



Technical Note: Methods for Calculating Fetal Dose in Medical Imaging and Radiotherapy

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1 Introduction

In medical physics, calculating fetal dose during radiological and nuclear medicine procedures is essential to protect the developing fetus from radiation exposure. The fetus is highly sensitive to ionizing radiation, particularly during certain stages of prenatal development, and excessive exposure can result in both deterministic and stochastic effects. This technical note outlines methods for calculating fetal dose, focusing on the application of a **three-level concept** for dose estimation and calculation. The methods discussed are widely used in radiography, computed tomography (CT), nuclear medicine, and radiotherapy.

2 Prenatal Radiation Sensitivity

Prenatal development can be divided into three main phases, each with varying sensitivities to radiation ¹:

- **Pre-implantation (0-2 weeks post-conception):** The “all-or-nothing” principle applies, meaning that if radiation damage occurs, it either leads to the loss of the embryo or no significant effect.
- **Organogenesis (2-8 weeks post-conception):** This phase is highly sensitive to radiation-induced malformations and functional disorders.
- **Fetal phase (8 weeks onward):** Central nervous system development is vulnerable, particularly between the 8th and 25th weeks, where exposure can lead to neurocognitive impairments.

3 The Three-Level Concept for Dose Calculation

The **three-level concept** is a systematic approach to estimate the radiation dose to the uterus and fetus based on the complexity of the exposure². The concept is structured to progressively refine the dose estimation, depending on the radiation exposure, to guide the decision-making process.

3.1 Level I: General Assessment Using Standardized Tables

In most cases of radiological examinations, the fetal dose is low and can be quickly estimated using standardized dose tables. These tables ^{3,4,5} provide dose estimates based on general parameters, such as:

- **Modality (radiography, fluoroscopy, CT, ..)**
- **Examined region/organ**
- **Technique (single or multiple exposure, with or without contrast ..., technical parameters)**
- Positioning of the uterus relative to the primary beam

3.2 Level II: Calculation Using Exam-Specific Parameters

For more complex cases where the standard tables do not provide a reliable estimate or where the Foetus dose could exceed 1-5 mGy (e.g., when the uterus is within or adjacent to the beam), Level II calculations are required. These calculations use specific examination parameters ^{2,6,7} such as:

- **Incident Air Kerma:** The radiation dose to the uterus is calculated from the incident dose at the patient’s skin (Entrance Skin Dose, ESD) and adjusted for patient thickness and tissue attenuation factors.
- **Dose-Area Product (DAP):** In fluoroscopy and radiography, DAP can be used to estimate the fetal dose based on the total exposure area and energy of the beam.
- **CTDI and SSDE:** For CT, the Computed Tomography Dose Index (CTDI) and Size-Specific Dose Estimates (SSDE) are used to calculate dose. Monte Carlo simulations can provide accurate dose distribution based on these inputs.

3.3 Level III: Individualized Dose Calculation

In situations where the fetal dose could exceed 20 mSv or when a high degree of accuracy is required, Level III calculations are performed. These calculations involve patient-specific data ^{2,6,8,9,10,11}, including:

- **Patient Geometry and Positioning:** Advanced dosimetry software, such as Monte Carlo simulation tools (e.g., PCXMC or FetalDose.org), is used to model radiation transport based on precise anatomical data. This approach takes into account patient-specific factors such as maternal body size, fetal position, and gestational age.
- **Fluoroscopy and Radiography:** For complex fluoroscopic exams, the Peak Skin Dose (PSD) is calculated by measuring the dose rate and exposure time, while correcting for beam angulation and attenuation.
- **Nuclear Medicine and Radiotherapy:** In nuclear medicine, dose estimates are based on biokinetic models of radionuclide distribution and decay. In radiotherapy, treatment planning systems calculate dose deposition using patient-specific radiological and anatomical data.

4 Estimating Risk Based on Fetal Dose

Risk assessment following radiation exposure to the fetus is guided by the dose received and the gestational age at the time of exposure ^{1,3,4}:

- **Below 5 mSv:** Typically no deterministic effects are expected, and the stochastic risk is minimal.
- **5-100 mSv:** Some stochastic risks, such as increased cancer incidence later in life, may arise, though the overall risk remains low. Deterministic effects are generally not expected below 100 mSv.
- **Above 100 mSv:** The risk of deterministic effects, such as developmental abnormalities, increases significantly, particularly during organogenesis and the early fetal phase.

5 Practical Considerations and Recommendations

When calculating fetal dose, medical physicists should:

1. **Use standardized tables and conversion factors (Level I)** for routine procedures with minimal exposure.
2. **Apply exam-specific data (Level II)** for cases requiring more detailed dose estimations, such as when the uterus is near the examination field.
3. **Engage in individualized calculations (Level III)** for high-dose procedures or when the dose exceeds 20 mSv.

Fetal dose estimation is crucial for counseling pregnant patients on the risks associated with diagnostic and therapeutic procedures. Following the three-level approach ensures that fetal exposure is accurately assessed, and appropriate measures are taken to minimize the risks to the fetus.

6 Conclusion

The three-level concept for calculating fetal dose provides a structured approach for managing radiation exposure in pregnant patients. By using a combination of standard tables, exam-specific parameters, and individualized calculations, medical physicists can ensure the safe application of diagnostic imaging and radiotherapy during pregnancy. Proper risk assessment and counseling are essential to minimizing fetal exposure and protecting maternal and fetal health.

See addendum for practical example.

7 References

1. Tremblay et al. Quality initiatives: guidelines for use of medical imaging during pregnancy and lactation. Radiographics. 2012
2. Scharwächter, C., Röser, A., Schwartz, C.A., et al. (2015). Prenatal Radiation Exposure: Dose Calculation. **Fortschr Röntgenstr** 187: 338-346.
3. McCollough et al.; Radiation Exposure and Pregnancy: When Should We Be Concerned? RG f Volume 27, Number 4;
4. International Commission on Radiological Protection (ICRP). (2000). Publication 84: **Pregnancy and Medical Radiation**. ICRP.
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6. S. L. Brady and R. A. Kaufman: Digital radiography examination DICOM metadata quality assurance; Medical Physics, Vol. 42, No. 5, May 2015
7. AAPM Report 204, Size Specific Estimates in Pediatric and adult body examination
8. Sensakovic et al. Fetal Dosimetry at CT: A Primer; RadioGraphics 2020; 40:1061–1070
9. Angel et al.. Radiation dose to the fetus for pregnant patients undergoing multidetector CT imaging: Monte Carlo simulations estimating fetal dose for a range of gestational age and patient size. Radiology 2008;
10. <http://embryodose.med.uoc.gr/index.php>
11. <https://www.fetaldose.org/>

Addendum: dose calculation examples

According to the Radioprotection Ordinance article 40, for pregnant female patient exposure in the medium-dose (>1mSv) or high-dose (>5mSv) range, the justification must take in account the unborn child.

If the beam directly exposes the Uterus, the dose for unborn child must be documented, so a more precise estimation is needed.

Below some dose estimation example for differ exposure situation (Fluoroscopy/radiography; Computer Tomography; Nuclear medicine; Radiotherapy). For each situation, two circumstances are distinguished: Uterus within or outside the examined area.

In general, several method can be used:

- a. *Extraction of typical values from literature;*
- b. *Conversion factor;*
- c. *Measurements;*
- d. *Monte Carlo Simulation;*

If with the first method the foetus estimated dose is far below the 1 mSv threshold, no additional estimation are needed, otherwise one of the other method can be used for a more precise dose estimation.

For comparison, exposure to the fetus from background radiation is about 1 mGy during pregnancy^{A1}. Exposure to the fetus from a transatlantic flight is about 0.01 mGy.^{A1}

Note: in general, it is supposed that foetus is uniformed irradiated, so the Equivalent dose in mGy and Effective dose in mSv are the same value in case of X ray, gamma or electrons irradiation.

8 Fluoroscopy/radiography

8.1 Foetus within the examined area

For the X Ray Ordinance art. 20.4 and 22, the cumulative Dose Area Product (DAP) of the exam must be at disposition.

Let us suppose for example an antero-posterior pelvis radiography, DAP = 1.95 Gy cm^2 ;

- a. *Extraction of typical values from literature*

First, compare the dose exam with the Diagnostic Reference Level (DRL), to assure that the exam executed is a standard one:

If the specific DAP exam < DRL → use Foetus dose from literature;

If the specific DAP exam >> DRL → rescale: (Foetus dose from literature)/DRL*DAP.

In our example:

DAP exam=1.95Gy cm^2 < DRL=2.5Gy cm^2 :

Foetus dose range* (mGy)	Reference
4.77	doi: 10.3348/kjr.2015.16.6.1276. Epub 2015 Oct 26. PMID: 26576117; PMCID: PMC4644749
0.1-1.0	doi: 10.1136/bmj-2022-070486. PMID: 35470230; PMCID: PMC9036096.
1.0-3.0	RadioGraphics 2007; 27:909–918 - Published online 10.1148/rg.274065149
1.4-4.2	ICRP Publication 84

*The variation is due to the different gestational age of the foetus, the size of the mother and the parameters used.

From all the references is clear that the foetus dose can be higher than 1 mSv, so it is good to proceed with additional evaluation based on one of the other three methods *b*, *c*, *d*. Some example are reported below.

b. Conversion factor

Several mode are possible^{A2}. Here as example, we use the calculation of the uterus dose using incident dose and Percent Depth Dose (PDD) table.

First, evaluate entrance skin dose (ESD) using acquisition parameter by the formula^{A3,A4}:

$$ESK=K*(Kv/100kV)^2*mAs*(1/SSD)^2*BSF$$

K= X-ray tube output (mGy·m²·mAs⁻¹); it is part of the tube commissioning; can be found in the installation acts;

SSD= Source Surface Distance;

BSF= Back scatter factor; can be assumed 1.3±0.1 or can be calculated^{A4}.

As alternative, in a first approximation ESK, can also calculated from DAP:

$$ESK \approx DAP / (\text{beam area @ patient skin}) * BSF$$

Then estimate the mean depth from skin to the foetus in the direction of beam entrance (clinically or by non-ionizing imaging as MRI or US).

Finally multiply ESK for the PDD value of the mean Uterus depth, to obtain a Foetus dose estimation. The PDD in water of the tube should be part of the tool characterization by the Medical Physicist or can be requested to the company taking care of the facility installation.

In our example:

$$DAP = 1.95 \text{ Gy cm}^2 = 1'950 \text{ mGy cm}^2;$$

$$\text{Beam field size @ skin entrance} = 1'240 \text{ cm}^2 (40 \times 31 \text{ cm}^2);$$

$$\rightarrow ESK \approx DAP / (\text{beam area @ patient skin}) * BSF \approx 1'950 / 1'240 * 1.3 = 2.04 \text{ mGy}.$$

Foetus mean dose depth = 5.5 cm;

PDD = 40%;

$$\rightarrow ESK * PDD = 2.04 * 0.4 = \mathbf{0.82 \text{ mGy}}.$$

c. Measurement

Measurements depends on what are the tool at disposition in the centre.

Essentially is used and anthropomorphic phantom or as a first approximation the geometry can be simulated by non-anthropomorphic phantom (as water phantom) or homemade phantom (for example of PMMA).

The phantom is exposed with the same facility and with the same parameter as the particular exam to be evaluated.

Absorbed dose is measured in the phantom @ depth simulating mean foetus depth.

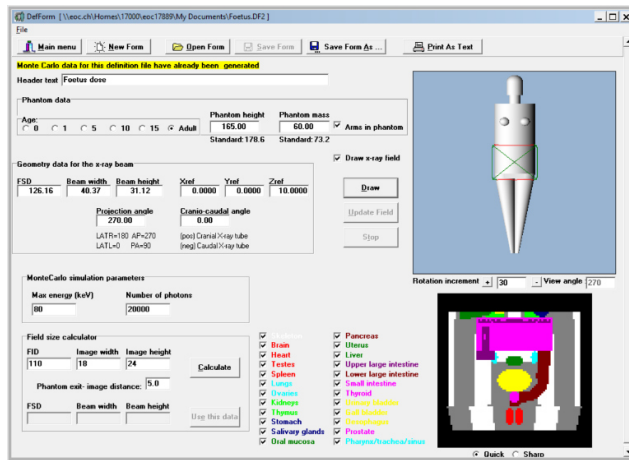
Dosimeter can be ionization chamber, TLD, film, mosfet, so long as calibrated for the energy and dose range of the particular exam.

d. Monte Carlo Simulation

There are several tool based on pre-calculated Montecarlo. If the tool does not include the foetus in the virtual phantom, then the uterus dose can be used to evaluate the foetus dose.

In our example:

Using the commercial software PCXMC^{A5}, the uterus dose results in **1.06 mGy**:

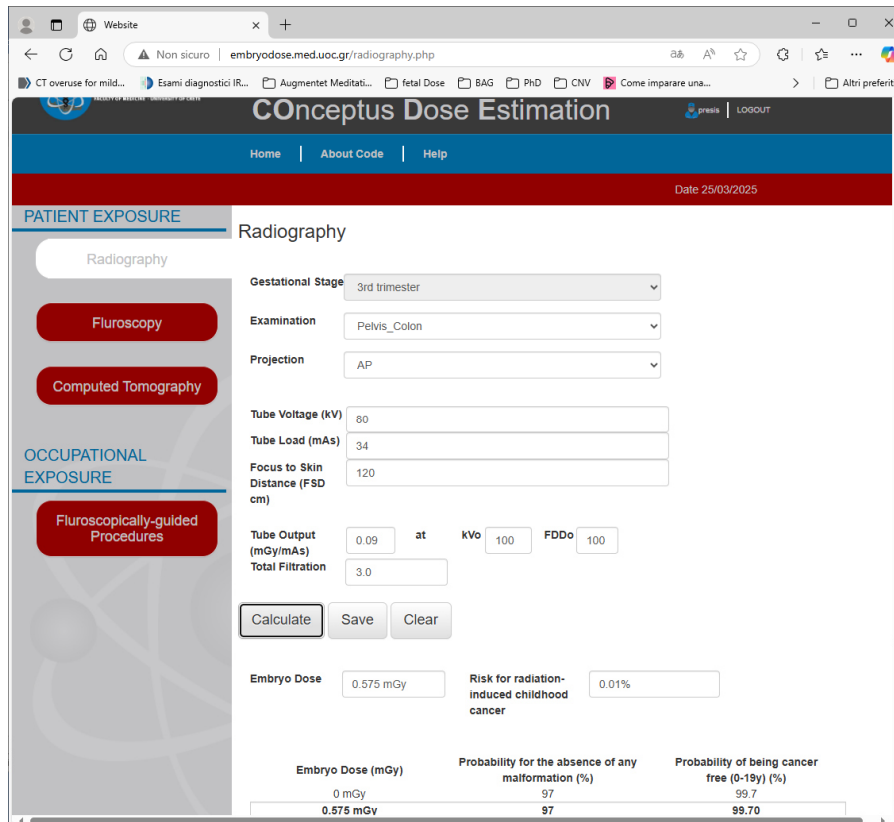


X-ray tube potential: 80 kV Filtration: 3 mm Al + 0.1 mm Cu
Anode angle: 14 deg

File: \\eoc.ch\Homes\17000\ecct\7889\My Documents\Foetus.en2
Foetus dose Phantom: Adult, Arms included Simulation: Photons: Energy level: 20000 Maximum energy: 80 keV
Projection angle (LATL=0,PA=90,LATR=180,AP=270): 270.000 Obl. angle: 0.000
Field width: 48.37 cm and height: 31.12 cm FSD: 126.160 cm Ref. point (x,y,z[cm]): (0.000, 0.000, 10.000)
Phantom height: 165.000 cm and mass: 60.000 kg Scaling factors (xk=ys): 0.942 and zk: 0.924
Incident air kerma:..... 1.552 mGy Tube voltage: 80 kV Filter:....3 mm Al + 0.1 mm Cu

Organs	Dose (mGy)	Error (%)	Organs	Dose (mGy)	Error (%)
Active bone marrow	0.168752	1.0	Scapulae	0.001604	40.2
Adrenals	0.003097	37.1	Clavicles	0.000296	100.0
Bran	0.000000	NA	Fibs	0.019048	7.9
Breasts	0.003659	28.9	Upper arm bones	0.000669	71.7
Colon (Large intestine)	0.949757	1.7	Middle arm bones	0.013783	19.8
(Upper large intestine)	1.040625	2.1	Lower arm bones	2.102075	1.6
(Lower large intestine)	0.829558	2.7	Pelvis	1.299645	1.1
Extrathoracic airways	0.000000	NA	Upper leg bones	0.863508	1.4
Gall bladder	0.264220	7.5	Middle leg bones	0.033022	5.9
Heart	0.004462	16.3	Lower leg bones	0.000056	70.5
Kidneys	0.079406	4.9	Skin	0.289883	0.9
Liver	0.093421	3.8	Small intestine	0.907487	1.3
Lungs	0.003751	12.3	Spleen	0.042401	12.1
Lymph nodes	0.301652	1.3	Stomach	0.156623	5.2
Muscle	0.263795	0.2	Testicles	1.976489	4.4
Oesophagus	0.007714	36.6	Thymus	0.000000	NA
Oral mucosa	0.000000	NA	Thyroid	0.000950	100.0
Ovaries	0.772012	9.7	Uterine bladder	1.524268	3.9
Pancreas	0.040066	15.3	Uterus	1.063228	3.6
Prostate	1.181968	7.9			
Salivary glands	0.000000	NA	Average dose in total body	0.341749	0.2
Skeleton	0.335478	0.7	Effective dose ICRP60 (mSv)	0.534211	2.2
(Skull)	0.000000	NA	Effective dose ICRP103 (mSv)	0.364092	1.5

The same calculation made with the free online tool COnceptus Dose Estimation^{A6} give a value of **0.575 mGy** for the foetus:



8.2 Foetus outside the examined area

In the case the foetus is outside the examined area, the absorbed dose to the foetus is usually far below 1 mGy, so the extraction of typical values from literature is enough for dose estimation.

Let us suppose for example an antero-posterior chest radiography, $DAP = 0.070 \text{Gycm}^2$;

a. Extraction of typical values from literature

First, compare the specific dose exam with the DRL, to assure that the exam executed is a standard one:

If the specific DAP exam < DRL → use Foetus dose from literature

If the specific DAP exam >> DRL → rescale: (Foetus dose from literature)/DRL*DAP

In our example:

$DAP_{\text{exam}} = 0.07 \text{Gycm}^2 < DRL = 0.15 \text{Gycm}^2$:

Foetus dose range* (mGy)	Reference
0.002 PA+ lateral	RadioGraphics 2007; 27:909–918 - Published online 10.1148/rg.274065149
<0.01 Two views	Tremblay et al. ; DOI: 10.1148/rg.323115120
<0.01	ICRP Publication 84

*The variation is due to the different gestational age of the foetus, the size of the mother and the parameters used.

From all the references, the foetus dose is far below than 1 mSv, so the extraction of typical values from literature is enough for the foetus absorbed dose estimation.

In any case if needed, methods *d* and *c* can be used.

For method *b* extended dose profile outside the beam are needed. Usually these measurements are not part of the tube characterization and are difficult to be measured due to a very low signal.

9 Computer Tomography (CT)

9.1 Foetus within the examined area

For the X Ray Ordinance art.20.4 and 22, the volumetric Computer Tomography Dose Index ($CTDI_{\text{vol}}$) and the Dose Length Product (DLP) of the exam must be at disposition.

Let us suppose for example a Abdomen-pelvis CT, $CTDI_{\text{vol}} = 5.77 \text{mGy}$;

a. Extraction of typical values from literature

Compare the dose exam with the DRL, to assure that the exam executed is a standard one:

If the specific $CTDI_{\text{vol}}$ exam < DRL → use foetus dose from literature

If the specific CTDI_{vol} exam >> DRL → rescale: (foetus dose from literature)/DRL*CTDI_{vol}

In our example:

CTDI_{vol} exam=5.77mGy < DRL=11mGy (75° percentile):

Foetus dose range* (mGy)	Reference
25 Abdomen pelvis routine	RadioGraphics 2007; 27:909 –918 - Published online 10.1148/rg.274065149
1.3-35	Tremblay et al. ; DOI: 10.1148/rg.323115120
8-49	ICRP Publication 84

*The variation is due to the different gestational age of the foetus, the size of the mother and the parameters used. The generation of the facility has also a big influence to dose as new technologies give less dose for the same image quality.

From all the references is clear that the foetus dose can be much higher than 1 mSv, so it is good to proceed with additional evaluation based on one of the other three methods *b*, *c*, *d* . Some example are reported below.

b. Conversion factor

A first raw foetus absorbed dose can be obtained using the CTDI_{vol} exam value that represents the mean absorbed dose in the scanned region.

In our example:

we would obtain an estimation of **5.77 mGy**.

This first evaluation could be improved by rescaling the CTDI_{vol} by the ratio of the mean mAs value in the foetus region (mAs_f) and overall exam mean mAs value. The overall mAs is usually in the dose report. The mAs_f can be evaluated by the modulation current curve or scrolling the CT slices where is reported the mAs for each slice.

In our example:

supposing an overall mAs exam=148 and a mAs_f = 210, the foetus dose will be:

→ Foetus dose=5.77/148*210= **8.19 mGy**

This value still do not consider the patient dimension but only the CT output.

To introduce the patient dimension, the Size Specific Dose Estimates (SSDE)^{A7} can be used.

In our example:

with a Lat+Ap mean dimension in the foetus region = 64 cm (AP=25, lat=39) we have a multiplication factor of 1.16.

→ in the approximation of foetus dose = CTDI_{vol}, the dose corrected for patient dimension will be

5.77*1.16=**6.69mGy**

→ If we add the correction for the relative current modulation, we have: 8.19*1.16=**9.5mGy**

Angel et al.⁸ propose another way to correct for patient dimension by the formula:

D (mGy)= (-0.119 (P)-0.029 (dc) +25.56)*mAs/(100*pitch)

P= Mother perimeter

dc= depth of most anterior portion of foetus

In our example:

Supposing the mother perimeter =100cm and foetus depth =5.5 cm, pitch=1.3, the foetus dose will results in:

→ D (mGy) = $(-0.119 (100) - 0.029 (5.5) + 25.56) * 148 / (100 * 0.6) = 15.4 \text{mGy}$

c. Measurement

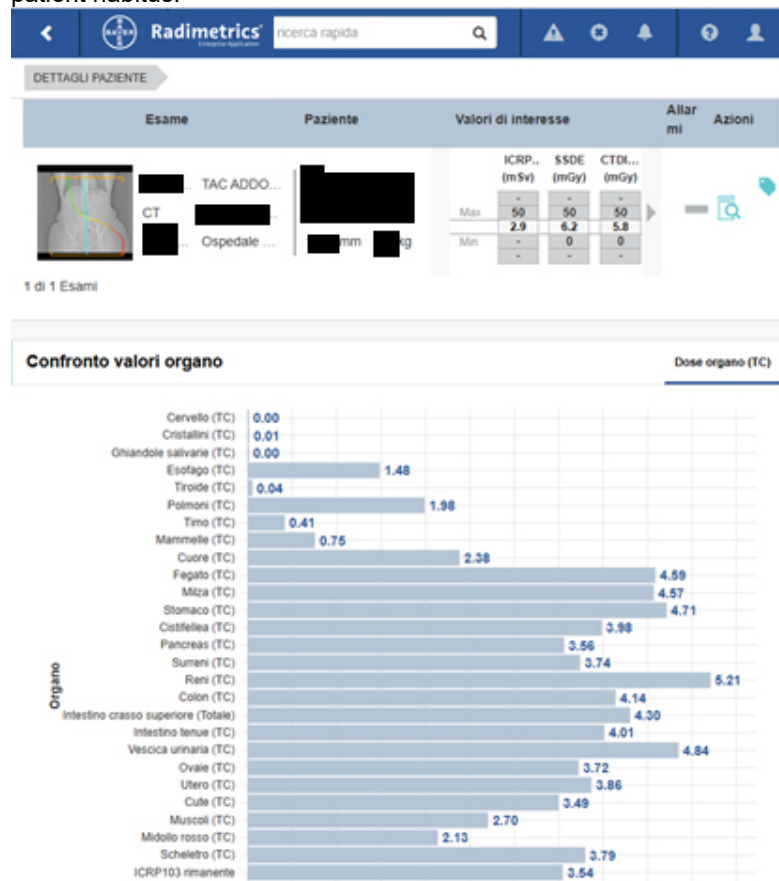
See point 1.1 for radiography/radioscopy case with foetus inside the exam region.

d. Monte Carlo Simulation

There are several tool based on pre-calculated Montecarlo. If case the tool does not include the foetus in the virtual phantom, the foetus dose is estimated by the uterus dose.

In our example:

using the commercial software Radimetrics by Bayer, the CT can be imported in the system and using monte-carlo pre-calculated virtual phantom, the organ dose are estimated from acquisition parameter and patient habitus.



The uterus dose calculation results in **3.86 mGy**.

The same calculation made with the free online tool COnceptus Dose Estimation^{A6} give a foetus dose value = **10.19 mGy**:

embrydose.med.uoc.gr/ct.php

Computed Tomography (CT)

8-12 week

Clear

Embryo Depth (cm) 5

Tube Load (mAs) 148

Tube Voltage (kV) 100

Pitch 1

Beam Collimation (mm) 38.4

Patient Circumference (cm) 100

CTDI_{free-in-air} (mGy/100 mAs) 9

CTDI_w (mGy / 100 mAs) 5.4

Start of scan -6 cm End of scan 30 cm

Calculate Save

Embryo Dose 10.194 mGy Risk for radiation-induced childhood cancer 0.12%

Embryo Dose (mGy)	Probability for the absence of any malformation (%)	Probability of being cancer free (0-19y) (%)
8 mGy	97	99.7
10.194 mGy	97	99.699

Calculation with a third tool, the free online fetaldose.org^{A9}, results in a foetus dose =**4.57 mGy**:

Calculator - Fetaldose.org

https://www.fetaldose.org/calculator.html

Gestational age, month 3.6

Tube voltage, kVp 100kVp

CTDI_{vol}, mGy 5.5

Volume CT Dose Index obtained from patient radiation dose report.

Maternal perimeter, mm (optional) 1000

Maternal perimeter in mm defined from the CT section containing the central area of the uterus.

Upper position, mm 1200

Lower position, mm 825

Patient ID (optional)

Calculate

Radiation dose to the fetus,
mGy: **4.57**

Disclaimer

This disclaimer informs readers that, although all reasonable efforts have been taken to ensure the accuracy and reliability of the radiation dose calculations, the dose values provided by this tool should not be solely used for taking medical decisions of any kind.

9.2 Foetus outside the examined area

In the case the foetus is outside the examined area, the absorbed dose to the foetus is usually below 1 mGy, so the extraction of typical values from literature is enough for dose estimation.

Let us suppose for example a chest CT with $CTDI_{vol} = 3.21 \text{ mGy}$ and $DLP = 114 \text{ mGy cm}$;

a. Extraction of typical values from literature

Compare the dose exam with the DRL, to assure that the exam executed is a standard one:

If the specific CTDI exam $<$ DRL \rightarrow use foetus dose from literature

If the specific CTDI exam \gg DRL \rightarrow rescale: $(\text{foetus dose from literature})/DRL * CTDI_{vol}$

In our example:

$CTDI_{vol} \text{ exam} = 3.21 \text{ mGy} < DRL = 7 \text{ mGy}$ (75° percentile):

Foetus dose range* (mGy)	Reference
0.2	McCollough et al. RadioGraphics 2007; 27:909 –918 - Published online 10.1148/rq.274065149
0.01-0.66	Tremblay et al. ; DOI: 10.1148/rq.323115120
0.06-0.96	ICRP Publication 84

*The variation is due to the different gestational age of the foetus, the size of the mother and the parameters used. The generation of the facility has also a big influence to dose as new technologies give less dose for the same image quality.

In any case if needed methods *d* and *c* can be used.

For method *b* extended dose profile outside the beam are needed. These measurements are not part of a CT characterization and can be performed with the appropriate dosimeter (high sensibility and low energy calibration) suited for scatter radiation measurements.

10 Nuclear Medicine

In the case of nuclear medicine, the radioactive source is systemic inside the patient, so does not make sense to speak about foetus inside or outside the examined region.

Let us suppose a whole body PET scan with 200 MBq F-18 choline.

a. Extraction of typical values from literature

Compare the dose exam with the DRL^{A10} , to assure that the exam executed is a standard one:

If the specific exam injected activity (A) $<$ DRL \rightarrow use Foetus dose from literature;

If the specific exam injected activity \gg DRL \rightarrow rescale: $(\text{Foetus dose from literature})/DRL * A$.

In our example:

$A = 200 \text{ MBq} < DRL = 210 \text{ MBq}$ (70kg patient):

Foetus dose range* (mGy)	Reference
10-15	RadioGraphics 2007; 27:909 –918 - Published online

	10.1148/rg.274065149
10-50	Tremblay et al. ; DOI: 10.1148/rg.323115120

*The variation is due to the different gestational age of the foetus, the size of the mother and the parameters used. The generation of the facility has also a big influence to dose as new technologies need less activity for the same image quality.

From all the references is clear that the foetus dose can be much higher than 1 mSv, so it is good to proceed with additional evaluation based on *b* method. Some example are reported below.

b. Conversion factor

A first raw Foetus absorbed dose estimation can be obtained using injected activity and evaluating the uterus mother absorbed dose.

In the ICRP 53^{A11} are tabulated adult uterus absorbed dose per unit activity administered (mGy/MBq) for F-18 Choline= 0.015 mGy/MBq;

In our example:

we obtain an uterus estimation dose of:

→ $0.015 \times 200 = 3.0 \text{ mGy}$.

Another way for the foetus dose estimation is to use UFSP DRL^{A10} document where are tabulated the effective dose absorbed in 50 year for a specific activity (E50) and exam.

We assume that the maximal effective dose of the foetus is not higher than the mother one. In addition we can assume that E50 is similar to the equivalent dose assumed in 70 years (E70), being F-18 a radioisotope with a short half time life.

Finally normalizing the E50 value reported for the standard activity to the specific injected activity, we obtain a foetus dose estimation.

In our example:

In VDR for F-18 Choline we have E50= 4.2mSv for injected activity of 210MBq.

→ $4.2/210 \times 200 = 4.0 \text{ mGy}$.

A calculation can be done also using the MIRD formalism^{A12}. Free excel file are available to use MIRD calculation^{A12}. Time –integrated activity (cumulated activity) in each organ is needed as input data: these can be found in ICRP publications^{A11}

In our example:

The Foetus dose is estimated by the uterus dose:

MIRDcalc_v1.23 - MIRDcalc

143 | 0.104

MIRD SCHEMA ORGAN LEVEL DOSIMETRY SPREADSHEET

Biodistribution Model INPUT

Element: Eu, F, Fe, Fr, Ga, Gd, Ge, H, I, Hg, Ho, I, In

Isotope: F-17, F-18

Sex: Female

Phantom: ICRP 10 year old female, ICRP 15 year old female, ICRP Adult Female

subject ID (optl):

Dosimetry Estimate OUTPUT

Input parameters:

Phantom: ICRP Adult Female ♀

Isotope: F-18

Half-life: 1.8295E+00 [hours]

Subject ID:

% injection accounted for: 98%

Input S value uncertainty: 20%

organs with nonzero TIACs: 6

Input isotope/organ UID: JVK

W_R: 1

Y: 1

β: 1

α: 20

Source organs			Target organs		
Organ name	Time integrated activity coefficients [hours]	σ (Std. Dev.) (optional) [hours]	Organ name	Patient organ mass (optional) [grams]	σ (Std. Dev.) (optional) [grams]
Adipose tissue			Adipose tissue		
Adrenals			Bone marrow - red (t		
Bone - cortical volur			Brain		
Bone - trabecular vo			Breast tissue		
Brain			Colon - ICRP133		
Breast tissue			Esophagus		
Cartilage			Extrathoracic region		
Esophagus wall			Eye lens		
Gallbladder content			Gallbladder wall		
Heart content			Heart wall		
Heart wall			Kidneys		
Kidneys	0.135		Liver		
Liver	0.415		Lymphatic nodes - IC		
Major blood vessels	0.267		Muscle		
Oral mucosa			Oral mucosa		
Pancreas			Ovaries		
Pituitary gland			Pancreas		
Salivary glands			Skin		
Spleen			Small intestine		
Stomach content	0.022		Spleen		
Thymus			Stomach		
Thyroid			Thyroid		
Urinary bladder cor	0.104		Tongue		
Rest of body	1.631		Urinary bladder wall		
Rest of body mass: 55.5 Kg			Whole body	60 ± Kg	
Organ model (S value) uncertainty: 20%					
Waste					

Total TIAC entered into table: 2.57
TIAC for 100% emissions (F-18): 2.64

% theoretical activity accounted for: 98%

Estimated dosimetry (absorbed dose) - 37/48 displayed here

Organ	Abs Dose [mGy / MBq]	Uncertainty (SD) [mGy / MBq]
Adipose tissue	1.10E-02	9.79E-04
Adrenals	3.37E-02	3.15E-03
Bone - endosteal cells	1.14E-02	6.42E-04
Bone marrow - red (act	1.56E-02	9.15E-04
Brain	8.92E-03	9.83E-04
Breast tissue	1.13E-02	9.89E-04
Bronchial basal cells	2.18E-02	1.97E-03
Colon - ICRP133	1.43E-02	8.46E-04
Esophagus	7.09E-03	1.68E-03
Extrathoracic region - I	7.85E-03	4.75E-04
Eye lens	6.74E-03	7.38E-04
Gallbladder wall	3.82E-02	4.15E-03
Heart wall	1.81E-02	1.37E-03
Kidneys	8.93E-02	1.09E-02
Liver	9.86E-02	7.46E-03
Lung - ICRP133	1.59E-02	1.24E-03
Lymphatic nodes - ICR	1.75E-02	1.10E-03
Muscle	1.17E-02	1.03E-03
Oral mucosa	1.34E-02	1.05E-03
Ovaries	1.71E-02	1.35E-03
Pancreas	2.58E-02	2.17E-03
Pituitary gland	1.00E-02	9.04E-04
Prostate	0.00E+00	0.00E+00
Salivary glands	1.02E-02	8.89E-04
Skin	8.45E-03	7.93E-04
Small intestine	1.70E-02	1.12E-03
Spleen	3.21E-02	3.46E-03
Stomach	1.93E-02	1.68E-03
Testes	0.00E+00	0.00E+00
Thymus	1.78E-02	1.55E-03
Thyroid	1.35E-02	1.13E-03
Tongue	1.17E-02	9.32E-04
Tonsils	1.03E-02	8.56E-04
Ureters	1.87E-02	1.22E-03
Urinary bladder wall	3.04E-02	3.19E-03
Uterus	2.16E-02	1.87E-03
Whole body target	1.37E-02	1.31E-03

Detriment Weighted & Effective Dose⁴⁰

MIRD Calc	[mSv / MBq]	[mSv / MBq]
EDW Detr Vght Dose	1.92E-02	4.63E-04
E Effective Dose	1.76E-02	4.23E-04

Dose per injection (top organs)

Injected activity: 200 [MBq]

Est. dose for injection: 200 MBq

5.41 mCi

mGy / injection

Projected EDW / 200 MBq injection
EDW: 3.52E+00 ± 8.46E-02

Legend: alpha (red), beta (blue), gamma (green)

error bars = SD of total dose

Uncertainty values are solely derived from propagating user entered biodistribution uncertainties.
E and E_{eff} calculated using ICRP 103 radiation and tissue weighting factors.

We have uterus dose=0.0216mGy/MBq
→ 0.0216*200=4.32mGy

c. Measurement

The measurements take in account the geometrical setup and the Biokinetic data for the specific radioisotope. This method is not easy to be used for foetus dose estimation in the routine contest.

d. Monte Carlo Simulation

As for measurements the monte-carlo simulation are rather complicated so not the easy choice for foetus estimation in the routine contest.

11 Radiotherapy

In radiotherapy when the foetus is near or in the target volume, the dose will be much higher than the 100 mSv threshold value to evaluate a preventive abort in early period of gestation^{A15}.

In general the Treatment Planning System (TPS) used for dose distribution calculation in the treated patient, can easily calculate the foetus dose. These systems use real patient imaging so are always patient specific calculations. Some of the system include simplified Monte-carlo calculator.

If needed measurements can be set-up to simulate the geometry of the foetus respect the treatment beam. In each radiotherapy centre there is at least a medical physicist able to do such measurements and are available water phantom and ionization chamber for measurements. Frequently the medical physicist even has an anthropomorphic phantom at his disposal for measurements.

In any case the easiest and most precise way to evaluate the dose is using TPS calculation.

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