.54E-03
180							2.55E-03	1.25E-03	9.55E-04	4.75E-03
210								2.54E-03	1.23E-03	3.77E-03
240									2.53E-03	2.53E-03

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Table C12. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{125}I Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	2.08E-05	1.12E-05	7.34E-06	1.34E-05	1.46E-05	6.07E-06	4.65E-06	3.01E-06	2.07E-06	8.31E-05
30		2.72E-05	1.05E-05	1.27E-05	1.40E-05	1.04E-05	7.27E-06	4.83E-06	3.31E-06	9.02E-05
60			2.74E-05	1.70E-05	2.23E-05	1.63E-05	1.15E-05	7.66E-06	5.28E-06	1.07E-04
90				1.64E-04	5.21E-05	3.23E-05	2.05E-05	1.31E-05	8.84E-06	2.91E-04
120					8.79E-04	2.88E-04	1.22E-04	5.70E-05	3.05E-05	1.38E-03
150						7.81E-04	3.12E-04	1.40E-04	7.08E-05	1.30E-03
180							6.78E-04	2.99E-04	1.48E-04	1.12E-03
210								5.97E-04	2.98E-04	8.95E-04
240									5.33E-04	5.33E-04

Table C13. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{131}I Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	5.93E-05	2.58E-06	1.88E-07	2.20E-08	3.39E-09	2.10E-10	2.29E-11	1.32E-12	6.35E-14	6.21E-05
30		9.73E-05	2.31E-06	3.38E-07	5.05E-08	3.22E-09	3.47E-10	2.01E-11	9.66E-13	1.00E-04
60			9.44E-05	4.14E-06	7.60E-07	4.75E-08	5.23E-09	3.02E-10	1.46E-11	9.94E-05
90				6.52E-04	2.11E-05	9.30E-07	9.12E-08	5.01E-09	2.33E-10	6.74E-04
120					3.54E-03	8.90E-05	6.03E-06	2.33E-07	7.82E-09	3.64E-03
150						2.35E-03	1.49E-04	5.56E-06	1.75E-07	2.50E-03
180							2.88E-03	1.15E-04	3.48E-06	3.00E-03
210								1.98E-03	6.80E-05	2.05E-03
240									1.00E-03	1.00E-03

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Table C14. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{132}I Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	8.43E-05	0	0	0	0	0	0	0	0	8.43E-05
30		1.06E-04	0	0	0	0	0	0	0	1.06E-04
60			1.27E-04	0	0	0	0	0	0	1.27E-04
90				1.30E-04	0	0	0	0	0	1.30E-04
120					1.51E-04	0	0	0	0	1.51E-04
150						1.53E-04	0	0	0	1.53E-04
180							1.56E-04	0	0	1.56E-04
210								1.56E-04	0	1.56E-04
240									1.56E-04	1.56E-04

Table C15. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{133}I Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	2.81E-04	0	0	0	0	0	0	0	0	2.81E-04
30		5.32E-04	0	0	0	0	0	0	0	5.32E-04
60			6.85E-04	0	0	0	0	0	0	6.85E-04
90				7.04E-04	0	0	0	0	0	7.04E-04
120					9.04E-04	0	0	0	0	9.04E-04
150						8.59E-04	0	0	0	8.59E-04
180							8.49E-04	0	0	8.49E-04
210								8.27E-04	0	8.27E-04
240									8.11E-04	8.11E-04

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Table C16. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{134}I Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	2.22E-05	0	0	0	0	0	0	0	0	2.22E-05
30		2.79E-05	0	0	0	0	0	0	0	2.79E-05
60			3.44E-05	0	0	0	0	0	0	3.44E-05
90				3.50E-05	0	0	0	0	0	3.50E-05
120					3.81E-05	0	0	0	0	3.81E-05
150						3.91E-05	0	0	0	3.91E-05
180							4.03E-05	0	0	4.03E-05
210								4.83E-05	0	4.83E-05
240									4.06E-05	4.06E-05

Table C17. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{135}I Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	1.95E-04	0	0	0	0	0	0	0	0	1.95E-04
30		2.63E-04	0	0	0	0	0	0	0	2.63E-04
60			3.07E-04	0	0	0	0	0	0	3.07E-04
90				3.04E-04	0	0	0	0	0	3.04E-04
120					3.65E-04	0	0	0	0	3.65E-04
150						3.66E-04	0	0	0	3.66E-04
180							3.72E-04	0	0	3.72E-04
210								3.69E-04	0	3.69E-04
240									3.70E-04	3.70E-04

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Table C18. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{134}Cs Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	2.55E-02	2.15E-02	1.69E-02	1.33E-02	1.05E-02	8.29E-03	6.35E-03	4.37E-03	2.81E-03	1.10E-01
30		2.82E-02	2.23E-02	1.75E-02	1.38E-02	1.09E-02	8.38E-03	5.75E-03	3.71E-03	1.11E-01
60			2.92E-02	2.30E-02	1.82E-02	1.44E-02	1.10E-02	7.59E-03	4.88E-03	1.08E-01
90				3.03E-02	2.40E-02	1.89E-02	1.45E-02	9.98E-03	6.43E-03	1.04E-01
120					3.16E-02	2.49E-02	1.91E-02	1.31E-02	8.46E-03	9.72E-02
150						3.28E-02	2.51E-02	1.73E-02	1.12E-02	8.64E-02
180							3.30E-02	2.28E-02	1.46E-02	7.04E-02
210								3.14E-02	2.03E-02	5.17E-02
240									3.24E-02	3.24E-02

Table C19. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{137}Cs Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	1.18E-02	1.13E-02	9.13E-03	7.36E-03	5.91E-03	4.74E-03	3.70E-03	2.60E-03	1.71E-03	5.83E-02
30		1.43E-02	1.17E-02	9.43E-03	7.59E-03	6.08E-03	4.74E-03	3.33E-03	2.19E-03	5.94E-02
60			1.50E-02	1.21E-02	9.72E-03	7.80E-03	6.09E-03	4.27E-03	2.81E-03	5.78E-02
90				1.55E-02	1.25E-02	1.00E-02	7.79E-03	5.48E-03	3.60E-03	5.49E-02
120					1.60E-02	1.29E-02	1.00E-02	7.02E-03	4.63E-03	5.05E-02
150						1.65E-02	1.29E-02	9.05E-03	5.96E-03	4.44E-02
180							1.65E-02	1.16E-02	7.60E-03	3.57E-02
210								1.56E-02	1.03E-02	2.59E-02
240									1.60E-02	1.60E-02

Table C20. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{233}U Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	N*	N	N	N	N	N	N	N	N	N
30		1.41E-03	2.31E-05	5.30E-06	1.19E-06	5.01E-07	2.71E-07	1.74E-07	1.24E-07	1.44E-03
60			4.30E-03	7.86E-04	1.89E-04	7.84E-05	4.25E-05	2.72E-05	1.94E-05	5.44E-03
90				6.29E-03	1.52E-03	6.29E-04	3.42E-04	2.19E-04	1.56E-04	9.16E-03
120					8.10E-03	3.25E-03	1.78E-03	1.13E-03	8.09E-04	1.51E-02
150						9.51E-03	5.11E-03	3.28E-03	2.34E-03	2.02E-02
180							1.40E-02	8.88E-03	6.36E-03	2.92E-02
210								1.49E-02	1.06E-02	2.55E-02
240									2.38E-02	2.38E-02

*N indicates that the metabolic pattern is such that the dose rates and doses would be negligible throughout gestation when activity is administered immediately after fertilization. Approximations of doses resulting from administration during the first month are described on page C-1.

Table C21. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{234}U Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	0-270
0	N*	N	N	N	N	N	N	N	N	N
30		1.40E-03	2.30E-05	5.26E-06	1.18E-06	5.00E-07	2.70E-07	1.73E-07	1.23E-07	1.43E-03
60			4.27E-03	7.82E-04	1.87E-04	7.79E-05	4.22E-05	2.70E-05	1.93E-05	5.41E-03
90				6.25E-03	1.51E-03	6.28E-04	3.39E-04	2.17E-04	1.55E-04	9.10E-03
120					8.05E-03	3.23E-03	1.77E-03	1.13E-03	8.07E-04	1.50E-02
150						9.46E-03	5.07E-03	3.26E-03	2.32E-03	2.01E-02
180							1.40E-02	8.88E-03	6.34E-03	2.92E-02
210								1.48E-02	1.05E-02	2.53E-02
240									2.36E-02	2.36E-02

Table C22. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{235}U Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	0-270
0	N*	N	N	N	N	N	N	N	N	N
30		1.29E-03	2.11E-05	4.84E-06	1.09E-06	4.60E-07	2.48E-07	1.59E-07	1.13E-07	1.32E-03
60			3.93E-03	7.19E-04	1.73E-04	7.18E-05	3.88E-05	2.49E-05	1.77E-05	4.98E-03
90				5.75E-03	1.39E-03	5.78E-04	3.12E-04	2.00E-04	1.43E-04	8.37E-03
120					7.40E-03	2.97E-03	1.62E-03	1.04E-03	7.41E-04	1.38E-02
150						8.70E-03	4.67E-03	3.00E-03	2.14E-03	1.85E-02
180							1.28E-02	8.12E-03	5.82E-03	2.67E-02
210								1.36E-02	9.69E-03	2.33E-02
240									2.17E-02	2.17E-02

*N indicates that the metabolic pattern is such that the dose rates and doses would be negligible throughout gestation when activity is administered immediately after fertilization. Approximations of doses resulting from administration during the first month are described on page C-1.

Table C23. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{238}U Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	N*	N	N	N	N	N	N	N	N	N
30		1.23E-03	2.01E-05	4.59E-06	1.04E-06	4.38E-07	2.36E-07	1.51E-07	1.08E-07	1.26E-03
60			3.75E-03	6.86E-04	1.64E-04	6.83E-05	3.70E-05	2.37E-05	1.69E-05	4.75E-03
90				5.49E-03	1.32E-03	5.49E-04	2.98E-04	1.90E-04	1.36E-04	7.98E-03
120					7.06E-03	2.83E-03	1.55E-03	9.91E-04	7.08E-04	1.31E-02
150						8.30E-03	4.45E-03	2.86E-03	2.04E-03	1.77E-02
180							1.22E-02	7.76E-03	5.54E-03	2.55E-02
210								1.30E-02	9.23E-03	2.22E-02
240									2.07E-02	2.07E-02

Table C24. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{238}Pu Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	N*	N	N	N	N	N	N	N	N	N
30		2.68E-03	4.38E-05	1.00E-05	2.26E-06	9.55E-07	5.14E-07	3.30E-07	2.35E-07	2.74E-03
60			8.19E-03	1.50E-03	3.58E-04	1.49E-04	8.05E-05	5.16E-05	3.67E-05	1.04E-02
90				1.20E-02	2.89E-03	1.20E-03	6.50E-04	4.15E-04	2.96E-04	1.75E-02
120					1.54E-02	6.18E-03	3.37E-03	2.15E-03	1.54E-03	2.86E-02
150						1.81E-02	9.70E-03	6.24E-03	4.43E-03	3.85E-02
180							2.66E-02	1.69E-02	1.21E-02	5.56E-02
210								2.84E-02	2.01E-02	4.85E-02
240									4.51E-02	4.51E-02

*N indicates that the metabolic pattern is such that the dose rates and doses would be negligible throughout gestation when activity is administered immediately after fertilization. Approximations of doses resulting from administration during the first month are described on page C-1.

Table C25. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{239}Pu Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	N*	N	N	N	N	N	N	N	N	N
30		2.52E-03	4.12E-05	9.40E-06	2.12E-06	8.97E-07	4.83E-07	3.10E-07	2.21E-07	2.57E-03
60			7.68E-03	1.40E-03	3.36E-04	1.40E-04	7.56E-05	4.85E-05	3.46E-05	9.71E-03
90				1.12E-02	2.71E-03	1.12E-03	6.07E-04	3.90E-04	2.78E-04	1.63E-02
120					1.45E-02	5.80E-03	3.17E-03	2.02E-03	1.44E-03	2.69E-02
150						1.70E-02	9.09E-03	5.85E-03	4.17E-03	3.61E-02
180							2.50E-02	1.59E-02	1.13E-02	5.22E-02
210								2.66E-02	1.88E-02	4.54E-02
240									4.23E-02	4.23E-02

Table C26. Radiation Doses to the Embryo/Fetus from 1 μCi of ^{241}Am Introduced into the Maternal Transfer Compartment (Blood)

Days of Gestation at Introduction	Dose (rad) to Embryo/Fetus During Indicated Gestation Periods (days)									Cumulated Dose 0-270
	0-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	
0	N*	N	N	N	N	N	N	N	N	N
30		5.36E-04	8.76E-06	2.00E-06	4.52E-07	1.91E-07	1.03E-07	6.60E-08	4.71E-08	5.48E-04
60			1.64E-03	2.99E-04	7.16E-05	2.97E-05	1.61E-05	1.03E-05	7.35E-06	2.07E-03
90				2.39E-03	5.76E-04	2.39E-04	1.30E-04	8.30E-05	5.92E-05	3.48E-03
120					3.08E-03	1.23E-03	6.75E-04	4.31E-04	3.08E-04	5.72E-03
150						3.61E-03	1.94E-03	1.24E-03	8.89E-04	7.68E-03
180							5.32E-03	3.38E-03	2.41E-03	1.11E-02
210								5.67E-03	4.02E-03	9.69E-03
240									9.04E-03	9.04E-03

*N indicates that the metabolic pattern is such that the dose rates and doses would be negligible throughout gestation when activity is administered immediately after fertilization. Approximations of doses resulting from administration during the first month are described on page C-1.

REFERENCES

- 1C. M. R. Sikov, R. J. Traub, and H. K. Meznarich, "Contribution of Maternal Radionuclide Burdens to Prenatal Radiation Dose—Interim Recommendations," NUREG/CR-5631 (PNL-7445), U.S. Nuclear Regulatory Commission, (in press).
- 2C. International Commission on Radiological Protection, "Limits for Intakes of Radionuclides by Workers," ICRP No. 30, Parts 1 through 4, including supplements, Annals of the ICRP, Volume 2, No. 3/4, Pergamon Press Inc., 1979.

REGULATORY ANALYSIS

A separate regulatory analysis was not prepared for this regulatory guide. The regulatory analysis prepared for 10 CFR Part 20, "Standards for Protection Against Radiation" (56 FR 23360), provides the regulatory basis for this guide and examines the costs and benefits of the rule as implemented by the guide. A copy of the "Regulatory Analysis for the Revision of 10 CFR Part 20" (PNL-6712, November 1988), is available for inspection and copying for a fee at the NRC Public Document Room, 2120 L Street NW., Washington, DC, as an enclosure to Part 20.

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