Automation of PCXMC and ImPACT for NASA Astronaut Medical Imaging Dose and Risk Tracking

Presentation

Section: Scientific – Imaging Topics

Category: DOSIMETRY, RADIATION PROTECTION, AND QUALITY CONTROL (IMAGING)

Subcategory: Imaging Dosimetry and Radiation Protection

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Purpose: To automate astronaut organ and effective dose calculations from occupational X-ray and computed tomography (CT) examinations incorporating PCXMC and ImPACT tools and to estimate the associated lifetime cancer risk per the National Council on Radiation Protection & Measurements (NCRP) using MATLAB®.

Methods: NASA follows guidance from the NCRP on its operational radiation safety program for astronauts. NCRP Report 142 recommends that astronauts be informed of the cancer risks from reported exposures to ionizing radiation from medical imaging. MATLAB® code was written to retrieve exam parameters for medical imaging procedures from a NASA database, calculate associated dose and risk, and return results to the database, using the Microsoft .NET Framework. This code interfaces with the PCXMC executable and emulates the ImPACT Excel spreadsheet to calculate organ doses from X-rays and CTs, respectively, eliminating the need to utilize the PCXMC graphical user interface (except for a few special cases) and the ImPACT spreadsheet.

Results: Using MATLAB® code to interface with PCXMC and replicate ImPACT dose calculation allowed for rapid evaluation of multiple medical imaging exams. The user inputs the exam parameter data into the database and runs the code. Based on the imaging modality and input parameters, the organ doses are calculated. Output files are created for record, and organ doses, effective dose, and cancer risks associated with each exam are written to the database. Annual and post-flight exposure reports, which are used by the flight surgeon to brief the astronaut, are generated from the database.

Conclusions: Automating PCXMC and ImPACT for evaluation of NASA astronaut medical imaging radiation procedures allowed for a traceable and rapid method for tracking projected cancer risks associated with over 12,000 exposures. This code will be used to evaluate future medical radiation exposures, and can easily be modified to accommodate changes to the risk calculation procedure.

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Innovation/Impact: This work provides automated methods for calculating organ doses resulting from X-ray and CT examinations of astronauts. The tools developed in this study are used to calculate doses from medical imaging radiation exposures. The procedures improve the accuracy over past methods and will standardize the methods used for reproducibility and transparency.

Introduction: An astronaut is exposed to a foreign radiation environment consisting of photons, electrons, neutrons, protons, and other heavy charged particles. Also, he or she may be required to be exposed to artificial sources of ionizing radiation as a part of his or her mission duties (examinations for fitness of duty, biomedical experiments, etc). Other than atmospheric exposures during flights on commercial aircraft, all exposures that are required for duty as an astronaut are considered to be occupational exposures.

NCRP Report 142, *Operational Radiation Safety in Low-Earth Orbit: A Basic Framework*, outlines recommendations of the NCRP for the NASA Operational Radiation Safety Program (1). These recommendations guide decisions on the structure of the program, including activities associated with exposure management and the calculation, categorization, recordkeeping, and reporting of risk from radiation exposures. Two recommendations in particular address medical exposures: Recommendation 5 states that "the dose limits for astronauts should include the cumulative dose from space flight, the dose associated with mission-related aviation activities (excluding commercial flights), the dose from biomedical research conducted as part of the astronaut's mission duties, and any other occupational doses including any received prior to work as an astronaut", while the discussion of Recommendation 18 states that "other radiation exposure files, such as diagnostic and therapeutic medical radiation exposures from overall health care that are maintained in the medical department, should also be linked to the dosimetry record" (1). NCRP Report 142 also states that astronauts should be provided with information that describes the significance of nonoccupational ionizing radiation exposures and the potential biological effects.

In accordance with these recommendations, all medical exposures are tracked in a NASA database. In the past, a variety of methods have been used to calculate the organ doses and subsequent effective dose resulting from these exposures. Currently, PCXMC (2) is used to evaluate X-ray exposures (including fluoroscopy), and ImPACT (3) is used to evaluate CT exposures. For reproducibility, the organ doses and effective doses for the examinations in currently in the NASA database will be recalculated using current methods. Due to the size of the database, automation of the calculations was required. MATLAB® was chosen as the code to calculate astronaut dose and risk from all occupational radiation sources including that from medical imaging exposures. The MATLAB® was written to quickly automate the recalculation of the legacy records by interfacing directly with the PCXMC executable; emulating the ImPACT spreadsheet; calculating effective dose and associated lifetime cancer risk; and interfacing with NASA SQL Server database using the .NET Framework.

PCXMC Automation: PCXMC allows the user to input the patient height and weight for simulation of organ dose. To take advantage of this feature, a library of astronaut height and weight measurements are used to find the height and weight of the astronaut from measurements taken nearest to the time of exposure. These values are then rounded to the nearest 5 cm and 10 kg and assigned a corresponding body type index. The body type index and anatomy description are used to find the appropriate positioning of the X-ray beam with respect to the phantom. The body type number, projection angle, and source-to-image distance are used to determine the source-to-surface distance. In addition to exam parameters such as image height and width, the tube voltage, anode angle, and filtration are required for Monte Carlo simulation. Once this simulation is complete, the doses must be scaled by the appropriate dose index quantity. PCXMC allows the user to scale by mAs or entrance skin air kerma (ESAK), among other quantities. ESAK is the preferred dose index quantity by which to scale, since it is directly relatable to dose. Historically, the ESAK has been determined in different ways, depending on the location and date of the exam. Previous to December 2001, the method of McGuire and Dickson (4), which involves correlating output to kVp through a series of polynomial fits, was used. Between December 2001 and June 2004, actual ESAK measurements at various kVp were made and a polynomial fitted to the data.

After June 2004, the method of Harpen (5) was used, which simply uses calibration data at two kV settings. Users of PCXMC, which is commercially distributed as an executable, can input data through a graphical user interface or through an input file. When the executable is opened, it automatically checks for the existence of the input file; if the file is present, PCXMC runs based on the parameters specified in it. Automation of PCXMC is easily achieved by creating the input file in the proper location and using MATLAB® to call the PCXMC executable.

ImPACT Automation: The ImPACT dose calculation spreadsheet uses previously-generated Monte Carlo-derived look-up tables for specific for CT machines and settings in order to determine organ doses from CT examinations. Based upon the scan start and stop positions, the Monte Carlo data for each phantom slice is summed using the principle of superposition, and then adjusted by the pitch, CTDI value, and time-integrated tube current. Since this calculation does not require the full Monte Carlo simulation performed by PCXMC, the ImPACT dose calculation spreadsheet was transferred completely to MATLAB®, eliminating the for the spreadsheet procedures.

Effective Dose and Risk: Effective dose is calculated from the tissue-weighted organs. The effective dose is related to cancer incidence and mortality risks based upon an age-at-exposure and gender modifier (6). Results are stored in the NASA database for later report generation. Since all organ doses are recorded, any changes to cancer risk models can be easily applied to past exposures.

References

(1) NCRP 2002 Operational Radiation Safety Program for Astronauts in Low-Earth Orbit: A Basic Framework *Recommendations of the NCRP* (Bethesda, MD: NCRP)

(2) STUK 2009 PCXMC - A PC-based Monte Carlo program for calculating patient doses in medical X-ray examinations http://www.stuk.fi/sateilyn_kaytto/ohjelmat/PCXMC/en_GB/pcxmc/

(3) ImPACT 2010 ImPACT's CT Dosimetry Tool http://www.impactscan.org/ctdosimetry.htm

(4) McGuire EL and Dickson PA 1986 Exposure and organ dose estimates in diagnostic radiology *Medical Physics* **13** 913-916

(5) Harpen MD 1996 A mathematical spread sheet application for production of entrance skin exposure nomograms *Medical Physics* **23** 241-242

(6) NCRP 2000 Radiation Protection Guidance for Activities in Low-Earth Orbit *Recommendations of the NCRP* (Bethesda, MD: NCRP)

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1 August 2011

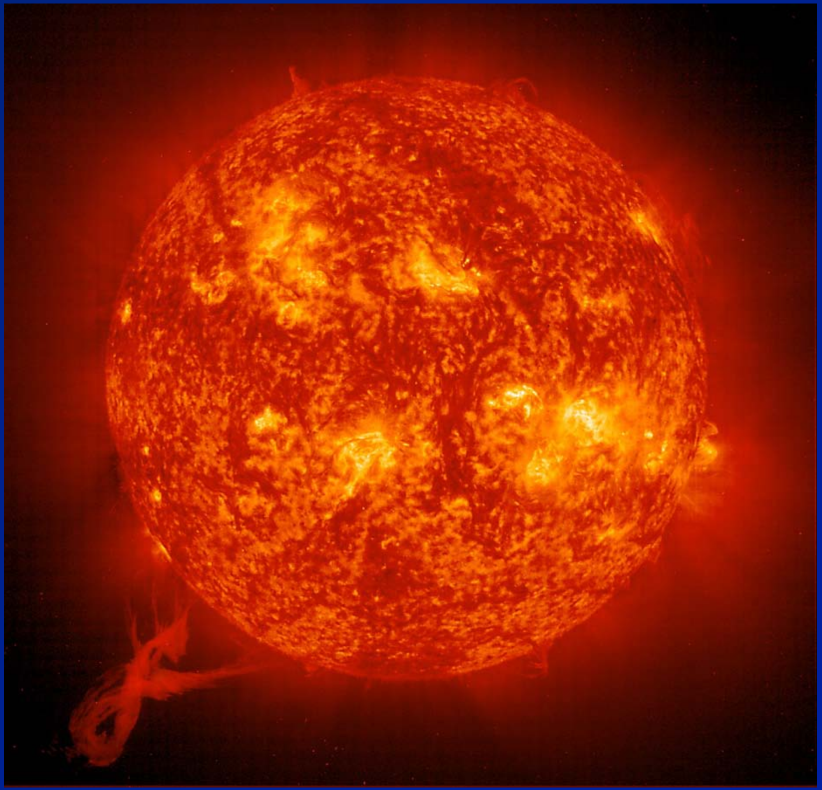
2011 Joint AAPM/COMP Meeting

Outline

- Introduction
- NCRP Recommendations
- Medical Exposures
- AREAS Database
- PCXMC
- ImPACT
- Medical Exam GUI
- Conclusion

Introduction

- Astronaut radiation exposures
  - Space flight
    - Trapped protons
    - GCR (H to U)
    - SPE
    - n^0, e^-, γ, etc.
  - Aviation
  - Medical
    - Fitness for duty
    - Biomedical experiments
    - General health care



SOHO (ESA & NASA)

NCRP Recommendations

- NCRP 142 – *Operational Radiation Safety in Low-Earth Orbit: A Basic Framework*
- Limit: 3% REID (95% CL)
- Recommendation 5: Dose Limits
  - Space flight
  - Mission-related aviation
  - Biomedical research
  - Prior occupational exposures

NCRP Recommendations

- Recommendation 18: Medical Exposures
  - Medical exposures related to health care
    - Diagnostic
    - Therapeutic
  - Should be linked to dosimetry record
  - Used to inform crew
    - Significance
    - Potential biological effects
- All medical exposures are tracked

NCRP Recommendations

- NCRP 167 – *Potential Impact of Individual Genetic Susceptibility and Previous Radiation Exposure on Radiation Risk for Astronaut*
  - Astronaut's prior exposure from medical does not impact risk per unit dose for future space exposure
  - Previous medical or non-occupational should not be taken into account for limits

Medical Exposures

Exam	Frequency
Bone Density (DXA)†	Selection Triennial Every 6 months post-flight (>30 d) until recovery
Chest X-ray (PA and LAT)	Selection Annual
Coronary calcification (MDCT or EBCT)	Selection Every 5 years for males > 40 y Every 5 years for females > 50 y
Dental‡	Bitewing every year Panoramic every 5 years
Mammogram	Selection Every 2 years 40 y – 50 y Annual > 50 y

† Exposures to extremities not recorded

‡ Risks from dental X-ray not recorded

Medical Exposures

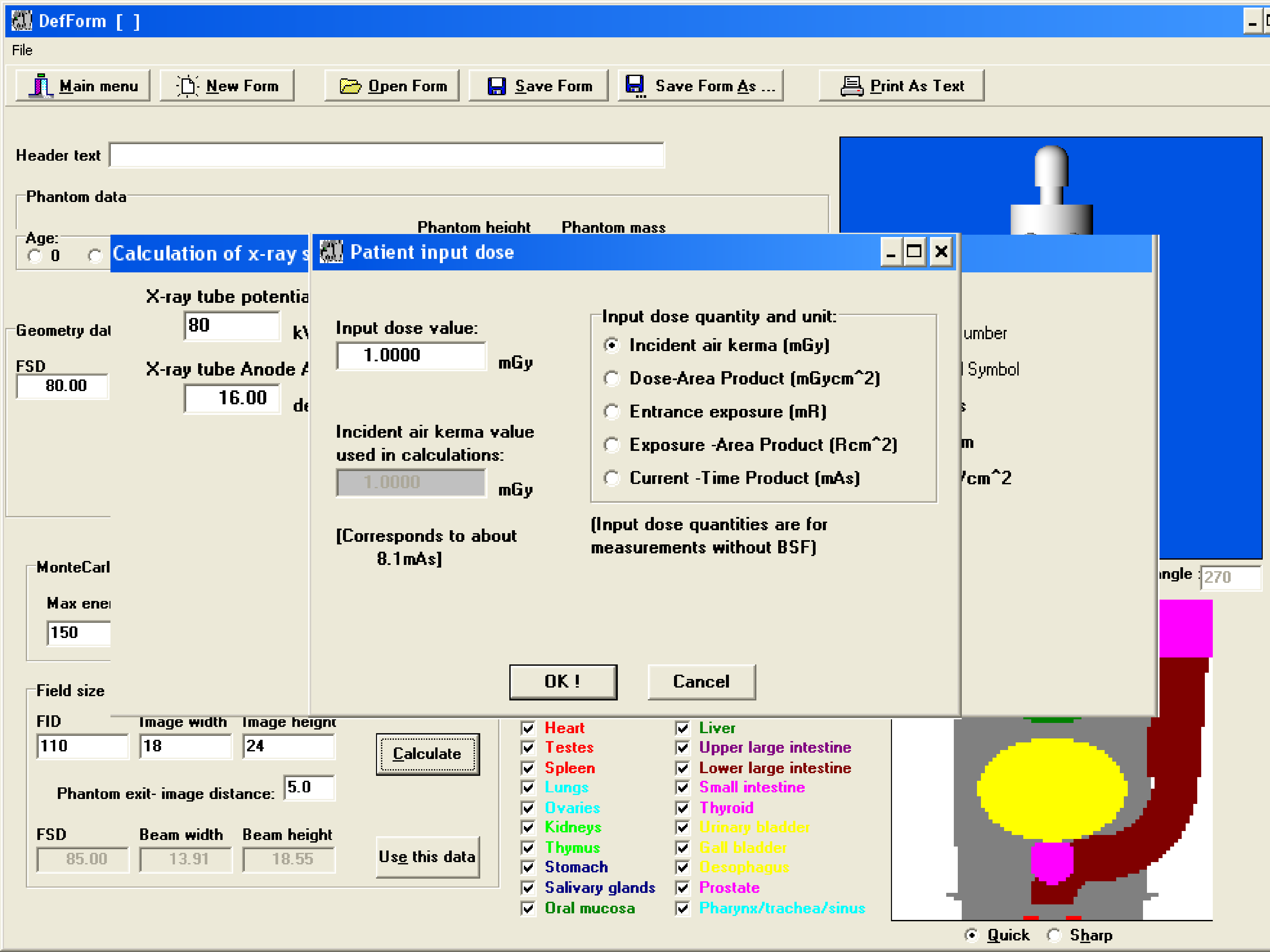
- Exposure evaluation resources
  - DXA
    - Effective dose estimates
    - Blake *et al* 2006 *Bone* **38** (935-942)
  - Mammography
    - Mean glandular dose
    - Sobol and Wu 1996 *Med Phys* **24** (547-554)
  - X-Ray and Fluoroscopy: PCXMC
  - CT: ImPACT

AREAS Database

- Astronaut Radiation Exposure Analysis System
- MATLAB®-based modules that interface with SQL Server database
- Communicates with other NASA JSC medical and space weather databases
- All exposure analysis resources integrated into MATLAB®-compatible format

PCXMC (STUK, Finland)

- Monte Carlo dose evaluation software
- Hermaphroditic mathematical phantom
  - Height
  - Weight
- Exam parameters entered for geometry, spectrum, and intensity
- Distributed as MS Windows executable
  - Automated run option
  - Program checks for file with parameters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File
Main menu
New Form
Open Form
Save Form
Save Form As ...
Print As Text
Header text
Phantom data
Age:
0
Phantom height
Phantom mass
Calculation of x-ray s
X-ray tube potentia
80
kV
Geometry dat
FSD
80.00
X-ray tube Anode A
16.00
de
MonteCarl
Max ener
150
Field size
FID
110
Image width
18
Image height
24
Calculate
Phantom exit- image distance:
5.0
FSD
85.00
Beam width
13.91
Beam height
18.55
Use this data
Patient input dose
Input dose value:
1.0000
mGy
Incident air kerma value
used in calculations:
1.0000
mGy
[Corresponds to about
8.1mAs]
Input dose quantity and unit:
Incident air kerma (mGy)
Dose-Area Product (mGycm^2)
Entrance exposure (mR)
Exposure -Area Product (Rcm^2)
Current -Time Product (mAs)
(Input dose quantities are for
measurements without BSF)
OK !
Cancel
umber
Symbol
m
/cm^2
ngle
270
Heart
Testes
Spleen
Lungs
Ovaries
Kidneys
Thymus
Stomach
Salivary glands
Oral mucosa
Liver
Upper large intestine
Lower large intestine
Small intestine
Thyroid
Urinary bladder
Gall bladder
Oesophagus
Prostate
Pharynx/trachea/sinus
Quick
Sharp

ImPACT (NHS, UK)

- Uses Monte Carlo data files from HPA (formerly NRPB)
- Each CT scanner and kV setting is matched to data file
- Single mathematical phantom
- Database of CTDI values
- Exam parameters entered for scan coverage, spectrum, and intensity
- Distributed as MS Excel spreadsheet

ImPACT CT Patient Dosimetry Calculator

Version 1.0.4 27/05/2011

Scanner Model:		
Manufacturer:	GE	
Scanner:	GE LightSpeed VCT	
kV:	120	
Scan Region:	Head	
Data Set	MCSET14	Update Data Set
Current Data	MCSET14	

Scan range			
Start Position	42.5	cm	Get From Phantom Diagram
End Position	64	cm	

Organ weighting scheme	ICRP 60

Acquisition Parameters:		
Tube current	30	mA
Rotation time	1	s
Spiral pitch	1	
mAs / Rotation	30	mAs
Effective mAs	30	mAs
Collimation	40	mm
Rel. CTDI (Look up	0.86	at selected collimation
CTDI (air) Look up	30.0	mGy/100mAs
CTDI (soft tissue)	32.1	mGy/100mAs
$_nCTDI_w$ Look up	21.7	mGy/100mAs

$CTDI_w$	6.5	mGy
$CTDI_{vol}$	6.5	mGy
DLP	140	mGy.cm

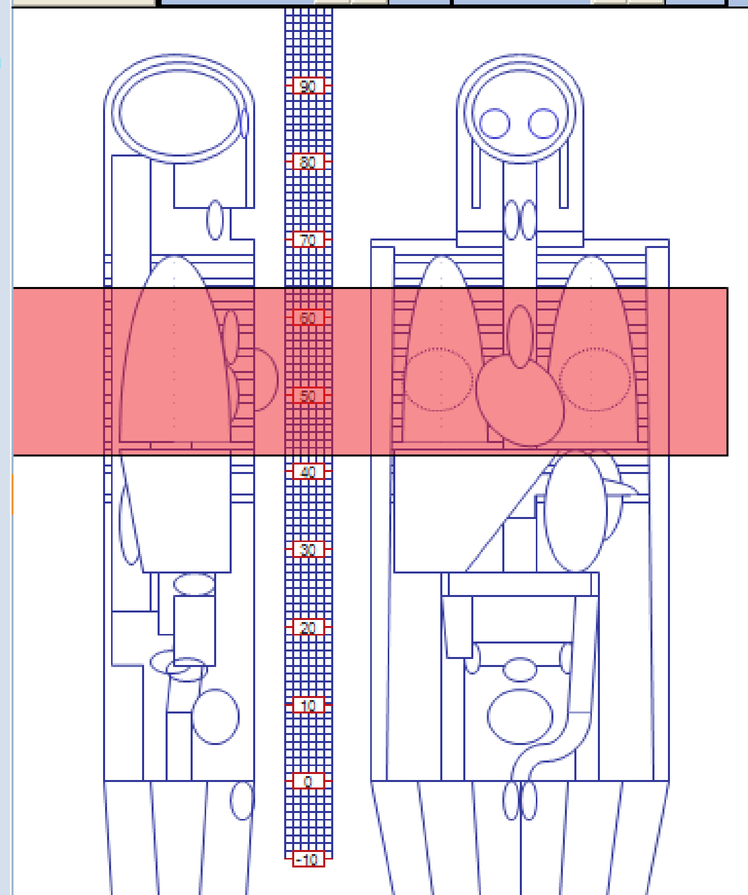
Organ	w_T	H_T (mGy)	$w_T.H_T$
Gonads	0.2	0.0047	0.00094
Bone Marrow	0.12	1.1	0.14
Colon	0.12	0.033	0.0039
Lung	0.12	4.7	0.56
Stomach	0.12	0.56	0.067
Bladder	0.05	0.0026	0.00013
Breast	0.05	4	0.2
Liver	0.05	0.89	0.044
Oesophagus (Thymus)	0.05	5.6	0.28
Thyroid	0.05	0.35	0.017
Skin	0.01	0.71	0.0071
Bone Surface	0.01	2	0.02
Not Applicable	0	0	0
Not Applicable	0	0	0
Remainder	0.05	0.73	0.037
Not Applicable	0	0	0
Total Effective Dose (mSv)			**1.4**

Remainder Organs	H_T (mGy)
Adrenals	1.1
Small Intestine	0.037
Kidney	0.22
Pancreas	0.79
Spleen	0.63
Thymus	5.6
Uterus	0.0075
Muscle	0.79
Brain	0.016
Not Applicable	N/A
Not Applicable	N/A
Not Applicable	N/A
Not Applicable	N/A

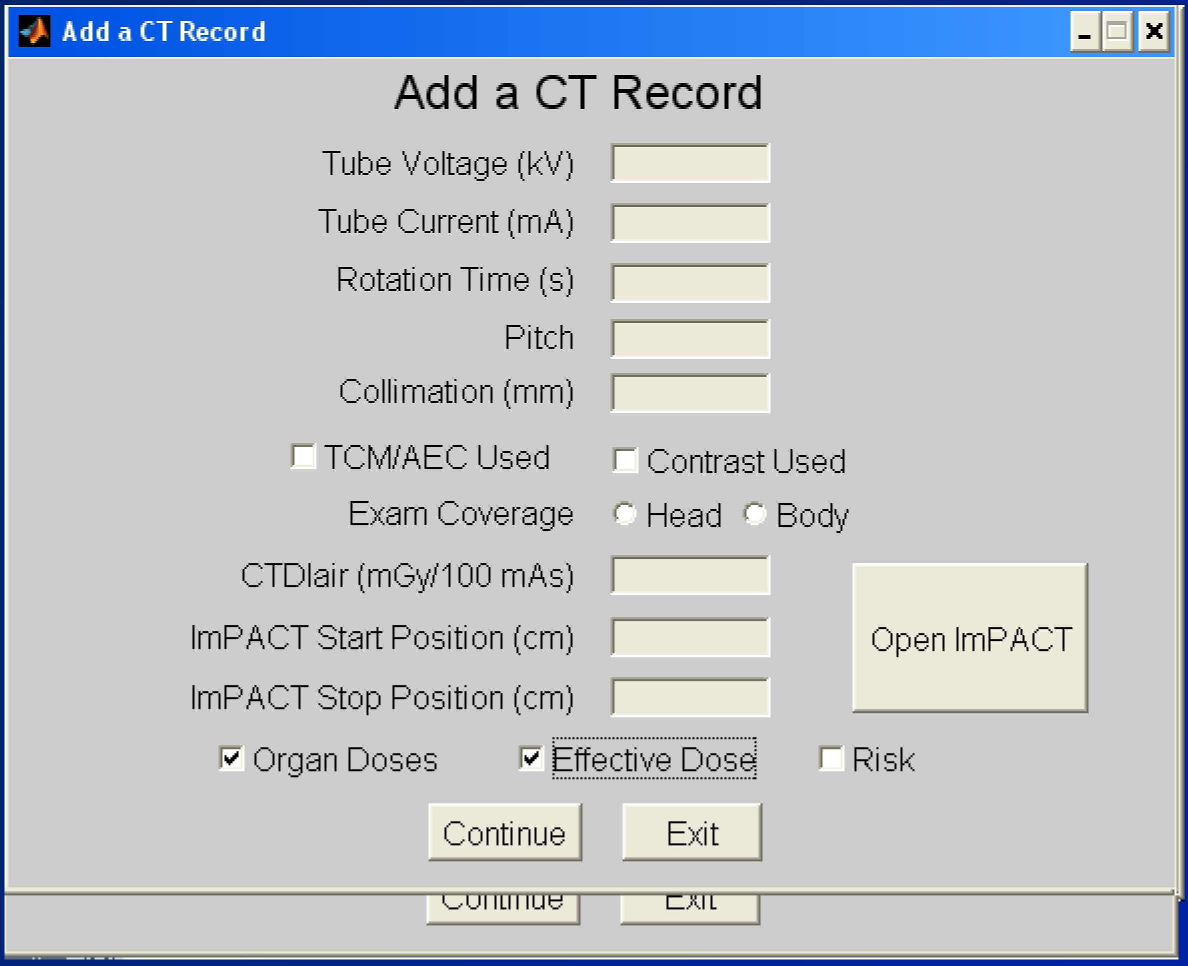
Other organs of interest	H_T (mGy)
Eye lenses	0.011
Testes	0.00015
Ovaries	0.0093
Uterus	0.0075
Prostate	0.0026

Scan Description / Comments	

Zoom In	Start:	+1	+10	End:	+1	+10
Zoom Out	42.5	-1	-10	64	-1	-10



Medical Exam GUI



Conclusion

- PCXMC and ImPACT were converted to MATLAB®-compatible format
- GUI developed for user-tool-database communication
- Risk based on effective dose (NCRP 132)
  - Sex modifier
  - Age-at-exposure modifier
- All organ doses recorded, so changes to risk models can be applied retrospectively

References

- Harpen MD 1996 A mathematical spread sheet application for production of entrance skin exposure nomograms *Medical Physics* **23** 241-242
- ImPACT 2010 ImPACT's CT Dosimetry Tool http://www.impactscan.org/ctdosimetry.htm
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