The Third International Workshop on Computational Phantoms for Radiation Protection, Imaging and Radiotherapy

August 8 and 9, 2011
Tsinghua University, Beijing, China

Organizers : Professor XU George, Rensselaer Polytechnic Institute, Troy, New York, USA
Professor LI Junli, Tsinghua University, Beijing, China

Host/Sponsor: Tsinghua University, Beijing, China

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Background

Since the 1960s, the radiological science community has developed computational models of the human body — referred to as "computational phantoms" — for ionizing radiation dosimetry studies covering occupational safety, medical imaging, and radiotherapy. The non-ionizing radiation community has also developed similar tools for applications related to the safety of devices that emit electromagnetic waves. Two workshops on "phantoms" were held in the past: the first in 1995 at National Board of Radiological Protection, UK and the second in 2000 at Oak Ridge National Laboratory, U.S. In the early 2000s, the International Commission on Radiological Protection decided to adopt voxelized computational phantoms as standards for radiation protection. As a result, many researchers were actively involved in activities associated with the so-called ICRP Reference Computational Phantoms. The Consortium of Computational Human Phantoms (CCHP) (http://www.virtualphantoms.org/) was formed in 2005 in an attempt to facilitate research collaboration and dissemination. Subsequently, the "Handbook of Anatomical Models for Radiation Dosimetry" was published in 2009 involving 64 authors from 13 countries. It became clear during the book project that the number of computational phantoms was rapidly increasing in the last decade, owing to powerful computer technologies and strong interests from the research community. Indeed, phantoms that utilize advanced BREP geometries — NURBS and triangular meshes — have been reported in the past a few years to model anatomical variations associated with gender, age, pregnancy, obesity, organ motion and postures. Application of these phantoms has diversified, covering a broad range of problems in radiation protection, medical imaging and radiation treatment. Various Monte Carlo radiation transport simulation and visualization techniques have also been developed. Built upon experience of the Visible Human Project, the Chinese Visible Human Project resulted in several cadaver image datasets and computational phantoms at < 0.2mm resolutions. The non-ionizing radiation community has also developed a large number of phantoms as well as a regulatory framework for assessing risk associated with exposure to wireless communication and MR imaging equipment. Despite the similarity in research methodologies, ionizing and non-ionizing dosimetry groups have not had the opportunity to directly interact. With exa-scale high-performance computers becoming available by the end of this decade, there is no doubt that computational phantoms will evolve rapidly and radically. The Third International Workshop on Computational Phantoms for Radiation Protection, Imaging and Radiotherapy is organized to provide the research community an opportunity to to discuss the current status and to develop a roadmap for the next 10 years. This workshop is hosted by the Department of Engineering Physics, Tsinghua University, Beijing, P. R. China.
(http://www.tsinghua.edu.cn/publish/epen/).

Organizers:
Prof X. George Xu, Rensselaer Polytechnic Institute, Troy, New York, USA
Prof. Junli Li, Tsinghua University, Beijing, China

Workshop General Information

Workshop Dress Code

Early August weather in Beijing is expected to be very warm, with average high temperature being ~ 30^{o}C (85 ^{o}F). Business casual attire is highly recommended. We expect the indoor areas to be air conditioned.

Registration and social events:

- Registration times
  - Sunday, August 7, 5:00-7:00pm at the hotel lobby
  - Monday, August 8, 8:10-8:30am at conference hall
- Registration fee in Chinese Renminbi (RMB): ¥2000 (or 2000 Chinese Yuan (CNY)) due on-site
- Lunch (on both August 8 and 9): One person included in the registration fee
- Workshop banquets (on both August 8 and 9): One person included in the registration fee (¥400 for an additional quest member to attend both banquets)
- Lao She Teahouse ticket: ¥180 to ¥380 per seat depending on the table location. Advanced reservation required. Please pay at registration.
- Please pay by cash in Chinese RMB (1 Chinese Yuan = 0.1547 US dollars)

Local host:

Prof. Junli Li
Professor and Director of Radiation Protection Division,
Engineering Physics Department,
Tsinghua University, Beijing, 100084, P.R. China

Hotel:

Wenjin Hotel, Beijing (http://www.wenjin.com.cn)
Address:
South Gate of Tsinghua University, Chengfu Road, Haidian District,
(文津国际酒店，中国北京海淀区成府路清华大学南门清华科技园)
Beijing, 100084 China (Tel: 86-10- 62525566)
Your reservation will be forwarded to the hotel and you can directly check-in. ***If you stay at a different hotel, please come to the Wenjin Hotel in the morning before 8am for shuttle bus that goes to the conference hall on campus.***

Local Transportation

Taxis are plentiful and affordable in Beijing and we highly recommend it for local transportation. Depending on the traffic, it takes about 1 hour to travel from Beijing Capital International airport to the hotel. The total cost which will be based on the meter should be ~ ¥100 (US $15) plus toll charges. There is no need to pay tips (taxi, hotel, or restaurant).

Publication:

- Workshop presentations will be videotaped and published online (permission needed)

Conference Hall Address: Liuqing Building, Department of Engineering Physics, Tsinghua University, Shuangqing Road, Haidian District, Beijing.（北京市海淀区双清路清华大学工程物理系新馆刘卿楼）

– *<u>Shuttle bus to the conference hall will pick up from the Wenjin Hotel at 8am on Monday and Tuesday</u>*.

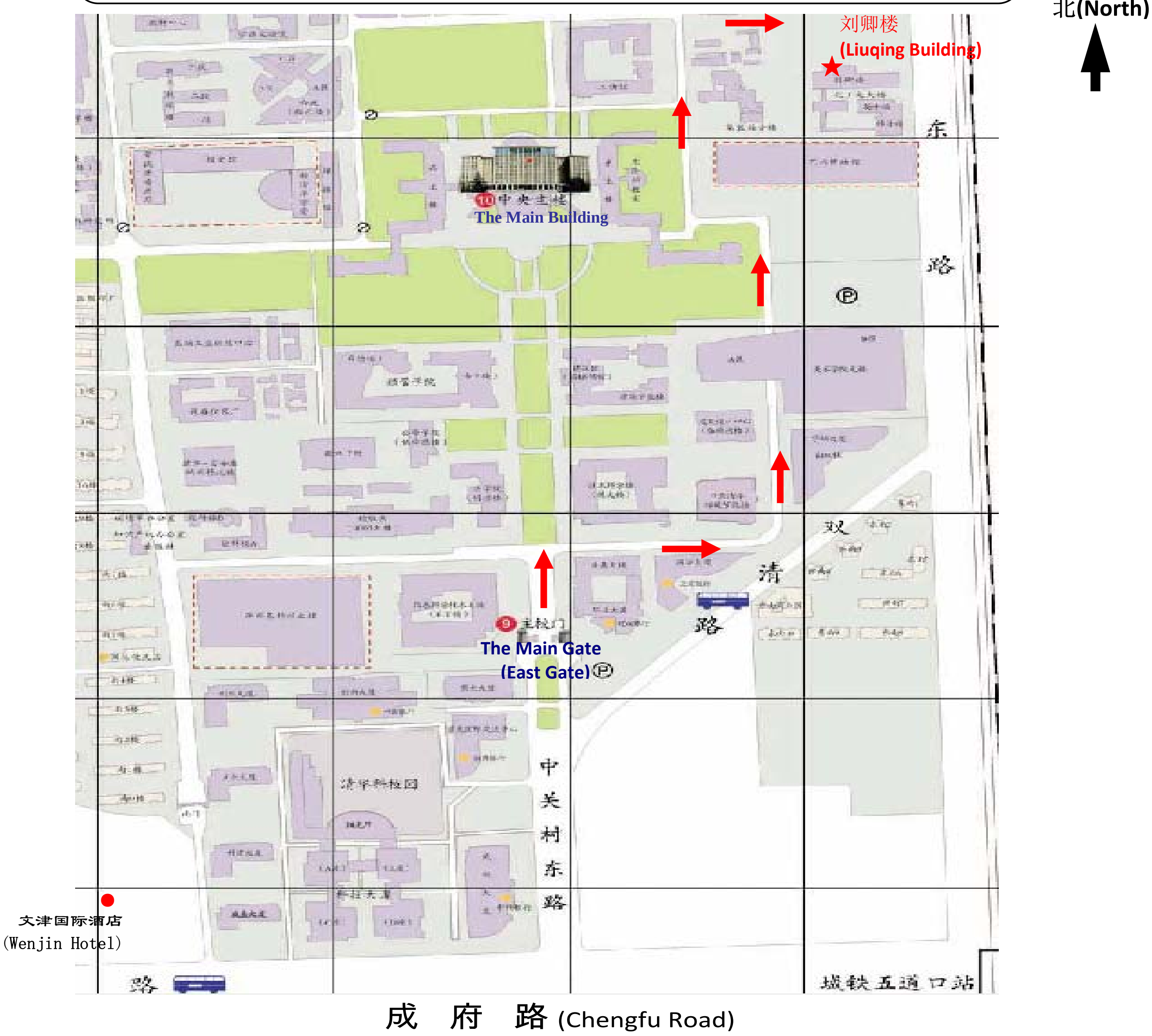
– If you need to come to the conference hall by yourself, you may print this page and show it to the taxi driver.

It takes about 25 minutes to walk to the conference hall from Wenjin hotel.

Notes:

请从清华东门进入，跟着地图箭头走，五角星位置即为目的地（会场），谢谢！

Please take the East Gate and follow the arrows on the map. The pentagram symbols the destination (the conference hall).Thank you.



Workshop Agenda

August 7, Sunday

Attendees arriving
5:00-7:00pm Early Registration, Wenjin Hotel lobby

Day 1
August 8, Monday – Focus: Ionizing Radiation Protection

8:00am Shuttle pickup from Wenjin Hotel
8:10-8:30am On-site registration, conference hall

Session-1 Chair: George Xu, Rensselaer Polytechnic Institute

8:40-9:25am **Keynote Presentation**
ICRP Reference Computational Phantoms and Helmholtz Family of Voxel Phantoms
Maria Zankl, German Research Center for Environmental Health

9:25-10:10am **Keynote Presentation**
The Chinese Visible Human Project
Junli Li, Tsinghua University, China

10:10-10:40 am *Break (coffee) (right outside the conference hall, registration accepted)*

Session-2 Chair: Maria Zankl, German Research Center for Environmental Health

10:45-11:10am The UF Series of Hybrid Computational Phantoms – Applications to Radiological Protection and Medical Patient Dosimetry
Wesley Bolch, University of Florida, USA

11:10- 11:35am Development of Reference Korean Phantoms For Ionizing Radiation Dosimetry
Chan Hyeong Kim, Hanyang University, Korea

11:35-12:00am Space Radiation Dose Estimation: A Comparison of Proton Doses for Male And Female VCH Phantoms
Qian Liu, Huazhong University of Science and Technology, PR China

12:00 –1:30pm *Lunch (buffet in Zhilan Yuan Restaurant, Tsinghua University)*

Session-3 Chair: Chan Hyeong Kim, Hanyang University, Korea

1:30 –1:55pm Monte Carlo and CAD Geometry Modeling for Computational Phantoms
Yican Wu, Chinese Academy of Sciences, China

1:55- 2:20pm Development and Application of Computational Phantoms at IRSN
David Broggio, Institut de Radioprotection et de Sûreté Nucléaire, France

2:20- 2:45pm The Development of Multi-Scale Voxel Phantoms for Chinese Reference Man and Woman
Rui Qiu, Tsinghua University, P.R. China

2:45-3:10pm Comparison of Anthropomorphic Reference Phantoms for Numerical Efficiency Calibration
Stefan Pölz, Karlsruhe Institute of Technology (KIT), Germany

3:10-3:40pm ***Break (coffee) (right outside the conference hall)***

Session-4 Chair: Wesley Bolch, University of Florida

3:40- 4:05pm Evaluation of Exposures in the Environment
Kimiaki Saito, Japan Atomic Energy Agency, Japan

4:05-4:30pm Plans for a New Series of Phantoms for the Calculation of Organ Doses of the Japanese Atomic Bomb Survivors by Dosimetry System DS02
Harry Cullings, Radiation Effects Research Foundation, Japan

4:30-4:55pm Quantifying Uncertainty in Radiation Protection Dosimetry Using Statistical Phantoms
X. George Xu, Rensselaer Polytechnic Institute, USA

4:55-5:40pm Panel Discussion: Maria Zankl, George Xu, Kimiaki Saito, Harry Cullings, Chan H Kim
Moderator: Wesley Bolch
Topics:

(1) What are future research needs in phantom development?
    a. Voxel vs NURBS vs. polygon meshes
    b. Gender, age, pregnancy, obesity
    c. Intercomparison
(2) How phantom research may affect future regulations related to non-ionizing radiation protection?
(3) What computational challenges and opportunities we face?
(4) How do we deal with uncertainty in dose assessment?

5:30pm Shuttle pickup of family members from Wenjin Hotel to the banquet

6:00–8:00pm ***1st Workshop Banquet***
Quanjude Peking Roast Duck (Location: 1st Floor, SP Tower A, TusPark)

8:00pm Shuttle back to Wenjin Hotel

Day 2

August 9, Tuesday – Focuses: Applications in Imaging/Therapy and Non-Ionizing Radiation

8:00am Shuttle pickup from Wenjin Hotel

Session-5 Chair: Junli Li, Tsinghua University

Keynote presentations:

8:20 -9:05am **Keynote Presentation**
The MCAT/NCAT/XCAT Series of Phantoms for Biomedical Imaging
Ben Tsui, Johns Hopkins University, USA

9:05-9:50 am **Keynote Presentation**
The "Virtual Population": Latest Developments and Novel Techniques
Niels Kuster, IT'IS Foundation, Switzerland

9:50-10:30am ***Break (coffee) (right outside the conference hall)***

Session-6 Chair: Niels Kuster, IT'IS Foundation, Switzerland

10:30-10:55am Safety Evaluation of Pregnant Woman under EM Emission Environments
Ji Chen, University of Houston, USA

10:55-11:20am Numerical Phantoms in Safety Assurance for Magnetic Resonance Imaging
Christopher Collins, The Pennsylvania State University, USA

11:20-11:45am Review of NICT computational models and their application for EMF dosimetry
Tomoaki Nagaoka, National Institute of Info and Communications Technology, Japan

12:00 – 1:15 pm ***Lunch (buffet in Zhilan Yuan Restaurant, Tsinghua University)***

Session-7 Chair: Ben Tsui, Johns Hopkins University, USA

1:20-1:45pm Computational phantoms for estimating the risk for radiation-induced cancers in radiation therapy
Harald Paganetti, Massachusetts General Hospital, USA

1:45-2:10pm The development of dual-resolution phantoms for assessing doses of head and neck radiation therapy
Tsi-chian Chao, Chang Gung University, Taiwan, ROC

2:10-2:35pm Voxel phantoms applied in calculating CT dose conversion factors for various CT scanners
Jan Jansen, Health Protection Agency, United Kingdom

2:35-3:00pm Joint RPI/UF Project on The Development of VirtualDose software for CT dose
X. George Xu, Rensselaer Polytechnic Institute, USA
Wesley Bolch, University of Florida, USA

3:00-3:25pm Modeling of clinically realistic phantoms with GATEv6 for imaging and radiotherapy applications
Charlotte Robert, CNRS (National Center for Scientific Research), France

3:30-4:00pm ***Break (coffee) (right outside the conference hall)***

4:00-4:40pm Panel Discussion: Harald Paganetti, Ben Tsui, Niels Kuster, Tomoaki Nagaoka
Moderator: Christopher Collins, The Pennsylvania State University
Topics:

(1) What are future research needs in phantom development?
    a. Voxel vs NURBS vs. polygon meshes
    b. Gender, age, pregnancy, obesity
    c. Intercomparison
(2) How phantom research may affect future regulations related to non-ionizing radiation protection?
(3) What computational challenges and opportunities we face?
(4) How do we deal with uncertainty in dose assessment?

4:40 -5:00pm Workshop Wrap-up (George Xu and Junli Li)
- Future activities of this group (when and where to host the 4th workshop, publication, website, guidelines to the research community, etc)

5:00pm Shuttle pickup of family members from Wenjin Hotel to the banquet

5:20–7:00pm ***2nd Banquet (sponsored by Tsinghua University)***
Xichunyuan Restaurant (Tsinghua University)

7:50-9:20pm Lao She Teahouse (optional and advanced reservation required)

Presentation Abstracts

(by order of presentation time)

Keynote Presentation:

ICRP REFERENCE COMPUTATIONAL PHANTOMS AND HELMHOLTZ FAMILY OF VOXEL PHANTOMS

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Introduction: Computational phantoms of the human body – together with radiation transport codes – have been used for the evaluation of organ dose conversion coefficients in occupational, medical and environmental radiation protection. During the last two decades, voxel models were introduced that are derived mostly from medical image data of real persons. Among other laboratories, the Helmholtz Zentrum München German Research Center for Environmental Health (i.e., the former GSF – National Research Center for Environment and Health) has developed 13 voxel phantoms of individuals of different stature and ages: 3 pediatric ones, 4 male and 6 female adult models. This phantom type having become the state of the art, the International Commission on Radiological Protection (ICRP) decided to use voxel phantoms for the update of organ dose conversion coefficients, following the recent revision of the ICRP Recommendations. These voxel models were requested to be representative of the adult Reference Male and Reference Female with respect to their external dimensions, their organ topology, and their organ masses. **Methods:** All members of the Helmholtz voxel phantom family have been segmented from computed tomographic (CT) medical image data of patients. In order to construct voxel phantoms of the Reference Male and Reference Female, two voxel phantoms were used as starting points that had external dimensions close to the ICRP reference values. Approximately 140 organs and tissues were segmented, including objects that were not previously contained in the MIRD-type phantoms, such as the main blood vessels, cartilage, muscles, and lymphatic nodes. The body height and mass as well as the organ masses of both models were adjusted to the ICRP reference values, without spoiling their realistic anatomy. **Results:** The Helmholtz voxel phantom family encompasses a variety of phantoms – whole and partial body, paediatric and adult, slim and heavily built, both genders, and with different voxel resolution. The reference computational phantoms are used by the ICRP in establishing radiation protection guidance, for example, effective dose coefficients and other secondary dosimetric quantities. **Conclusion:** The reference computational phantoms are the official computational models representing the ICRP Reference Male and Reference Female. The ICRP will publish recommended values for dose coefficients for both internal and external exposures using these phantoms. The emergence of such reference computational phantoms, does not, however, mean that the other voxel phantoms are becoming obsolete. To a certain extent, they could be used as tools towards a more personalised dosimetry. Since the currently existing voxel phantoms range from slim persons to heavy persons, the dose values published so far give a dose range in which an individual dose may be expected to lie, together with an indication of the magnitude of dose differences to be expected between individual persons. Furthermore, it is believed that they can be used to roughly estimate the doses to an individual by selecting those for the voxel model fitting best to the person under consideration. However, it should be clear that existing voxel models – both individual and reference – cannot represent any real individual, and that organ dose conversion coefficients from literature cannot be directly applied to an individual person. Especially in those situations where a reliable dose assessment for an individual is required, this approach is not possible, e.g. for radiation treatment planning purposes.

Keynote Presentation:

THE CHINESE VISIBLE HUMAN PROJECT

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The American Visible Human Project (VHP) datasets consist of whole-body magnetic resonance, computed tomography, and cryosectioned anatomical images (with slice thickness of 1 mm for the male and 0.33 mm for the female). Since the public release of the VHP datasets in 1994, Korea and China started similar projects of their own. The Chinese Digital Human Project was initiated in November 2001 with major funding from the Ministry of Scientific and Technology and National Science Foundation Committee of China. The first dataset was completed in February 2003. Up to now, ten datasets of the whole human body (5 males and 5 females) have been obtained. The original cryosectioned image slices are as fine as 0.2 mm and the whole-body data size exceeds 500GB. Some of the 3D anatomical structures of the whole body have been segmented and reconstructed to create computational phantoms. In recent years, these Chinese digital human phantoms have been widely used in the radiation dose calculation, image-guided neurosurgery, virtual acupuncture, assessment of nuclear facility safety, health science education and other research fields. Improvement and application of these digital human phantoms and other applications are being pursued by several Chinese research groups.

THE UF SERIES OF HYBRID COMPUTATIONAL PHANTOMS – APPLICATIONS TO RADIOLOGICAL PROTECTION AND MEDICAL PATIENT DOSIMETRY

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Gainesville, Florida, USA
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Introduction: Computational phantoms are computerized representations of human anatomy for use in radiation transport simulation of either internal or external radiation exposures. For medical applications, they are needed for modeling organ doses resulting from medical image acquisition or from radiation therapy procedures. In this paper, we will review the development, status, and application of a series of hybrid phantoms created at the University of Florida. **Methods:** CT and MR images of adult, pediatric, and fetal subjects were acquired and used to create an array of ICRP 89 compliant hybrid phantoms based upon combinations of polygon-mesh and NURBS surfaces. For the post-natal models, phantom-specific skeletal models were assembled based upon either 3D microCT images of trabecular spongiosa or previously acquired linear pathlength distributions in pediatric bone. Values of intra-skeletal electron absorbed fractions were then assembled and used to generate photon fluence-to-dose response functions for reporting photon dose to active and shallow marrow during radiation transport. Data on body morphometry characteristics of the current U.S. population were further reviewed and used to design an expanded library of patient-dependent adult and pediatric hybrid phantoms for patient-phantom matching in medical dosimetry. **Results:** Reference and patient-dependent phantoms of the UF series have been applied to clinically relevant studies of organ dosimetry for (1) nuclear medicine, (2) computed tomography, (3) interventional fluoroscopy, and (4) radiation therapy in both retrospective and prospective patient studies. **Conclusions:** Since the mid-2000s, significant advancements in phantom-based dosimetry studies have been made by many investigative teams using hybrid phantom technology. In situations where medical images of the individual patient are either unavailable or cover only a portion of the relevant anatomy, phantom-based assessments of organ dose are essential for characterizing risks associated with therapy or diagnostic imaging procedures. Advances in patient-specificity via patient-dependent hybrid phantom libraries can significantly lower dose uncertainties over traditional methods based upon fixed-anatomy stylized or even voxel-based models.

DEVELOPMENT OF REFERENCE KOREAN PHANTOMS FOR IONIZING RADIATION DOSIMETRY APPLICATIONS

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Introduction: The surface phantoms are developed by converting tomographic voxel phantoms to polygon or non-uniform rational B-spline (NURBS) surfaces or by assembling artificially modeled 3D data set of the human anatomy. This paper reviews the development of Reference Korean phantoms, emphasizing the importance of developing surface phantoms that can be directly used in a Monte Carlo code. **Methods:** The Reference Korean adult male and female voxel phantoms, named 'High-Definition Reference Korean Man and Woman (HDRK-Man, HDRK-Woman),' were developed using serially sectioned color slice images of Visible Korean Human (VKH) which were obtained from Korean cadavers. Both of the voxel phantoms have clearly defined organs whose masses were adjusted to Reference Korean data. The polygon phantom PSRK-Man (Polygon-Surface Reference Korean-Man) was developed by converting a voxel phantom, which is the original phantom of HDRK-Man, i.e., before the adjustment to the reference Korean data, to a polygon phantom. The conversion of the voxel phantom to a polygon phantom was carefully performed to preserve the shape of the organ and to make fully enclosed polygon-surface objects without overlapping among the organs. The PSRK-Man is the first surface phantom which can be directly implemented in Monte Carlo code without voxelization process. The organ dose results of PSRK-Man using Geant4 Monte Carlo code showed a very good agreement with those of HDRK-Man. However, the calculation speed of the polygon phantom was slower by 70-150 times for external photon beams and ~3 times for external neutron beams than the voxel phantom. To improve the computation speed of the PSRK-Man, the algorithms of direct accelerated geometry Monte Carlo (DAGMC) toolkit were adopted to Geant4. The algorithm is based on the oriented bounding box (OBB) tree, with which it is not necessary to calculate the distances from a particle position to every face of polygon-surface geometries for particle tracking. Consequently, the computation speed was improved by at least 30 times for the photon beam cases. **Conclusion:** We are now trying to improve the computation speed of the polygon phantom by developing a dedicated navigator in Geant4 for the polygon phantom and by using the general-purpose computing on graphics processing units (GPGPU). If the necessary algorithms of 3D graphics such as deformation and collision detection algorithms are successfully developed and adopted to a Monte Carlo code with enough computation speed, the polygon phantom can be used for a more advanced simulation, i.e., 4D Monte Carlo dose calculation involving realistic modeling of the respiratory and cardiac motion of a patient.

SPACE RADIATION DOSE ESTIMATION:
A COMPARISON OF PROTON DOSES FOR MALE AND FEMALE VCH PHANTOMS

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And
Key Laboratory of Biomedical Photonics of Ministry of Education, College of Life Science and Technology, Huazhong University of Science and Technology, 1037 Luoyu Rd., Wuhan 430074, P.R. China
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During the space exploratory missions, astronauts and crews are exposed to Galactic Cosmic Rays (GCR) and Solar Particle Events (SPEs). The typical radioactive particles are protons, high charge and energy (HZE) ions and secondary neutrons et al., which are harmful to the crew members. It is necessary to evaluate the human doses within space radiation conditions, predict the potential radiation hazards, and design the radiation protection plans before obtaining the direct measurement results of the actual space flight. For the purpose of providing effective doses data and device design suggestions for radiation protection, the organ absorbed doses of male and female Visible Chinese Human (VCH) adult phantoms were calculated respectively with the energies of the simulated isotropically proton ranging from 20 MeV to 10 GeV. In addition, the obtained proton doses were compared with the sex-averaged doses to investigate the discrepancies caused by anatomical variations and other factors.

CAD AND IMAGE-BASED MONTE CARLO MODELING FOR COMPUTATIONAL PHANTOM - APPLICATIONS TO RADIATION PROTECTION AND RADIOTHERAPY

Yican Wu, Mengyun Cheng, Daping Sheng, Kai Zhao, Wen Wang, Tongqiang Dang, Guozhong Wang, Tao He, Qi Yang, Shaoheng Zhou, Qin Zeng, Pengcheng Long, Shanqing Huang, Gui Li, Huaqing Zheng, Ruifen Cao, Xi Pei, Jing Jia, Liqin Hu and FDS Team

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Description and verification of the full and detailed models for Monte Carlo (MC) particle transport codes, is one of the most important tasks to achieve accurate simulations for complex systems. However, manual description and verification of the models for the MC simulation are time-consuming and error-prone. Consequently, MCAM was developed as an interface program to achieve both CAD-based and image-based automatic modeling for MC simulation by FDS Team, China (www.fds.org.cn). The advanced version (Version 6) of MCAM can achieve automatic conversion from tomographic images (CT/ segmented color photographic images) to computational phantoms with 3D geometrical (anatomic structure and shape) and physical (density and material) information as well as bi-directional automatic conversion between CAD models and MC models such as MCNP and TRIPOLI models. In addition, a scientific visualization program named SVIP was developed to supports visualization of time-varying 1D/2D/3D data field and mixed rendering with data and geometry, including dynamic visualization in virtual human roaming environment. A whole-body computational phantom of Chinese adult female called FDS-HUMAN was created by using MCAM from color photographic images of a Chinese visible human dataset obtained from a Chinese female cadaver who was dead without any pathological changes. The conversion coefficients from kerma free-in-air to absorbed dose in FDS-HUMAN computational phantom segmented into 44 organs was calculated with MCNP5. The 3D dose maps of the whole-body as well as the absorbed dose of main organs were given. Differences were observed between the doses from ICRP 74 data and those of other female phantoms. Volume visualization of organ dose, iso-dose line visualization and mixed-rendering of geometry model and 3D dose map were realized by using SVIP based on the MCNP results and FDS-HUMAN phantom. FDS-HUMAN phantom was applied for prediction and evaluation of dose distribution in the Treatment Plan System (TPS) e.g. the Advanced/Accurate Radiotherapy System (ARTS) as well as the assessment of radiation exposure on human body and various organs in radiation protection. This contribution gives an overview of activities on the development of both CAD-based and image-based MC modeling programs and the applications both for radiotherapy and radiation protection by FDS Team.

DEVELOPMENT AND APPLICATION OF COMPUTATIONAL PHANTOMS AT IRSN

D. Broggio[a], E. Courageot[b], J. Farah[a], L. Hadid[a], A. Desbree[a], C. Huet[b], and D. Franck[a]
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Computational phantoms can be used in situations where calculation results can be compared with experimental data, in situations relatively close from an experiment and in situations far from any experimental confirmation. In this last case the confidence in the result merely depends on the realism of the phantom. We will present several situations involving computational phantoms and different levels of proximity with experiment. We will then address some questions regarding the current trends in computational models development: Can we give up the voxel format? How to compare computational models? How to fix target values for developed models? Can we confidently use public tools developed for body deformation? Situations involving computational phantoms and different level of proximity with experiment. Computational phantoms can be built from CT images of physical phantoms. When the phantom contains radioactive sources the simulated and experimental gamma spectra can be compared. Similarly, doses can be measured and calculated inside or outside physical phantoms holding dosimeters. Such experiments serve as benchmark for relatively close situations. For subjects for whom a phantom has been built the radioactive contamination of organs can be assessed. In case of accidental irradiation, the dose calculation on a computational model helps in deciding on the extent of the surgical resection. Finally, computational models are used for calculations that cannot be checked by experiments. For example, when computational models are built to investigate the differences between an average and a specific individual. We have developed two libraries of computational phantoms. One of female torsos, in order to correct calibration coefficients used for the monitoring of nuclear workers. The other, of full body males, to investigate the body type influence on radiation protection quantities. In the two cases the difficulty consisted in specifying target values for the organs of the models. Question, opinions and challenge regarding computational phantoms: Can we do Monte Carlo calculations without the voxel format? It seems that the tracking of particle cannot be more efficient than in a voxel universe. If this is true, developments are still necessary to dispose of performing voxelisation tools, in order to take the full advantage of models developed with CAD software. The increasing development of phantoms' libraries makes essential the geometrical comparison of models. Quantitative measurements, like the Dice index, can be used for phantoms supposed to be superimposable. However, when models are not similarly aligned, or have body parts in different positions, more advanced tools should be used. Multi component analysis seems a promising way. The development of phantoms requires the definition of target masses for the organs of individuals basically defined by their height and weight. The literature shows that the mass of organs and skeleton could depend on height only while the fat and muscle mass depends on height and weight. Finally, some publicly available tools make it easy to deform body shapes. Even if these tools seem to produce realistic results we can wonder if they were developed following the principles of the scientific community. To what extend can we rely on them? Can these tools be adapted to deal with internal organs?

THE DEVELOPMENT OF MULTI-SCALE VOXEL PHANTOMS FOR CHINESE REFERENCE MAN AND WOMAN

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Department of Engineering Physics, Tsinghua University,
Beijing,100084, P.R. China
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The development and application of the phantoms constructed at Tsinghua University in recent years were summarized in this work. These phantoms include the Chinese Mathematical Phantoms (CMP), Chinese Voxel Phantom (CVP), Chinese reference adult male voxel phantom (CAM) and Chinese reference adult female voxel phantom (CRAF). They were widely used in different fields, such as the space radiation dose assessment for astronauts in spaceflight, organ dose conversion coefficients calculation for idealized external photon exposures and neutron exposures, specific absorbed fraction calculation for internal exposure and calibration of in-vivo measurement systems, etc. Furthermore, construction of the Chinese bone micro-structure model is initiated. 3D micro-CT scan for the whole skeleton of one male and one female is ongoing. A "basic spongiosa unit" method is conceived to construct a comprehensive voxel phantom that combines the bone micro-structure model with the macro voxel phantom for more precise skeletal dosimetry research. In addition, the atom high-level DNA model, i.e. the chromatin model is being constructed. A code is being developed to simulate DNA strand breaks induced by low-energy electron in early physical and chemical stages using the simple volume model of DNA. In the near future the damage of the atom DNA model can be calculated once the whole chromatin model is built.

COMPARISON OF ANTHROPOMORPHIC REFERENCE PHANTOMS FOR NUMERICAL EFFICIENCY CALIBRATION

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In vivo measurements are an important tool for incorporation monitoring. Since partial body counting effectiveness is strongly dependent on detector placement and individual anatomy in the target region, accurate efficiency calibration is necessary. This can be performed numerically using Monte Carlo radiation transport simulation in anthropomorphic phantoms. State of the art phantom development combines medical imaging data of individuals and anatomic background knowledge in form of stylized organ models. Several whole-body phantoms have already been created implementing the ICRP reference man paradigm by using ICRP-89 reference organ masses and external body dimensions. A study is presented comparing six of these phantoms (ICRP-AF/AM, RPI-AF/AM, FASH/MASH) in standard lung and liver counting scenarios to contribute to the quantification of uncertainties in partial body counting due to variation in organ shape and position. Detectors and other equipment were modeled according to the conditions found at KIT’s In Vivo Measurement Laboratory (IVM). Radiation transport simulations were performed with MCNPX using voxelized phantoms. Individual counting efficiencies for each phantom were calculated and compared in context of several anthropometric parameters and effective chest wall thickness in their gender groups. Since body and organ shape are rather unrestrained in phantom development, high variability was observed among the analyzed phantoms. As expected, counting efficiencies show significant deviations for low energy photon emitters (<100 keV). These results cannot be explained by effective chest wall thickness in the detector regions. Also, anthropometric parameters show relatively small variation. Considering the small amount of phantoms evaluated, this study only offers quantification of the order of magnitude of uncertainty in partial body counting regarding organ shape and position. However, results suggest that the range of variation of lungs and liver cannot be covered with standard detector positions and may lead to high uncertainty. So far, no concept to formally integrate statistical shape information in phantom development has been applied. An approach using complex shape descriptors and surface registration may lead to more variant phantoms and help to further contribute to this problem.

EVALUATION OF EXPOSURES IN THE ENVIRONMENT

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The Fukushima nuclear plant accident reminded us the importance of dose evaluation in the environment. Further, radiation protection of animals and plants in the environment has been paid attention in recent years. For dose evaluation in the environment, specific models are necessary. Following two issues concerning evaluation of exposures in the environment will be discussed in this paper. External exposures of the public In order to properly evaluate external exposures of the public in the environment, dose conversion factors have been prepared considering the characteristics of environmental radiations. Several typical environmental sources conditions have been postulated for anthropogenic and natural radionuclides, and the dose conversion coefficients have been determined. Difference in doses due to age was investigated by using phantoms for children, and the variation of effective doses was found to be within a factor of two under general conditions. Effects of alteration in source distribution and human body posture on doses were also clarified. Internal exposures of small animals Presently ICRP employs simple models for evaluating environmental doses in animals and plants. The simple models might be sufficient to meat the required accuracy in conclusion; while, the errors due to use of the simplified models should be clarified to draw the conclusion. From this viewpoint, we have investigated internal doses of small animals using voxel phantoms. Mouse and rat voxel phantoms developed elsewhere and the frog phantom developed at JAEA have been used to obtain absorbed fractions.

PLANS FOR A NEW SERIES OF PHANTOMS FOR THE CALCULATION OF ORGAN DOSES OF THE JAPANESE ATOMIC BOMB SURVIVORS BY DOSIMETRY SYSTEM DS02

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The Radiation Effects Research Foundation (RERF) uses a dosimetry system to calculate radiation doses that were received by the Japanese atomic bomb survivors from direct exposure to neutrons and gamma rays, based on their reported location and shielding at time of exposure. The current system, DS02, a product of a binational scientific working group completed in 2003, uses new source terms and transport calculations and some other improvements in the calculation of terrain and structural shielding, but continues to use methods from an older dosimetry system, DS86, to calculate organ doses, for the DS86 set of 15 organs. The recent development of detailed models of the human body from medical imaging, along with contemporary computer speed and software, motivated a plan to expand and improve the calculated organ doses. A major aspect of this effort will be an improved series of phantoms to replace those currently in use, which are almost 30 years old and include only three phantoms: infant, child, and adult, with several sex-specific organs but no sex-specific body size and shape. Before undertaking such an endeavor it is important to quantitatively evaluate the improvements that can be made and their potential contribution to RERF's research. An initial analysis suggests that the most important improvements can be made by providing calculations for more organs than the 15 organs currently calculated, to avoid errors from use of surrogate organ doses, and by providing a larger number of age- and sex-specific models of the human body from birth to adulthood, as well as fetal models. An important quantitative and statistical problem in the planned work is to decide scaling of all parts of the body to reflect age- and sex-specific population mean values of the Japanese in 1945.

QUANTIFYING UNCERTAINTY IN RADIATION PROTECTION DOSIMETRY USING STATISTICAL PHANTOMS

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Introduction: To date, more than 130 computational phantoms have been reported for ionizing and non-ionizing radiation dosimetry. Existing phantoms can be divided into three generations: (1) Stylized phantoms based on surface equations describing simple anatomical shapes (1960s to 2000s); (2) Voxel or tomographic phantoms constructed from segmented and labeled 3D volumetric images (1980s to 2000s) (3) Phantoms based on the "boundary representation" (BREP) geometries involving non-uniform rational b-splines (NURBS) or triangular meshes that are realistic and deformable (after 2000s). Despite impressive modeling techniques, organ dose values differ remarkably between voxel phantoms that are representative of individual anatomy. As such, uncertainties in applying standardized organ dose values to a population of people exist but are practically unknown today. This paper proposes a method to create a series of deformable phantoms that follow statistical distributions of possible anatomical variations. **Methods:** Two tasks were performed: (1) Organ doses from irradiation of 0.05 MeV photon beams in anterior-posterior (AP) direction were compared for the ICRP Computational Phantom (Male) and RPI Adult Male phantoms. (2) A series of simplified lung phantoms having organ volumes that follow a Gaussian distribution are created to calculate doses for photon beams of 0.05, 0.1 and 5 MeV. All calculations use the MCNPX Monte Carlo code. **Results:** (1) ICRP Male and RPI Male phantoms have different lung volume, mass, density, and thickness in the AP irradiation direction. Doses to the lung from these two phantoms were found to differ by 18%. For the bladder, the dose difference was found to be 40%. (2) Using Gaussian distribution and an average lung volume of 2500 cm^3, a total of 100 "statistical phantoms" having different volumes were randomly created. Monte Carlo calculations for these phantoms show that the dose to the lung follows a Gaussian distribution. For 0.05 MeV photons, the dose to the lung was 22.03 ± 1.92 (10^{-14} Gy cm^2). For 0.1 MeV, the dose to the lung was 35.70 ± 1.55 (10^{-14} Gy cm^2). For 5 MeV, the dose to the lung was 135.78 ± 2.22 (10^{-13} Gy cm^2). **Conclusions**: With the use of "statistical phantoms," the average value and the range of fluctuation in the organ doses (i.e., uncertainties due to anatomical variation) may be quantified and reported. Such information can be useful to situations where a limited set of organ dose values are applied to a group of individuals. The approach takes advantage of a large number of deformable phantoms. More research is needed to define the statistical models for organ shape, volume, and location.

Keynote Presentation

THE MCAT/NCAT/XCAT SERIES OF PHANTOMS FOR BIOMEDICAL IMAGING

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The MCAT/NCAT/XCAT series of digital phantoms is a result of a continuous effort to develop digital phantoms for use in biomedical imaging. The phantoms evolved from a mathematical phantom of a standard man used in internal dosimetry calculations. While the masses of various organs modeled that of an average human, the organ shapes were very different from that of the actual organs. The three-dimensional (3D) mathematical cardiac torso (MCAT) phantom modified the mathematical equations that described the shapes of major organs in the torso region to a closer match of the actual organs while maintaining the same organ masses. The 3D MCAT phantom enjoyed wide adaptation and application to myocardial perfusion SPECT studies. While the 3D MCAT phantoms provided closer resemblance of the organ shapes with increasingly complex mathematic equations, it was difficult to model the exact shape of human organs. The 3D NURB based cardiac torso (NCAT) phantom represented a significant improvement over the 3D MCAT phantom. The 3D NCAT digital phantom was based on the Visible Human data. The organs in the torso region were modeled using non-uniform rational b-spline (NURB) computer graphics tools that allowed much closer resemblance to the organ shapes. The 3D NCAT phantom was extended to four-dimensions (4D) that included cardiac motion derived from cardiac gated tagged MRI images of the heart from a normal subject and respiratory motion derived from respiratory gated CT images of the torso region also from a normal subject. The 3D and 4D MCAT and NCAT phantom provided realistic models of the anatomical structures and cardiac and respiratory motions of an average normal human subject. The 3D and 4D NCAT phantoms were extended to include anatomical variations to model abnormalities and populations of human subjects. The 3D and 4D extended cardiac torso (XCAT) phantoms represented an extension of the 3D and 4D NCAT phantoms to the entire body from head to toe. Also, special efforts are being made to further improve the anatomical details and motion models such as the brain, lungs and heart. They continued to enjoyed wide-spread use in the SPECT and PET imaging research community and more recently, in x-ray CT imaging. They have been found useful in the design and development of imaging equipment, data acquisition techniques and image reconstruction and processing methods. In particular, with known ‘truth’, they allowed quantitative evaluation which is difficult and expensive to performed using clinical data.

Keynote Presentation

THE “VIRTUAL POPULATION”: LATEST DEVELOPMENTS AND NOVEL TECHNIQUES

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Objectives: The aim of the ‘Virtual Population’ is to create, maintain and offer a comprehensive set of high resolution anatomical human models to the scientific community that enable simulating the interaction of physical agents with various anatomies in the population. **Introduction:** The current Virtual Population models of humans (children, adults, elderly, obese, pregnant woman at various gestation stages) distinguish more than 80 different tissues and organs. These models have been developed jointly by IT’IS and the FDA and have already been widely applied for EM exposure and safety assessment, device development, and mechanism studies. However, in parallel with the increasing power of numerical tools, the demand for additional and even more detailed anatomical models is growing. To meet these needs, a series of new tools has been developed that will be employed to generate the Virtual Population 2.0. It will provide more models to optimally cover the variability of the human population and offer greatly improved quality for different types of simulations even beyond the field of computational electromagnetics. **Methods:** The models have been created by segmenting MR images from healthy volunteers using a specially developed, flexible image-processing and segmentation platform that has been commercialized by Zurich Med Tech (Switzerland). Subsequently, conformal surfaces have been extracted, smoothed, and simplified. A tool for creating voxels from these surfaces is distributed along with the models. Different algorithms have been developed to allow the generation of high quality tetrahedral meshes (suitable, e.g., for FEM simulations) with flexible resolution and varying refinement strategies. Real-time posing functionality has been added by defining rigid bones together with influence regions and applying algorithms from the field of computer graphics. Existing models can be morphed by using a set of interactive widgets that let the user specify deformation fields visually, which are then interpolated and applied to the model. Real-time visualization is achieved by using multiresolution rendering. Additionally, it is possible to change the BMI of existing models in a realistic manner by performing a deformation simulation assuming rigid bones, passively deforming soft tissue and actively shrinking or growing fat tissue. **Results:** A detailed database of dielectric and thermal material parameters has been composed based on extensive literature data. It will soon be publicly available online together with a user forum which will encourage continuous development and discussion by the online community. Quality assurance procedures are currently being developed to ascertain the quality of the models and to track identified issues as well as improvement ideas. **Conclusion:** The Virtual Population Project 2.0 will provide a larger number of increased quality anatomical models using the new tools. Posing and morphing functionality is available to change the posture, shape and BMI of the models in a realistic manner and voxeling as well as meshing tools make these models accessible to various types of simulations. It is the goal to make these models available to a wide user community (beyond the EM related fields) and to continue developing further models. The functionality of Virtual Population 3.0 is currently being defined.

SAFETY EVALUATION OF PREGNANT WOMAN UNDER EM EMISSION ENVIRONMENTS

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Introduction: Numerous electronic devices operate in the close vicinity of human bodies. Such proximity can lead to a fraction of electromagnetic energies being deposited into human bodies. If the power absorbed is sufficiently large, it may lead to tissue damage. Consequently, interactions of electromagnetic fields with human subjects have been a subject of scientific interest and public concern. Although various safety standards have been developed, they were mainly based on adult male models. Therefore, there is a need to investigate the safety for pregnant woman models. In particular, we investigated the electromagnetic interactions between walk-through metal detector and MRI scanner with pregnant woman models. **Methods:** Since we are only concerned with the tissues surrounding the fetus, only seven different tissues are used in these models. Each tissue has its own representative permittivity and conductivity. The body models for months 1-4, representing the early stages of pregnancy, are based on a female model from 3DSpecial. While the body models for months 5-9, representing the late stages of pregnancy, are based on laser scans of a woman in her 34th week of pregnancy. The fetus model, together with the surrounding tissues such as fetus, bladder, uterus, placenta and bones, is based on an MRI dataset of a woman in her 35th gestational week. The numerical modeling tools used here are based on impedance method for low frequency WTMD application while the high frequency MRI energy deposition studies were performed using a full-wave finite-difference time-domain method. **Results:** The induced current densities and induced electric fields within pregnant woman models exposed to walk-through metal detector (WTMD) emissions were investigated. Through comparisons to current safety limits, it is shown that internal tissues might experience potentially hazard effects due to external magnetic fields. The electromagnetic and thermal simulations were combined to study the heating effects of strong RF fields on internal tissues within pregnant woman models exposed to magnetic resonance imaging (MRI) RF coil radiations. Simulation results demonstrated that fetus tissue might have higher specific absorption rate and resultant temperature rise than recommended safety limits. **Conclusion:** Our preliminary investigations showed the induced fields inside our pregnant woman models may exceed the safety limits at some specific locations. However, more studies are necessary to confirm these findings.

NUMERICAL PHANTOMS IN SAFETY ASSURANCE FOR MAGNETIC RESONANCE IMAGING

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Introduction: In magnetic resonance imaging (MRI) a variety of magnetic fields are applied to the human body. Time-varying magnetic fields (including those experienced by tissue moving through a static magnetic field) can induce a variety of biological effects including nerve stimulation and heating. Over the past several years numerical models of the human body have become an integral part of engineering and safety assurance for MRI. In this talk the basic physics of MRI and existing MRI-specific safety regulations will be reviewed and current methods of utilizing numerical phantom will be discussed. **Methods**: In MRI engineering and safety assurance, numerical phantoms having data arranged on a regularly-spaced Cartesian grid are used most often, although some other approaches are seen occasionally. The Finite Difference Time Domain (FDTD) method for electromagnetics is the most popular approach to solving the Maxwell equations for the field distributions throughout the numerical phantom. Specific energy Absorption Rate (SAR) values averaged over 10-gram, partial-body, head, and whole-body regions are most often used in safety assurance. Electric permittivity, electric conductivity, and tissue mass density are the most important tissue-specific properties in this process for consideration of safety, with magnetic susceptibility also being important in some engineering applications. Occasionally, temperature is also calculated based on a bioheat equation, requiring additional information about thermal conductivity, perfusion by blood, and rate of metabolic heat generation. Results of these calculations can be used alone to evaluate possibilities and design new hardware and paradigms with consideration of safety, or linked to the MRI system and calibrated to real-time estimates of total input power in order to assure safety during the MRI examination. In recently-developed transmit arrays, where the electromagnetic field distribution can be controlled in real time by the system operator, results of numerical calculations are used heavily to assure patient safety. **Results**: In general, MRI is very safe and under normal circumstances field-related injury and discomfort are rare. This is largely due to observation of reasonable limits on exposure to fields. In cases where injuries occur it is often due to failure to follow standard protocols, including introduction of foreign materials (including non-MR safe implants) to the MRI environment. The use of numerical phantoms has greatly increased understanding of field-tissue interaction in MRI and has influenced MR-specific safety guidelines. For example, previous IEC limits on local SAR caused by volume excitation coils have been removed after numerical calculations indicated that they were likely exceeded regularly in practice with no consequence. Increasingly, regulatory bodies such as the FDA and IEC expect to see numerical calculations in cases where local SAR levels may be high. Numerical calculations have clearly indicated the dependence of SAR distribution on subject morphology, thus pointing out the need for more patient-specific phantoms in order to improve accuracy. **Conclusion**: Numerical phantoms are now an integral part of engineering and safety assurance for MRI. Current efforts to create more patient-specific numerical phantoms and integrate calculation results with the MR system for improved real-time safety assurance promise to further increase the impact of numerical phantoms in MRI.

REVIEW OF NICT COMPUTATIONAL MODELS AND THEIR APPLICATION FOR EMF DOSIMETRY

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Introduction: There is growing concern about the health effects of electromagnetic waves emanating from wireless communication devices. To evaluate in detail the electromagnetic dosimetry for Japanese or Asian peoples, the National Institute of Information and Communications Technology (NICT) have developed several Japanese computational models. **NICT computational models:** NICT has developed the voxel-based models of Japanese adult male and female, children (three-, five- and seven-year-old) and pregnant female models at various gestational ages for electromagnetic dosimetry. The computational models of Japanese adult and children were constructed on the basis of magnetic resonance imaging (MRI) data of healthy subjects suitable for average heights and weights of Japanese. Pregnant female models were also developed by combining the fetus models including gestational tissues, constructed on the basis of the abdominal MRI from a healthy pregnant female, and a Japanese female model (non-pregnancy). These models are composed of voxels of 2×2×2 mm^3 and they are divided into over 50 different tissue and organs. **Applied techniques:** These computational models have become one of the most important tools for electromagnetic dosimetry. However, the models have some limitations when used as part of numerical simulation. We are therefore working on improving the models. Since the models are generally upright configurations, simulations of the actual situations in which wireless telecommunication devices and wireless terminals are greatly limited. We have previously developed two posture transformation techniques. One of the posture transformation technique was applied the free-form deformation (FFD). This method enables smooth posture transformation while keeping the continuity and masses of the model's internal tissues and organs. However, the this techniques was disadvantageous in that the structure quality of tissues and organs in the postured models greatly depended on the allocating and numbering of the control lattice points of the FFD. To relieve this issue, we proposed anther posture transformation technique. In this technique, the polygon mesh data of the model are generated based on the body surface contour of the voxel-based models and the meshes are deformed using a skeleton animation tool in commercial three-dimensional computer graphic software. Arbitrary voxel-based posture models are constructed by utilizing the volume refilling to the deformed mesh data. The NICT models have a spatial resolution of 2 mm and currently enable us to evaluate exposure to high-frequency electromagnetic radiation up to approx. 3 GHz. We have to use higher-resolution models to be able to evaluate exposures to electromagnetic fields of higher frequencies, because the wireless communication devices will be used at frequencies above 3 GHz in the near future. We have developed a technique for creating arbitrary higher-resolution models by smoothing the irregularities between tissue boundaries. **Conclusion:** The NICT models are optimal models for electromagnetic dosimetry for Asians, who account about 58% of the world's population and will be able to simulate with high precision. In addition, the advanced models constructed by our applied technique will be able to provide electromagnetic dosimetry for realistic exposure situations.

COMPUTATIONAL PHANTOMS FOR ESTIMATING THE RISK FOR RADIATION-INDUCED CANCERS IN RADIATION THERAPY

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A potential long-term risk for patients treated with radiation to cure cancer is the occurrence of a second malignancy caused by radiation. With the average age of patients decreasing due to improved cancer screening, this issue is becoming more and more important. In addition to well-established treatment modalities, such as 3D conformal photon therapy, new treatment modalities, like intensity-modulated photon therapy and proton therapy are becoming more and more popular. These techniques aim at higher dose conformity and at low dose to organs in the primary radiation field but they can potentially cause significant scattered or secondary dose in an area far outside of the main radiation field. When analyzing late effects from scattered and secondary radiation one can define three (overlapping) volumes in the patient; the target (e.g., CTV), treated with the therapeutic dose; organs at risk in the tumor vicinity that are imaged (considered) in treatment planning, which may intersect with the beam path and are allowed to receive low to intermediate doses (in-field volume); the rest of the patient body, which typically receives low doses (way below 1% of the target dose) that are not considered, or even imaged, for treatment planning (out-of-field volume). Organs not directly considered in the treatment planning process are typically not imaged and accurate patient specific geometrical information is thus not available. Consequently, whole-body computational phantoms can play an important role when combined with Monte Carlo dose calculations to simulate scattered or secondary doses (e.g., neutron doses) to organs. Reference phantoms for different patient age groups might be used for this purpose. In order to match a particular patient as closely as possible using a voxel phantom in a Monte Carlo simulation, one might have to interpolate between two different phantoms of a specific age. Better patient matching can be achieved by adjusting weight and height by applying adjustable phantoms. This presentation will outline how computational phantoms can be used in the framework of Monte Carlo simulations and review recent work on Monte Carlo transport calculations in highly realistic computational whole-body phantoms. Further, the formalism for quantifying equivalent doses and risk will be outlined briefly. The role of computational phantoms in epidemiological studies will be discussed and future directions for the use of computational phantoms in radiation therapy risk modeling will be outlined.

THE DEVELOPMENT OF A HIGH RESOLUTION VOXELIZED PITUITARY GLAND MODEL FOR BRAIN RADIATION THERAPY

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Purpose: Dose over- or underestimation is a common problem for modern radiation treatment techniques, which often involve a large intensity gradient and rely heavily on many small and irregular fields of dose delivery, leading to a significant partial volume effect causing unexpected normal tissue complications or tumour recurrence. Special attention should be paid to the voxel size to avoid the partial volume effect especially for treating tiny and heterogeneous tissues such as the mucosa/epidermis near teeth/false teeth, skin, bone marrow, vestibulocochlear nerve, and pituitary glands. The aim of this study is to development of a high resolution (0.33*0.33*0.33 mm^3) voxelized pituitary gland model for brain radiation therapy. **Material and method:** In reality, there is not yet a CT image set of patients available at such a high resolution. VIP-Man (with 0.33*0.33*1 mm^3 resolution) was used to generate a pitugary gland voxel model with organs including pars distalis and cleft infundibular process in pituitary gland, hypothalamus, optic chiasm, thalamus, neutral and anterior lobe in hypophysis, hypothtalamus tuber, optic tract, ventral and nuclei of thalamus, anterior nuclei and lateral and medial in thalamus, subthalamic, left and right optic nerve. A Matlab R2010a macro was coded to produce this (0.33*0.33*0.33 mm^3) voxelized pituitary gland model using Euclidean distance interpolation. **Results:** Totally 19 tissues/organs was modeled with 0.33*0.33*0.33 mm^3 resolution and visualized for validating 3D volume continuity. **Conclusion:** Such a high resolution model can be applied to assess dose for small field irradiations or of voxels proximity to an internal source such as brachytherapy or nuclear medicine.

TOOLS FOR AND APPLICATION OF VOXEL PHANTOMS FOR CT DOSE CALCULATIONS

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Introduction: The International Commission on Radiological Protection has provided in Publication 103 updated information on organs at risk and a new definition of effective dose (E_{103}), and also introduced in Publication 110 the Adult Reference Computational Phantoms. These new data are being used to update for contemporary practice, on the basis of scanner details supplied by CT manufacturers, previous normalised organ doses for CT calculated using Monte Carlo techniques, as published in NRPB-SR250 (1993). This report provided data for non-spiral single slice CT scanners that are extrapolated for application to modern scanners by the widely-used ImPACT CT Patient Dosimetry Calculator. Implementation of the Adult Male (AM) and Adult Female (AF) phantoms is discussed with the choices that are still available, some important changes, validation and some short comings. These phantoms have been used to study the effect on dose of their arms being in or out of the scan area and, in addition, the presence of a CT couch. **Methods:** The AM and AF phantoms have been implemented in the Monte Carlo All-Particle Transport code System, MCNPX, version 2.6.0. This was accomplished with a home-made program that transfers the ICRP Publication 110 data in the short MCNPX implementation and in the byte format suitable for ImageJ and vice versa. For validation purposes, AP photon irradiations have been simulated and compared with the published data in ICRP 110. Using ImageJ the AM and AF phantoms have been visualised and the arms removed. For backwards compatibility, the HPA18+ mathematical hermaphrodite phantom has also been used, with and without arms. Simulations were performed for the Siemens Definition under a range of operating conditions. Further simulations were conducted for the Philips Brilliance 64 with and without a patient couch. Although the reality of anatomy is greatly improved, the new voxelised phantoms have geometric problems in modelling an organ with at least one dimension shorter than the pixel size. This is illustrated by the absorbed dose to the breast from a parallel broad beam of 300 keV mono-energetic electrons at various angles in the horizontal plane for the AF and HPA18+ phantom. **Results**: AP dose conversion coefficients for the colon, lungs, stomach wall and breast showed similar results to the data published for the EGSnrc, GEANT4 and MCNPX 2.5.0 codes. Our MCNPX 2.6.0 results are no closer to MCNPX 2.5.0 compared to both other codes, showing that user assumptions have a significant influence, especially in the 30 keV breast AM situation. For the electron angular exposure conditions, differences in breast dose by more than two orders of magnitude are observed between the AF and HPA18+ phantom, due to the voxelisation of the skin and a strong angular dependence of the breast dose of more than three and one order of magnitude, respectively. The ratio of the normalised effective doses ($E_{103}/D_{FIA,-couch}$) without a patient couch, versus with the couch showed deviations up to about 3% along the phantom and ratios for whole body exposure of about 1.5% to 1.9%, for tube voltages of 140 kV to 80 kV, respectively. **Conclusion:** Although the ICRP phantoms are broadly defined in Publication 110, the red bone marrow and endosteal cell dose enhancement factors are not specified, and therefore a complete reference system is not yet established. Comparison of calculated dose conversion coefficients depends not only on the code used but also on the user's underlying assumptions, even for organ doses. Short comings in geometric voxelisation of AF can under specific circumstances lead to large uncertainties in calculated dose to the breast. For radiological purposes, the influence of the arms being in or out of the scanned area or the influence of the patient couch on the organ or effective doses is too small to justify inclusion in CT simulation.

JOINT RPI/UF PROJECT ON THE DEVELOPMENT OF VIRTUALDOSE SOFTWARE FOR CT DOSE

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Introduction: The potential radiation risk from rapidly increasing usage of computed tomography (CT) has led to concerns from the medical imaging community and regulatory bodies. An accurate and easy-to-use dose reporting software would be a very useful tool for the medical physics community. This paper describes a joint project funded by the National Institutes of Health to develop a modern software package, VirtualDose, for estimating and reporting the organ doses for adult and pediatric patients. **Methods:** A database of organ doses and effective doses is established from a large number of Monte Carlo simulations involving CT scanner models and anatomically realistic phantoms using the MCNPX code. CT scanners by the GE, Philips, Siemens and Toshiba operated have been systematically investigated. Detailed CT X-ray sources and bowtie filter geometries are modeled for Monte Carlo simulations using the MCNPX code. A number of anatomically realistic voxel phantoms are used: the RPI Pregnant Women (RPI-3, -6 and -9 month pregnancy) and RPI Adult Male (RPI-AM) and Adult Female (RPI-AF), the UF Pediatric Phantom Series, and the ICRP Computational Phantoms. These adult phantoms are adjusted to match ICRP Reference Man parameters. The software is developed using Microsoft .NET platform. **Results:** CT scanner models have been carefully validated against experimental data. The Monte Carlo calculations have been performed for most of the phantoms. Preliminary software GUI development has resulted in a product that allows a user to specify the patient type, body scanning region, and various scanner operating parameters. Using the object-oriented programming technology, 3D phantoms can be displayed interactively to improve the user interaction. Organ and effective doses can be rapidly archived and reported in the software according to the user-specified protocols. All organ doses are incorporated into a database compiled using Microsoft SQL server 2005. With user specified scanner parameters - the axial scan range, the scan pitch, the tube current and scanning time in milliamp-seconds (mAs), the tube voltage in the kilovolt peak (kVp) - the software package can quickly report organ doses and effective doses. Capabilities for tube current modulation (TCM) protocols are currently under development. A preliminary smart-phone version of the VirtualDose is developed for the Android market.

MODELING OF CLINICALLY REALISTIC PHANTOMS WITH GATE V6 FOR IMAGING AND RADIOTHERAPY APPLICATIONS

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The GATE (Geant4 Application for Emission Tomography) opensource simulation software is developed by the international OpenGATE collaboration (http://www.opengatecollaboration.org) since 2001. While initially dedicated to the simulation of nuclear medicine imaging procedures, this platform currently makes it possible to model planar scintigraphy, Single Photon Emission Computed Tomography (SPECT), Positron Emission Tomography (PET) and Computed Tomography acquisitions. It is used worldwide to assist the design of new medical imaging devices and to develop or assess image reconstruction algorithms or quantification techniques. In 2010, a new version of GATE, GATE v6, has been released. This version further allows the modeling of radiation therapy treatments. We will present a brief overview of the use of realistic phantoms in GATE simulations for imaging and radiotherapy applications. Compared to other simulation tools used in emission and transmission tomography, one of the distinctive features of GATE is the management of time-dependent phenomena. This feature makes it possible to simulate realistic acquisition conditions including detector motion, patient movements, respiratory and cardiac motions and changes in activity distribution over time. Simple phantoms or more sophisticated phantoms based on real clinical data such as the XCAT phantoms including motions can thus be introduced in the GATE simulations. In SPECT and PET simulations, a main challenge lies in the realism of the modeled activity distributions. These distributions are often simulated as piecewise-constant activity distributions, where the activity level set in each organ is based on mean activity values observed in real scans. Recent work has been reported to fully model activity distributions that can be heterogeneous within an organ and that closely mimic heterogeneous activity distributions observed in real patients. Such an approach, which will be described in this talk, can yield simulated PET and SPECT scans that are indistinguishable from real patient scans. The method can be extended to model serial PET scans, for instance in the context of patient monitoring where the change in activity over time is of interest. Such very realistic simulated data might play a crucial role in the future to thoroughly evaluate quantification methods. GATE v6 also supports modeling of radiation therapy equipments and treatments. These developments have been largely motivated by the increasing interest in combining radiotherapy and imaging. For instance, PET imaging can be used to delineate metabolically active tumor tissue to be treated by radiotherapy or to control patient positioning in proton or ion therapy. For these new fields of applications, the role of voxelized realistic phantoms is important too. Based on our in-beam PET experience, we will illustrate how GATE can be used to simulate a realistic complete hadrontherapy treatment and to predict the induced beta+ activity distribution. These studies are essential to investigate the feasibility of in-beam PET to detect inaccuracy in patient positioning and to control dose deposit in hadrontherapy. In conclusion, new features included in GATE v6 as well as the development of new realistic phantoms now make it possible to use GATE as a reference integrated tool for the modeling of imaging, treatment and dosimetry.