# CALDose_X online: Web-based, real time Monte Carlo calculations for patient dosimetry in X-ray diagnosis

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Abstract

CALDose_X 5.0 is a software package for the calculations of organ and tissue absorbed doses, as well as cancer risks for patients submitted to examinations of conventional radiography which can be downloaded from www.caldose.org. The program is based on conversion coefficients (CCs) between organ and tissue absorbed dose and measurable quantities, calculated with the MASH and FASH adult reference phantoms in standing and supine posture. In order to cover a greater variety of patient anatomies, 36 adult human phantoms, 18 per gender, 9 in standing and 9 in supine posture, for 3 different body masses and 3 different standing heights have been developed at the Department of Nuclear Energy in Recife/Brazil. However, the calculations of CCs for 36 phantoms would increase the data files to be downloaded by users dramatically. Therefore, it was decided to develop a software program, called CALDose_X **online,** which allows for the calculation of CCs or absolute organ and tissue absorbed doses, as well as cancer risks using real time MC executed from the website www.caldose.org. This software covers 24 X-ray examinations for standing and supine posture for adult patients with body masses between 59.3 kg and 108.5 kg for males and between 48.6 kg and 94 kg for females. Standing heights cover the range from 167.3 cm to 185.6 cm for males and from 155.5 cm to 172.2 cm for females. Typical run time for the simulation of a radiograph is 60-90 seconds.

## 1. Introduction

CALDose_X 5.0, available at www.caldose.org for download, is a software program [1] for the calculation of absorbed doses and radiological risks in the human body caused by exposure of patients in radiodiagnostic. The software uses conversion coefficients (CCs) between organ absorbed doses and measurable quantities for the MASH and FASH phantoms in standing and supine position [2] which represent a reference adult male and female, respectively, according to ICRP89 [3]. However, most patients have not the anatomical properties of the ICRP reference adults. Therefore, a series of 36 adult male and female phantoms with different body mass, standing height and posture have been developed at the University of Pernambuco. Body masses and standing heights reflect the 10th, 50th and 90th percentiles derived from statistical data for Caucasian populations and were used to develop 18 phantoms having standing posture [4]. 18 phantoms in supine posture were derived from the standing phantoms using methods reported earlier [2].

Calculation of CCs for 36 phantoms would produce large data files to be downloaded by users and a recalculation of all data would become necessary for every single update. The answer to this problem is CALDose_X **online**, a dosimetric service on the internet (www.caldose.org) for real time Monte Carlo (MC) calculation of organ and tissue absorbed doses as well as radiological risks from conventional diagnostic X-ray examinations taking into account the body mass, the standing height and the posture of the patient.

## 2. Materials and methods

### 2.1 Dosimetry

Triggered by users on the website www.caldose.org , the MC calculations are executed on computers located in the Department of Nuclear Energy at the University of Pernambuco in Recife/Brazil. 36 phantoms, 18 in standing and 18 in supine position, 9 per gender and posture with combinations of 3 different body masses and 3 different heights are connected to the EGSnrc MC code [5], considered to be one of the most reliable MC codes for simulating medical applications of ionizing radiation. 24 different X-ray examinations with various projections can be simulated using spectra with 2.0 – 5 mm Al filtration between 60 and 150 kVp and different focus-to-detector distances (FDD). The MC codes calculate CCs between organ and tissue absorbed doses and measurable quantities such as incident air kerma (INAK), entrance surface air kerma (ESAK) and air kerma area product (AKAP) and also cancer incidence and mortality risks per INAK, ESAK and AKAP for the age defined by the user. CALDose_X **online** outputs also absolute absorbed doses and radiation risk if the user provides a value for at least one of the measurable quantities (INAK, EASK, AKAP). 36 user code folders containing the user source program, one of the 36 phantom files, 5 sets of micro matrices for skeletal dosimetry based on μCT images of trabecular bone [6], input files for 24 different X-ray examinations and a file with the X-ray tube spectra have been installed within the EGSnrc system on a PC with an Intel® Core™2 Quad CPU Q9650 @ 3.00GHz processor, 4 GB RAM and a P5KPL-AM (ASUS) motherboard. The calculations run on the LINUX/Ubuntu 9.10 64 bits operational system using the Intel compiler ifort 11.1 64 bits. Using the 4 processors in parallel, the runtime for the simulation of an X-ray radiograph with 5 million source photons is 60-90 seconds for most examinations. CALDose_X **online** outputs organ and tissue absorbed doses to the user if the statistical error of the MC calculation is smaller than 10%. For most organs and tissues located inside the X-ray beam the statistical errors are typically around 1%; for small organs, such as ovaries and adrenals 2-3%. The phantom's names express gender, posture, body mass and height. "MSUP_m50_h90" represents a male (M) phantom in supine (SUP) posture with 50$^{th}$ percentile body mass (m50) and 90$^{th}$ percentile height (h90), or "FSTA_m90_h10" stands for a female (F) phantom in standing (STA) posture with 90$^{th}$ percentile body mass and 10$^{th}$ percentile height, for example.

### 2.2 The Internet connection

CALDose_X **online** was designed to work via the Internet as a web server [7]. Communication between the server and the database, containing information about user records and examinations, are made using PHP and SQL scripting. The correct exhibition of the information to the user is done with HTML (*HyperText Markup Language*) [8] by generating a web-page [9]. The final HTML document is readable with any web browser available to the user. PHP (*Personal Hypertext Preprocessor*) is an interpreted language widely used to generate dynamic content for the World Wide Web. PHP runs on the computer that hosts the page, while HTML will configure the page to be exhibited to the user via the web browser. The HTML interface receives the data from the user and sends them via PHP to the server where it triggers the Monte Carlo simulation. HTML and PHP are standardized, efficient languages of the Internet, which make CALDose_X **online** accessible to computers of any size which are capable of connecting to the Internet, including third generation (3G) cell phones.

## 3. Results

On the first page of the CALDose_X **online** website, shown in figure 1, the user is asked to select gender and posture. Here, "Male Adult Supine" was selected.

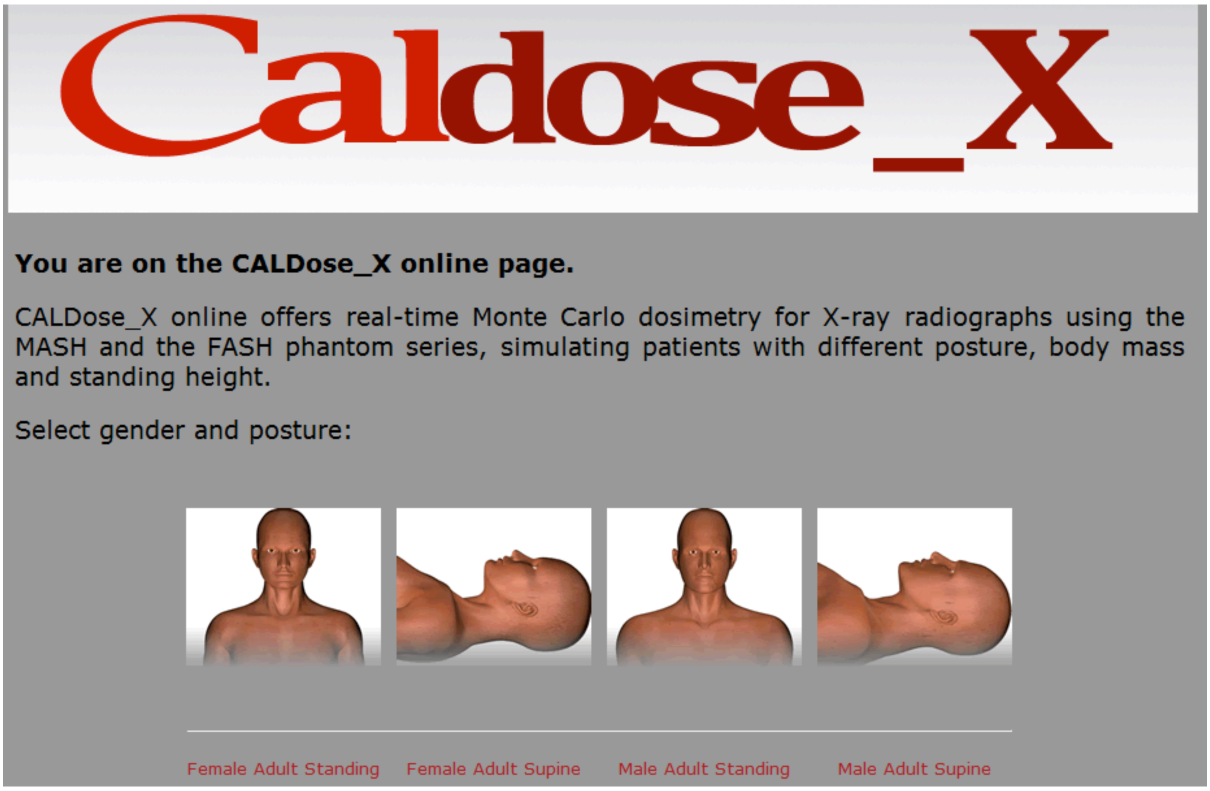


**Figure 1.** CALDose_X **online**: Selection of gender and posture

The next page, shown in figure 2, presents the phantoms available to the user and a drop down window to define the examination. The male supine phantom MSUP_m50_h90 and a radiograph of the small intestine in anterior-posterior (AP) projection were selected for this demonstration. Exposure parameters like peak voltage, aluminium filter and FDD, as well as the age are defined on the page shown in figure 3. At this point, CALDose_X **online** is ready to calculate CCs for organ and tissue absorbed doses, as well as cancer risks normalized to INAK, ESAK and AKAP for the X-ray examination selected.

If the user wants absolute organ doses and radiological risks to be calculated then a value for at least one of the measurable quantities has to be provided. Additionally, CALDose_X **online** offers to calculate the INAK based on the X-ray tube charge (mAs). Similar to CALDose_X 5.0, the INAK calculation is using a theoretical output curve for each aluminium filter derived from the spectra used for the Monte Carlo simulations [10]. In figure 3 the INAK was calculated as 6.147 mGy based on 63 mAs, a FDD of 110 cm and the sagittal diameter of the RMSUP_m50_h90 phantom. CALDose_X **online** does not calculate age-dependent organ and tissue absorbed doses, but information of the patient's age is necessary for the calculation of radiological risks.

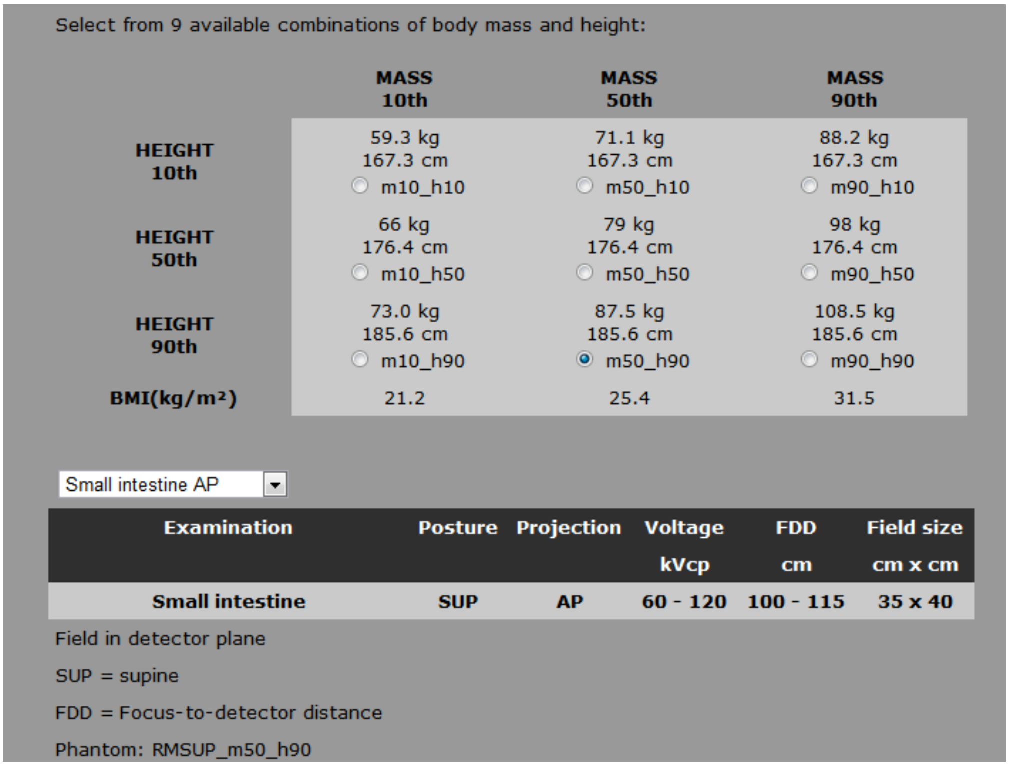


**Figure 2.** CALDose_X **online**: Selection of phantom and examination

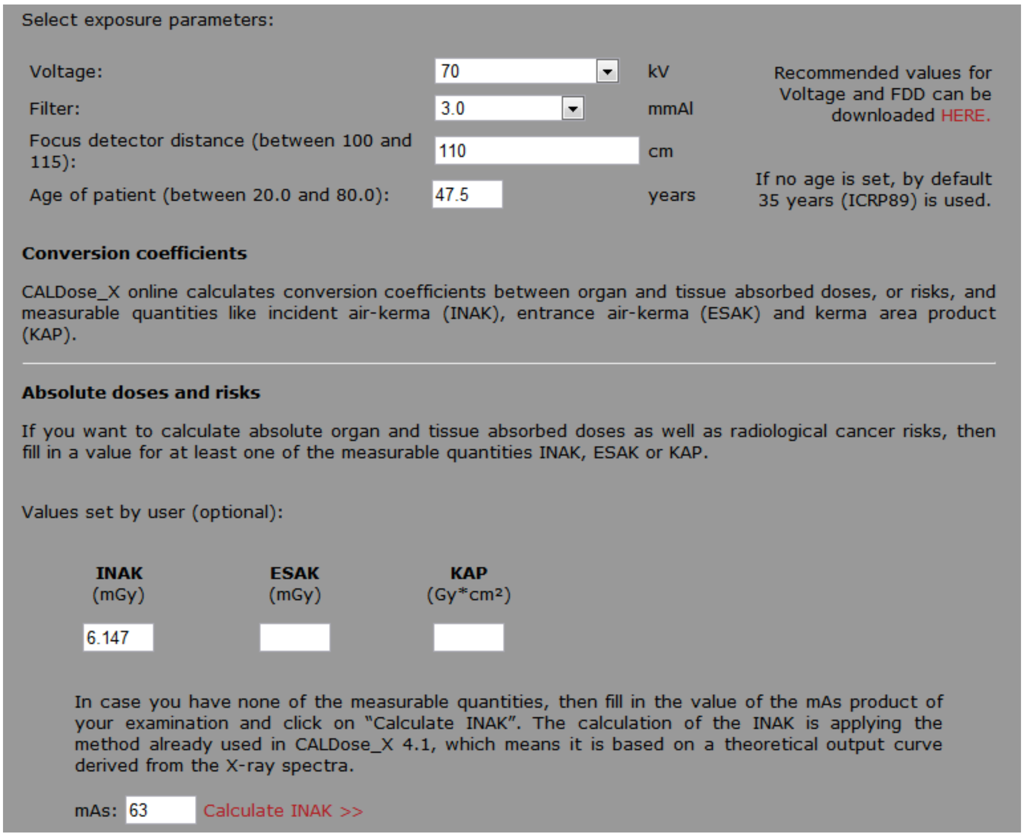


**Figure 3.** CALDose_X **online**: Selection of the exposure parameters and of the adult age. Definition of measurable quantities.

**Table 1.** CALDose_X **online**: Results for organ and tissue absorbed doses, as well as cancer risks

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MASH3_m50_h90_SUP: SMALL INTESTINE, ANTERIOR-POSTERIOR (AP)
IMAGE BEHIND THE BODY    MALE ADULT
  70 kVcp  3.0 mm Al  17 Deg  Tungsten  IPEM/SR78
MEAN SPECTRAL ENERGY:  39.9 keV   ABSORBED FRACTION:  0.62
SOURCE-TO-DETECTOR (FILM):   110.0 cm
SOURCE-TO-SKIN:    83.4 cm
FIELD SIZE IN DETECTOR PLANE:  35.0 cm x   40.0 cm
FIELD POSITION: STANDARD              POSTURE:   SUPINE
BODY MASS: 87.5 KG, STANDING HEIGHT: 185.6 CM
AGE:  47.5 YEARS   USER INAK:     6.147 mGy

               ABSORBED DOSE

   ORGAN/TISSUE                  mGy          %
ESAK CALCULATED FROM USER INAK  8.735       1.18
ADRENALS                        0.481       3.48
BLADDER WALL                    0.247       2.56
COLON WALL                      1.975       0.33
BREASTS,glandular               0.099       8.07
KIDNEYS                         0.538       0.73
LIVER                           2.307       0.14
LUNGS                           0.124       0.71
OESOPHAGUS                      0.110       4.28
PANCREAS                        1.943       0.58
SMALL INTESTINE WALL            1.729       0.27
SKIN ENTRANCE 7.2cm X 7.2cm     8.835       1.18
SPLEEN                          1.186       0.67
STOMACH WALL                    2.950       0.42
THYMUS                          0.059       7.39
HEART WALL                      0.143       1.35
LYMPHATIC NODES                 0.761       0.54
GALL BLADDER WALL               4.283       1.34
SKELETON AVERAGE                0.377       0.17
MAXIMUM RBM ABSORBED DOSE       0.242       1.01
MAXIMUM BSC ABSORBED DOSE       0.308       2.46
 WEIGHTED MASH DOSE             0.857       0.40

RISK OF CANCER INCIDENCE:    4.050 CASES PER 100000
RISK OF CANCER MORTALITY:    2.243 CASES PER 100000
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The results of the MC calculation are displayed as tables on the user's screen for most examinations after 60-90 seconds, like those shown in table 1 for the small intestine radiograph. The table can be saved to the user's computer and, if requested, CALDose_X **online** sends the results additionally to an e-mail address provided by the user. For the small intestine radiograph, a value of 6.147 mGy for the INAK was passed on to CALDose_X **online**. Therefore, table 1 present absolute organ and tissue absorbed doses, as well as the risks of cancer incidence and mortality. The header contains all information of the phantom and the X-ray examination. The results are given in mGy together with the statistical error in %, representing absorbed dose averaged over the volume of the organ or tissue. However, a 7.2cm x 7.2cm square of skin, centred on the central axis of the X-ray beam, was used for calculating the entrance skin absorbed dose, and the red bone marrow (RBM) and the bone surface cells (BSC) absorbed doses were taken from those bones located inside the beam volume which showed the greatest values for these skeletal tissues. X-ray radiographs represent partial body exposure, i.e. that volume averaged absorbed doses for tissues which are distributed over the whole body are rather less meaningful from the point of view of medical radiation protection. Table 1 also contains a “WEIGHTED MASH DOSE”, which is the male contribution to the effective dose. A calculation with the FSUP_m50_h90 phantom for the same exposure conditions would output the female contribution, called “WEIGHTED FASH DOSE”. The effective dose is simply the arithmetic mean of the two gender-specific contributions.

Following a proposal by Brenner [11], the cancer risks are calculated by CALDose_X **online** as “whole body effective risk”, which is a sum of risk-weighted organ absorbed doses using the risk factors given in the BEIR VII report [12]. For the small intestine radiograph, shown in table 1, the risks of cancer incidence and mortality are 0.0041% and 0.0022%, respectively. Statistical errors for the risk estimates are similar to those given for the MASH/FASH weighted doses. Similar tables are given by CALDose_X **online** for the normalization quantities ESAK and AKAP. A more detailed description of the method used for the risk calculation was given earlier by Kramer et al [1].

## 4. Conclusion

CALDose_X **online** provides organ and tissue absorbed dose assessment for male and female adults as a function of posture, body mass and height by real time Monte Carlo calculation via the internet. Additionally, the software allows for the calculation of effective dose and radiation-induced cancer risks. To the best of the authors’ knowledge, this paper presents the first work for real time Monte Carlo dosimetry for X-ray diagnosis executed via the Internet. (For optical photons, online Monte Carlo is available at http://biophotonics.otago.ac.nz/Default.aspx). After one year since it was launched, CALDose_X **online** became a daily tool used by physicists, radiologists and others working in scientific institutions, hospitals, companies and organizations of the health sector (more than 700 registered users from more than 40 countries)

- to calculate organ and tissue absorbed doses for patients submitted to conventional radiography using the 36 anthropometric phantoms as a function of gender, posture, body mass and height,
- to assess the effective dose based on ICRP103 [13] and/or the patient’s cancer risk based on the BEIR VII report [12],
- to demonstrate how organ and tissue absorbed doses, i.e. the radiation risk for the patient, depend on the proper selection of the exposure parameters. This information can be used in educational programs to train radiologists and technicians to understand how to perform X-ray examinations with the minimum exposure to the patient,
- to compare organ and tissue absorbed doses, effective doses and radiation risks from different radiological procedures, or from different X-ray units, or from different hospital, etc., to identify high and low risk examinations, or cases of good and bad practice and
- to make risk assessments for surveys on radiological exposures, taking into account risk factors for the age and gender distribution of the patient population under consideration.

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