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MPI

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MEDICAL PHYSICS INTERNATIONAL
The Journal of the International Organization for Medical Physics

Aims and Coverage:

Medical Physics International (MPI) is the official IOMP journal. The journal provides a new platform for medical physicists to share their experience, ideas and new information generated from their work of scientific, educational and professional nature. The e- journal is available free of charge to IOMP members.

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EDITORIALS

Slavik Tabakov, MPI Co-Editor in Chief

This issue of the Journal, Medical Physics International (Dec 2019), has a focus on the countries of Africa, on the 10th Anniversary of the creation of FAMPO (Federation of African Medical Physics Organizations). It continues the focus on specific Regions of our profession - the focus in the previous issue of MPI (May 2019) was South and Central America and the Caribbean Region. Africa needs many more medical physicists, as it currently has less than 0.5 medical physicists per million of inhabitants.

This MPI issue also presents abstracts of several PhD theses from African colleagues, and introduces the new African Journal of Medical Physics (launched in 2019), that supports the professional development on the continent. We are grateful to Dr Taofeeq Ige and Dr Francis Hasford from FAMPO - our Contributing Co-Editors of the MPI Dec 2019 – who solicited the papers from the African continent.

This current MPI issue also presents papers associated with the 35th anniversary of the IOMP Newsletter Medical Physics World, and also the 35 anniversary of the CRC Press Series in Medical Physics and Biomedical Engineering - this continues to be a very effective collaboration between IOMP, IFMBE and CRC Press which has delivered so far 60 textbooks (40 of which in the past 10 years).

The collaboration of IOMP with the ISR (International Society of Radiology) is also discussed. Another closely collaborating organization is the IFMBE (International Federation of Medical and Biological Engineering) - a brief paper is included about its 60th anniversary. IOMP and IFMBE form the IUPESM (International Union for Physical and Engineering Sciences in Medicine). This Union had a very successful year creating several activities of collaboration between medical physicists and engineers. Through this collaboration we are presenting to the readers a paper related to Deep Learning for Chest X-Ray Screening. Another “How-To” paper is associated with PET performance measurements.

The Educational topics include, the ASEAN Accreditation and Certification Recommendations, a method to present physics information to diagnostic radiologists, and a full list of the CRC published textbooks.

The two invited papers are: one discussing the history and evolution of CT Dosimetry, the other one - a summary of the International Conference on Radiological Emergency Management [ICONRADEM-2019]. In an ANNEX we provide the readers with another very important digest from IAEA to the International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS 2019).

We believe that many colleagues will find interesting information in the new issue of the MPI Journal. The consistently high number of our readers underlines the importance of the free MPI Journal aim -supporting of the global development of our profession.

Perry Sprawls, MPI Co-Editor in Chief

Every medcal physics jounal makes specific contributions to the profession and practice of medical physics around the world. Most journals provide opportunities for physicists to publish reports of their research in a peer-reviewed process that validates their scientific acheivments and contributes to the advancement of the field of medical physics and related clinical applications. This journal, Medical Physics International, is different and publishes in many significant areas beyond research that is generally not within the scope of other journals. One of the major goals is enhancing medical physics education to meet the needs created by the many advances in clinically applied physics in both diagnostic imaging and therapy applications. With the many scientific and technological advances in radiology and radiation oncology and the more complex procedures, an effective knowledge of physics by the medical professionals, especially physicists and physicians, becomes a major element in the quality of medical care. A major factor is with the more complex methods, both diagnostic and therputic, quality is more dependent on the adjustment and optimization of the procedures by the medical professionals using their knowledge of physics.

This is creating an evolution in the medical physics education process both in content and educational methods. With the comunications and connectivity provided by the internet there is now the opportunity for medical physicists around the world to collaborate with the sharing of their knowledge, experience, and educational resources.

Medical Physics International is facilitating this effort by publishing a variety of articles including tutorials, links to resources for study and teaching, and guides for the development and delivery of effective educational activities. This provides an opportunity for medical physicists to use the published materials to enhance their educational programs and to consider publishing materials they have created that can be used by others.

COLLABORATING JOURNALS AND ORGANIZATIONS

35 YEARS IOMP MEDICAL PHYSICS WORLD: PROUDLY SERVING OUR PROFESSIONAL COMMUNITY

Colin G. Orton and Magdalena Stoeva

Editors IOMP Medical Physics World Special Issue, Vol. 35 (10), No. 2

Abstract— **The Special Issue of Medical Physics World dedicated to IDMP 2019 & MPW's 35th anniversary turned into a remarkable selection with contributions from the guest Editor Colin Orton, IOMP ExCom members, RCB, WHO, IAEA, AAPM, MPI Editors, Virginia Tsapaki (immediate past EiC), Ibrahim Duhaini (IDMP coordinator and calendar editor) and the valuable input from Azam Niroomand-Rad and Kwan Ng with excellent papers on MPW and EMPW history.**

2019 marked an important milestone in Medical Physics World's history – our 35th anniversary. To acknowledge MPW's contribution to the medical physicists worldwide 2 key events have been planned for 2019 - IOMP dedicated the International Day of Medical Physics (IDMP) 2019 to Medical Physics World, and MPW published a special issue. The special issue of eMPW is dedicated to celebration of both the 35th anniversary of the founding of Medical Physics World in 1984, and IDMP on November 7th.

The origins of Medical Physics World.

It all began at the 2nd World Congress on Medical Physics and Biomedical Engineering, Hamburg, 1982, when Professor Larry Lanzl was elected President-Elect of the IOMP. He realized that communication between the Officers and the representatives from the, then, 27 member countries on the IOMP Council, was difficult since it only occurred once every three years at the World Congresses. This was before e-mail and the internet. He decided that what was needed was a newsletter and, because he knew that I was a Past-Editor of the AAPM newsletter (AAPM Quarterly Bulletin), he asked me to help him establish an IOMP newsletter. He did not want this to be a financial burden on the IOMP, so he asked me to try to find corporations willing to advertise in the new newsletter in order to cover the cost. We soon realized that corporations would be unwilling to spend much money to advertise in something that would be distributed to just a few individuals in these countries, so we decided to find a way to distribute the newsletter to all members of all the IOMP member countries. We even envisaged that, ultimately, the newsletter might be able to generate a profit for the IOMP! It was then that we decided to give the newsletter an important sounding title so as to be attractive to potential advertisers. Medical Physics World (MPW) was born.

Since there were about 7,000 individual members of the IOMP member countries, for the IOMP to print and distribute all 7,000 copies of MPW was clearly going to be prohibitively expensive, so it was decided that the IOMP would pay for the printing but would send all national societies enough copies for them to distribute to their members by whatever means they decided to adopt. Larry was able to convince the IOMP Council to provide $2,500US as seed money to finance this new publication, which represented about 50% of the total income of the IOMP at the time. He must have been very persuasive! The first issue appeared in 1985 and advertising income was significant enough to soon be able to repay the IOMP for this seed money and, within ten years, to generate an annual profit of over $10,000US, a very significant fraction of the total income of the IOMP. The rest is history.

The Special Issue of Medical Physics World

Medical Physics World has been the voice of IOMP and medical physicists worldwide for the last 35 years. It also comes with a Special cover page to outline the milestones in the development of Medical Physics World:

- The very 1st issue of Medical Physics World, 1984
- The 1st eMPW issue, 2010
- Medical Physics World Volume 10, 1994
- Medical Physics World Volume 20, 2004
- Medical Physics World Volume 30, 2014
- The 1st Medical Physics Issue with ISSN, 2014
- The 1st Special Issue of Medical Physics World, dedicated to Marie Curie's 150th Anniversary and the International Day of Medical Physics, 2017

This Special Issue of Medical Physics World is about to mark another milestone in our history – the first issue dedicated to MPW's anniversary and the biggest MPW issue so far.

Medical Physics World

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Fairmount House
230 Tadcaster Road
YORK YO24 1ES, UK

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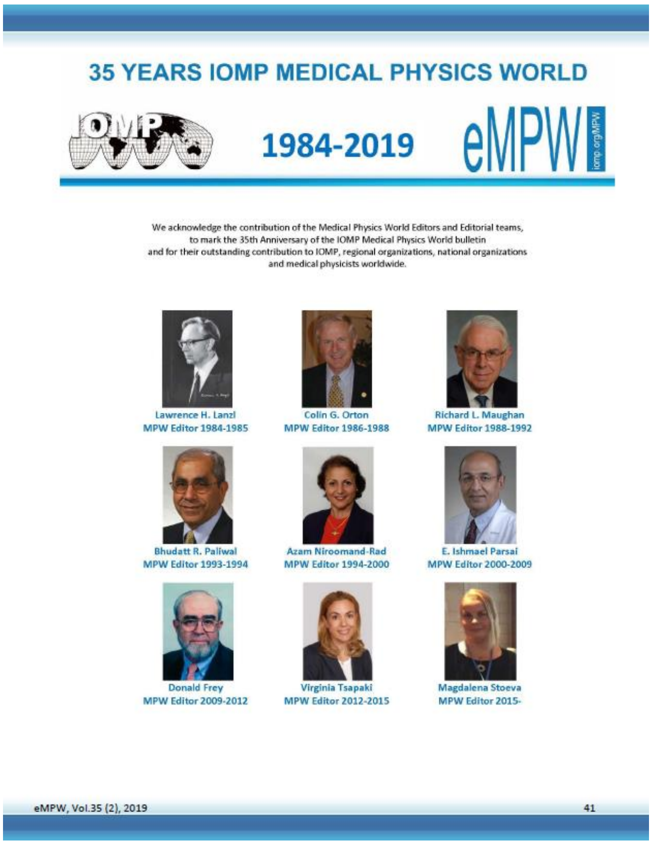
Zimbabwe
Bangladesh - AFFILIATE

To commemorate the 35th anniversary and to celebrate the International Day of Medical Physics there are messages in this Special Issue from the IOMP (President Madan Rehani and Vice-President John Damilakis), the IOMP Regional Collaboration Board (Slavik Tabakov), the WHO (Maria del Rosario Perez and Adriana Velasquez), the IAEA (Karen Christaki, Giorgia Loreti, Paula Toroi, Virginia Tsapaki and Debbie van der Merwe), the AAPM (Cynthia McCollough, M. Saiful Huq, Bruce Thomadsen), the IDMP Coordinator (Ibrahim Duhaini), a reprint of the Immediate Past Editor-in-Chief of MPW (Virginia Tsapaki) 2017 interview for MPW, and the co-Editors-in-Chief of Medical Physics International (Perry Sprawls and Slavik Tabakov). In addition, we have articles on the histories of MPW (Azam Niroomand Rad), the first version of Electronic Medical Physics World, EMPW (Kwan Hoong Ng, et al) and a reprint of Colin Orton's 2015 interview for MPW, some tables showing the contents of past MPWs and the MPW Editors compiled by our current Editor-in-Chief Magdalena Stoeva, a Calendar of some innovations in Medical Physics that happened during the existence of MPW presented by our calendar editor Dr. Duhaini, as well as an article "Exposure to low dose CT for lung and colorectal cancer screening: What are the risks of radiation?", by John Damilakis, which demonstrates how MPW and eMPW have often published scientific articles as well as just "news".



35 YEARS IOMP MEDICAL PHYSICS WORLD

1984-2019

We acknowledge the contribution of the Medical Physics World Editors and Editorial teams, to mark the 35th Anniversary of the IOMP Medical Physics World bulletin and for their outstanding contribution to IOMP, regional organizations, national organizations and medical physicists worldwide.

Lawrence H. Lanzl
MPW Editor 1984-1985

Colin G. Orton
MPW Editor 1986-1988

Richard L. Maughan
MPW Editor 1988-1992

Bhudatt R. Paliwal
MPW Editor 1993-1994

Azam Niroomand-Rad
MPW Editor 1994-2000

E. Ishmael Parsai
MPW Editor 2000-2009

Donald Frey
MPW Editor 2009-2012

Virginia Tsapaki
MPW Editor 2012-2015

Magdalena Stoeva
MPW Editor 2015-

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The IOMP Medical Physics World has a long history of serving our professional community and contributing to the advancement of medical physics worldwide by providing a bulletin to all members covering IOMP activities and matters of best interest to medical physicists worldwide. Thanks to the professionalism of the MPW Editors and their editorial teams, who produced 67 successful issues of MPW throughout the last 35 years, Medical Physics World always succeeded to fulfill the mission it was charged with and has proven many times the first commitment made by the first MPW team "… to make ‘Medical Physics World’ worthy of its title” [Medical Physics World, 1984, vol. 1, no. 1, p. 1-2]

References:

1. www.iomp.org/mpw
2. Medical Physics World, November 2019, Vol.35 (10), No. 2, Special Issue, https://www.iomp.org/wp-content/uploads/2019/11/MPW-2019-02-SI.pdf
3. Medical Physics World 1984, Vol.1, No. 1, https://www.iomp.org/wp-content/uploads/2019/02/mpw_Volume_1_Number_1.pdf

IFMBE CELEBRATES ITS 60TH ANNIVERSARY

Prof. M Nyssen (IFMBE Treasurer) and Prof. R Magjarevic (IFMBE Vice-President)

60 years ago, a few pioneers in the field of biomedical engineering, engineers and physicians, founded the Federation in Paris on November 22nd 1960. Originally, the international not for profit association was called: “Fédération internationale d’électronique médicale”. Its official registration in France was approved by the Ministry of Interior Affairs and publication in the French Official Journal appeared in January 1961.

Although in practice, the current name “International Federation for Medical and Biological Engineering” (IFMBE) was already widely used in practice, in the Statutes the name had been changed only in 2001 at the time the President was Dov Jaron.

IFMBE was always considered as a “federation”, complementing the local, national and regional member associations on the international scene:

- by representing the biomedical engineering field at the International Science Council (ISC) - level via the International Union for Physical and Engineering Sciences in Medicine - IUPESM, together with the colleagues of the medical physics field, associated in the International Organization for Medical Physics -IOMP;
- as the representative of the biomedical engineering community, in official relation with the World Health Organization;

as the representative of the biomedical engineering community in the World Federation of Engineering Organizations;

- through its publications, mainly the scientific journal Medical and Biological Engineering and Computing - MBEC, published by Springer, a regular newsletter, informative web-site and other publications;
- through its conferences, workshops and dissemination activities.

The Federation is managed by its “Administrative Council” elected it the General Asembly that takes place every three years, in conjunction with the “World Congresses”, organized in the context of the union IUPESM. The “daily management” is taken care by the officers: President Prof. Shankar Krishnan (Boston), Secretary General Prof. Kang Ping Lin (Taiwan), President Elect Prof. Ratko Magjarevic (Croatia), Past President Prof. James Goh (Singapore) and Treasurer Prof. Marc Nyssen (Belgium).

Main structures in the Federation are the different committees and working groups, just to cite a few: the “Industry working group”, the “Education and Accreditation working group”, the “Women in biomedical engineering working group.

There are also two very active divisions: the “Clinical Engineering” division and the “Health Technology Assessment” division.

All these structures are run by very dedicated volunteers.

Currently, the Federation has more than 70 member associations, national societies spanning all continents, as well as “transnational” organisations.

N.B. The first MPI History issue during 2020 will include a large material related to the History of IFMBE

Part of the celebrations of IFMBE 60th Anniversary at MEDICON, Coimbra, Portugal

AN INTRODUCTION TO THE INTERNATIONAL SOCIETY OF RADIOLOGY (ISR)

José Luis del Cura, Chair of the ISR Communications Working Group[1]

[1] c/o ISR – International Society of Radiology, 1891 Preston White Drive | Reston, VA 20191 | USA

Abstract — **This article briefly presents the role, activities and objectives of the International Society of Radiology**

I. INTRODUCTION TO ISR

The foundation for the ISR was laid 94 years ago, when a series of international radiology congresses took place in London, England, in 1925. Although the official establishment of the ISR took place only in 1995, the idea behind it is still the same, namely, to assemble national radiology societies for them to speak with a common voice for advancing our specialty.

Thanks to its status of Non-Governmental Organization (NGO) in the World Health Organization (WHO) and as primary advisor of the International Atomic Energy Agency (IAEA), the ISR has a powerful role in representing the global radiological community with a focus on quality and safety as well as education.

II. QUALITY AND SAFETY IN RADIOLOGY

To promote global radiological quality and safety, the ISR cooperates not only with WHO and IAEA, but also with stakeholders such as the International Council for Radiation Protection (ICRP), the International Society of Radiographers and Radiological Technologists (ISRRT) and the International Organization of Medical Physicists (IOMP). The ISR was one of the international bodies that launched specific measures to support 10 proposed actions in the IAEA's and WHO's 2012 Bonn Call for Action, which identifies responsibilities and proposes priorities for stakeholders regarding radiation protection in medicine.

In 2016 the ISR set up the ISR Quality and Safety Alliance (ISRQSA) to gather and facilitate regional, national and international quality and safety campaigns in radiation protection. ISRQSA is co-chaired by Guy Frija (Chair of EuroSafe Imaging) and Donald Frush (Chair of Image Gently) and aims to establish a strategic plan for global efforts related to quality and safety, embracing contributions towards justification and optimisation, education, equipment performance, regulatory guidance, effective communication, as well as research related to medical radiation protection. Along with EuroSafe Imaging and Image Gently, the following radiology-led, mostly multi-stakeholder professional organisations are ISRQSA members: AFROSAFE (E-Afrosafe and F-Afrosafe), Arab Safe, Canada Safe Imaging, Image Wisely, Japan Safe Imaging, and LatinSafe.

The ISRQSA represented the ISR at the 2017 IAEA "International Conference on Radiation Protection in Medicine: Achieving Change in Practice", whose main aim was to review progress and developments in response to the Bonn Call for Action. The ISRQSA will have additional responsibilities as a result of this conference.

III. RADIOLOGICAL EDUCAITON

The ISR collaborates with international organisations to bring radiology education from manifold resources to underprivileged areas in the world. In the WHO symposium "Imaging for Saving Kids – The Inside Story About Patient Safety In Pediatric Radiology" that was held in the framework of a recent World Health Assembly, the ISR presented strategies for radiation protection in pediatric imaging that are available to the international community.

The ISR also provides technical advice to the WHO for the implementation of the project on Radiation Safety Culture in Medicine, which is jointly organized by WHO, IOMP and the International Radiation Protection Association (IRPA) with the goal to develop a framework supporting the establishment and maintenance of a radiation safety culture in healthcare facilities. The ISRQSA recently published a series of lectures on the "Radiation Protection Training Program for Patients/Public" to inform patients and the public about the safe use of ionising radiation.

The ISR also advised the WHO regarding the "WHO List of Priority Medical Devices for Cancer Management" and collaborates with it in the promotion of tuberculosis detection in less affluent areas through its ISR GOED project, which provides online educational material for free.

Through its global outreach program GoRAD, the ISR provides up to date practical radiology literature to underserved regions. Thanks to agreements with major radiological journals, the GoRAD platform offers open access to a limited amount of otherwise restricted content at the time of first publication. The ISR Resource Center offers educational content, media case conferences, lectures and teaching files, imaging informatics resources and content for radiologic technologists and radiology educators. In terms of face to face education, the ISR organises the International Congress of Radiology (ICR), whose upcoming 30th edition, ICR 2020, will take place in Muscat/Oman, from October 1-4, 2020. Organised in collaboration with the Oman Radiology and Molecular Imaging Society (ORMIS), ICR 2020 will offer an exciting programme around the theme of “Building Bridges”, including the full range of current and future practice of radiology. For more information, please see ICR 2020 website icr2020-oman.org. Aside from its own congress, the ISR also brings representatives to meetings of its member societies in the framework of the “Meet the ISR” programme.

IV. ISR MEMBERSHIP

By being part of the International Society of Radiology, member societies have an input into how the radiology community interacts with the international governmental organizations such as the WHO and the IAEA. No other national or regional radiology organization has the same input and level of interaction with these agencies as the ISR. Through the ISR, member societies can express the needs of their local communities to the WHO and the IAEA, and impact the regulatory decisions being made by these governmental agencies. By participating in the ISR, member societies can also provide input regarding the educational needs of their communities and assist the ISR and its partner societies in providing education content tailored to their specific needs. The ISR is the sum of the endeavours of all member societies to work together to boost the practice of radiology for radiologists to benefit our patients and global population health.

Sources:
http://www.isradiology.org/2017/isr/about_whitepaper.php
http://www.isradiology.org/2017/isr/quality.php
http://www.isradiology.org/2017/isr/about_01.php

Appendix: **The ISR Executive Council 2018 – 2020**

President: Luis Donoso (Spain)
Past President: Ricardo Garcia-Monaco (Argentina)
President-Elect: Renato Mendonca (Brazil)
Secretary-General: Bibb Allen (USA)
Treasurer: Sudhir Vinayak (Kenya)
American College of Radiology (ACR): Geraldine McGinty (USA)
European Society of Radiology (ESR): Paul M. Parizel (Australia)
Radiological Society of North America (RSNA): Umar Mahmood (USA)
Asian Oceanian Society of Radiology (AOSR): Dinesh Varma (Australia)
African Society of Radiology (ASR): Tarek El Diasty (Egypt)
Interamerican College of Radiology (CIR): Henrique Carrete (Brazil)
National delegate: Antonio Carlos Matteoni de Athayde (Brazil)
National delegate: Eman Naguib (Egypt)
National delegate: Hubert Ducou-le-Pointe (France)
National delegate: Leon Janse Van Rensburg (South Africa)
National delegate: Yi-Hong Chou (Taiwan)
ISRQSA Co-Chair: Guy Frija (France)
ISRQSA Co-Chair: Don Frush (USA)
International Commission on Radiology Education (ICRE) Chair: Eric Stern (USA)
Communications Working Group Chair: José Luis del Cura (Spain)

Contacts of the corresponding author:

Author: José Luis del Cura
Institute: Hospital Universitario Donostia, Head of Department of Radiology
City: 20014 Donostia-San Sebastian
SPAIN
Email: joseluis.delcurarodriguez@osakidetza.eus

EDUCATIONAL TOPICS

RECOMMENDATIONS FOR ACCREDITATION AND CERTIFICATION IN MEDICAL PHYSICS EDUCATION AND CLINICAL TRAINING PROGRAMMES FOR THE RCA REGION

I.D. McLean[1], B.J. Healy[2], K. Adhikari[3], N. Jamal[4], M. B. Kakakhel[5], A. Krisanachinda[6], J.C.L. Lee[7], K. H. Ng[8], S.A. Pawiro[9], K.A. Quadir[10], B. San Juan[11], B.J. Thomas[12], W.A.K. Wan Abdullah[13]

[1]The Canberra Hospital, Canberra, Australia, [2]Icon Group, Brisbane, Australia, [3]NAMS, Bir Hospital, Kathmandu, Nepal, [4]Planning and International Relation Division, Malaysia Nuclear Agency, Bangi, Malaysia, [5]Department of Physics and Applied Mathematics, Pakistan Institute of Engineering and Applied Sciences, Islamabad, Pakistan, [6]Department of Radiology, Faculty of Medicine, Chulalongkorn University, Bangkok, Thailand, [7]Department of Radiotherapy, National Cancer Centre, Singapore, [8]Department of Biomedical Imaging, University of Malaya, Kuala Lumpur, Malaysia, [9]Department of Physics, Universitas Indonesia, Depok, Indonesia, [10]Bangladesh Atomic Energy Commission, Dhaka, Bangladesh, [11]Ministry of Health, Manila, Philippines, [12]Queensland University of Technology, Brisbane, Australia, [13]Universiti Sains Malaysia, Kota Bharu, Malaysia

Abstract— **In a regional environment of expansion of radiation medicine services, often associated with cancer treatment, it is critical that the medical physicist is equipped to play their critical role. This requires the successful implementation of education and clinical training for medical physicists to lift the quantity and quality of medical physicists. This in turn demands formal national governance structures consisting of accredited centres providing education and training and a nationally recognised process of certification of medical physicists against agreed international standards of best practice. Recommendations on accreditation and certification for the East Asia and Pacific region have recently been developed through an IAEA/RCA regional project. These advocate a three-layered approach with a multi-disciplinary national body responsible for national registration, a predominantly profession-based body to steer professional standard processes, and a specialised accreditation and certification board responsible for professional standards and their assessment. Accordingly, accreditation should be awarded to academic institutions and clinical training centres who have been assessed as being consistent with agreed educational standards. Similarly, certification should only be awarded to residents assessed, typically through written, oral and practical examination, as competent in the needed knowledge and skills for a clinically qualified medial physicist. The spirit of such recommendations is importantly one of promoting encouragement and improvement.**

Keywords— **medical physics, education, training, accreditation, certification**

I. INTRODUCTION

The Regional Cooperative Agreement (RCA) is an intergovernmental agreement between Government Parties of the East Asia and Pacific region, under the auspices of the International Atomic Energy Agency (IAEA). The aim of the RCA is to promote and coordinate cooperative research, development and training projects in nuclear science and technology through their members' appropriate national institutions (www.rcaro.org). Each Government Party appoints a National Project Coordinator (NPC) to collaboratively manage a specified regional project with the proposing Government Party appointing a Lead Country Coordinator (LCC). The list of RCA Government Parties can be found here www.rcaro.org/states. One area of training that the RCA has been supporting for some time is in medical physics, particularly encouraging sustainability through locally based education and training.

The IAEA/RCA regional project RAS6077 on "Strengthening the Effectiveness and Extent of Medical Physics Education and Training" is a multi-faceted project which attempts to address through one of its outputs issues of professional standards and recognition of the work of medical physicists. Two technical meetings were implemented to develop recommendations on accreditation of relevant education and training institutions and certification for medical physicists in the East Asia and Pacific region. This paper presents those recommendations which have been endorsed by the RAS6077 national project coordinators at their concluding meeting in 2017. These recommendations are addressed to professionals and administrators involved in the development, implementation and management of medical physics education and training programmes in the Asia Pacific region as well as informing those that utilise medical physics services in the diagnosis and treatment of cancer and other diseases. It is recognised that such recommendations may also have relevance outside of this region.

II. BACKGROUND TO ACCREDITATION AND CERTIFICATION

The role of the medical physicist in radiation medicine is critical to the safe, effective and economic delivery of medical services that typically include radiation oncology, diagnostic radiology and nuclear medicine. The roles of a medical physicist as described recently [1] apply generally to the Asia Pacific region with lessons learnt from previous practice in radiation oncology [2] and in diagnostic radiology [3]. Furthermore, the region is undergoing increasing expansion in radiation medicine in both the complexity of technical innovation and in its general application to the population, due to the increasing living standards, aging population and expectation of medical services in the region. Medical physicists are uniquely placed to address needs in increasingly technical sophistication of service delivery as well as basic safety requirements, including shielding and occupational and patient safety. Unfortunately, medical physics workforce needs are not always met in the East Asia and Pacific region [4, 5], and expansion in radiation medicine services will place further stress on the current medical physics workforce.

The IAEA Basic Safety Standards [6] has defined the Medical Physicist as “a health professional, with specialist education and training in the concepts and techniques of applying physics in medicine, and competent to practise independently in one or more of the subfields (specialties) of medical physics”. The IAEA [1] has also stated that a clinically qualified medical physicist (CQMP) must have:

- A university degree in physics, engineering or equivalent physical science;
- Appropriate academic qualifications in medical physics (or equivalent) at the postgraduate level;
- At least two years (full time equivalent) structured clinical in-service training undertaken in a hospital.

A CQMP is therefore one who has successfully completed an appropriate academic postgraduate medical physics degree and has successfully undergone an appropriate clinical residency training programme in a chosen speciality or subfield of medical physics.

In order to ensure that the above process has produced a CQMP with the level of expertise needed to practise independently in one or more specialisation of medical physics, the CQMP needs to be certified by an appropriate professional certification body. In a similar way the integrity of both the postgraduate education and the clinical training programmes need to be assured through the accreditation of these programmes, by an appropriate accreditation body. There have been commendable efforts by many East Asia and Pacific countries in establishing medical physics education and training, but more effort is required in fully implementing the international recommendations on accreditation and certification throughout the East Asia and Pacific region. Regional cooperative initiatives rather than individual national initiatives may be required to create self-sustaining education and training programmes.

The above certification and accreditation bodies may exist separately or as one board. This may vary from country to country. In any case the board(s) must be independent and duly appointed for their purpose. For simplicity in this document we shall refer to a joint accreditation and certification board (ACB) which might need to be expanded appropriately for multiple specialities. Such a board, although independent, is closely associated with the appropriate national or regional professional body and will be largely composed of appropriate professionals from the professional body, ideally represented by the official professional society for medical physics. The ACB will be responsible for setting the professional standards and criteria for accreditation and certification, as well as maintaining strict standards in the conduct of the accreditation and certification processes. The ACB is made up of at least two senior Clinically Qualified Medical Physicists (CQMP). In the absence of an ACB, the National Steering Committee (NSC) will assume this responsibility and make the arrangements for the appointment of suitable external examiners. Three independent ACBs (Radiation Oncology, Diagnostic Radiology, and Nuclear Medicine) can be set up. Alternatively, a single board having expertise in all sub specialities can be constituted. The ACB functions in some capacities in a similar way to a national steering committee mentioned in the IAEA clinical training guides TCS 37, 47 and 50 although the national steering committee as described applies only to clinical training and the processes necessary to maintain its integrity and standards

A formal health care industry recognition of CQMP by the appropriate National Responsible Authority (NRA) is a realistic expectation since the medical physicist profession has been recognised by the International Labour Organization (ILO). The NRA would most likely be an arm of government. In order for the certification process to be effective within the health care industry, the process needs to be recognised by an appropriate NRA that is able to grant registration for a CQMP. Ideally this would be done directly by a suitable government body (such as the Ministry of Education, or Ministry of Health), since registration of professions is usually a function of government. However, in some cases another professional body (for example from the medical profession or a university) may be required as an intermediary to allow government recognition. A simplified generic outline of the association of bodies and process in medical physics accreditation and certification is given in Fig. 1. Note that the IAEA TCS publications on medical physics clinical training [7-9] refer to a National Steering Committee (NSC) for oversight of the programme. The NSC would typically appoint a training coordinator with needed support mechanisms for successful administrative and training outcomes. However in some countries this role is taken by the medical physics Professional Body. Note the ACB is independent of the national steering committee, even if composed of national steering committee members. A professional body acting as the national steering committee must be legitimately operating in the country having complied with the relevant government requirements. If there are two or more competing professional bodies in the country the NRA would need to recognise only one and this would likely be the professional body which has the largest membership. Also, the role of the NRA is simply recognition of the process which in turn enables the national level of the registration process.

Fig. 1 Outline of generic relationships between the accreditation and certification board (ACB), national steering committee (NSC) and national responsible authority (NRA)

In order to maintain and enhance their professional competence, and their ability to work independently, CQMPs should undertake a continuing professional development (CPD) programme which ideally would be determined and overseen by the ACB (Fig. 2). Such a programme should include attendance at national and/or international conferences, publications in refereed journals and courses on topics related to their field of specialization.

While the outline processes for CQMP certification and associated accreditations is designed to ensure the quality of medical physicists practicing in a country, attention also needs to be given to the competitiveness of the provision of medical physicists in an environment of unparalleled expansion in the development of radiation medicine in the Asian region [10-12]. The need for workforce expansion should clearly be balanced against the need for competently trained personnel in the name of efficacy of patient services and patient safety. Added to this imperative is the management of a transition to higher qualifications inherent in a new and evolving certification process, where established persons, currently performing medical physics roles need to be carefully considered.

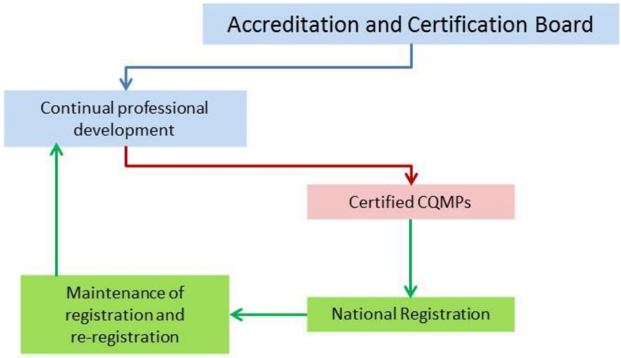

Fig. 2 Abridged outline of generic relationships involved in the maintenance of national registration through the use of continual professional development (CPD) ideally under the oversight of the accreditation and certification board (ACB). Note that a national registration process by an NRA is required before registration and or re-registration occurs. This process also allows the enforcement of a CPD requirement for the lifelong learning of the CQMP

When the NRA assumes a major role in the registration process of CQMPs in the regulated health care industry, it is also assumed that there is an adequate number of CQMP to satisfy the manpower requirements of the country or the region. Essentially what this means at the time of writing, is that there is a need for an increase in CQMPs by a factor ranging from 2 to 10 in many of the Asian countries in the RAS6077 technical cooperation project. While many of the factors needed for such an expansion in CQMP numbers are beyond the control of the profession, accreditation and certification processes need to be carefully designed nationally and perhaps regionally in such a way so as not to obstruct expansion in the profession. Further consideration needs to be given to upgrade paths to allow existing personnel and migrating personnel to have a manageable path to be recognised as CQMPs as appropriate. Having ACBs across the Asian region adopting a common set of accreditation and certification criteria will also benefit from mutual training support, shared resources and cross-border recognition of CQMP.

III. RECOMMENDATIONS FOR ACCREDITATION OF MEDICAL PHYSICS ACADEMIC PROGRAMMES

Accreditation is the formal process by which an independent recognized body (professional and/or governmental) evaluates and recognizes that an academic programme or a clinical site meets pre-determined requirements or criteria. It is highly desirable that both the postgraduate academic programme and the clinical residency be formally accredited by a professional body authorized by the government or by a relevant government office. It is emphasized that a system of accreditation does not constitute a permanent status, and should be renewed periodically [1].

A compulsory component of a physicist’s education and training to become a clinically qualified medical physicist specialist, certified in a particular specialty area, is the acquisition of an appropriate postgraduate degree in medical physics. The professional body and the universities collaborate to enable universities to provide this essential component.

While the accreditation of medical physics postgraduate programmes can be viewed as a voluntary process, for example for research focussed institutions, the emerging trend is for accreditation of medical physics postgraduate programmes to be mandated, especially when linked to a certification process by a professional body. A typical accreditation process for a postgraduate programme is given in Fig. 3 which illustrates that accreditation readiness can be achieved through self-assessment first be carried out internally within the university department before submission to the ACB. The assessment of the ACB is made against a number of criteria as seen below.

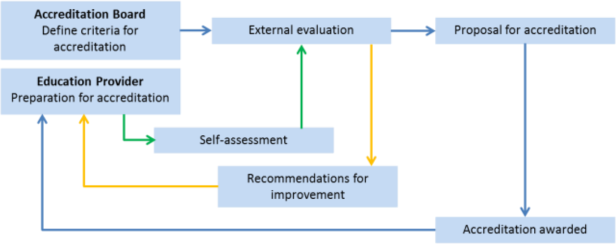

Fig. 3 Accreditation process flow chart

There are four assessment criteria for accreditation of medical physics postgraduate programmes, namely, admission criteria, faculty members, facilities and teaching modules.

Admission Criteria

The 3 to 4 year undergraduate degree of students entering a post-graduate medical physics academic programme should be in Physics or an equivalent relevant physical or engineering science. Because there are significant differences in the level and composition of tertiary education worldwide, it is often necessary for qualifications authorities to determine the local degree equivalence prior to student registration. For admission to the medical physics programme, it will in addition be necessary to examine the academic transcript of the degree and it is recommended that:

- At least 2 years of undergraduate level mathematics were completed successfully including:
    - Applied Linear Algebra
    - Advanced Calculus
    - Complex Variables
    - Differential Equations
    - Numerical methods;
- The following physics topics should be covered during undergraduate study. If not, they should be completed prior to entry into the postgraduate medical physics programme:
    - Electricity and Magnetism
    - Atomic Physics/Nuclear Physics
    - Quantum Mechanics
    - Classical Mechanics
    - Solid State Physics
    - Modern Physics and Relativity
    - Thermodynamics/Statistical Physics
    - Signal Processing/Fourier Transform
    - Physics of Fluids and Gases
    - Optics
    - Computational Physics/Computer Programming;
- The admission requirements for other individuals, who have already completed a graduate or post-graduate degree in any other field, should be the same.

Faculty Members

The academic faculty should include at least one instructor holding a PhD, in at least a physics related discipline, preferably with clinical experience in medical physics. The lack of faculty with a PhD will most likely limit the ability of the institution to offer the course at a post-graduate level.

The structure must therefore include a formal link with a clinical department, utilising medical physics services for radiation oncology, diagnostic radiology and nuclear medicine in a hospital setting. Such links should include both teaching and practical contributions. The university should recognise this input with an appropriate appointment for the staff involved. Costs incurred by the clinical department should be considered by the university.

Facilities

The university should have access to clinical equipment utilised in clinical radiation oncology, diagnostic radiology and nuclear medicine for practical experience. Such equipment is listed below.

Radiation oncology services should have:

- A teletherapy unit;
- A treatment planning system;
- A simulator (conventional and/or computed tomography (CT));
- Dosimetry and quality control equipment, including a 3D water phantom;
- A Brachytherapy facility;
- Access to medical imaging services.

Diagnostic radiology services should have:

- General X ray units;
- Fluoroscopy X ray units;
- Computed Tomography (CT);
- Mammography unit;
- Dental units;
- Ultrasound units;
- Dosimetry equipment and quality control tools;
- In addition, it would be advantageous to have access to dual energy X ray absorptiometry (DXA) unit, a solid state dosimetry system (TLD or OSL) and a magnetic resonance imaging (MRI) unit.

Nuclear medicine services should have:

- A gamma camera, single photon emission computed tomography (SPECT) or SPECT/CT system;
- Dose calibrator, probes and counters;
- Phantoms and calibration sources;
- Survey meters and contamination probes;
- Radionuclide therapy services;
- Internal dosimetry;
- In addition, it would be advantageous to have access to positron emission tomography (PET) or PET/CT.

Teaching Modules

Suitable measures need to be in place to maintain and develop quality and excellence in teaching and learning. Suitable methods of assessing and monitoring student progress need to be evident.

The academic modules contained within the medical physics programme should aim at preparing a student to conduct research and to apply critical and innovative thinking to problem solving. At least a small research project should be included.

A suggested core syllabus for an academic programme is given in Table 1. It is important that the modules have the necessary depth, breadth and balance in its requirements on intellectual effort. While it is not required that the units of study have the names shown in Table 1 the substance of the units are considered compulsory although there is some scope for flexibility in extending the syllabus to adapt the course to match local interest and expertise. Detail of typical core modules are found in IAEA TCS 56 [13], AAPM Report No.197 [14], ACPSEM [15], IPEM [16], and IOMP [17] academic programme guidelines. Practical sessions or laboratory work are possible in all modules, bearing in mind that one practical session could cover multiple modules. Examples of practical sessions or laboratory work are given IAEA TCS 56 [13]. A typical structure for a medical physics postgraduate programme, outlining core modules, contact hours and laboratory hours is given in Table 1.

Table 1 An example of a medical physics academic programme structure [13]

Module	**Weighting**	**Contact Hours**	**Lab Hours**
Anatomy and Physiology as applied to Medical Physics	5%	30	
Radiation Physics; Radiation Dosimetry	10%	40	10
Radiation Protection; Radiobiology	15%	50	
Professional and Scientific Development	10%	40	
Medical Imaging Fundamentals; Physics of Nuclear Medicine; Physics of Diagnostic and Interventional Radiology	20%	80	40
Physics of Radiation Oncology	15%	60	40
Advanced Subject or Additional Topics	5%	20	10
Research Project	20%	10,000 words	
Total	**100%**	**320**	**100**

IV. ACCREDITATION OF MEDICAL PHYSICS CLINICAL TRAINING CENTRES

As mentioned previously, it is highly desirable that the clinical residency programme as well as the postgraduate academic programme be formally accredited by a professional body authorized by the government or by a relevant government office.

The purpose of the clinical training is to provide medical physicists with relevant knowledge and appropriate problem-solving skills as part of the medical physics training programme in the selected speciality. The academic knowledge necessary for certification will be primarily acquired through the postgraduate educational component, however it is necessarily and extensively supplemented with knowledge acquisition throughout the training period.

Accreditation of a hospital facility for a medical physics clinical training programme in one of the specialties of medical physics is recognition that such a programme conforms to the guidelines such as IAEA TCS 37 [7], 47 [8] & 50 [9], AAPM [18], ACPSEM [19, 20], including general standards, physical and human resources and training activities. Hospital facility accreditation ensures their suitability in preparing medical physicists with the necessary depth and breadth of knowledge and clinical opportunities. Where an entire programme is not available in a single facility, accreditation may be granted to a training "network" provided the network can demonstrate a satisfactory method by which the required in-service clinical training can be achieved. Those who complete such a programme should be qualified for professional practice in one or more of the specialties of medical physics.

In reviewing a hospital facility for accreditation purposes, the ACB will consider general standards, physical resources, human resources and training activity as listed below.

General standards

- The resident must have the opportunity to be involved in a full range of (diagnostic radiology, nuclear medicine or radiation oncology, depending on speciality offered) medical physics services, consistent with national expectations. It is the responsibility of the hospital facility to arrange appropriate rotation of the resident to other clinical centres to fulfil these requirements, if considered necessary by the ACB;
- Appropriate arrangements should be made for university study as part of the course if applicable;
- Links are needed to appropriate universities for research as available;
- The performance of previous residents (where applicable) should be considered;
- The level of quality control practiced by the hospital facility as is evident from records of work undertaken should be reviewed;
- It should be noted whether the hospital facility is situated in a teaching hospital, or in a network with formal links to a teaching hospital.

Physical resources

- Adequacy of resources for the training of residents needs to be assessed, including access to major treatment or diagnostic equipment modalities (see Section 2.1.1), hardware such as physical phantoms, radiation detectors, test equipment, computing facilities, etc. and recommended text books and journals;
- The facilities available need to be reviewed including office space, equipment, libraries, internet access, e-resources, physics laboratories, workshops etc.;
- Facilities available for video conference and training need to be reviewed including access to audio visual facilities to permit the preparation of audio-visual aids for lectures, demonstrations and teaching.

Human resources

- The number of clinical medical physics staff in the hospital facility, their professional qualifications and experience needs to be reviewed. A minimum of 1 (full-time equivalent) clinically qualified senior medical physicist (or other medical physicists approved by the ACB) is recommended to be employed in the department for each resident. However local expertise might be supplemented by external online supervision if available and appropriate;
- If the full range of necessary skills in supervision is not present in the one hospital facility, a plan of how this required supervision expertise will be realised through a network of physicists should be available;
- A suitably qualified clinical supervisor is required (preferably not the hospital facility Head of Medical Physics in larger hospital facilities), responsible for overseeing the training programmes of residents in the hospital facility. Where more than two residents are employed, additional suitably qualified clinical supervisors should be appointed. The clinical supervisors must be senior medical physicists (or other medical physicists approved by the ACB).

Training activities

- The training programme must meet the recommendations made by the ACB;
- The hospital facility must ensure that the resident is given adequate time and training under supervision in all areas of the medical physics speciality such that the resident gains the required knowledge and competencies;
- The hospital facility must ensure records of supervision and a training evidence portfolio and logbook are kept by residents in the hospital facility. They are to be available for inspection by the ACB at any time;
- The clinical supervisor must meet regularly with residents and at these meetings progress must be reviewed in accordance with the appropriate clinical training guide (e.g. IAEA TCS 37[7], 47 [8], and 50 [9]). Formal documented performance evaluations are recommended to be performed as per hospital policy in conjunction with bi-annual external reviews by the National Programme Coordinator (NPC). The NPC is responsible for coordination of the clinical training programme nationally (the NPC role is defined in the IAEA TCS 37 publication [7]).

V. RECOMMENDATIONS FOR CERTIFICATION OF MEDICAL PHYSICISTS

The criterion for entry into a clinical training programme is a postgraduate degree in medical physics from an accredited institution. The clinical training programme involves a modular/competency framework based on a nationally adopted Clinical Training Guide (CTG). For step-by-step details on the conduct of a clinical training programme, which is beyond the scope of this document, the IAEA TCS 37 [7], 47 [8] and 50 [9] publications can be referred to for guidance.

For certification of medical physicists, a process of assessment needs to be in place (see Fig. 4). The assessment involves continuous monitoring of the progress of the resident by the clinical supervisor and formal external assessment by qualified examiners that report to and are directed by the ACB. The form of examination typically includes written, oral and if possible a practical component. As mentioned previously, in the absence of an ACB in the country, the NSC has the responsibility to appoint external examiners for the written examination and oral/practical examination.

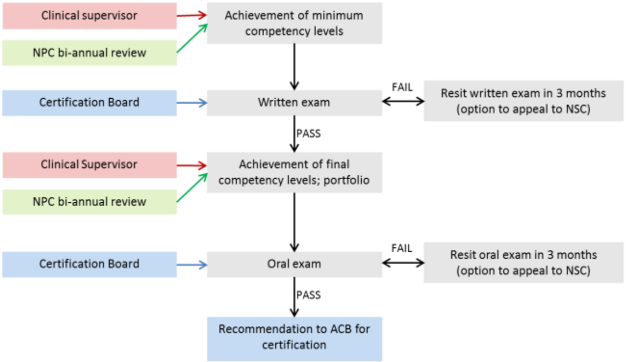

Fig. 4 Certification process flow chart

The length of clinical training programme is two years in one of three sub-specialities including core modules (with competency levels as directed by the Professional Body or NSC) and non-core modules. The CTG is the list of all modules and sub-modules along with the desired competency levels. The CTG is set by the NSC by adapting available international CTGs (e.g. IAEA [7-9], ACPSEM, AAPM [18]) while keeping in view the local needs. The roles and composition of the NSC are defined by the IAEA TCS 37 publication [7].

A portfolio is required to be maintained by the medical physics resident. The portfolio provides residents with an opportunity to demonstrate the breadth and depth of their knowledge on certain topics. The portfolio incorporates the follow documents:

- Curriculum vitae;
- Progress reports “Summary of Competency Achievement” demonstrating the level of competency achieved in each sub-module;
- Samples of work prepared by the resident from at least five of the modules of the CTG. The samples of work could be departmental reports, e.g. commissioning and clinical implementation of new equipment or treatment technique, assignments on key competencies, a research paper published in a peer-reviewed journal/ national or international conference or in-house presentations delivered covering key aspects of the core modules.

The clinical supervisor will examine the portfolio at regular (at least 6 monthly) intervals and provide feedback to the resident.

There will be bi-annual reviews by the NPC of the resident’s progress. As part of the review the NPC will meet the resident and the clinical supervisor (individually) to monitor the smooth progress of the resident. The NPC will also review the resident’s portfolio and rate the portfolio as satisfactory or unsatisfactory. An example of a review template is given as in Appendix II.

The resident is required to present once (oral or poster) at a national/international conference. The presentation must be completed before the oral examination.

Furthermore, the resident is required to maintain a logbook to record all activities in the clinical training programme for self-tracking and record purposes.

Written Examination

The written examination takes place after the achievement of a minimum level of competency in all of the core modules. The written examination is to be set and marked by examiners from the ACB or as appointed by the Professional Body or the NSC. A suggested written examination procedure is given as follows:

The written examination will consist of two parts. Part I: General Medical Physics (90 minutes for 45 multiple choice questions). Part II: Core modules (90 minutes for 45 multiple choice questions). The multiple choice questions will comprise five options with one correct answer. For successful completion of the written examination, the resident should score 60% or more in each part.

The written examination evaluation is sent to the NPC by the examiners. In case of a non-satisfactory examination report, a repeat examination (Part I or Part II or both) will be conducted with at least 3 months gap after the initial examination. Consideration needs to be given by the NSC as to the maximum number of fails each resident can make in the written examination before they are removed from the residency programme.

Oral Examination

The oral examination takes place after all elements of the clinical training programme have been completed. The oral examination will be conducted by at least two external examiners from the ACB or as appointed by Professional Body or the NSC. The questions are to be devised from the core modules, clinical scenarios and the submitted portfolio. The resident’s clinical supervisor could participate in the oral examination as an observer. The recommended duration of the examination is between

90 – 150 minutes. Each of the set questions will receive a mark in the range 0 – 10. In order to pass the examination, the candidate must score 60% or more over in all questions asked and must score 50% or more in each module/scenario/portfolio. Consideration needs to be given by the NSC as to the maximum number of fails each resident can make in the written examination and/or practical examination before they are removed from the residency programme.

Practical Examination (If Feasible)

The practical examination takes place after all elements of the clinical training programme have been completed. The practical examination will be conducted by at least two external examiners from the ACB or as appointed by the Professional Body or the NSC. The clinical scenario given in the practical examination is to be devised from the core modules. The resident's clinical supervisor could participate in the practical examination as an observer. The duration of the examination is 2 – 3 hours.

Recommendation for Certification

After the accomplishment of the oral examination and practical examination if applicable, the result is sent by the examiners to the Accreditation and Certification Board (ACB)/NSC through the National Project Coordinator.

Appeal Process

An appeal process needs to be established by the Professional Body or the NSC. After the resident is notified of the result of written examination or oral/practical examination, he/she can file an appeal within two weeks to the NSC. The NSC would appoint suitable senior persons independent of the examination process and independent of the resident's hospital to conduct the appeal.

VI. CONCLUSIONS

The experience of RCA regional projects in medical physics has been that academic and clinical training programs in all medical physics specialties can be successfully run utilizing the above guidelines. Experience also reinforces the understanding that each Government Party is unique in its circumstance relating to the involvement of medical physicists in radiation medicine and the available educational and training opportunities. It is therefore suggested that the above recommendations be applied appropriately to create new or strengthen existing education and training processes needed to equip an increasing number of qualified clinical medical physicists to address needs in the region.

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Contacts of the corresponding author:

Author: Ian Donald McLean
Institute: The Canberra Hospital
Street: Yamba Drive
City: Canberra
Country: Australia
Email: donald.mclean@act.gov.au

Conflict of Interest Statement.

No conflict of interest was found with author or organization that has either had influence on the content of the manuscript or who could potentially benefit from the publication of the manuscript.

IOMP COLLABORATION WITH CRC PRESS / TAYLOR & FRANCIS

Rebecca Davies[1] and Kirsten Barr[1]

[1]CRC Press, Taylor and Francis Group, Abingdon, Oxfordshire OX14 4RN, UK

I. INTRODUCTION

The International Organization for Medical Physics (IOMP) has a longstanding collaboration with the publishing company CRC Press / Taylor & Francis, a collaboration that is celebrating its 35th anniversary in 2020. This has been subject to several official agreements and has been mainly related to the book series entitled the *Series in Medical Physics and Biomedical Engineering*. Based on these agreements the series has been adopted as the official book series of the IOMP and a brief description of the role of the IOMP appears in every book in the series. The IOMP and its sister organisation IFMBE (International Federation for Medical and Biological Engineering) support joint Editors for the series.

The series aims to describe the applications of physical sciences, engineering and mathematics in medicine and clinical research and to meet the need for up-to-date texts in this rapidly developing field of science. Books in the series range in level from upper-level undergraduate and graduate textbooks to practical handbooks and advanced expositions of current research. The authors are leading experts in the field, often recommended by the IOMP and IFMBE.

The book series was initiated in 1985 with *Fundamentals of Radiation Dosimetry, Second Edition* by J G Greening and the next books appeared in 1991 (*Prevention of Pressure Sores: Engineering and Clinical Aspects*, Webster J G) and in 1993 (*The Physics of Three Dimensional Radiation Therapy: Conformal Radiotherapy, Radiosurgery and Treatment Planning*, Webb S). The latter already used the distinctive red colouring on its cover. The series intensified after 1997, when three books were published. The Series Editors at that time were R F Mould (UK), C G Orton (USA), J A E Spaan (The Netherlands) and John G. Webster (USA).

69 books in various fields of the profession have been published since the beginning of the collaboration between IOMP and CRC Press / Taylor & Francis. In 35 years the *Series in Medical Physics and Biomedical Engineering* has established itself as a leading international book series in the field. Three of the world's leading academics in the field serve as current Series Editors – Kwan-Hoong Ng, Russell Ritenour, and Slavik Tabakov (and formerly John G. Webster, who very recently retired from the position), curating the series and carefully selecting the highest quality publications for inclusion. These Editors formed a very effective team, responsible for the soliciting and assessment of about 2/3 of the books in the series. The current Commissioning Editor from CRC Press is Rebecca Davies.

Recent and forthcoming publications in the Series include: Rancati & Fiorino, *Modelling Radiotherapy Side Effects: Practical Applications for Planning Optimisation*; Kirby and Calder, *On-Treatment Verification Imaging: A Study Guide for IGRT*; Dewji & Hertel, *Advanced Radiation Protection Dosimetry*; Dixon, *The Physics of CT Dosimetry*; Ng, Yeong & Perkins, *Problems and Solutions in Medical Physics: Nuclear Medicine Physics.* A full listing of books in the series can be found at http://www.crcpress.com/browse/series/chmephbioeng.

The books are priced in such a way as to make them affordable to as many medical physicists and biomedical engineers worldwide as possible (both professionals and students). In addition, all books in the series are available at a discount to members of the IOMP. As a member of the IOMP, simply enter code **IMP19** when ordering at www.crcpress.com to save **25% off all books** (t*his code will only be valid until 31/12/2022).*

For 35 years, the team of Academic and Commissioning Editors of the CRC *Series in Medical Physics and Biomedical Engineering* has supported the development of research and education in medical physics. We warmly welcome new book proposals, or suggestions of valuable books, for the series. Colleagues who are interested in writing or editing a book for the series should contact Rebecca Davies, Editor for Physics books (Rebecca.Davies@tandf.co.uk) or write to any of the Series Editors. The proposal guidelines can be accessed at http://www.crcpress.com/resources/authors.

II. BOOKS AND HYPERLINKS

Books resulting from the collaboration between IOMP and CRC Press / Taylor & Francis:

-Modelling Radiotherapy Side Effects: Practical Applications for Planning Optimisation

2019, Tiziana Rancati, Claudio Fiorino

- *On-Treatment Verification Imaging: A Study Guide for IGRT*
2019, Mike Kirby, Kerrie-Anne Calder

- *Advanced Radiation Protection Dosimetry*
2019, Editors: Shaheen Dewji, Nolan E. Hertel

- *The Physics of CT Dosimetry: CTDI and Beyond*
2019, Robert L. Dixon

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Author: Rebecca Davies
Institute:. CRC Press, Taylor and Francis Group
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Country: UK
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EFFECTIVE PHYSICS KNOWLEDGE FOR DIAGNOSTIC RADIOLOGISTS

Perry Sprawls
Emory University, Atlanta and Sprawls Educational Foundation, www.sprawls.org

Abstract— — **Physics is one of the fundamental sciences of radiology along with the biological sciences anatomy, physiology, and pathology. Physicians, especially radiologists, require a comprehensive knowledge of physics, along with the other sciences, for the purpose of performing diagnostically effective and optimized medical imaging procedures. This requires learning objectives that are generally different from learning physics in preparation for certifying examinations. Physics educational activities for residents beginning with and structured around images as the principle physical object provide many values. It is of more interest to residents and provides a strong connection between physics and clinical radiology. The most significant factor is that learning physics from images develops higher levels of mental knowledge structures and conceptual networks that are required in clinical radiology. The innovative contributions of three pioneers in the field of education, Blume, Dale, and Gagné, provide guidance in developing and conducting physics education for residents that is of value in the practice of clinical radiology. Most of the activities described are based on radiology education programs in North America but have applications in other regions of the world.**

Keywords— **Images, Concepts, Clinical, Examinations, Educator.**

I. INTRODUCTION, OVERVIEW, AND OBJECTIVES

Images are the most significant physical objects used for the detection, diagnosis, and management of therapeutic procedures within the practice of clinical medicine. The appropriate and effective use of medical images for specific clinical conditions depends on the knowledge and experience of physicians, especially radiologists, who perform the procedures. This includes knowledge of both the biological conditions within the human body and the physical characteristics of the images and the imaging procedures. It is the physical characteristics of the images that determine the visibility of specific anatomical structures, biological functions, and signs of pathology. In principle there are images with optimum characteristics for each specific clinical procedure and imaging objective. The responsibility of the radiologist is to assure that the selected image characteristics are appropriate for the specific clinical objective. Especially with the more complex imaging methods, CT, MRI, etc. the radiologist is a significant factor in image quality control and assurance.

This requires a comprehensive *conceptual knowledge* of physics organized around *images* as the major mental element. This is somewhat different from knowledge learned, applied, and often taught by physicists that is more *symbolic and quantitative* in nature. Effective physics education for radiology residents and practicing radiologists must be different from traditional medical physics courses in both content and organization.

Images are physical objects with a combination of physical characteristics, and physics is a basic science of radiology. This is as significant as anatomy, biochemistry, physiology, and pathology as the basic biological sciences of the human body. All of these are the fundamental sciences of diagnostic radiology. Knowledge of each is essential to the practice of radiology as illustrated in Fig. 1.

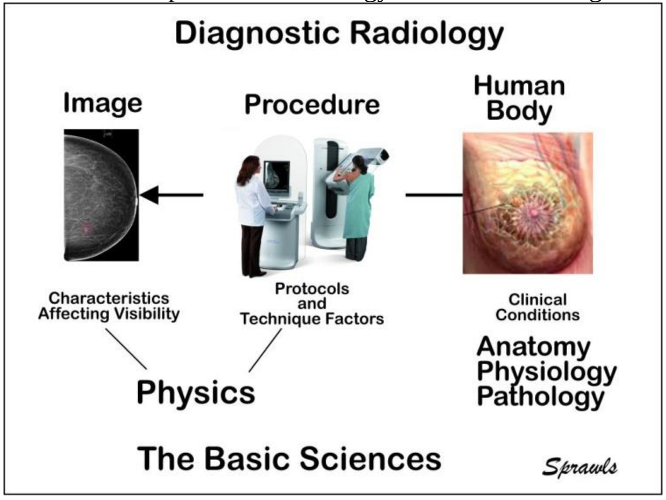


Fig.1. The basic and foundation sciences of diagnostic radiology.

There is a major factor distinguishing physics from the other basic sciences. The sciences related to the human body are included in medical school curricula and applied and enhanced throughout clinical activities. Physicians entering radiology residencies have extensive knowledge of these sciences, but not of physics, specifically the physics of images and the imaging process.

The significance of physics knowledge is officially recognized by the radiology profession through several requirements. Physics is a required subject to be provided in accredited radiology residency programs. It is also a specific topic within radiology board certifying examinations. The assumption is knowledge of physics is a significant requirement for the practice of clinical radiology and the role of certifying examinations is to verify that residents have acquired that knowledge. However, the reality is that effective clinical practice versus passing examinations requires different types of physics knowledge.

This is not intentional but results from the format of written physics examinations and the passing of the examinations as a major priority for residents.

Within radiology residency programs physics learning activities (classes, modules, board reviews and practice examinations, etc.) generally fulfill the requirements to pass examinations. However, they do not provide adequate knowledge of physics relating to images and the imaging process. This is especially significant for the complex decisions that need to be made by radiologists in the optimization of procedures with the highly- advanced contemporary imaging methods.

The objectives of this article are not to provide a detailed step-by-step "cookbook" instruction on how to teach physics to radiology residents. Around the world and in our individual institutions there are many different conditions, requirements, needs, and challenges relating to teaching physics in radiology programs. There is no one approach that is appropriate for all. The objective is to provide a review of some major developments and innovations in the educational process along with resources so that those of us who are medical physics educators/teachers can continue to optimize our programs to help radiologists develop mental knowledge structures that support their practice of clinical radiology.

II THE ELEMENTS OF AN EFFECTIVE PHYSICS PROGRAM FOR RADIOLOGISTS

To be effective and provide radiologists with physics knowledge that can be applied to enhance clinical performance throughout a career the program must be designed and conducted based on established principles of both the learning and teaching process. A major factor is the recognition of the types of mental knowledge structures required to support specific functions, especially in the clinic, and then the design of learning activities to develop the required knowledge. There is a longstanding and continuing challenge that results from a combination of factors relating to the balance of *effectiveness* and *efficiency* of physics learning activities within residency programs. It is also heavily driven by the goals and objectives for the physics classes and study activities, either teaching for the *test* or teaching for the *task* of being a highly effective clinical radiologist. There is a relationship between characteristics of *learning activities* and *levels of learning* that determine how knowledge can be used. A critical factor is connecting physics knowledge to clinical activities, both for learning and applying in the practice of diagnostic imaging. Our opportunity as medical physics educators is to use the extensive research, developments, and innovations in the broader field of education to provide highly effective physics learning activities for radiologists, now and into the future.

III. LEARNING FROM THE PIONEERS

Our profession of medical physics and clinical applications is built on the work and innovations of many pioneers in the field, especially beginning with Roentgen and many to follow. There are also pioneers in the field of education that provide us with an understanding of the process of learning and the development of knowledge structures in the brain and the characteristics of learning activities for developing the different types of knowledge. Here we will learn from three.

Blooms Taxonomy

Benjamin Bloom, an educational psychologist, developed a model of the learning process, *Blooms Taxonomy* that consists of six levels of knowledge ranging from simple memory to the higher cognitive levels supporting functions including analysis, problem solving, and creativity. This has provided educators with guidance in developing learning activities that provide effective knowledge for "high level" professional activities and goes beyond teaching to the test. For additional information and references search on "Blooms Taxonomy" in Wikipedia at: https://en.wikipedia.org/

Dale's Cone of Experience

Edgar Dale developed a model, *Dale's Cone of Experience* that organizes the different types of learning activities in relationship to their *effectiveness* and their *efficiency*. Effectiveness ranks learning activities in their ability to develop knowledge for specific mental functions--generally those as described by Bloom. Efficiency ranks the "cost" of the learning activities for a combination of factors including time and effort for both teachers and students, availability of resources for learning, and conflicts with other activities and scheduled events. For additional information and references search on "Edgar Dale" in Wikipedia at: https://en.wikipedia.org/

These two models as they apply to the physics of diagnostic radiology are illustrated in figure 2.

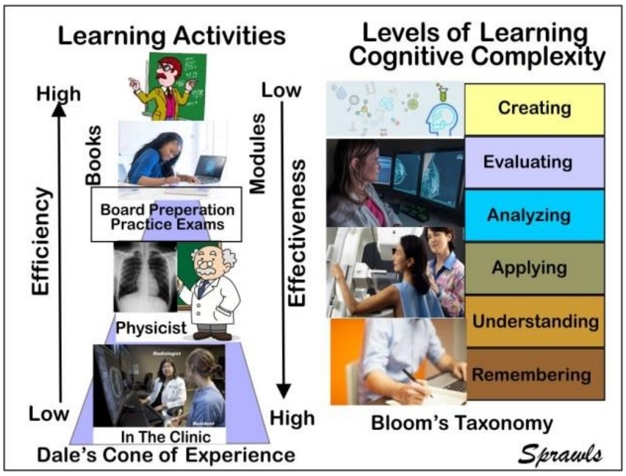


Fig.2. Two models of the learning process as they apply to the physics of diagnostic radiology.

A major factor as illustrated by Bloom's Taxonomy is that there are different levels of learning, or cognitive/mental complexity, associated with or required for the range of mental activities. Here we will emphasize a major difference between two, taking examinations and conducting appropriate medical procedures including the analysis of images or effective diagnosis and guidance of treatment.

Gagné's Conditions of Learning Events of Instruction

Robert Mills Gagné was an American educational psychologist best known for his *conditions of learning*. His pioneering work was in adult education developing educational methods to train aircraft pilots. A result was his model of the educational process as a series of nine specific events, each requiring actions by the educator. For additional information and references search on "Robert M. Gagné " in Wikipedia at: https://en.wikipedia.org/.

The application of his model to learning physics by radiology residents is illustrated in Figure 3.

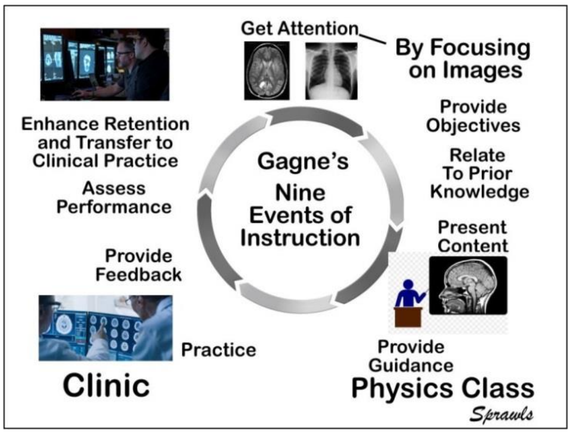


Fig.3. The series of nine events applied to the development of physics knowledge for clinical radiology.

The value of this is not to provide a detailed step-by-step guide to teaching but for those of us who are the physics educators to provide some perspectives on the adult learning process and find appropriate applications. Both the physics class/conference room and the clinic are necessary learning environments for physics that can be applied in clinical radiology. A major value of the physics class/conference is the medical physicists who use their knowledge and experience to connect residents to images as physical objects with specific characteristics that determine their clinical applications. The first of the nine events is to get the resident's attention. This is achieved by beginning with images, not physics equations. This provides the opportunity for explaining the objectives, which is the capability to understand image characteristics for all of the modalities and apply to both producing and interpreting clinical images. Along with this residents can recall from their prior clinical knowledge and experience clinical procedures in which a better knowledge of the image characteristic would have been helpful. This now provides a receptive opportunity for the presentation of the physics of imaging and guiding the learning process.

The image-based physics learning process then continues in the clinic and will benefit from guidance provided by radiologists. The significance is that many subjects, and especially physics, are most effectively learned under conditions where the knowledge is to be applied. The opportunities are to observe and interact with actual clinical imaging procedures, be evaluated and mentored, and use this learning experience in continuing clinical practice.

IV. DIVERGING OBJECTIVES OF PHYSICS EDUCATION FOR RESIDENTS

Traditional written examinations, including computer based, are designed to test the recall and perhaps some degree of understanding of factual knowledge generally in a symbolic form. This includes verbal definitions and quantitative mathematical relationships. This is driven by two factors. A word or mathematical based examination is relatively easy to develop and score and the content of examinations is determined by the curriculum of the educational programs that is the general preparation for the examinations.

It is this strong inter-dependence between radiology residency physics education and the certifying examination process that is a major factor in moving to more clinically valuable and effective physics knowledge.

With the first professional objective being to pass certifying examinations it is human nature to have educational activities with residency programs to prepare for this. A significant factor is physics classes within a residency program completely separated from clinical activities and restricted to times that will not interfere with a resident's clinical work. It is an issue of priority within a Radiology Department. The directives to the medical physicists, who provide the educational activities within a residency program, direct or implied, are to make sure the residents pass the certifying examinations.

A general result is that the physics education within residency programs is significantly isolated from clinical education in several ways. A major one is the limited "quality" time that is available with residents and not interfering with clinical work and clinical education. Physics education to prepare for certifying examinations and within limited time and available resources must be highly *efficient* as illustrated in Dale's model, Figure 4. This can be achieved with lectures by physicists, self-study of books and online modules, and especially board-preparation courses, mock examinations, etc. This is not being critical but is recognizing the requirements and limitations applied to physics education for radiology residents and *future radiologists!*

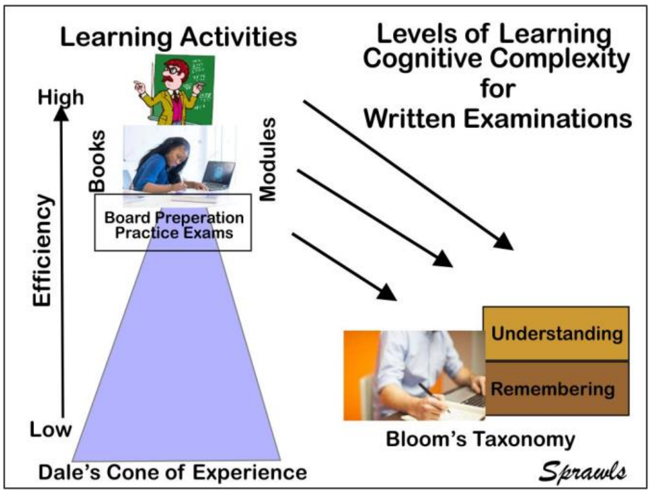


Fig.4. The learning activities that provide preparation for written examinations.

Compared to more clinically related physics learning activities to be described later the process of teaching and learning physics for written examinations is relatively *efficient*. It can be provided with lectures to groups and individual self-study. It does not require access to clinical facilities or one-to-one faculty involvement.

While the physics knowledge developed in these activities and tested for in written examinations is of significant value in the practice of radiology it is heavily symbolic, consisting of words and mathematical quantities and relationships. It does not provide the highly visual conceptual knowledge that contributes to the practice of clinical radiology.

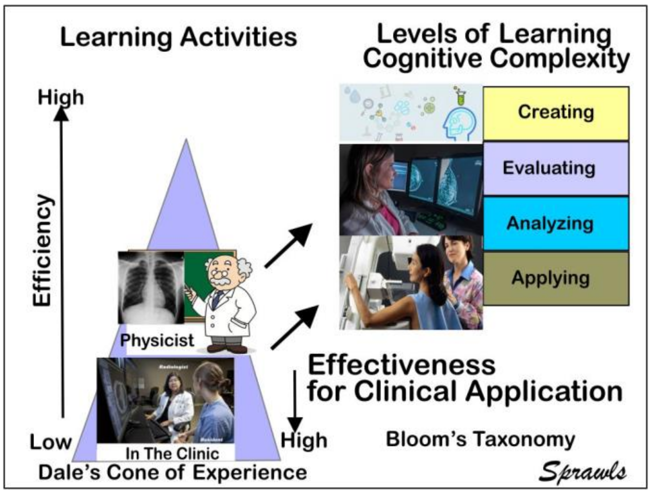


Fig.5. Physics teaching and learning activities that contributes to the effective practice of clinical radiology.

V. IT'S ALL ABOUT THE IMAGE

Radiology is the process of producing and evaluating conditions within the human body with *images*. An image is a physical object with specific physical characteristics with physics as its basic science. It is the interface between the field of physics and clinical medicine. It is the logical beginning and first activity for radiology residents learning physics with the guidance of medical physics educators.

A Transition from Tradition

The typical published curricula, textbooks, and physics courses for radiology residents begin with topics including the structure and characteristics of atoms and nuclei, forms of energy, electrical circuits and some associated technology. While this is essential knowledge it is not the optimum point to begin with for learning the physics of radiology.

Residents find it boring, a repetition of previous physics courses, and of little apparent significance to clinical radiology. This has contributed to the traditional physics course being perceived as something to be endured because attendance might be required and it will be on certifying examinations. Also, the physics classes might be scheduled at undesirable times so they do not interfere with clinical productivity and learning real radiology!

These are the conditions and perceptions that are being changed to provide more effective and clinically related physics education for radiology residents and future radiologists. The objective is not to eliminate the fundamental topics of atoms, radiation, etc. but to place them in more appropriate places within the curriculum.

Begin With the Image

Beginning a physics course for residents with an introduction to image characteristics as illustrated in Figure 6 provides several values.

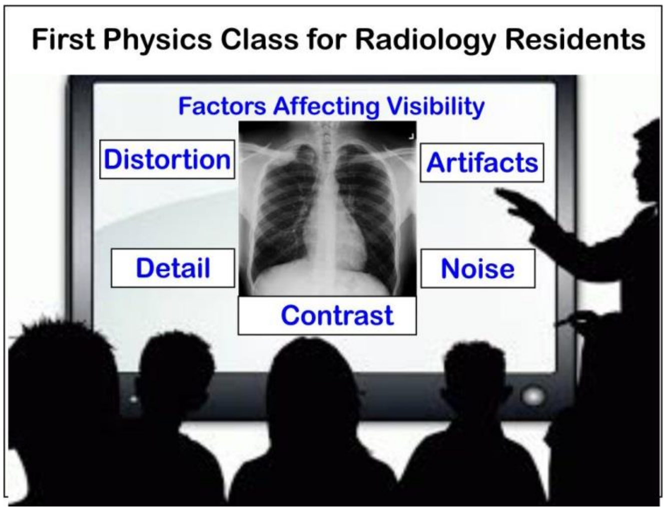


Fig.6. Beginning a Physics Course with Images as the Topic.

Beginning the learning of physics for radiology residents with a focus on images has many values. Images are physical objects with physical characteristics. The most significant factor is that images provide the most direct interface between physics, the science, and clinical radiology.

Residents come to the first physics class with extensive experience and interest in images. There is an inherent motivation to learn. This begins to provide an understanding of the complexity of medical images as produced with the various modalities and the combination of characteristics and factors that determine the visibility of specific anatomical structures and pathological conditions within the human body. Images establish an immediate interaction between physics classes and clinical activities, enhancing the role of physics as one of the clinical sciences.

The Universal Image Characteristics that Affect Visibility

A major and fundamental concept to be established, before studying the individual imaging modalities and methods, is that all medical images have a set of common characteristics that collectively determine clinical visibility. These image characteristics apply to all modalities. It is the physical characteristics, technology, and procedure protocols of each modality that determines the value of each of the image characteristics.

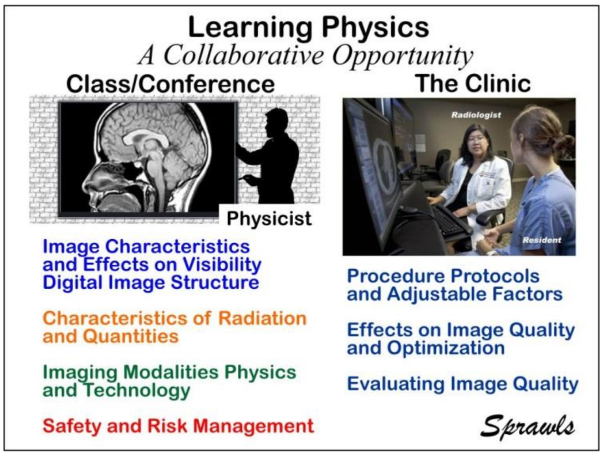
After developing knowledge of the common physical characteristics of images, contrast, detail (as determined by blurring), visual noise, artifacts, and spatial distortion, and their effects on visibility in relationship to the physical characteristics of objects within the human body, a next topic is the structure of digital images and the relationship of their structural and quantitative characteristics to image quality. This is fundamental and applies to all imaging methods.

The general characteristics of radiation, especially spectra, along with radiation quantities and units, are fundamental to most imaging methods and fit into the curriculum at this point. Details on production and controls will be of more interest when learning about specific modalities. Mammography is a good example.

The Imaging Modalities, Methods, and Procedure Protocols

The process of medical imaging consists of a hierarchy of three specific domains, *modality*, *method*, and *protocols*, with each based on physical principles. An example: MRI is a *modality*, spin echo is a *method* within that modality, and the *procedure protocol* consists of the selection and adjustment of factors within the method, including values for TR and TE. The characteristics and quality of images along with factors such as radiation exposure or image acquisition time are determined by the physics associated with each domain. Radiologists interact at each of these domain levels but in different ways.

The significance is physics learning activities for each domain have different requirements. The physics of the modalities and methods is most effectively and efficiently taught in classes or conferences by medical physicists. However, the procedure protocols and associated physics are learned in the clinic under the guidance of radiologists. This is most effective only if it is built on the physics knowledge of the modalities and methods provided by the medical physics educators. This is through a collaborative relationship between physics classes and clinic activities as illustrated in Figure 6.



Learning Physics

A Collaborative Opportunity

Class/Conference

Physicist

Image Characteristics and Effects on Visibility

Digital Image Structure

Characteristics of Radiation and Quantities

Imaging Modalities Physics and Technology

Safety and Risk Management

The Clinic

Radiologist

Resident

Procedure Protocols and Adjustable Factors

Effects on Image Quality and Optimization

Evaluating Image Quality

Sprawls

Fig.7. The comprehensive and collaborative process for developing clinically effective physics knowledge for radiologists.

VI. REMOVING THE BARRIER

One of the continuing challenges in physics education for radiologists is the real or perceived barrier between the physics classroom and clinical radiology, *and the recognition of physics as one of the fundamental clinical sciences.* Some of the factors contributing to this barrier have already been described. These have included the requirements to "teach to the test" with little vision for preparing radiologists for clinical careers. Perhaps an overlooked reality is that physics knowledge enhanced in the clinic is valuable preparation for certifying examinations. This is supported by the evolution of the physics sections on certifying examinations to be more image based and clinically relevant.

The more effective integration of physics knowledge into clinical radiology is being achieved by efforts on "both sides of the barrier".

The Physics Class or Conference

The major values of physics classes within a residency program are the medical physicists who are interacting and leading the learning process. They provide an opportunity for residents to see medical physicists as collaborating professionals in the practice of radiology and medical imaging. It is where medical physicists can help establish *physics* as one of the significant *clinical sciences* specific to the field of radiology.

This value is especially realized when medical physicists use their knowledge of physics and continuing experience to help residents view and interact with images. This is a critical action in removing the barrier between physics classes and clinical radiology. It is in the physics classes, conducted by medical physicists, that residents learn the characteristics of images that affect and control visibility of conditions within the human body, the physics, technology, and capabilities of the many imaging modalities and methods. This is an essential foundation for using images in clinical applications.

The scheduling and location of physics classes can convey considerable factors contributing to the barrier. This is especially true when physics education is "something different" from clinical education and should not be allowed to interfere.

Physics Education in the Clinic

Physics is the foundation science of medical imaging in all clinical applications. Knowledge of physics is required to effectively utilize the many imaging methods in relationship to the clinical conditions within the human body. It is the extensive diagnostic capabilities and complexity of the modern imaging methods that enhance this requirement for a comprehensive and applied knowledge of physics for radiologists.

A major characteristic of learning a topic, including physics, which is to be used and applied in a clinical activity, is that the learning needs to occur along with actually performing the activity. Effective learning of the topic—physics--requires interaction with the activity, the physics environment, and a cycle of events as illustrated in Figure 8. This is a major factor between *learning to know* (for examinations) and *learning to apply* (for performing clinical procedures). The effective application of physics in clinical procedures requires more complex knowledge structures in the brain, specifically the development of mental sensory concepts, which are different from developing a collection of symbolic knowledge elements, including verbal descriptions, definitions, mathematical symbols, equations, and quantities. That has been described in previous publications included in the bibliography. An overview is provided in Figure 8.

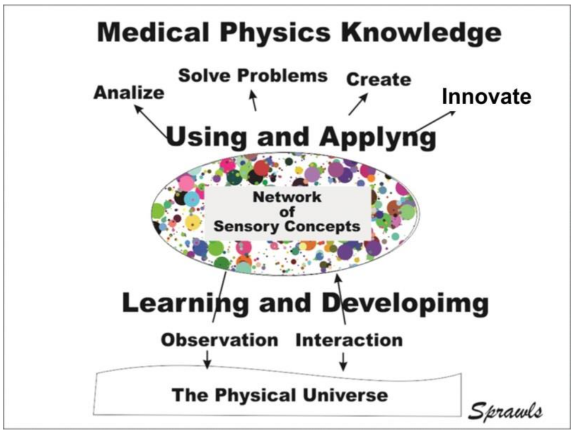


Fig.8. The significance of conceptual knowledge in medical physics education, the link between learning and applying.

The significance is that medical images are physical objects with specific physical characteristics. Sensory concepts are the necessary mental knowledge structures for clinical physics characteristics and related factors.

The two necessary actions required for the development of useful sensory physics concepts as illustrated in Figure 8 are *observation* and *interaction.* This can be a progressive process beginning with class and conference discussions with physicists and followed by interactions between residents and the imaging procedures and interoperations guided by experienced radiologists.

The medical image is the unifying object among the clinical sciences: applied physics on one side and the biological sciences of the human body on the other as illustrated in Figure 9.

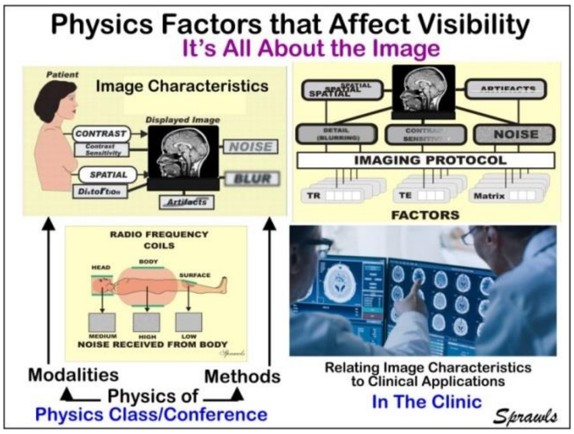


Fig.9. Unifying the physics classroom with clinical applications using the image as the interface.

VII. CLINICAL IMAGES FOR PHYSICS EDUCATION

The clinical practice of radiology and radiology education is based on images. Residents learn about medical imaging by viewing and studying images. This is well established in clinical radiology and is the opportunity for more effective physics education within residency programs.

Clinical Teaching Files

Major resources for residency education are the "teaching files" with extensive collections of images covering the range of pathological conditions as visualized with the different imaging modalities' and methods. The files relate the images to conditions within the human body and the procedures used to produce the images. Every institution has its teaching files that have been developed over time. There are also excellent teaching files provided online by radiology organizations and institutions. The clinical teaching files are often used for individual study by residents and are also a valuable source of images for class and conference discussions.

Physics Teaching Files

Effective image-based teaching files for physics will contain images that illustrate the range of physical characteristics, especially those affecting visibility, how the images are produced, and the relationship to the many factors that determine and can be used to adjust image characteristics. The goal is for physics classes to have the resources to, in effect, simulate the clinical imaging procedures where physics educators can demonstrate and discuss the physics of images that apply to and are encountered in clinical practice. This would consist of a collection of images for each modality produced with the range of imaging factors that affect characteristics, object visibility, and related factors such as radiation dose. An example: for mammography this includes images produced with different x-ray spectra determined by the KV and filter combinations. For MRI it is even more complex because of the many adjustable protocol factors that affect image characteristics. As of now, such a complete and available physics teaching file does not exist. The clinical teaching files used by radiologists consist of images collected from routine clinical procedures. However, a complete physics teaching file needs images over a range of imaging conditions such as KV values. These are not available from routine clinical images and not appropriate to produce on living humans because of radiation exposure, unnecessary examinations, and other limitations. It is possible to produce multiple images on phantoms that demonstrate effects of imaging methods and factors on image characteristics and visibility, but they do not provide the desired connection of physics to clinical radiology as images of the human body. Artifacts are one image characteristic where examples can be collected from clinical procedures.

Local Physics Teaching Files

The effort now is to include images as the major object in physics education for residents and radiologists as illustrated previously. Individual physics educators can develop their image teaching files with images from within their institution and in collaboration with clinical colleagues. However these will be limited in scope with respect to the range of imaging conditions.

The Internet

A major source of images for teaching is the internet and world-wide-web (WWW). Many institutions, professional organizations, and medical imaging equipment manufacturers have posted extensive collections of images. These can be located by using Google Image search at: https://images.google.com/ and entering a term to search, like "mammograms." Give it a try.

The Sprawls Resources

The Sprawls Resources on the web at http://www.sprawls.org/resources/ is a comprehensive collection of visuals, modules, and textbooks that are available as an open and free resource for medical physics education, especially for residents in radiology.
A major feature is that the physics curriculum is structured around images as the beginning point and principle focus for the physics educational activities.

Simulations

Because a complete collection of images for teaching physics cannot be obtained from routine clinical procedures or additional imaging of living humans, other methods must be developed. Computer based simulations are a potential source for images demonstrating many image characteristics and related factors. The general "photo" image processing programs can be used to produce images with different contrast characteristics, detail (resolution), and noise characteristics and demonstrate effects on visibility within clinical images. There is the potential for developing more complex computer-based simulations of various imaging procedures with which factors can be changed and the effects on image characteristics observed.

Simulated images for teaching physics can be used in several forms. A series of individual images can be included in Power Point preservations or in a web-based simulation that can be projected and interacted with during physics classes and discussions. An example is on the web at: http://www.sprawls.org/thelab/ .

The various simulation methods can be used to produce highly effective images for physics teaching files, but they require considerable effort and resources for individual physicists to produce for their teaching.

Collaborative Teaching, Sharing Resources, And On to the Future

There is now the opportunity for medical physicists to collaborate by producing images on specific topics and then sharing them on the internet for all to use. It is a practice that radiologists use for clinical images. The online sharing of clinical images for teaching and study is encouraged and supported by the major radiological organizations including the RSNA and ACR. Both provide capabilities for posting and sharing images on their websites.

A physics image teaching file was developed by the ACR as a component of the extensive clinical teaching file that was printed and distributed on x-ray film, before the time of digital radiography. In 2005 these films were digitized and posted online by the AAPM for members to use. As of now none of the medical physics organizations provide opportunities for individual medical physicists to post and share clinically related images they have collected or produced. That can be a project for the future.

VIII.SUMMARY AND CONCLUSIONS

Images are physical objects that are the foundation of radiology. They are the interface between clinical medicine and physics. The effective practice of radiology requires a comprehensive knowledge of the traditional biological sciences and the physics of images, including their characteristics, methods of production, and factors affecting visualization of clinical conditions. Physics education within radiology residency programs has two major but often conflicting learning objectives. The first and short-term is preparation for certifying examinations. The other and more long-term (professional life-time) is applying physics knowledge in the practice of clinical radiology. Sources of the conflict include different knowledge structures (symbolic or conceptual) to meet the different objectives, interests and motivation of residents, and demands on physics educators to “teach-to-test,” either directly or implied.

A reality is that physics education that begins with and is structured around images can meet both objectives and overcome some of the conflicts. Learning the physics of images and imaging procedures is a continuing process. It begins in the class/conference room with medical physicists using their knowledge and experience to guide residents’ observation and analysis of images and understanding of relationships to methods and procedures. With this physics class foundation the clinical activities provide an opportunity for additional learning and applying physics concepts and principles to the process of producing and evaluating optimized images.

The continuing enhancement of physics education for radiology residents structured on images and their physical characteristics requires an extensive collection of images for teaching, similar to the well-established clinical teaching files used by radiologists. This need can be met by individual medical physicists developing and sharing images for teaching on specific topics.

Models of the learning and teaching process as developed by three pioneers in the field of education, Blume, Dale, and Gagne, provide guidance for developing physics educational activities for radiologists.

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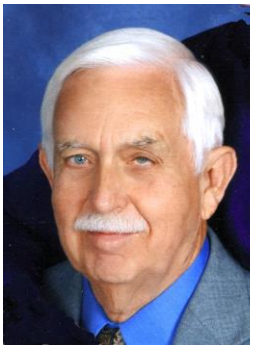
X. ADDENDUM

Clinically Focused Physics Education
Visuals for study, discussion,
and in presentations

See p. 361

XI. ACKNOWLEDGEMENT

Special appreciation to Dr. Debra Monticciolo, MD, Department of Radiology, Baylor Scott & White Healthcare - Central Texas for providing the clinical radiologist perspective and collaboration in the continuing development of clinically focused physics education.



Author Perry Sprawls, Ph.D., is a clinical medical physicist and educator with extensive experience in medical imaging science, technology, and clinical applications. At Emory University, where he is now a Distinguished Emeritus Professor, much of his effort is devoted to introduction and optimization of new imaging methods, especially mammography, CT, MRI, and digital imaging in general. Throughout his career he has used his clinical medical experience to develop educational resources to help others. His belief is that clinically effective medical imaging requires both high-quality imaging technology and optimized procedures supported by medical physicists as members of the imaging staff, consultants, and as educators. A major focus of his activities is medical physics education for radiology residents and practicing radiologists. This is through authoring textbooks (now available as a free resource online along with other resources for teaching), providing courses at many national and international conferences on the learning and teaching process of medical physics. As a Co-Director and faculty for the College on Medical Physics at the International Centre for Theoretical Physics (ICTP) he has provided to medical physicists from most countries of the world both classes and resources to use in their educational programs. These, The Sprawls Resources, are provided to all by the Sprawls Educational Foundation, www.sprawls.org.

Author Contact: sprawls@emory.edu

PROFESSIONAL ISSUES

FAMPO – TEN YEARS ON

Dr. Taofeeq A. IGE, President FAMPO

Background to Formation

At the sideline of the 48th Annual SAAPMB (South African Association of Physicists in Medicine and Biology) meeting, held at the Southern Sun Elangeni Hotel in Durban (South Africa), the then IOMP Vice-President (Prof. Fridjtof Nuesslin) espoused the need to have a regional body of the Medical Physicists in Africa which shall be affiliated to the IOMP therefore, a short meeting was convened on 7th June, 2008 in one of the small committee rooms with representatives of the 5 African countries in attendance at this annual meeting and scientific conference. It was suggested that the members present should reach out to all the member states via the email to galvanize opinions towards the establishment of a virile regional chapter that will be the pride of all Medical Physicists in Africa. Meanwhile Taofeeq was mandated to put forward a letter of intent to the IOMP executive committee on this development and encomiums were showered on the convener of the meeting (Prof. Nuesslin) as well as the host of the meeting (Dr. William I. D. Rae) who also submitted the first draft of the *Federation of African Medical Physics Organizations (FAMPO)* constitution on Friday 13th June, 2008. The final draft, after the initial one which was circulated among members, was unveiled on Wednesday 25th March 2009.

First Executive Committee

The first executive committee of FAMPO was elected at the margins of the AFROG (African Radiation Oncology Group) conference in Harare (Zimbabwe) on Friday 11th December 2009. Prof. W.A. Groenewald from South Africa chaired the meeting with fifteen delegates from 12 countries and Dr. Ahmed Meghzifene (the then Head of DMRP – Dosimetry and Medical Radiation Physics – section of the International Atomic Energy Agency – IAEA) was in attendance as an observer.

Ahmed ibn Seddik (Morocco) was elected the President, Vice-President was Rebecca Nakatudde (Uganda), Khaled El-Shahat (Egypt) became the Treasurer and Taofeeq Ige as the Secretary-General. The minutes of this delegates meeting together with the FAMPO constitution were submitted by Ahmed and Taofeeq to the then IOMP Secretary General – Prof. Madan Rehani – at the IAEA,Vienna on Tuesday 15th December 2009 as part of the requisite instruments (formal application) needed in order to admit FAMPO into the IOMP fraternity.

Aims and Functions

In March 2010, the IOMP council approved FAMPO’s application as the newest and youngest regional organization of the IOMP. FAMPO was therefore established to improve and solve the challenges faced by Medical Physicists in Africa and with aims and functions as follows: (i) To promote improved quality service to patients and the community in the region (ii) To promote the co-operation and communication between medical physics organisation in the region, and where such organizations do not exist between individual medical physicists (iii) To promote the profession and practice of medical physics and related activities in the region (iv) To promote the advancement in status and standard of practice of medical physics profession (v) To promote and improve the training of medical physicists (vi) To promote research and development in the field of medical physics (vii) To promote appropriate use of technology to the benefit of rural populations (viii) To organize and / or sponsor international conferences, regional and other meetings or courses (ix) To collaborate or affiliate with other scientific organizations and lastly (x) It’s a non-profit organisation.

Current Status and Some Achievements

The current executive committee are: Taofeeq Ige – Nigeria (President), Chris Trauernicht – South Africa (Vice-President), Ahmed ibn Seddik (Past President), Odette Samba – Cameroon (Treasurer) and Francis Hasford – Ghana (Secretary General). The three committee chairs are: Nadia Toutaoui-Khelassi – Algeria (Education and Training); Graeme Lazarus – South Africa (Professional Development) and Ehab Attalla – Egypt (Scientific). The 24 member FAMPO Council was inaugurated on 10th October 2018, thus, devolving the governance of the body to the “grass-root/member-state” level and fulfilling a major constitutional requirement. The AJMP (African Journal of Medical Physics) was launched in November 2018 and the second edition was recently released. The FAMPO website (www.fampo-africa.org) has been a success story and major information dissemination attraction. The FAMPO newsletter debuted in January 2019 and the fourth edition is set to be released soon.

AFRICAN JOURNAL OF MEDICAL PHYSICS (AJMP): VISUALIZING THE FUTURE OF HEALTHCARE IN AFRICA

M.O. Dada[1], W.F. Ngwa[2], B.O. Awojoyogbe[1], M.A. Aweda[3], T.A. Ige[4]
[1]Department of Physics, Federal University of Techology, Minna, Niger State, Nigeria.
[2]Brigham and Women's Hospital, Harvard Medical School Boston, MA 02115, USA
[3]College of Medicine, University of Lagos, Lagos-State, Nigeria.
[4]Department of Medical Physics, National Hospital, Abuja, Nigeria

#Corresponding author's email:

Abstract— **This paper information on African Journal of Medical Physics (AJMP), the official journal of the Federation of African Medical Physics Organizations (FAMPO). The paper presents sneak preview on the motivation for the formation of AJMP, the publication methods, history of the journal and proposal for an Africa model of the ICTP medical physics**

Keywords— **healthcare, medical physics, journal**

I. BACKGROUND

Africa accounts for 13% of the world's population and 24% of world's disease burden but only 3% of the world's healthcare workforce [1]. This imbalance creates vulnerability and may as well define the enormous responsibility and reward faced by the very few medical physicists in Africa. Medical Physics plays critical role in the modern healthcare delivery system. The term medical physics traditionally means the physics used to diagnose and treat diseases. Originally, this was often primarily the physics of X-rays; as ultrasound was developed for diagnostic purposes, it also became part of medical physics.

The areas of interest to medical physicist have expanded as still more diverse and sophisticated instruments are used for diagnosis and treatment. For example, the American Board of Medical Physics (ABMP) decided to start a board certification program in magnetic resonance imaging physics (MRI Physics). The first written examination in MRI Physics was held on August 8th and 9th, 1998.

This motivates the need to ensure the production of highly competitive Medical Physics journal that will be able to contribute meaningfully to the global healthcare system. It is of great concern to note that the uptake of Medical Physics in sub-Saharan Africa is very low because of the costs and expertise involved in acquisition and operation of medical imaging technology. In order for Medical Physics to be a sustainable technology for developing countries, some of the support structures are needed to be in place.

Pivotal among those support structures is the development of local expertise. Therefore, the development of training software to simulate Medical Physics experiments and provide visual training tools to help understand medical imaging technology is critical. The software should be a good way of starting to develop expertise and training that might provide support for the development, maintenance and operation of appropriate Medical Physics devices for developing countries. Our goal is to develop the African Journal of Medical Physics that will be intellectually fascinating and powerfully serve as invaluable link between research, health authorities and medical institutions in Africa and beyond.

II. PUBLICATION METHODS

The African Journal of Medical Physics (AJMP), (ISSN 2643-5977), the official scientific journal of Federation of African Medical Physics Organization (FAMPO), is published by the Harvard University Press. It is published in both print and electronically as a transitional strategy in moving from print to online and as an attempt to gain the benefits of both methods.

III. MOTIVATION

Recently, the cost of disease diagnosis and treatment has been on the rise. Unfortunately, the rising cost is not translating to significant reduction in disease related deaths. Recent disease management strategies are now gradually shifting from the traditional "one drug fits all" approach towards personalized medicine, in which drugs are specifically administered to a patient at the right time. Although the possibilities and prospects of personalized medicine are undoubtedly impressive, its potential is yet to be fully explored because the physics needed to understand the molecular undertone of personalized medicine and drug management is still not available [2].

African journal of medical physics can answer many complex questions related to personalized medicine and drug management by publishing researched articles on advanced techniques and computing methods that can positively improve the quality and efficiency of healthcare. Use of these medical physics models can benefit entities for which the models are applied, and healthcare worldwide through the dissemination of the methods and applications. The superior understanding of disease and its effects on tissue will allow new therapies and surgical procedures to be developed that can be tuned to the specific needs of the patient. Finally, thick-tissue imaging will lead to breathtaking insights into the working mechanisms of organs. In particular, imaging brain activity will be fascinating. The advances that have been seen in the 20th century may seem incremental and predictable in comparison with the advances that will be made in the 21st century.

HISTORY OF THE JOURNAL

The concept of a Medical Physics journal was conceived as a product of a proposal to The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste Italy in 2006 [3].Through interactions with the leadership of Nigerian Association of Medical Physicists (NAMP), the concept of The Nigerian Journal of Medical Physics was adopted at the Annual Scientific Conference of the Nigerian Association of Medical Physicists held in November 2017 at the National Hospital, Abuja, Nigeria where "The Nigerian journal of Medical Physics" was officially announced as the official journal of Nigerian Association of Medical Physicists.

In our efforts to ensure high quality and regularity of the new journal, extensive consultations with International professionals, experts and colleagues were made. We were advised to broaden the scope of the journal to cover the entire African region. We consented to this advice and change the name of the journal to African journal of Medical Physics (AJMP). Prof. Wilfred Ngwa, a Professor of Radiation Oncology at Harvard and University of Massachusetts USA, officially launched the first edition (Volume1, Number 1, 2018) of African journal of Medical Physics at the annual conference of Nigerian Association of Medical Physicists held between November 22nd – 24th, 2018 again at the National Hospital Abuja, Nigeria. The second edition (Volume 2, Number 1, 2019) has been published. The Volume 2, Number 2, 2019 issue will be published in December 2019. Two special editions have been scheduled to be published in 2020 in addition to the regular editions. One of the special editions will focus on

PROPOSAL FOR AN AFRICA MODEL OF ICTP MEDICAL PHYSICS RESEARCH AND TRAINING

All countries should cooperate in a spirit of partnership and service to ensure primary health care are obtainable for all people since the attainment of health by people in any country directly concerns and benefits every other country. [4]. Primary health care is by no means universal, both infectious and non infectious diseases commonly threaten the health of billions of people on earth especially in Africa. Even with the best intentions, health authorities find themselves handicapped in their fight against diseases.

Based on the proposal made to International Centre for Theoretical Physics (ICTP), Trieste Italy in 2006 [3] "The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste I*taly*, a multinational meeting place can be proposed as the ideal centre for MEDICAL PHYSICS research and training…". It is of great interest to note that ICTP has successfully maintained the training of Medical Physicists since 2012. It is strongly proposed here that a model of Medical Physics research and training in ICTP be reproduced and hosted in Africa to be responsible for manpower development of Medical Physicists in collaboration with the Universities and tertiary hospitals in Africa. The centre when established will also be responsible for all aspects of disease models which may include: Developing mathematical formulations (through mathematical modelling, algorithm development and computational analysis and simulations) of disease models based on the human physiology and patho-physiology, finding relevant data about the initiation and progression of diseases, all current treatments for the disease and side effects.

Cataloging a complete set of processes associated with the detection and treatment of diseases. Programming, in the appropriate computer languages, diseases and testing the results as well as documenting the programming. Validating, updating and documenting diseases models. Advising on the application, strengths, limitations and interpretations of disease models and raising awareness of the power and value of a particular disease. Directing the application of the model to forecast medical care outcomes, relevant to these and related disease models. Publication, dissemination, presentation of the disease model and its results will be the responsibility of the African Journal of Medical Physics.

ACKNOWLEDGEMENTS

The journal has benefitted immensely from the Association of Nigerian Medical Physicists. We salute the humility and maturity of the leadership of Nigerian Association of Medical Physicists that courageously with great foresight agreed to transform the "Nigerian Journal of Medical Physics" to "African Journal of Medical Physics" after extensive consultations with prominent colleagues nationally and internationally. The contribution of Dr. Michael Dada in the editorial office is invaluable and highly commendable. We deeply appreciate Dr, T. Ige the current FAMPO president and Professor M. Aweda the current NAMP president for their unquantifiable passion for AJMP. The cooperation of the reviewers has been unique and encouraging. The Editorial Board is ever grateful to The Global Health Catalyst, Harvard Medical School **USA** for the immense support and encouragement provided to ensure quality and making the visibility of the journal quite global and relevant.

May all of us jealously carry AJMP by the two hands, hold it dearly to our chest and carry it on our head so that it can take us to places and through generations.

IV. Conclusion

The editorial team encourages members of FAMPO to take advantage of the establishment of AJMP and submit high quality research studies for publication.

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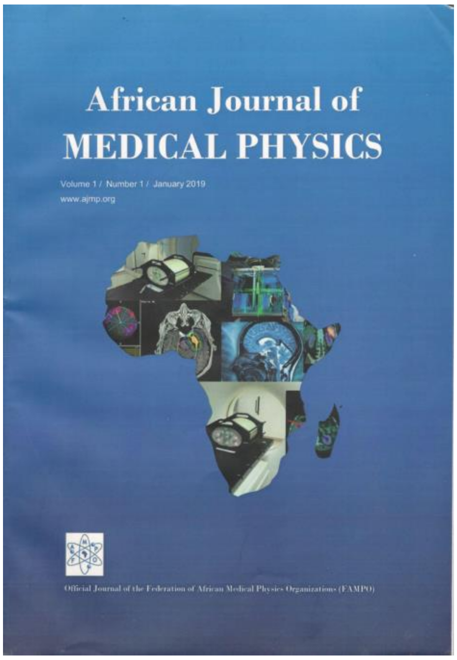
Contacts of the corresponding author:

Author: M.O. Dada
Institute: Department of Physics, Federal University of Technology, Minna, Niger State, Nigeria
City: Abuja
Country: Nigeria
Email: abamidele@futminna.edu.ng



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Official Journal of the Federation of African Medical Physics Organizations (FAMPO)

MEDICAL PHYSICS EDUCATION AND TRAINING IN SOUTH AFRICA

C.J. Trauernicht[1], A. Rule[2]

[1] Tygerberg Hospital and Stellenbosch University, Division of Medical Physics, Cape Town, South Africa – FAMPO Vice-President
[2] Livingstone Tertiary Hospital, Division of Medical Physics, Port Elizabeth, South Africa – FAMPO Council Member

Abstract — **Six institutions offer academic training for medical physicists in South Africa, while seven institutions offer clinical training. A minimum of two years' of clinical training is required for registration by the Health Professions Council of South Africa. The medical physics association will celebrate its 60th birthday in 2020. The regulations defining the scope of the profession were published in 1988.**

Keywords — **education, medical physics, training**

I. INTRODUCTION

On 2 February 1960 eight medical physicists (with support from a ninth one who could not attend) founded the "SA Association of Medical Physicists", making it one of the older medical physics associations in the world. In 1968 the association expanded to include health physicists and became known as "The South African Association of Physicists in Medicine and Biology" (SAAPMB)[1]. The SAAPMB forms the umbrella body of three societies, namely the South African Medical Physics Society (SAMPS), the South African Radiation Protection Society (SARPS) and the South African Radiobiology Society (SARS).

The first Co-60 teletherapy unit in South Africa was installed in 1958, but radionuclides were imported in the late 1940's already. Specialization in medical physics began in the late 1950's, when physicists and engineers were appointed at some hospitals around South Africa.

II. INFRASTRUCTURE

South Africa has large disparities between the public and private healthcare sectors. The private sector serves around 15 - 20 % of the population, while the public system is funded by the National Budget. There are efforts underway to introduce a National Health Insurance (NHI)[2,3], but this is not without controversy.

In 2015 an analysis of licensed diagnostic imaging equipment (not including Nuclear Medicine equipment) was published[4]. The regulator's database was analysed by modality, province and healthcare sector. They found that general X-ray units were the most equitably distributed and accessible resource (34.8/million). For fluoroscopy (6.6/million), mammography (4.96/million), computed tomography (5.0/million) and magnetic resonance imaging (2.9/million), there were at least 10-fold discrepancies between the least- and best-resourced provinces in South Africa and an average 13-fold discrepancy between the public and private sectors. Magnetic resonance imaging showed a 46-fold discrepancy between the public and private sectors. Only three of eleven provinces have the full spectrum of diagnostic imaging modalities in both the public and private sectors. A request to the regulator for an updated list in August 2019 was turned down.

A questionnaire was sent out to the public institutions that employ medical physicists to determine medical physics staffing and infrastructure levels.

Table 1 Medical Imaging and Radiotherapy Equipment at Public Institutions that Employ Medical Physicists

Equipment	Total
Linear Accelerator	32 (17 Elekta, 11 Varian, 4 Siemens)
Co-60 EBRT	2
HDR Brachytherapy	12
LDR Brachytherapy (eye, prostate)	1
CT in Radiotherapy	13
MR in Radiotherapy	1
SPECT/CT	16
SPECT	10
PET/CT	5
Dose calibrators	Between 1 and 7 per site
General X-Ray*	116
MRI*	14
CT*	27
Mammography*	13
Lodox*	13
Interventional*	27

*not all sites supplied data, number represents a lower limit

All sites do at least 2D and 3D radiotherapy, most sites do IMRT or VMAT treatments as well, some sites do SRS and TBI.

The private sector has 53 linear accelerators and one Gammaknife. All treatment techniques are offered in the private sector, including HDR and LDR brachytherapy.

The medical physicists of the one private hospital group deliver services to 58 hospitals and 106 primary care clinics, which include 44 interventional radiology units and the exposure monitoring of around 2100 radiation workers.

III. REGULATION OF MEDICAL PHYSICS

The regulatory framework in South Africa is well established.

The Hazardous Substances Act (No. 15 of 1973)[5] provides regulations for X-ray devices and radioactive substances. Regulation R 1332 of 1973[6] provides the framework concerning the control of electronic products and regulation R 690 of 1989[7] provides the regulations regarding the "licensing for the purpose of sale of listed electronic products". Regulation No. R.1302 of 1991[8] defines the schedule of listed electronic products.

Most importantly for medical physics, the scope of the profession was published under Government Notice R 310 in Regulation Gazette 4179 of 1988[9]. An upgrade to the scope of profession is waiting to be gazetted. This means that, in terms of the Health Professions Act 56 of 1974[10] (paragraph 33), all medical physicists must be registered by a professional board. Hence all medical physicists in South Africa must be registered with the Health Professions Council of South Africa (HPCSA).

The five main areas, according to the scope of profession, where medical physicists are required, are in:

1. Radiation Protection
2. Radiotherapy
3. Nuclear Medicine
4. Radiology
5. Applied General Medical Physics,

all in areas where ionizing and non-ionizing radiation is used in medical practice.

The regulator recommends one full-time equivalent medical physicist per 600 patients receiving radiotherapy[11] and also insists that "a medical physicist must be appointed in writing to establish and implement an optimization program for Interventional Radiology procedures…" and that dose-area product data must be collected and submitted for the setting of diagnostic reference levels (DRLs)[12]. A number of DRL publications over the last few years confirm that there was some work done in this regard [13-22].

According to the HPCSA website there are 156 registered medical physicists, as well as 27 registered interns (last updated on 1 October 2018)[23]. However, this also includes retired medical physicists who are no longer practicing, but keeping their registration current. It also includes a handful of medical physicists outside of South Africa.

The replies from the public institutions are summarized in Table 3. A total of 59 full-time medical physicists and two part-time (5/8th) medical physicists are employed at the 13 facilities that responded, with two more smaller facilities that may or may not have medical physicists employed currently. Even though the majority of medical physicists are based in Radiotherapy, quite a few generally still render services to both Nuclear Medicine and Diagnostic Radiology. This is more likely the case in the smaller institutions.

Table 3 Distribution of registered medical physicists in the public sector in South Africa

Medical Physicists	Total
Radiotherapy	33 + 1 x 5/8th
Nuclear Medicine	10.5
Radiology	9.5 + 1 x 5/8th
University appointed	6
Total	59 + 2 x 5/8th

Table 3 represents the medical physicists currently employed in the public sector. A number of medical physicists employed in the public sector also work in the private sector, particularly in nuclear medicine.

Table 4: Distribution of registered medical physicists in the private sector and industry in South Africa

Medical Physicists	Total
Radiotherapy	51
Nuclear Medicine	2
Radiology	6
Metrology (SSDL)	3
Regulators	3
Industry and other	8
Total	73

IV. EDUCATION AND TRAINING

It is not quite clear when medical physics education and training started in South Africa, but it seems to be in the 1950's, because regulations from 1956 required the registration of "hospital physicists" by the Atomic Energy Board. This required one year in-service training at a recognized hospital after an MSc degree in Physics, and two years after a BSc (Hons) degree[1]. Thus, South Africa became one of the first countries to regulate the profession.

The minimum academic training required to be allowed entry into a medical physics internship is a BSc (Hons) degree in medical physics. As a minimum, this includes "Physics of Radiotherapy", "Physics of Diagnostic Radiology", "Physics of Nuclear Medicine" and "Radiation Protection", on top of all the pure physics modules. Various universities offer additional compulsory or elective modules, which may include e.g. "Treatment Planning", "Radiobiology", "Digital Image Processing" or similar. One university starts their medical physics academic training at undergraduate level already.

There are 23 current MSc students in medical physics in South Africa, as well as 13 PhD students.

There are six universities that offer academic medical physics training, each with an affiliated teaching hospital that offers the clinical training component. Unfortunately, two of these academic programmes are currently suspended. One additional hospital can offer clinical training. There are currently a total of 44 full-time medical physicists and 2 part-time (5/8th) medical physicists appointed at these seven hospitals, including the academic appointments at only two universities (data included in Table 3). There another 13 full-time posts available on the various organograms, which are currently not filled, either due to budget constraints or vacancies waiting to be filled. Three of the seven "Head of Medical Physics" positions are currently filled with acting heads only. It has been an ongoing problem to fill these posts in the last five or so years and this needs urgent addressing.

The seven teaching hospitals are allowed to train up to 58 medical physics interns (intern = medical physicist undergoing clinical training), but only 28 interns are currently on training, with a large majority training without proper funding. This also needs urgent addressing at national level. Clinical training consists of a two-year long programme at an accredited training institution, with time spent in radiotherapy, nuclear medicine and diagnostic radiology, as defined by the HPCSA. After an oral exit assessment and the evaluation of intern portfolios of evidence by HPCSA appointed examiners, an intern may register as Medical Physicist (Independent Practice). It is not possible to register only in one area of expertise.

The SAAPMB, established in 1960, forms a vital component in the medical physics environment in South Africa. Membership currently stands at about 119 full members, with another 71 associate/ student/ institutional/ retired/ honorary members. Annual conferences are held, usually in combination with a school with invited international speakers. These meetings are popular to obtain continuous professional development (CPD) points / continuing education units (CEU), as required by the HPCSA, but also present a great networking opportunity and a perfect opportunity to deal with the logistics of an association and the attached societies (council meetings, AGMs, election of office bearers, etc.). Each of the three societies under the SAAPMB umbrella also has a representative to its respective international organization, namely the IOMP, IRPA and the IARR.

It was unfortunate that in South Africa very little medical physics training happened in the 1990's, which had the unwelcome side-effect that by the 2010's a lot of medical physicists had retired, leaving an almost 20-year void of experience to the next generation of medical physicists. Only one head and one acting head of medical physics currently have a PhD, which is concerning. This is being addressed, also through communication to the Department of Health through the association.

In addition, the regulator is severely understaffed and under-resourced. While an unprecedented 14 medical posts were advertised by the regulator in May 2019, the interviews are yet to happen.

V. CONCLUSION

Medical physics is well established, but very underrepresented, at many hospitals in South Africa. A regulatory framework guides the profession. There are six academic training sites in South Africa; unfortunately only four are currently offering the BSc (Hons) course, which is the minimum entrance requirement to an internship.

Less than half of the available clinical training posts are currently filled, with most interns doing their internship on minimal to no funding, just in order to register with the HPCSA. Private facilities are sponsoring interns to later employ these medical physicists.

There are some very worrying signs for medical physics on the horizon, but on the other hand there are also a number of young and enthusiastic medical physicists, who are very keen to take medical physics forward in South Africa.

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Contacts of the corresponding author:
Author: Christoph Trauernicht
Institute: Tygerberg Hospital and Stellenbosch University
Street: Francie van Zijl Drive
City: Cape Town
Country: South Africa
Email: cjt@sun.ac.za

MEDICAL PHYSICS EDUCATION AND TRAINING IN ZIMBABWE

G. Azangwe[1,2], D. Ndlovu [2], T Thatha[3], L. Mhatiwa[4], E Mhukayesango[4]

[1] NUST, Applied Physics Department, Bulawayo, Zimbabwe
[2] Mpilo Central Hospital, Radiotherapy Department, Bulawayo, Zimbabwe
[3]United Bulawayo Hospitals, Bulawayo, Zimbabwe
[4]Parirenyatwa Group Hospitals, Radiotherapy Department, Harare, Zimbabwe

Abstract — **Medical Physics is a branch of applied of physics concerned with the application of the concepts and methods of physics to the diagnosis and treatment of human disease. It is allied with medical electronics and instrumentation, bioengineering. The term 'Medical Physics', as is used here, includes medical imaging physics, therapeutic medical physics, nuclear medical physics and medical health physics. The three areas of activity for a Medical Physics are research and development, clinical service and consultation and teaching. In Zimbabwe, Medical Physics training is offered by a group of institutions which includes two universities (National University of Science and Technology and University of Zimbabwe) and three central hospitals (Mpilo Central Hospital, United Bulawayo Hospitals and Parirenyatwa Group Hospitals)**

Keywords — **medical physicist, radiotherapy, nuclear medicine, Zimbabwe, NUST.**

I. INTRODUCTION

There is a growing incidence of cancer especially in the developing world as clearly outlined in the Lancet Oncology Commission Report [1] Based on the input data to the Lancet Oncology Commission Report, the estimated cancer incidence in Zimbabwe was 15,520 cases in 2012. This is expected to increase to 27,720 by 2035, i.e., an 80% increase. It was estimated that 41% of these cases will benefit from having radiation therapy thus at the present time at least 6,400 patients should be receiving radiation therapy.

For any expansion to take place to meet the growing needs to fight against cancer, trained professionals including medical physicists will be required. In order to address the shortage of medical physicists, the National University of Science and Technology (NUST) introduced a MSc Degree in Medical Physics to fulfil the academic requirements for training medical physicists which has been running since 2015. The curriculum for the programme was developed with support of the International Atomic Energy Agency (IAEA) in the form of funding for experts to come and teach and review the modules. At national level, the program has been approved by the Zimbabwe Council for Higher Education (ZIMCHE) and accepted by the Allied Health Practitioners Council of Zimbabwe (AHPCZ) as fulfilling the academic requirements of medical physicists. The initial enrolment to the program was 13 students in September 2015 and has been restricted to a maximum of 10 students for subsequent intakes to ensure adequate supervision for their projects and clinical placements. The program is structured to take two years with the second year dedicated to a research project and clinical placements. The taught modules include: basic physics and biology of radiation, anatomy and physiology, physics of non-ionising radiations, radiotherapy physics, medical imaging physics, nuclear medicine physics, medical electronic and instrumentation and safety and quality management.

Challenges that faced the program included lack of lecturers to cover teaching of all modules, limited funding to set up a medical physics laboratory, limited computing infrastructure to support computer simulations and image processing. The country had no capacity to bring in external lecturers to support the teaching. This was coupled with a government freeze on recruitment. We were able to get assistance from the IAEA through a National Project which was aimed at capacity building for medical physicists and other professionals involved in cancer management.

The government is fully supportive of the initiative to train medical physicists locally. When the program started, there were only three experienced Medical Physicists who had completed an MSc degree in medical physics and undergone supervised clinical training, working in the two cancer centres and could teach at the university. The program has now enrolled four intakes, the first intake graduated in 2017. The future of the program looks bright as the government plans to recruit more lecturers to teach on the program and is also investing in service contracts for equipment in the public institutions to ensure minimal downtime and reliable provision of clinical service as well as a good training environment for the students enrolled on the program.

All the centres have computerized treatment planning systems, a comprehensive information management system. The country has one functional nuclear medicine department equipped with a SPECT gamma camera. There are many conventional X-ray scanners in both public and private institutions as well as CT scanners, mammography units and interventional radiology units. A summary of medical equipment for medical imaging and radiation therapy is shown in Table 1.

II. INFRASTRUCTURE

Zimbabwe, with a population of approximately 15 million people, has three radiotherapy centres; two public and one private. One public institution is in Bulawayo while the other two centres are in Harare. The two public centres have five linear accelerators and three brachytherapy units while the private centre has one linear accelerator.

Table 1 Medical equipment for medical imaging and radiation therapy

Equipment	Total
SPECT	1
Dose calibrators	1
Accelerator	6
MRI	2
CT	23
Mammography	8
Standard Radiology	307
Interventional	15

III. REGULATION OF MEDICAL PHYSICS

In the regulatory framework of Zimbabwe, the presence of a medical physicist is mandatory for all Radiation therapy and Nuclear Medicine centres. The requirement is a bit relaxed for diagnostic radiology centres where the system only requires the services of a medical physicist. The Medical Physics professional is regulated by the Allied Health Practitioners Council of Zimbabwe (AHPCZ). The AHPCZ keeps a record of all practicing Medical Physicists and enforces the need for Medical Physics training. Practicing certificates are renewed annually. Distribution of Medical Physicists in the country is given in Table 2.

Table 2 Distribution of medical physicists in Zimbabwe

Medical Physicists	Total
Radiotherapy	8
Nuclear Medicine	1
Radiology	0
Total	9

IV. EDUCATION AND TRAINING

Medical physics education and training in Zimbabwe has traditionally been completion of a BSc degree in Physics or Applied Physics followed by a two-year internship. A full year Medical Physics clinical attachment, as part of the degree in Physics or Applied Physics was also required before was one could be considered for a position as a Medical Physicist. After completion of the degree program, one would be allowed to work as a Medical Physicist for two years under the supervision of a Clinically Qualified Medical Physicist, after which he/she would be allowed for independent clinical work as a Medical Physicist. The current set up is such that one completes a taught MSc Medical Physics Degree followed by a two-year internship. The taught MSc degree has a requirement for clinical placements in different areas of medical physics when students are in their second year.

V. CONCLUSION

Medical physics training and practice has seen steady progress over the past 4 years and to date we have had four intakes of students. We now follow a curriculum which is harmonized with the AFRA training syllabus for Medical Physicists which was derived from IAEA training publications [2-5]. We also use materials from Emerald [6]. Students are expected to gain competences in all areas where we have the equipment as specified in the IAEA documents. The remainder of the competences are usually acquired through IAEA or government funded fellowships. The second group of students is expected to graduate in November 2019.

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Contacts of the corresponding author:

Author: Prof Godfrey Azangwe
Institute: National University of Science and Technology
Street: Corner Gwanda and Cecil Avenue
City, Country: Bulawayo, Zimbabwe
Email: godfrey.azangwe@gmail.com

MEDICAL PHYSICS EDUCATION AND TRAINING IN NIGERIA

T. A. Ige[1], M.A. Aweda[2] and M. A. Adewole[1]

[1] Medical Physics Department, National Hospital Abuja, FCT, Nigeria
[2] College of Medicine, University of Lagos, Lagos-State, Nigeria

Abstract— **Medical Physics training and education in Nigeria is currently being offered in eight universities as a purely academic postgraduate program. This ensure that all medical physicists practicing in the country are master's degree holder and a few being PhD holder. The Clinical Residency programme in Radiation Oncology Medical Physics commenced in 2012 using the IAEA TCS-37 (Clinical Training of Medical Physicists Specializing in Radiation Oncology), the first cohort of trainees are set to graduate soon. Nigeria currently has 10 (ten) Government and Privately owned Radiotherapy centres. More centres are expected to go operational shortly. More Medical Physicists are also being trained academically and are expected to give a boost to the professional practice of Medical Physics in Nigeria in the coming years.**

Keywords — **Medical Physics, Nigeria, Radiotherapy, Radiology, Nuclear Medicine**

I. INTRODUCTION

Medical physicists are professionals with education and specialist training in the concepts and techniques of applying physics in medicine. Medical Physicists work in clinical, academic or research institutions. Medical physics may further be classified into a number of sub-fields including the following; Radiation Oncology, Medical Imaging, Nuclear Medicine, Radiation Protection, Non-ionizing Medical Radiation Physics and Physiological Measurement [1].

Nigeria is a Country located in the west coast of the African continent and has a proximity to the Gulf of Guinea and bordered southerly by the Atlantic Ocean. It is a diverse country with over 200 Million people [2]. It currently have 10 centres to cater for the radiotherapy needs of her citizenry.

Medical Physics practice in Nigeria started as far back as 1968 when the first Radiotherapy and Oncology centre was established at the Lagos University Teaching Hospital (LUTH).

Medical Physics Academic traning programme currently takes place in eight (8) Universities in Nigeria. These ensures that all practicing Medical Physicists in Nigeria are Master's degree holder with extremely few exceptions and a few more having a doctorate degree.

The Clinical training of Medical Physicists with bias towards Radiation Oncology (Radiotherapy) due to national exigencies was started in 2012 through the support of IAEA by the Nigerian Government under the country project NIR/6/023 using the IAEA TCS 37 course modules.

II. INFRASTRUCTURE

Nigeria has infrastructure for medical imaging, radiation therapy, and nuclear medicine service points situated in the private and public (government) centres. Radiation protection services are also available in Nigeria through the NNRA's Dosimetry Laboratory (SSDL) in Ibadan and some public institutions including the National Hospital Abuja OSLD services and some four other privately owned enterprises.

There are numerous medical imaging facilities in Nigeria with them having machines such as CT, MRI, X-ray, C-arm and Ultrasound. An appropriate estimation would be over 1000 centres.

For Radiotherapy, a vast majority of them (8) are government-owned, They are Ahmadu Bello University Teaching Hospital (ABUTH) in Zaria, University of Benin Teaching Hospital (UBTH) in Benin-City, University Colleage Hospital (UCH) in Ibadan, National Hospital Abuja (NHA) in Abuja, University of Nigeria Teaching Hospital (UNTH) in Enugu, Usmanu Danfodiyo University Teaching Hospital (UDUTH) in Sokoto, Federal Teaching Hospital (FTH) in Gombe, Lagos University Teaching Hospital (LUTH) in Lagos and also the privately owned EKO Hospital and the Imo project near Owerri

Table 1 Medical equipments for medical imaging and radiation therapy

Equipment	Total
SPECT/CT	None
SPECT	2
PET/CT	None
Dose calibrators	4
Co-60 EBRT	4
Accelerator	7
MRI	85
CT	150
Mammography	60
Standard Radiology	3000
Interventional	8
Brachytherapy	8

III. REGULATION OF MEDICAL PHYSICS

The Medical Physics Interim Registration Committee under the Department of Hospital Services in the Federal Ministry of Health currently performs the regulatory functions on Medical Physicists in the country. This is done in conjunction with the professional association – Nigerian Association of Medical Physicists (NAMP). NAMP is a National Member Organisation (NMO) of the International Organization of Medical Physics (IOMP) and Federation of African Medical Physics Organization (FAMPO). NAMP members meet annually at the association's annual scientific conference and workshop. This conference features discussion on trending topics in the medical physics world and moving the practice forward in the country.

Table 3 Distribution of Medical Physicists in Nigeria

Medical Physicists	Total
Radiotherapy	40*
Nuclear Medicine	4
Radiology	10
Total	54

IV. EDUCATION AND TRAINING

Medical physics education and training in Nigeria is mainly through postgraduate programs in the following Universities; Benue State University, Makurdi (Benue State), Federal University of Technology, Minna (Niger-State), Nasarawa State University, Keffi (Nasarawa State), Nnamdi Azikiwe University, Awka, (Anambra State), Obafemi Awolowo University, Ile-Ife (Osun State), University of Benin, Benin-City (Edo-State), University of Lagos (Lagos-State), and University of Nigeria (Enugu Campus), Enugu State. Three (3) new programmes will soon commence at the University of Calabar, Calabar, (Cross River State), Federal University, Lafia and the Usmanu Danfodiyo University, Sokoto (Sokoto-State).

This Program has in their curriculum Radiotherapy Physics, Radiodiagnostic Physics, Radiation Biology, Nuclear Medicine, Radiation Protection, Ultrasound, Dosimetry, Advanced Dosimetry, Anatomy, Physiology, Medical Statistics and some other few elective courses. These programmes are purely academic as no clinical training is attached to them.

Clinical residency training started in Nigeria in 2012, seven young physicists were selected from across various centres in the country to be the first set to go through the programme. This was being done through the IAEA supported country/national project NIR/6/023 (Developing the National Capacity to Train Medical Physicists to Support Radiotherapy Facilities in Tertiary Hospitals in Cancer Management). It involved clinical rotation between National Hospital Abuja, Usmanu Danfodiyo University Teaching Hospital Sokoto, University College Hospital Ibadan and Ahmadu Bello University Teaching Hospital Zaria. It also has the NNRA's SSDL in Ibadan on its list of clinical rotation sites.

The programme has been managed by the Federal Ministry of Health and was based on the IAEA TCS-37 (Clinical Training of Medical Physicists Specializing in Radiation Oncology) modules. It suffered several set-backs due to paucity of funds. Resources are currently being mobilized so that the first set of trainees whose number have now dwindled from 7 (seven) to 4 (four) can complete the programme thus, paving way for the second cohort of trainees who have appeared to have waited endlessly.

V. CONCLUSION

Medical physics training and practice in Nigeria has been very slow but steady. In the past year, it witnessed lots of young people being recruited into the profession. More graduates are also being churned out through the Master's and Ph.D. programmes in the various universities earlier mentioned. With the new centres coming up in the country (both government and privately owned), It is expected that the practice is going to receive a boost in the coming years.

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Contacts of the corresponding author:

Author: Dr. Taofeeq A. IGE
Institute: National Hospital Abuja
Street: Plot 132 Central District (Phase II), Yakubu J. Pam Street
City: Abuja
Country: Nigeria
Email: igetaofeeq@yahoo.com, taofeeqige@gmail.com

MEDICAL PHYSICS EDUCATION AND TRAINING IN GHANA

F. Hasford[1], S. Inkoom[1], A.K. Kyere[1], C. Schandorf[1], J.H. Amuasi[1]

[1] Medical Physics Department, School of Nuclear and Allied Sciences, University of Ghana, Accra, Ghana

Abstract — **Medical physics education and training programme in Ghana involves a two-year masters degree and one-year clinical internship. The programme has grown over the years and produced medical physicists from several African countries. Owing to high standards of the training programme, Ghana has been recognized by the African Regional Cooperative Agreement of the International Atomic Energy Agency as Regional Designated Centre for Medical Physics Training within the African Region. Relevant stakeholders in Ghana jointly contribute to ensure that the education and training programme sees constant improvement. Several collaborative projects are also pursued with international institutions, making the programme meet international standards. This has contributed to placing Ghana's medical physics programme on the World map.**

Keywords — medical physics, radiotherapy, diagnostic radiology, nuclear medicine.

I. INTRODUCTION

Medical physics is a major stakeholder in radiation medicine delivery in Ghana and the practice has supported radiation oncology and medical imaging services over the years. Medical physics education and training in Ghana dates back to 2004, when the Masters programme was introduced by the University of Ghana [1]. This was in response to the need of adequately trained medical physicist in the health delivery system of the country and in the Africa sub-region.

The academic programme is hosted by the School of Nuclear and Allied Science (SNAS) of the University of Ghana. Clinical training is undertaken in three main medical centres in Ghana, namely Korle-Bu Teaching Hospital, Komfo Anokye Teaching Hospital and SGMC Cancer Centre [1]. Through collaborative projects with the International Atomic Energy Agency (IAEA) and other stakeholder institutions, a strong training programme has been built and producing medical physicists who feed into healthcare, research and academic institutions [2, 3].

The medical physics programme has grown and currently admits foreign trainees from across Africa, in addition to Ghanaian nationals.

II. EDUCATION AND TRAINING

Ghana's medical physics education and training programme is structured in line with the academic and clinical training syllabi produced by the African Regional Cooperative Agreement (AFRA) of the IAEA [5, 6]. The syllabi were produced for Africa as means of harmonizing and achieve equivalence in the levels of training in the region. The medical physics education and training programme in Ghana (Figure 1) is comprised of two-year Masters (MPhil) programme and one-year clinical internship.

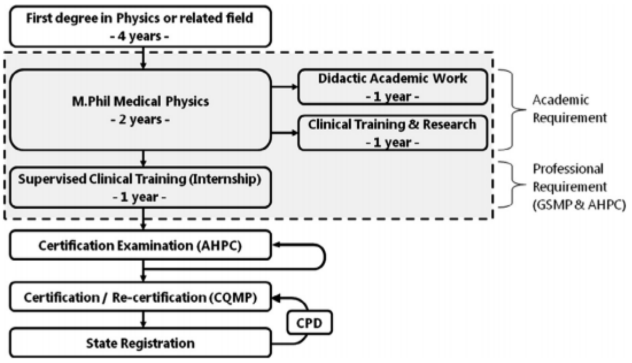

Fig. 1: Training structure for medical physics in Ghana [1]

The MPhil programme comprises two semesters of didactic academic work in the first year and clinical training with research in the second year. Academic courses offered in the first year include: Anatomy and Physiology; Radiation Physics; Radiobiology and Radiation Protection; Electronics and Signal Analysis; Dosimetry for Photon and Electron Beams; Research Methods; Professional and Medical Ethics; Ultrasonics and Instrumentation; Magnetic Resonance Spectroscopy and Imaging; X-rays and Diagnostic Radiology; Nuclear Medicine; Radiotherapy; Applications of Computers in Medicine [4, 6]. The medical physics academic programme has since its inception produced 91 graduates, 26% of whom are foreigners.

As a requirement by the medical physics professional association and the allied health regulatory body, the two-year academic programme is followed by one year clinical internship for local graduates. This arrangement ensures that clinically qualified medical physicists receive minimum of two years clinical training. A four-year PhD programme in medical physics is also run with academic and clinical training components.

The three hospitals that are primarily used for the clinical training of medical physicists are:

- Korle-Bu Teaching Hospital, Accra.
- Komfo Anokye Teaching Hospital, Kumasi.
- SGMC Cancer Centre, Accra.

A few other diagnostic radiology centres, most of which are privately-owned, are also used for student practical demonstrations.

III. INFRASTRUCTURE

Ghana has three radiotherapy centres, one nuclear medicine unit and a host of diagnostic radiology centres scattered around the country. Equipment available in the facilities for radiation therapy and medical imaging are presented in Table 1.

Table 1 Medical equipments for radiation therapy and medical imaging

Equipment	Total
Co-60 External Beam Radiotherapy	2
Linear Accelerator	3
HDR Brachytherapy	2
LDR Brachytherapy	2
CT Simulator	2
C-Arm Fluoroscopy	2
Radiotherapy Simulator	2
Radionuclide Dose Calibrator	3
SPECT	1
MRI scanner	16
Diagnostic CT scanner	55
Mammography	32
Conventional X-ray (fixed)	350
Conventional X-ray (mobile)	148
Dental X-ray	71
Interventional	24

IV. HUMAN RESOURCE

The practice of medical physics in Ghana is impinged on international set guidelines and recommendations [7]. In view of this, stakeholders such as the allied health regulatory body (Allied Health Professions Council) and the national medical physics body (Ghana Society for Medical Physics) have put in place systems to check medical physics practices in the country. Table 2 provides a snapshot of medical physics workforce in Ghana.

Table 2 Distribution of medical physicists in Ghana

Medical Physicists	Total
Radiotherapy	32
Nuclear Medicine	6
Diagnostic Radiology	20
Total	58

Clinical medical physicists are predominantly employed in radiation oncology facilities in the country and their responsibilities include performance of treatment planning, quality control, dosimetry, radiation safety, equipment specification and commissioning. Those specializing in nuclear medicine and diagnostic radiology are mostly employed as research scientists at Ghana Atomic Energy Commission (GAEC) and additionally offer periodic clinical services to the hospitals through special arrangements between the institutions. In academia, senior medical physicists actively engage in the education and training of students not only in the field of medical physics but in other fields such as radiology, radiography, oncology, health physics, radiation protection and biomedical physics.

V. REGULATION OF MEDICAL PHYSICS

The National Accreditation Board (NAB) of Ghana and the National Council for Tertiary Education (NCTE) accredits the academic component of the Medical Physics programme at the University. Assessment of academic programmes by these regulatory bodies are carried out periodically (between 2 – 3 years) using the services of international experts and consultants to ensure neutrality. Recommendations from the NAB and NCTE are precisely applied to ensure that international standards are upheld.

The Ghana Society for Medical Physics (GSMP) promotes the application of physics in medicine and collaborates with stakeholder institutions to raise the standards of practice [8]. The GSMP draws its inspiration from the International Organization for Medical Physics (IOMP) and it ensures that the roles and responsibilities of medical physicists are clearly adhered to [9]. The Society affiliates to IOMP and the Federation of African Medical Physics Organizations (FAMPO).

Clinical practice of medical physicists is regulated by the Allied Health Professions Council (AHPC) of Ghana through the Health Professions Regulatory Bodies Act (Act 857 of 2013) [10]. Act 857 gives medical physics and other disciplines the recognition as health professions in Ghana. This is in conformity with the classification of medical physics as a health profession by the International Labour Organization (ILO) in 2011 [11]. Among other things, AHPC regulates internships of trainees by placing them in hospitals to undergo one-year supervised clinical training in the fields of radiotherapy and/or medical imaging. Interns are required to undergo licensure examination before being certification to practice clinically [10].

VI. COLLABORATION & PARNERSHIPS

Ghana has collaborated and partnered with a number of institutions locally and internationally in the promotion of medical physics education and training as well as professional practice. Some international partners include International Atomic Energy Agency (IAEA), International Organization for Medical Physics (IOMP), Federation of African Medical Physics (FAMPO), International Centre for Theoretical Physics (ICTP), Argonne National Laboratory (ANL), Norwegian University of Science and Technology (NTNU), National University of Science and Technology (NUST) in Zimbabwe, World Health Organization (WHO) and the University College London (UCL).

VII. CONCLUSION

Medical physics education and training in Ghana has been hugely successful since its introduction. The programme has been a channel through which several medical physicists in Africa have been trained. It is envisaged that the programme will grow further to solidify the gains so far made.

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Contacts of the corresponding author:

Author: Francis Hasford
Institute: Medical Physics Department, School of Nuclear and Allied Sciences, University of Ghana
Street: Atomic Street
City: Accra
Country: Ghana
Email: fhasford@ug.edu.gh

MEDICAL PHYSICS STATUS IN MOROCCO: EDUCATION, TRAINING AND EVOLUTION

H. Saikouk[1,2], I. Ou-Saada[2], F. Bentayeb [2], S. Boutayeb[3], K. Eddaoui[4]

[1] Nuclear Medicine department, Oncology and Hematology Center, Mohammed VI University Hospital, Marrakech, Morocco
[2] Faculty of Science, Mohammed V University, Rabat, Morocco.
[3] Oncology National Institute, Moulay Abdellah Hospital, Ibn Sina University Hospital, Rabat, Morocco
[4] Nuclear Medicine department, Ibn Sina University Hospital, Rabat, Morocco

Abstract— **Medical physicist plays an important role in radiology and oncology departments, including responsibilities in diagnosis, treatment and radiation protection areas.**

Even if Medical Physics education and training were organized for the first time in 2007 at the faculty of science of Rabat, through a master and a bachelor degree, medical physics has been introduced in Morocco since late 1970s, as a preparation for the establishment of the National Oncology Institute in Rabat, the capital of Morocco, which became a reference for the profession and the radiation therapy national wide.

Despite the progression in the technical plateau dedicated for treatment and diagnostic using ionizing radiation, lot of efforts has to be done in the aim to improve the actual state of the education, training and professional situation of medical physicists.

Keywords— **Medical physics, Morocco, education, training.**

I. INTRODUCTION

The Kingdom of Morocco is a North African country. It is composed of 12 regions with a population of 35 Millions (2019) with 61% of the urban population. Morocco is a demographically young country with 29% of its population under the age of 15, 62% between 15 and 59 years old and 9% of the population aged 60 and over [1].

An important interest is dedicated by the ministry of health to control and improve the quality of treatment and diagnosis for patient with cancer. These late years has known an increase in the inauguration of hospitals and centers dedicated for oncology, and further projects are prepared for this purpose by the creation of regional centers of oncology, including radiation therapy and nuclear medicine departments, to facilitate the access of treatment for patients. Hence, masters and bachelor degrees in medical physics, radiation protection and dosimetry are created in different universities in Morocco. However, more efforts have to be done to improve the environment of work for medical physicists.

II. INFRASTRUCTURE

Morocco has developed an important infrastructure of medical imaging, radiation therapy, including the private and public centers, and radiation protection. This development, translated by an increase in the number of medical equipment (table 1 and 2), needs high qualified staff to insure a secure and safe use of radiation. Thus, many efforts are needed to train qualified medical physicists.

Morocco has a set of public and private oncology and diagnostic radiology centers including: 24 radiotherapy department and centers, 19 nuclear medicine departments and centers, and over 424 radiology departments and centers located in the most populated areas. This number is bound to increase in the future with the creation of new regional oncology centers.

Table 1 Medical equipments for nuclear medicine and radiation therapy

Equipment	Total
SPECT/CT	7
SPECT	12
PET/CT	10
Dose calibrators	21
Accelerator	40

Table 2 Medical equipments for diagnostic radiology

Equipment	Total
MRI	> 40
CT	360
Mammography	110
Standard Radiology	>4500
Interventional	60

III. MOROCCAN REGULATION

In the Moroccan regulation, the presence of a medical physicist is mandatory in radiation therapy and nuclear medicine departments. But since the new law 142-12, appeared in 2014, the medical physicist's presence is necessary in radiology departments too:

"*Every health installation, which offers nuclear medicine or radiation therapy services, has to have at least one medical physicist; radiology centers, which respond to the criteria fixed by the regulation, have to have a medical physicist. However, a contract can be passed with a medical physicist for a limited period, depending on the establishment needs; the required qualifications for medical physicist and the modalities of practicing his missions are fixed by the regulation*" [2].

However, until now, there is no medical physicist in radiology departments (table 3). In the other hand, in the actual regulation, there is a lack of recognition of the medical physicist required qualification, specific tasks and work status. Actually, medical physicists are recruited as medical assistants, administrators, or engineers. This situation has created a lack of harmonization in the medical physics practice at national level.

Table 3 Medical physicists' distribution

Medical Physicists	Total
Radiotherapy	57
Nuclear Medicine	4
Radiology	0
Total	61

IV. EDUCATION AND TRAINING

Before 2007, there was no education program, Bachelor or Master, involving the Moroccan universities in the training and graduation of the Moroccan medical physicists. Most medical physicists were trained abroad, especially in France, and they took part, until now, in the International Atomic Energy Agency training programs. In 2007, the first medical physics master degree, of two years, was created in the Mohammed V University, Faculty of Science of Rabat. In the same year, a bachelor degree in dosimetry, of one year (for candidates who have already obtained undergraduate academic degree in physics), was created at the same university for the first time in Morocco.

For the Masters degree, it is composed of 4 semesters. Three of them are dedicated for the fundamentals and theoretical courses, where the final semester is dedicated for an obligatory practical training, taking place in the Moroccan hospitals for about 4 months before graduation.

This step was important to establish an official national program for the education and training of medical physicists. Other universities in Morocco created Master's degrees in radiation protection, for example the Ibn Tofail university, faculty of science of Kenitra in 2014, or medical physics, Faculty of Medicine and Pharmacy of Casablanca (2012-2014), Higher Institute of Health and Science of Settat (ISSS) (since 2016). All these universities are awarded a Ph.D degree in medical physics. Nevertheless, the programs do not adopt the training courses recommended by the IAEA in the TCS N°37 [3], N° 47 [4] and N° 50 [5], which created discordance in the education programs between the universities. Concerning the medical physicists in practice, some of them benefited from The IAEA training programs, under the African Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology (AFRA), and the training courses organized by the Abdus Salam International Centre for Theoretical Physics (ICTP).

V. CONCLUSION

Medical physics in Morocco has known an important progress in the last few years by the creation of master and bachelor degrees at different Moroccan universities, in a step to follow the interest of the official authorities for the control of cancer treatment, the evolution of the number of the medical equipment at national level, and the progress of the creation of new centers and departments dedicated for oncology and diagnostic radiology. Nonetheless, the state of medical physicists needs to be improved by the creation of specific laws in order to organize and harmonize the profession, including the education level and requirements, the qualification and training conditions to practice as medical physicist.

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Contacts of the corresponding author: H. Saikouk
Nuclear Medicine department, Oncology and Hematology
Center, Mohammed VI University Hospital,
BP2360 Principal ‘Avenue Ibn Sina, Marrakesh, Morocco
Email: saik.hind@gmail.com

MEDICAL PHYSICS EDUCATION AND TRAINING IN ALGERIA

A. Toutaoui[1], N. Khelassi-Toutaoui[2], Z. Brahimi [2]

[1] Départment de Radiothérapie et d'Imagerie Moléculaire, Hôpital Chahids Mahmoudi, Tizi Ouzou, Algeria
[2] Départment de Physique Médicale/Division de la Physique Radiologique, Centre de Recherche Nucléaire d'Alger, Algiers, Algeria

Abstract— **In Algeria, it is in the field of radiotherapy that medical physics has begun to play an important role with the first radiotherapy center which began its activity in 1959 and then extended to radiodiagnostics and applications of radioisotopes in nuclear medicine. Training in medical physics began in 1983 and then went through several stages and accompany the development of medical activities using ionizing radiation.**

Keywords— **Algria, medical physics, clinical training.**

I. INTRODUCTION

In Algeria, cancer has become a public health problem with the launch of the National Cancer Plan. According to assessments made by the National Cancer Committee and the National Institute of Public Health (INSP), there are currently approximately forty thousand to fifty thousand (40,000-50000) new cases of cancer per year. The distribution of the incidence of cancer cases between the sexes is fairly equal, with 48.6% of cases occurring in men and 51.4% of cases in women. In addition, during the last two decades, there has been a rapid increase in the number of radiological equipment used in medical imaging and in the treatment of cancers, as well as the introduction of new equipment and new techniques using ionizing radiation. With the technological developments of radiation treatment and imaging equipment, the need for medical physics has increased in recent years. This has helped to make the medical physics intervention in the diagnosis and treatment processes necessary and mandatory to achieve the required objectives and to ensure the protection of patients, staff and the public as well as to maintain the level of performance of equipment used. In Algeria, it is in the field of radiotherapy that medical physics have begun to play an important role, extending to radiodiagnostics and applications of radioisotopes in nuclear medicine.

II. INFRASTRUCTURE

The management of cancers in Algeria began in the 1940s and the first radiotherapy center, Centre Pierre et Marie Curie (CPMC), was inaugurated in 1959 in Algiers. After independence, the number of radiotherapy and medical imaging infrastructures has steadily increased and in the last decade and especially after the launch of the cancer plan, the number of infrastructures using radiological equipment for treatment and for the diagnosis has seen a phenomenal leap.

Algeria has twenty-two (22) cancer treatment facilities in University Hospital Centers, Specialized Hospital Establishments or Private Hospitals throughout the national territory (16 in the public sector and 6 in the private sector).

The specialty of nuclear medicine is exercised in the public hospital sector (10 departments and 02 units) and in the private sector (Several private facilities currently provide scintigraphic examinations).

In addition, Algeria has a large number of medical imaging equipment throughout the national territory in both the public and private sectors (15 University hospitals, 481 Regional hospitals, 75 Specialized Hospitals, 1659 Polyclinics, 299 private offices of radiology, 01 private hospital).

Table 1 Medical equipments for medical imaging and radiation therapy

Equipment	Total
SPECT/CT	11
SPECT	24
PET/CT	1
Dose calibrators	≈50
Co-60 EBRT	3
Accelerator	55
MRI	150
CT	574
Mammography	281
Standard Radiology	3000
Interventional	50

III. REGULATION OF MEDICAL PHYSICS

In view of the Algerian regulations on radiation protection, the presence of medical physicists (radiation physicists) is mandatory in the radiotherapy departments (see Decree 05-117 of 11 April 2005 on protective measures against ionizing radiation) [3]. Algerian regulations also require the presence of a medical physicist in nuclear medicine units. In particular, in each radiotherapy department, the presence of at least one qualified medical physicist, who is competent in the subject concerned, is required on a full-time basis. For routine practices in therapeutic nuclear medicine and for diagnostic nuclear medicine practices, a medical physicist, who is competent in the subject area, should be available. For other radiological practices, a qualified medical physicist, who is competent in the subject concerned, must be involved, in particular, for optimization purposes, including for patient dosimetry and quality assurance (cf. 68, 69 & 70 Decree 05-117).

Table 2 Distribution of medical physicists in Algeria

Medical Physicists	Total
Radiotherapy	112
Nuclear Medicine	13
Radiology	4
Total	129

IV. EDUCATION AND TRAINING

In Algeria, the training and practice of medical physics began in 1983 as part of the Magister in radiation protection. In 1988, a DPGS (Diploma) training in Medical Physics was launched by the Haut Commissariat à la Recherche (HCR), followed in 1990 by a Magister program in Medical Physics. This training stopped during the nineties following the saturation of the national needs. Training in medical physics resumed in 2004 following the expression of the needs of the Ministry of Health, Population and Hospital Reform (MSPRH) with the launch of new Anti-Cancer Center as part of the cancer plan. This training, of the postgraduate level Magister, was provided by the Faculty of Physics of the University of Science and Technology Houari Boumediene (USTHB) in collaboration with the Center of Nuclear Research of Algiers (CRNA) of the Commissariat for Atomic Energy (COMENA) and hospital departments (Radiotherapy, Medical Imaging and Nuclear Medicine) of the MSPRH . The Magister program includes one year of academic training in medical physics and a period of 12 to 18 months of clinical training and dissertation preparation [1]. At the same time, a technical cooperation project was launched with the International Atomic Energy Agency (IAEA) on Strengthening National Training Capacities in Medical Physics (ALG6014). Project in which, the program benefited from the contribution of international expertise in the field of training in medical physics. The major remark of the audit report highlighted the need to strengthen clinical training and make it an independent part of academic education program and well formalized [2].

In 2007 the university education system in Algeria moved to the LMD system and several Algerian universities launched Master's degree programs in medical physics. In 2009, as part of the ALG6014 project, an expertise was requested for the evaluation of the training program of the Master of Medical Physics taught by the USTHB in collaboration with COMENA and the MSPRH. The report of the expert mission highlighted in a major way [4]:

- The harmonization of the academic training programs of the Masters of Medical Physics.
- The need for the introduction of a clinical training which must be independent and complementary to the academic program with a well-defined and harmonized program.
- The establishment of an accreditation and registering mechanism for the exercise of the profession of medical physicist.

Currently, seven (07) universities offer a Master's degree program in Medical Physics.

V. CONCLUSION

Medical Physics is a growing discipline in Algeria with the launch of a new cancer treatment center and the introduction of new diagnostic and treatment techniques. This has led to an increase in the number of qualified medical physicists operating at the level of hospital structures using radiation as well as the strengthening of training capacities in the field of medical physics.

However, in order to strengthen the framework for education and training in medical physics and to be in conformity with the international standards in the matter, it is necessary to proceed to

- Reorganization of medical physics education and training programs and introduction of a regulated and harmonized clinical training program
- Standardization and harmonization of academic education programs in Medical Physics.
- Strengthening of national regulations in this area.
- The introduction of a continuous professional development scheme for the discipline

Several documents and proposals have been produced by different groups of national experts to respond to these recommendations. These documents even included proposals for regulatory texts relating to the organization and regulation of clinical training.

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Contacts of the corresponding author:

Author: Abdelkader Toutaoui
Institute: Hôpital Chahids Mahmoudi
Street: 1, Bd Krim Belkacem, Nouvelle ville Tizi Ouzou
City: Tizi Ouzou
Country: Algeria
Email: abdelkader.toutaoui@gmail.com

MEDICAL PHYSICS EDUCATION AND TRAINING IN TUNISIA

M. Besbes[1], L. Bensalem[1], C. Nasr[1]
[1]Radiotherapy department, Salah Azaiez Institute, Tunis, Tunisia

Abstract — **Radiotherapy was introduced with the opening of the first cancer center (Institute Salah Azaiez of Tunis) in 1969. The radiotherapy department was directed by the radiotherapist Pr. Ahmed GHIRAB supported by French co-workers; At the time the service is composed of three units namely: external radiotherapy (Co60 and conventional radiotherapy:100-400 kV), low dose rate brachytherapy gynecological used Cs 137, Radium and in 1972 the introduction of Ir192 by Pr. Raouf Ben ATTIA and medical physics led by Mr. Hédi DAMMAK. With the installation in 1992 of the first high-energy accelerator and the expansion of the staff (6 radiotherapists and 2 medical physicists), we thought about the academic education and training of medical physicists then in 2007-2008 a professional master of radio physics was established to train 9 medical physicists and in 2012 we opted for the PhD of medical physics which Pr Mounir BESBES was the coordinator to remedy the lack of medical physicists in the country especially that with the opening of many regional public and private radiotherapy centers.**

Keywords: **Tunisia, radiotherapy, medical physics, education and clinical training.**

I. INTRODUCTION

In Tunisia, We are witnessing a rapid increase of new cases of cancer per year, it is estimated to 15000 new cases cancer, so it's a real public health problem. We need to multiply cancer centers, medical and paramedical staff. Since 1992, there has been a rapid increase in the number of the new anticancer centers equipped by modern equipment of irradiation using new techniques (CRT, IMRT, VMAT) and medical imaging (EPID, IGRT) With the technological developments of radiation treatment and imaging equipment, the need for medical physics has increased in recent years to achieve the required objectives and to ensure the quality irradiation treatment, the protection of patients, staff and the public as well as to maintain the level of performance of equipment used in Tunisia.

II. INFRASTRUCTURE

Tunisia has 5 public radiotherapy centers and 7 private centers equipped with 13 high energy accelerators and 8 coblat therapy devices and 6 dedicated simulation scanners and two brachytherapy units.

In addition, Tunisia has a large number of medical imaging equipment throughout the national territory in both the public and private sectors.

Table 2Medical equipment's for medical imaging and radiation therapy

Equipment	Total
SPECT/CT	3
Gamma camera	7
PET/CT	4
Co-60 EBRT	8
Ir192 HDR BT	1
Accelerator	13
MRI	++++
CT	++++
Mammography	++++
Standard Radiology	++++
Interventional	++

III. REGULATION OF MEDICAL PHYSICS

In view of the Tunisia regulations on radiation protection, the presence of medical physicists (radiation physicists) is mandatory in the radiotherapy departments on protective measures against ionizing radiation). In particular, in each radiotherapy department, the presence of at least one qualified medical physicist, who is competent in the subject concerned, is required on a full-time basis.

Table 2Distribution of medical physicists in Tunisia

Medical Physicists	Total
Radiotherapy	31
Nuclear Medicine	0
Radiology	0
Students	5
Total	36

IV. EDUCATION AND TRAINING

In Tunisia, the education and clinical training of medical physics began in 2007 as part of the Master in radiophysics, The clinical training in Medical Physics was launched by the radiotherapy departments of Salah Azaiez institute and Habib Bourguiba hospital of Sfax following the Master program in Medical Physics. The Master program includes one and half years of academic training in medical physics and a period of 6 months of clinical training and dissertation preparation.

Since 1990, some technical cooperation projects and RAF projects was launched with the International Atomic Energy Agency (IAEA) on Strengthening Capacities in Medical Physics. Project in which, the program benefited from the contribution of international expertise in the field of training in medical physics. Since 1990, IAEA project have contributed to improve radiotherapy and medical physics in Tunisia with seven cooperation projects.

V. CONCLUSION

In Tunisia with the launch of a new cancer treatment center and the introduction of new treatment techniques we need to Increase in the number of qualified medical physicists operating at the level of hospital structures using radiation as well as the strengthening of training capacities in the field of medical physics. Reorganization of medical physics education and training programs and introduction of a regulated and clinical training program

- Harmonized clinical training program to comply with international requirements
- Strengthening of national regulations in this area.
- The introduction of a continuous professional development scheme for the discipline
- The establishment of an accreditation and registering mechanism for the exercise of the profession of medical physicist

Contacts of the corresponding author:

Author: Prof. Mounir Besbes
Institute: Salah Azaiez Institute
Street:
City: Tunis
Country: Tunisia
Email: mounir.besbes@rns.tn

MEDICAL PHYSICS EDUCATION AND TRAINING IN EGYPT

Nashaat A. Deiab*[1], Khaled M. Elshahat[2], Ehab M. Attalla[1]

[1]Radiotherapy Department, National Cancer Institute, Cairo University, Cairo, Egypt
[2]Radiation Oncology Department, Faculty of Medicine, Al-Azhar University, Cairo, Egypt

***Abstract*:** **The aim of this paper was to investigate the current status of education and training programs for medical physics in Egypt. Most Medical Physicists work in Radiotherapy and Nuclear Medicine and medical Imaging departments in University Teaching Hospitals, Institutions and private centers. Medical physics education in Egypt is provided at biophysics departments of 18 universities as master MSc and doctorate PhD levels program. Egypt has infrastructure for medical imaging, radiation therapy and radiation protection including the private and public centers.**

Keywords*:* medical physics, education program, infrastructure, Medical equipment

I. INTRODUCTION

Medical physics is a profession classified by the International Labor Organization in 2011 [1]. The role and responsibility of the medical physicist refer to medical exposure, patient protection and safety. Specialized education, clinical training and competencies are required for the clinically qualified medical physicist [2].

Table (1): Universities offered Academic Education

University Name	Postgraduate program
Cairo	-Radiation Physics Diploma -Health Physics Diploma. - Medical Biophysics MSc, PhD
Ain Shams	- Health Physics Diploma. - Medical Biophysics MSc, PhD
Al-Azhar	-Radiation Physics Diploma, MSc, PhD
Helwan	- Medical Biophysics MSc, PhD
Alexandria	-Radiation Physics Diploma, MSc, PhD
Mansoura	-Medical Biophysics MSc, PhD
Port Said	-Radiation Physics Diploma
Suez Canal	-Medical Biophysics MSc, PhD
Tanta	-Radiation Physics Diploma, MSc, PhD
Menoufia	-Radiation Physics Diploma, MSc, PhD
Assiut	-Medical Biophysics MSc, PhD
Aswan	-Radiation Medical Physics Diploma
Fayoum	-Medical Biophysics MSc, PhD
Sohag	-Radiation Medical Physics Diploma
Minia	-Medical Biophysics MSc, PhD
South Valley	-Radiation Physics MSc, PhD

The recognition of medical physicists remains a challenge in Egypt [3]. The existing educational program is to produce scientific elites specialized in medical physics that have the ability to keep abreast of the tremendous recent developments in basic and medical sciences and activating the research and technical role of the medical physicist in the hospitals of universities of Egypt and other specialized medical centers, to deepen the academic study of applied medical physics and directly link it to the needs and requirements of the labor market, and produce a new generation with broad knowledge in understanding the physical sciences closely associated with direct clinical work to serve patients, develop health care and create specialized academic schools with practical experience in medical physics. The educational situation (course syllabus, number of faculty members, number of PhD and MSc students and sub-fields offered in the department) and the professional situation (work experience, workplaces of medical physicists, postgraduate degrees that were granted and the amount of therapy and imaging equipment). The Universities offered academic education shown in table 1. [4]

II. INFRASTRUCTURE

It has infrastructure for medical imaging, radiation therapy and radiation protection including the private and public centers, where the equipment`s for medical imaging facilities and radiation therapy are listed as shown in table 2 [5, 6]. Most medical physicists (65%) work in the radiotherapy physics sub-specialty. Also, about 24% in nuclear medicine and little number of medical physicists in medical imaging sub-specialty as operators for MRI and CT machines and distribution of medical physicists in Egypt listed as shown in table 3 [7].

III. REGULATION OF MEDICAL PHYSICS

Most medical physicists work in radiotherapy and nuclear medicine and medical imaging departments in university teaching hospitals, institutions and private centers. medical physics education in Egypt is provided at more than 12 universities as master MSc and doctorate PhD program levels in most physics / biophysics departments, faculties of science, e.g. Cairo university, Ain Shams university, Al_Azhar university, Mansoura university, Alexandria university, Helwan university, Fayom university, Banha university, Suez Canal university, Port Said university and Assiout university, where medical physics students graduate every year (1).

Table (2): Medical equipment's for medical imaging and radiation therapy

Equipment	Total
SPECT/CT	15
SPECT	72
PET/CT	52
Dose calibrators	238
Co-60 EBRT	18
Linear Accelerator	92
MRI	230
CT	725
Mammography	185
Standard Radiology	3852
Interventional	622

Table (3): Distribution of medical physicists in Egypt

Medical Physicists	Total
Radiotherapy (Qualified+ Under supervision)	232
Nuclear Medicine	56
Radiology (operators)	86
Total	374

IV. EDUCATION AND TRAINING

Medical physics education and training started in Egypt, three decades ago. The structural organization of the program divided into two parts; the first one academic Part, It is a specialized course in medical physics taught by a group of distinguished professors in this specialization in addition to that during this period the student training one day a week in one of the specialized medical centers and clinical research institutes. The second one is practical part, where the student is trained in medical imaging and diagnostic equipment, nuclear medicine facilities, radiation therapy, health physics, radiation protection.

V. CONCLUSION

Medical physics training and practice has seen steady progress over the past 21 years .The formation of the recorder files for Medical Physicists and Egyptian Association for Medical Physics has been a major step in helping to establish medical physics carriers .The process of establishing such organizations and recognition by the respective of Egyptian Ministry of Health and Population, that participated in this project. Overall, however, they have proven to be an effective channel to facilitate education, training, and research in all universities in Egypt. Survey shows that the number of the medical physicists in the Egypt was almost doubled during the past 10 years. This achievement requires special congratulations to all

colleagues who supported and worked for the development of the medical physics profession in the Egypt.

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6. Egyptian Nuclear & Radiological Regulatory Authority (ENRRA), the Prime Minister, Cairo, Egypt.
7. Egyptian Association for Medical Physics, EAMP, Cairo, Egypt.

*Contacts of the corresponding author:**
Associated Prof. Nashaat Ahmed Deiab
SG Egyptian Association for Medical Physics, EAMP
Build no.1, Shahin squire, El-Agoza, Dokki
Giza, Egypt
Email:nashaatad@hotmail.com

INVITED PAPERS

THE HISTORY AND EVOLUTION OF CT DOSIMETRY

R.L. Dixon

Dept of Radiology, Wake Forest University School of Medicine

Abstract- **A historical description of the development of CT dosimetry and its evolution; including the flaws in the present-day dose-descriptors which have not kept pace with modern CT techniques, and the required modifications for same - which corrections can be applied by the medical physicist.**

I. INTRODUCTION

The following historical vignette lends some perspective to the development of CT dosimetry. This material has been excerpted from my recent Book: **The Physics of CT Dosimetry**, CRC Press.

The early workers referenced here could not have imagined the explosive growth in CT methodology which would occur over the ensuing decades.

II. THE EARLY UNIVERSE

The early measurement of CT dose and mapping of the dose distribution was primarily done using Thermoluminescent Dosimetry (TLD) which was tedious and had relatively low spatial resolution. In the early days of CT when scan times were slow and x-ray tube heat capacities were low, obtaining the dose (or dose distribution) resulting from multiple axial slices was difficult. Ed McCollough and Tom Payne (beginning in 1976) did some early work using TLD.

In 1977, the pencil chamber method was introduced by Jucius and Kambic – the same year the Apple II computer was released, and people were playing the Atari video game, PONG.

Bob Jucius and George Kambic of Ohio Nuclear, Inc. (a US CT manufacturer) provided the first comprehensive look at CT dosimetry, presenting various options including TLD *as well as the introduction of the long pencil ion chamber* which they commissioned Capintec, Inc. to manufacture for them [1]. They derived an equation which showed that the integral of a single slice dose profile could be used to *predict* the average dose about the central scan location ($z = 0$) for multiple slices. This is far from obvious, and their insight was quite impressive. Their derivation involved a (relatively opaque) summation of integrals. They also mapped dose distributions using TLD and surface dose using Kodak RP/M (mammography) film, but concluded that “at this time, TLD is the technique of choice”.

Dixon and Ekstrand [2] independently introduced surface dose mapping using a slower radiation therapy verification film (Kodak Xomat /V), digitized using a scanning densitometer for various scanners of the day (resulting in some unexpected dose spikes).

III. THE BIRTH OF CTDI – 1981

Perhaps the best-known paper was that of a US FDA group Shope, Gagne, and Johnson [3] who refined the integral concept of Jucius and Kambic described above. To avoid confusion we will henceforth adopt the following simplified notation used in our Medical Physics Publications and in my Book [4]. Shope et al. defined the “Multiple Slice Average Dose” (MSAD) resulting from a series of N identical axial dose profiles $f(z)$ spaced at equal intervals of $b = \Delta d$ along z as

$$MSAD = D_L(0) = \frac{1}{b}\int_{-L/2}^{L/2} f(z')dz' \qquad (1)$$

Where the MSAD is the average dose over ± $b/2$ about $z = 0$ (at the center of the scan length L) and where $L = Nb$ (the integration limits and the divisor b are necessarily coupled). For axial scans (“step and shoot”) the dose distribution over the scan length is quasi-periodic of period b, hence the average is over one period (± $b/2$) about $z = 0$. Note that their nomenclature “multiple scan average dose” (MSAD) is rather misleading, since it is not the average dose over the total scan length, but rather only *about the center of the scan length* $z = 0$. They also stated that L in the above MSAD equation was intended to be long enough for the dose at the center of the scan length to reach its limiting, *equilibrium value*. From this they defined a “dose index” CTDI as

$$\mathrm{CTDI}_\infty = \frac{1}{T}\int_{-\infty}^{\infty} f(z')dz' \qquad (2)$$

where T is “the slice thickness as stated by the manufacturer” and $f(z)$ is the *dose profile* generated by a single axial scan centered at $z = 0$. This is the value of MSAD when L is large enough such that MSAD approaches its limiting (equilibrium) value (which we denote by D_{eq}) – such that profiles beyond $z = \pm L/2$ contribute negligible scatter back to $z = 0$; $z = 0$ being the relevant location for MSAD or CTDI. Note also that $CTDI_\infty$ represents the dose that accrues at the center of the scan length for a table increment $b = T$, which represented “contiguous axial scans”. With the advent of multi-detector

CT (MDCT), T is replaced by "N x T" (nT in our more concise notation used herein). A common misconception is that T or nT represent a beam width, but physically (in any valid dose formula) they represent a table increment, as illustrated by our derivations of same [4,5].

The derivation of the MSAD equation by Shope and Gagne [3] involved a tedious summation of integrals (following Jucius and Kambic). The derivation for axial scans has been simplified to a few steps [5] using convolution mathematics; this derivation produces the "running mean" dose $D_L(z)$ as an average over $z \pm b/2$ *at all values of* z (and not just $z = 0$ as for the MSAD of Shope et al.). This derivation is shown in Chapter 2 of the Book [4].

IV. ENTER THE REGULATORS (1989)

Codification of physical law rarely turns out well, and once the law has been laid down it is devilishly hard to change (also "too many cooks spoil the broth").

The original definition of CTDI put forth by Shope et al 1981, as well as the original US FDA regulatory proposal [6], used the *infinite* line integral of the single-slice, axial dose profile $f(z)$, viz. $L \to \infty$ with $b = T$. The meaning and intent of "infinity" were clear and unambiguous to the physicists, symbolically indicating that the integration limits ($-L/2$, $L/2$) must be at least large enough to encompass the complete width of $f(z)$ including its long scatter tails, such that any further increase in L would provide a negligible additional contribution to the accumulated dose at $z = 0$ for a scan length L. This in turn assured that the CTDI, thus defined, would represent the *maximum limiting value* of the accumulated dose at the center of the scan length resulting from multiple, contiguous ($b = T$) scans, namely, *the equilibrium dose* D_{eq}. Had the FDA retained it as originally proposed, it would have been self-correcting and "bullet proof", since many of the ensuing difficulties with CTDI were produced by attempting to define suitable, *finite* integration limits.

But alas, "infinity" did not survive the transformation to the "final FDA rule" (due to public comment; and perhaps because the concept of "infinity" is not in the legal lexicon); and thus the $\pm 7T$ integration limits were adopted - which length the FDA stated [6] "*would produce little difference from the originally- proposed infinite integral for the largest slices then available*" (T = 10 mm), and "*would be representative of typical clinical scan lengths of 10 -15 T.* " (100 – 150 mm). In hindsight, both conclusions were flawed and rapid technological advances led to typical body scan lengths of 250 mm or greater. The FDA did, however, retain the required coupling between the integration limits and the divisor T.

A. *The Standard Dosimetry Phantoms*

FDA [6] defined "standard dosimetry phantom" as a right circular cylinder of polymethl-methacrylate (PMMA) of diameters of 32 cm (body) and 16 cm body (head) 14 cm in length which can accommodate a dosimeter both along its axis of rotation and along a line parallel to the axis of rotation 1.0 centimeter from its surface. This truncated length gives a shortfall of $CTDI_{100}$ of 7% on the central axis and 1.3% on the peripheral axes due to missing scatter in a 15 cm long phantom [6].

V. THE QUIESCENT PERIOD

Nevertheless, a long period of quiet acceptance prevailed, during which time the mathematical theory behind the pencil chamber and subscripted CTDI methodology was forgotten (many likely had not even seen the derivation) – and some began to believe that they were making an actual "dose" measurement with the pencil chamber. One does not, and cannot, directly measure a dose with a pencil chamber. Not even in air. Among other things, a pencil chamber reading defies the inverse square law ($1/r^2$). Its reading varies as $1/r$. Many "unwary" diagnostic physicists have fallen into the trap of using the pencil chamber outside of its limited, approved use; supporting the old adage "*if the only tool you have is a hammer, you tend to treat everything as if it were a nail*". The pencil chamber measures *a dose-integral* in units of *mGy.cm*; so even though your electrometer may read *mGy* (or mR) it is likely not programmed for a pencil chamber (and is actually only measuring the charge collected in Coulombs). See [4,7] for pencil chamber calibration methods and units.

VI. ENTER $CTDI_{100}$ - 1995

$CTDI_{100}$ (based on a 100 mm long pencil chamber measurement) was introduced [8] around 1995 as a *more practical* indicator of patient dose, and then widely adopted (based on a European Commission Study Group 1998). The widespread use of the 100 mm chamber seems to have been an *ad hoc* decision, and not supported by the physics. The FDA kept the required coupling between the integral divisor and the integration limits; but variable integration limits were not practical for the pencil chamber methodology. However, a fixed integration length can (and does) lead to anomalies.

Since $CTDI_{100}$ has a different value for the central and peripheral phantom axes, a desire to have a single CTDI number (dose index) to represent "dose" for a national survey in Sweden [8] led to an approximate "weighted average" dose across the central scan plane at $z = 0$ assuming an *ad hoc* linear variation of $CTDI_{100}$ from the central phantom axis to the peripheral axis (p) namely,

$$CTDI_w = \frac{2}{3}CTDI_{100}(p) + \frac{1}{3}CTDI_{100}(c) \qquad (3)$$

The (1/3, 2/3) weighting proves adequate for $CTDI_{vol}$ (based on $CTDI_{100}$); however, the central axis to peripheral axis dose ratio increases as scan length increases beyond

100 mm due to increased scatter thereon. We also note that the actual dose curve $D(r)$ is not linear, but is sigmoidal, with *zero slope* on the central axis ($r = 0$) and again near the phantom surface.

VII. THE ADVENT OF MULTIDETECTOR CT (MDCT) - 1998

The divisor of the CTDI integral now becomes nT (or "N x T") which is the *active detector length* as projected back to scanner isocenter, and represents the total available scan width for reconstruction. The actual primary beam width (*fwhm*) $a > nT$ is required to keep the penumbra beyond the active detectors, called "over-beaming". MDCT allowed reconstruction of smaller slices than nT but with a concomitant increase in noise, e.g., an acquisition using $nT = 20$ mm, can be reconstructed as four 5 mm slices.

VIII. ENTER CTDI$_{vol}$ (A MISNOMER) BUT AN IMPROVEMENT SINCE IT ELIMINATES *nT* (N x T)

$CTDI_w$ was later modified by the IEC in 2001 to include the effect of "pitch" (table increment b) on dose as

$$CTDI_{vol} = p^{-1}\, CTDI_w \qquad (4)$$

where $p = b/nT = \Delta d/nT$ applies to both helical and axial scans. The nomenclature $CTDI_{vol}$ is again a misnomer since it does not represent a volume average as its subscript might imply- no average having been taken over the 100 mm scan length; rather it still represents *the planar average dose over the central scan plane* (at $z = 0$) for a 100 mm scan length. Its basis is still $CTDI_{100}$ which is hidden. We also note that *nT cancels out in $CTDI_{vol}$* such that *only the inverse of the table increment per rotation b^{-1} matters* – the divisor nT in $CTDI_{100}$ serves only as a place-keeper.

As the table increment $b \rightarrow 0$, then $CTDI_{vol} \rightarrow \infty$; however, this is nonsensical since the actual dose remains finite. The oft-forgotten required coupling of scan length $L = Nb$ and table increment b in Eq. (1) also requires the integration limits to approach zero, resulting in the dose approaching the eminently-plausible value $Nf(0)$ where N = number of rotations; i.e., the N dose profiles $f(z)$ simply pile up on top of each other at $z = 0$, and $CTDI_{vol}$ (calculated from $CTDI_{100}$) *no longer has any relevance*. This is shown mathematically in [9] as well as Chapter 5, Dixon 2019 [4] for stationary table CT, although it is fairly obvious.

IX. DOSE LENGTH PRODUCT

DLP = L X $CTDI_{vol}$ is a *measure* of the total energy deposited in the phantom. Note that DLP does not depend on the scan length L per se´ since $L = Nb$ and $CTDI_{vol}$ is proportional to b^{-1}; thus b cancels in the product, and DLP really depends only on the number of rotations N or total mAs. Increasing scan length L by increasing pitch alone does not change DLP. Even if the table translation is slowed to a stop ($L \rightarrow 0$) DLP remains the same. DLP is by no means *equal* to the total energy deposited since $CTDI_{vol}$ is based on $CTDI_{100}$ – the total energy deposited is calculated in Chapter 2 in Dixon's book[4]. DLP remains robust for shift-variant techniques, whereas $CTDI_{vol}$ is not.

X. HELICAL SCANNING - SCANNING WITH CONTINUOUS TABLE MOTION - 1990

Willi Kalendar [10] introduces helical scanning ("spiral CT"). Dixon [5] in 2003 derived the dose equations for helical scanning for the *dose* $D_L(z)$ over the entire scan length L, for both the central phantom axis and likewise for the peripheral axis where an angular average over 2π at a fixed value of z is used. This derivation treats the dose rate profile as a traveling wave in the phantom (and is accomplished in a few steps for the central axis on which the dose rate is constant) and is given by the form of a traveling wave $\dot{f}(z-\upsilon t) = \tau^{-1} f(z-\upsilon t)$ where $f(z)$ is the single-rotation (axial) dose profile acquired with the phantom held stationary, υ is the table speed, τ is the gantry rotation period (in sec), and t_0 is the total scan time as illustrated in Fig. 1

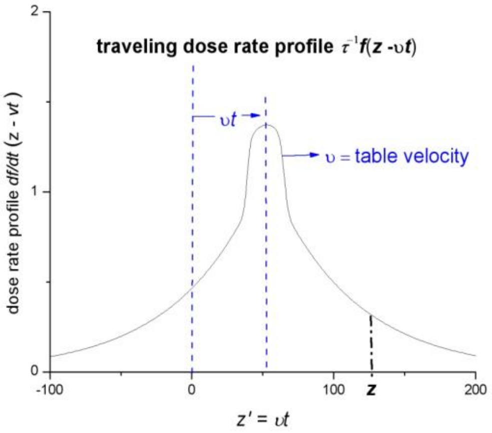

Fig. 1. A traveling *dose rate profile* $\dot{f}(z-\upsilon t) = \tau^{-1} f(z-\upsilon t)$ in the phantom reference frame is created when an axial dose profile $f(z)$ is translated along the phantom central axis z by table translation at velocity υ, where τ is the gantry rotation period (in sec), which has the familiar form of a traveling wave (z´ in mm). Note the long scatter-tails on the dose profile in Fig. 2.1 such that the point z will begin accumulating dose long before the primary beam component of width a = 26 mm (nT = 20 mm) has arrived and long after it has passed.

Integrating the dose rate over the total scan time t_0 gives

$$D_L(z) = \tau^{-1} \int_{-t_0/2}^{t_0/2} f(z-\upsilon t)\,dt \qquad (5)$$

$$D_L(z) = \frac{1}{b} \int_{-L/2}^{L/2} f(z-z')\,dz' \qquad (6)$$

$$D_L(z) = \frac{1}{b} f(z) \otimes \Pi(z/L) \qquad (7)$$

the conversion from the temporal to the spatial domain in Eq.(6) having been made using $z' = \upsilon t$, scan length $L = \upsilon t_0$, and a table advance per rotation $b = \upsilon\tau$, resulting in the above convolution in Eq.(7) describing the total dose $D_L(z)$ accumulated at any given z-value during the complete scan, expressed as a convolution with the rect function $\Pi(z/L)$. This reduces to the $CTDI_L$ equation by setting $z = 0$ with a *table increment* $b = nT$, i.e.

$$D_L(0) = \frac{1}{b} \int_{-L/2}^{L/2} f(z')dz' = \frac{nT}{b} CTDI_L \qquad (8)$$

where b/nT is equal to the helical pitch. When $CTDI_L$ is arbitrarily truncated to a scan length of $L = 100$ mm, it becomes $CTDI_{100}$..

The same equation for $D_L(z)$ was also shown by Dixon [5] to also apply to axial scanning when a longitudinal "running mean" (average over $z \pm b/2$) is used, which also reduces to the *CTDI* paradigm at $z = 0$ as previously discussed. This derivation is likewise shown in Chapter 2 of Dixon 2019 [4], and is easily accomplished using convolution mathematics (as opposed to the tedious summation of integrals previously used by Shope et al.[3] to calculate MSAD and CTDI).

We also note from the derivation, that *the integral format of CTDI devolves from the motion of the phantom,* and that it does not apply to a stationary patient support technique such as use of a wide cone beam without any table motion; and likewise, *a pencil chamber acquisition of the integral* to compute $CTDI_{100}$ has no relevance or utility to such stationary table techniques.

XI. SLIPPING THE SURLY BONDS OF CTDI

The CTDI-paradigm has many limitations which are not widely-appreciated as described in this section. The CTDI-paradigm requires *shift-invariance* for which no scan (or phantom) parameters can vary with *z*, therefore it cannot apply to many modern *shift-variant* CT techniques such as tube current modulation (TCM). It also only applies to phantom-in-motion techniques, and not to stationary patient-support protocols.

A. *An Alternative To The Pencil Chamber – 2003*

Dixon in his 2003 paper [5] also described an alternative measurement method to that of the pencil chamber of fixed length which is much more versatile. Unlike early CT scanners, modern CT scanners can scan over any desired length of phantom in a few seconds, therefore integrating the dose from a small ion chamber fixed in a moving phantom can give the accumulated dose for any scan length or clinical protocol, and thus can emulate a pencil chamber of any arbitrary length (and can even be used to measure $CTDI_{100}$). That is, the small ion chamber can be used in this way to create a "virtual pencil chamber" of any desired length. This method has been validated experimentally in detail in Dixon-Ballard [7] and is also described in Dixon Chapter 3 [4] where a 0.6cc Farmer ion chamber is shown to give the same result as a 100 mm and 150 mm pencil chamber – and for any other scan length *L* as well. It is also immune to the *shift-variant* problems discussed below.

B. *AAPM TG-111 - 2010*

A Task Group of The American Association of Physicists in Medicine published AAPM Report 111 [11] entitled "Comprehensive Methodology for the Evaluation of Radiation Dose in X-ray Computed Tomography" in which the small ion chamber is utilized for measurements rather than the pencil chamber, and which recommends a return to the equilibrium dose D_{eq} as the measurement goal (as originally recommended by Shope et al. 1981 [3] and the FDA[6]). There is no mention in this report of CTDI nor the pencil chamber.

C. *Limitations Of The CTDI-Paradigm And The Pencil Chamber Acquisition.*

The CTDI-paradigm has significant limitations. It only applies to moving patient-support techniques, such as helical scanning or an axial scan series, as discussed above. Every dose profile *f* (*z*) in such a scan series must be identical to that integrated by the pencil chamber in order for *the predictive method* of CTDI to be valid; in other words, it requires *shift-invariance* for which no scan parameters can vary with *z*. That is, it requires constant tube current (mA), constant pitch (or table increment *b*), and a constant phantom cross-section along *z*. Therefore, it cannot apply to Tube Current Modulation (TCM) which is commonly-utilized today. Dixon and Boone [12] derive the proper dose equations for such *shift-variant* techniques (TCM and pitch modulation) shown in Chapters 7 and 8 of Dixon 2019 [4] as well as in [13] and [14].

The small ion-chamber method has no such restrictions. It can even be deployed in an anthropomorphic phantom. It is measuring an actual accumulated dose, and not relying on the predictive methodology of CTDI, which uses the integral of a single scan to *foretell* the dose at the center of the scan length which would accrue if *identical* scans were laid down at equal intervals over, a 100 mm scan length as for $CTDI_{100}$ and thence for $CTDI_{vol}$.

XII. THE IEC ATTEMPTS TO CIRCUMVENT THE LIMITATIONS OF CTDI

"If the only tool you have is a hammer, you tend to treat everything as if it were a nail"

$CTDI_{100}$ (thence $CTDI_{vol}$) does in fact have a precise physical meaning: it is equal to the actual accumulated dose in-phantom at the center of a series of contiguous scans ($b = nT$) *covering one specific scan length,* $L = 100$ mm; but it underestimates the limiting equilibrium dose D_{eq} (as well as the accumulated dose for any scan length above 100 mm) - particularly for typical clinical body scan lengths of 250 – 500 mm which approach the equilibrium dose. It also *over-estimates* the dose for $L < 100$ mm.

The IEC [15] has attempted to "prop-up" $CTDI_{vol}$ and its "hand maiden" the 100 mm long pencil chamber, in a series of patches. *These patches govern the scanner-reported* $CTDI_{vol}$, as discussed below.

A. *For shift-variant techniques* such as TCM, the IEC version uses the average of *mA*(*z*) *over the entire scan length* as if it were a constant mA in the CTDI-paradigm; whereas $CTDI_{vol}$ *applies only to a 100 mm scan length* – a clear disconnect. This creates a "$CTDI_{vol}$ of the second kind" and the disconnect negates a possible physical interpretation of "$CTDI_{vol}$ (TCM) as illustrated in Chapter 7 in Dixon's book[4]. IEC also introduces the absurdities which are supposed to represent local doses: $CTDI_{vol}(z)$ and $CTDI_{vol}(t)$; but which (apart from having units of dose) are not doses at all, but merely surrogates for *mA*(*z*) as likewise shown in [4]. The *local dose* at *z* does not track *mA*(*z*) [or *mA*(*t*)] since it also consists of scatter from the entire scan length – to paraphrase Charles Dickens "local dose also depends on "mA past and mA yet to come". See Fig. 1 in which the height of the traveling profile for TCM now varies with time or $z' = vt$. The correct equation for TCM derived in Chapter 7 Dixon 2019 [4] is given by

$$\tilde{D}_L(z) = \frac{1}{b}\int_{-L/2}^{L/2} i(z')\,\hat{f}(z - z')\,dz' \qquad (9)$$

$$\tilde{D}_L(z) = \frac{1}{b}\hat{f}(z) \otimes \left[i(z)\Pi(z/L)\right] \qquad (10)$$

in which the tube current at all locations *z'* along *z* contributes to the dose depending on the magnitude of the scatter tails of the axial dose profile *f*(*z*) per unit current at *z'*, via a convolution with the *i*(*z*) = mA(*z*) profile in brackets; rather than a direct product as the IEC definition would imply (the latter being tantamount to removing *i*(*z'*) from the integral and replacing it with its average value over *L* – not to mention truncating the integral to 100 mm). In point of fact, for a scan length of 100 mm, fully 44% of the energy deposited about the central phantom axis is deposited *outside the scan length* where mA(z) = 0 (Table 7.1 Dixon 2019[4]); and where $CTDI_{vol}(z)$ likewise drops to zero although the actual dose does not.

B. *Stationary phantom/table*

For the stationary phantom/table to which the CTDI-paradigm does not apply, the IEC solution is $CTDI_{vol} = N$ x $CTDI_w$ where *N* is the number of rotations. Its failure by up to 300% for narrow beam perfusion studies and for wide cone beams (and a cure) is illustrated in detail in Dixon Chapters 5 and 9 [4] and in Dixon & Boone [12] and in the AAPM TG-111 report [11]. To wit, A pencil chamber cannot be used to directly measure the peak central dose $f(0)$, nor can the value of $f(0)$ be deduced (or even approximated) using a pencil chamber reading (even one of extended length), since such a reading represents the integral of $f(z)$.

Since $f(0)$ is the "point dose" on the central ray of the cone beam at depth in the phantom, the most obvious (and simplest) method is to directly measure the dose $f(0)$ at that point using a small ionization chamber (such as a 0.6 cc Farmer-type chamber) – the same method used for decades to measure depth- dose in a stationary phantom.

A study in simplicity compared to the integral method required for the CTDI paradigm which applies only to phantom-in-motion techniques – no pencil chamber required (or desired) in this case.

C. *Wide beam widths.* Another such IEC patch is a response to a paper by John Boone [16] which illustrates a significant drop-off in the value of $CTDI_{100}$ as the primary beam width becomes comparable to the pencil chamber length ($nT > 40$ mm). This patch is designed to keep $CTDI_{100}$ at the same fraction of $CTDI_{\infty}$ as that for narrow beams (this fraction being about 0.6 on the central axis of the body phantom). It does so for "phantom-in-motion" scan protocols, but it fails in the realm of stationary phantom dosimetry for which wide cone beams are more commonly used, and for which we provide the *appropriate correction* as shown in Chapter 9 [4] and in [12].

There is, inexplicably, no patch which provides a correction of $CTDI_{100}$ (thence $CTDI_{vol}$) for scan length using $CTDI_L = H(L)\ CTDI_{100}$ although a plethora of such robust *H*(*L*) data exists as described in book Chapter 9 [4] as well as in other chapters. This correction would provide an appropriate (albeit approximate) physical interpretation for CTDI (TCM) as illustrated in Dixon's book [4], and in which rigorous methods of correcting $CTDI_{vol}$ for all modalities are provided.

XIII. USE OF THE SCANNER-REPORTED CTDI

Despite these differences, CTDI has been widely interpreted and used as an indicator of clinical patient dose by *regulators* and *medical physicists* alike, in *national dose surveys*, in *imaging literature*, *in the clinic*, etc.; and *on the CT monitor for every patient scan*.

XIV. SIZE-SPECIFIC DOSE ESTIMATES (SSDE)

The basic *SSDE* dose index concept presented in the Report of AAPM Task Group 204 [17] and as revised in [18] is an approach to develop a more reasonable *estimate* of patient dose using the scanner-reported $CTDI_{vol}$ and conversion factors that account for differing patient “sizes”. In situations where a fixed tube current is employed and the patient anatomy and circumference is reasonably homogeneous over an entire CT scan, *SSDE* provides an improved *estimate* of dose as compared to $CTDI_{vol}$. The IEC has developed (but not yet implemented) a model by means of which SSDE will additionally be reported by the scanner which is based on a water-equivalent patient diameter d [18] , and once again using $CTDI_{vol}$ as a basis (and which SSDE values may soon be coming to a CT scanner near you). The various CT manufacturers will be responsible for the methodology (and validation of) the computation of water-equivalent diameter d, and thence SSDE.

XV. ESTIMATION OF ORGAN DOSES

There is a growing movement to calculate individual organ doses in CT, primarily based on Monte Carlo simulations, which begs the question: What are we to do with such data? Even if we could calculate organ doses accurately, are the risk factors for the individual organs that well known? Or will they even be?

Some *commercial dose-tracking software* now include an organ-dose computation for each patient; for example, by matching the patient’s body habitus to a particular humanoid phantom on which Monte Carlo calculations of organ dose have been made. If these are further normalized to the patient, based on the scanner-reported value of $CTDI_{vol}$, then the above-mentioned caveats concerning $CTDI_{vol}$ remain in play.

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About the Author: Robert L. Dixon, Ph.D, FACR, FAAPM is *Professor Emeritus* in the Dept. of Radiology, Wake Forest University School of Medicine and holds a *Ph.D. in Nuclear Physics*.

He is a past president of the American Association of Physicists in Medicine (AAPM), past Chairman of the AAPM Science Council and CT Committee, and was lead author of AAPM Report 111 on the Future of CT Dosimetry. He has published many papers on CT dosimetry in the journal *Medical Physics* and is a member of the IEC MT30 CT committee and a designated US CT Expert (ANSI). His recent book *The Physics of CT Dosimetry - CTDI and Beyond* that is published by CRC Press provides a comprehensive coverage of the developments and innovations that is highly significant area of medical physics,

Contact

Author: Robert L. Dixon
Institute: Wake Forest School of Medicine, Department of Radiology
Email: rdixon@wakehealth.edu

ROLE OF MEDICAL PHYSICIST IN RADIOLOGICAL EMERGENCY AND MANAGEMENT

Arun Chougule[1], Mary Joan[1]

[1]Department of Radiological Physics, SMS Medical College and Hospitals, Jaipur, India

Abstract— **This paper presents an overview of the International Conference on Radiological Emergency Management [ICONRADEM-2019], hosted by the Department of Radiological Physics, SMS Medical College and Hospitals, Jaipur, India, during 9-11 February 2019, with 400 delegates from 13 countries.**

Keywords— **radiological emergencies, management of radiological emergencies**

I. BACKGROUND

Ionizing radiation has found its use in almost every sector in the current times; from healthcare and medical field to construction and infrastructure industries, from geological and historical researches to study of ocean currents and water tables, from increasing the food production through genetic modification to increasing the shelf life of the agricultural produce. Such vast applications highlight the need of trained workforce to avoid accidents and unprecedented incidents. In India nuclear power is the fifth-largest source (3%) of electricity in India. As of March 2018, India has 22 nuclear reactors in operation in 7 nuclear power plants, having a total installed capacity of 6,780 MW. More than 4000 X-Ray diagnostic centers with about 80000 X ray machines, 4000 CT Scanners are functional in our country and thousands of people undergo X-Ray and CT scans every day. More than 400 radiotherapy centers and 150 nuclear medicine centers are functioning in India and using high activity radiation sources, delivering very high radiation doses for treatment.

In the present era of information revolution, misleading social-media articles, unreliable information sources on the internet, lack of knowledge about radiation among the masses are some of the major factors that have lead to unnecessary resistance and fear in the public. Such a scenario has highlighted the need for creating awareness in the society and educating them about the justified and beneficial uses of radiation. This task of instilling trust in the public can happen only when the radiation professionals, scientists and researchers are well-trained to deal with any adverse situation and have the confidence in their own abilities. However, with the multitude of applications, radioactive isotopes of varying strengths and physical forms are being extensively used and though the spectrum of benefits has widened, the probability of hazards has also increased. This necessitates development in teaching and training facilities to keep the radiation professionals updated in terms of safety and security measures.

Although nuclear emergencies are rare occurrences, in past we have witnessed to certain nuclear and radiological accidents which have instilled fear in the masses due to their long-term effects. Beginning with the atom bomb in Japan during the World War II, to the Chernobyl Nuclear Disaster in 1986 in Ukraine and the Fukushima accident in Japan in 2011, an air of confusion and distress surrounds the use of nuclear power and radiation. Though trained professionals deal with the safety and protection of the radiation sources and the people, but human error, negligence or even ignorance can lead to such high potential disasters. In India, the incident in Mayapuri, New Delhi in 2010 is an example of a small negligence turning into a radiological emergency and leading to the first death due to radiation injuries in India.

The need of the hour is to frame proper policies and mitigation protocols under the supervision of experts of radiological emergency management. Medical Physicists and Radiation Safety Professionals are trained to deal with any kind of radiological or nuclear emergency and hence are the key persons when it comes to efficient enactment of all-round radiation safety and protection. Also, the role of medical physicists is of pivotal importance in the hospital management of an emergency but is often unrecognized. Looking to the need and to emphasize role of medical physicists & health workers in the eventuality of nuclear and radiological emergency and the need to rekindle and reckon the role of medical physicists as emergency managers is what led to the idea of organizing International Conference on Radiological Emergency Management [ICONRADEM-2019]. The department of Radiological Physics, SMS Medical College and Hospitals, Jaipur hosted this conference during 9-11 February 2019 wherein 400 delegates from 13 countries participated. The theme of the conference was ‘Better the awareness and preparedness: Better the emergency management’.

II. CONFERENCE OBJECTIVES AND ORGANISATION

ICONRADEM-2019 focused on bringing knowledgeable professionals from across the world on a common platform to discuss, dispense and deliberate on radiological safety and protection. The conference dealt with the various myths and misconceptions surrounding the use of ionizing radiation; safety in the medical use; protection of the staff, patients and general public and emergency preparedness in case of a radiological emergency. Currently the role of medical physicist is confined to radiotherapy, diagnostics and research; but this conference served as a platform to rekindle and reckon their role as radiation safety experts and will be instrumental in dissolving the fear and stigma.

The main objectives of the conference at a glance were,

- To create awareness amongst the professionals, the general public and the media; regarding radiological technologies and their justified use
- To strengthen the awareness regarding possible safety and security issues associated with these technologies
- To eliminate the stigma concerning radiological procedures and professions
- To prepare and train medical/ radiation physicists and medical professionals to support the response to radiological emergencies at the hospital or at a regional or national level
- To promote safe application of radiation in healthcare, industry and applications in other fields for the welfare of mankind
- To impart skills to hold responsibilities and be leaders in case of radiological accidents/ emergencies
- To increase the coordination between the various medical professionals and other communities in face of a radiological emergency
- To promote cooperation and sharing of knowledge and expertise amongst the various scientific communities and agencies.

This conference was organized in cooperation with IAEA (International Atomic Energy Agency), under the auspices of AFOMP (Asia-Oceania Federation of Organizations for Medical Physics) and RUHS (Rajasthan University of Health Sciences) and was endorsed by AAPM (American Association of Physicists in Medicine), IOMP (International Organization for Medical Physics), MEFOMP (Middle East Federation of Organizations for Medical Physics), INS (Indian Nuclear Society), AMPI (Association of Medical Physicists of India), AERB (Atomic Energy Regulatory Board), NMPAI (Nuclear Medicine Physicists Association of India), IARP (Indian Association for Radiation Protection), INSA (Indian National Science Academy) and ISRB (Indian Society for Radiation Biology). DAE (Department of Atomic Energy), Government of India was a knowledge partner.

The inaugural programme was held at ‘Sushrut Sabhagar’, SMS Hospital auditorium presided by Dr Sudhir Bhandari, Principal and Controller, SMS Medical College and Hospitals, Jaipur. Dr Pradeepkumar K S, Distinguished Scientist, Head, Radiation Safety Systems Division and Associate Director Health, Safety and Environment Group, Bhabha Atomic Research Centre Mumbai was the Chief Guest. Mr. V K Jain, Outstanding Scientist and Director Nuclear Power Corporation India Ltd. [NPCIL], Rawatbhata Atomic Power Plant [RAPP] Kota was Guest of Honor and Ramon De La Vega, Emergency Preparedness Coordinator, IAEA was Special Guest for the inauguration. Dr. DS Meena, Medical Superintendent, SMS Hospital Jaipur, Dr Arun Chougule, Organizing Chairman, and Mrs. Rajni Verma Organizing Secretary also addressed the gathering.

An exhibition on Radiological Safety, Bio-dosimetry, Emergency response and various radiation monitoring systems was arranged by BARC (Bhabha Atomic Research Centre), Mumbai, AMD (Atomic Minerals Directorate), Jaipur and RAPP, NPCIL (Rajasthan Atomic Power Plant, Nuclear Power Corporation of India Ltd), Kota team for public awareness. An Emergency Response Mobile unit was also at display.

III. CONFERENCE SCIENTIFIC PROGRAMME

The scientific programme was started with a key-note address by Dr Pradeepkumar K S on Development of Systems and Methodologies for National level preparedness for response to Nuclear and Radiological emergencies/ threats. He has given overview of readiness of India to tackle any kind of nuclear and radiological emergency. He also described and showcased the various equipment developed and laboratories setup, trained and experience human resources and coordination with national disaster response management team to deal with an eventuality.

More than 40 invited talks from renowned radiation safety and management experts and 70 papers from radiological professionals and young researchers on various related fields were the major highlight of the conference. The invited talks covered all relevant topics during the sessions titled introduction to radiological emergencies and incidents, radiation emergencies in radiotherapy and radio-diagnosis, radiation effects and emergency preparedness, IAEA session, cancer epidemiology and radiobiology, potential threats in radiological emergencies - response measures, radiological disaster management and role of armed forces, radiation dosimetry & preparedness for radiological emergencies, Incident reporting, radiation protection & legislations and safety considerations, emergencies & their management in nuclear medicine.

A plenary talk on IAEA safety standards on preparedness and response to nuclear or radiological emergencies by Ramon de la Vega was the highlight of the second day. He gave details of strategies, training programmes, manuals and documents developed by IAEA for member states to tackle with nuclear and radiological emergencies. He described in detail the support and guidance IAEA has provided to member states in this field and the coordination with member states for safeguarding for any kind of eventually and better use of ionising radiation for human welfare. Two teaching sessions for students and young professionals were also arranged, which was attended by not only students, but also majority of the delegates very enthusiastically. Very active interactions, critical comments and strong discussions made this conference an outstanding one.

We are highlighting some of the invited talks.

The invited talk by Prof. Brad Cassel, radiation expert from Australia titled ‘Discussion of a real-time large scale radiation exercise and the lessons learned’ emphasized the possibility to properly plan for large-scale radiation events without testing the written plans and response arrangements first hand. His talk examines a government exercise using a simulated release of a radiological agent in a football stadium. An analysis of the lessons learned was discussed and examples of how such lessons translated into revised government arrangements and enhanced standard operating procedures were provided.

The talk by Prof. Franco Milano of University of Florence on ’Medical physicists and their contribution to radiation protection in emergency exposure situations’ has referred IAEA publication 1578 radiation protection and safety of radiation sources: International Basic Safety Standards issued in 2014 Medical Physicists were mentioned as specific persons that should have specified responsibilities in relation to protection and safety. He further informed within the same publication 1578 emergency exposure situation are also considered. In many countries the Governments thought specific national organizations have ensured that an integrated and coordinated emergency management system is established and maintained. The international community developed a series of procedures and schemes to face and mitigate the effect on humans and environment of nuclear accidents or incidents. He put forth that a Medical Physicist has a cultural background to deal with many of the points (knowledge of physical law and dosimetry, expertise in radiation detection…) that are needed to be professionally active in radioprotection. Very often Medical Physicist acts for their institution as radiation protection adviser who are also exclusively deputed to radioprotection. In the presentation opinions on the operational role of Medical Physicists, based on the personal experience, were expressed considering events with different level in the international nuclear event scale (INES).

The presentation by Prof. Hugh Wilkins, Vice President, International, Institute of Physics and Engineering in Medicine, UK on “ contributions to a global programme developing Medical Physics support for nuclear or radiological emergency response’’ has underline the training and involvement of Medical physicists in tackling the nuclear and radiological emergency. He referred to the 2016 draft revision of the IAEA safety glossary which defines the emergency as a non routine situation that necessitates prompt action, primary to mitigate a hazard or adverse consequences for human life and health, property and the environment; and emergency arrangements as the integrated set of infrastructural elements made in advance that are necessary to provide the capability of performing a specified function or task required in response to a nuclear or radiological emergency. These elements may include authorities and responsibilities, organization, coordination, personnel, plans, procedures, facilities, equipment or training. These are significance undertakings, and require a team having appropriate knowledge, skills and experience for successful emergency response. He re-emphasized that clinically qualified medical physicist working in radiation protection, nuclear medicine, diagnostic radiology and radiotherapy have substantial knowledge, skills and experience relevant to medical exposure to radiation, further they have a good understanding of radiological sciences and are familiar with concerns of people exposed to ionizing radiation. They have access to radiation detection instrumentation and contacts through various networks which can facilitate emergency response. They are able to place radiation doses and risks in perspective and know what the numbers mean. Such skills are likely to be in short supply in nuclear or radiological emergency (NRE) response. Whilst such attributes are a necessary ingredient, they are not on their own sufficient for successful NRE response. From his presentation it’s clear that medical physicists play leading role in response to a variety of radiation untoward events in healthcare settings, and are a potentially valuable resource in supporting NRE response in other contexts. However, in order to be effective members of the team, they need to have a good understanding of overall emergency arrangements, and their role within them.

In another important and informative talk by Ramon de la Vega, Emergency Preparedness Coordinator, Incident and Emergency Centre, IAEA Vienna, on Main challenges for an effective preparedness and response to nuclear or radiological emergencies has reiterated that nuclear and radioactive applications and facilities are subject to strong safety and security requirements. However, experience showed that, despite this, accidents or malicious acts may lead to emergencies where the population may be subjected to radiation exposure. Experience shows that nuclear or radiological emergencies may have important consequences and are complex to manage, requiring strong preparedness activities to deliver sound response. In his opinion there are aspects that make this kind of emergencies being particularly challenging as:

-They happen rarely, which makes more difficult keeping the response arrangements effective;

-Radiation is not well known at all by the public and even by managers and experts in different technical or scientific fields. There is a lot of misinformation that leads to exaggerated fears that creates a tendency in emergency managers and public opinion to over-react in response to radiation related emergencies;

-These emergencies, if affecting nuclear reactors, involve complex physical phenomena. This makes assessment of the situation and likely evolution quite difficult and involving significant uncertainties, especially during the initial phase of the emergency;

-They may produce transboundary consequences and raise significant public opinion concern at the international level.

All these features raise relevant challenges to proper preparedness for and response to nuclear or radiological emergencies, as the recent experience of Fukushima has shown, therefore he advised to conduct training programmes for medical physicists in different parts of world to deal with such an eventuality.

Prof. A. Fukumura from National Institutes for Quantum and Radiological Science and Technology (QST), National Institute of Radiological Sciences (NIRS), Japan presented his experience in the “FUKUSHIMA DAI-ICHI nuclear power plant accident – Challenges to medical physicists in Japan’’. He made it clear that medical physicists (MPs) and radiological technologists having in-depth knowledge of radiation dosimetry, including medical dose measurements and estimation. They are possibly expected to be potentially able to support and involved in nuclear and radiological emergency (NRE) situation. However, in a major NRE event such as Fukushima Dai-Ichi nuclear power plant accident, these professionals can face many kinds of difficulties that they have to deal with, without enough knowledge and experience in the NRE situation. He informed that after the Fukushima accident, the MPs of NIRS were involved in primarily three kinds of activities such as (a) development of external dose estimation system for Fukushima residents, (b) a survey on actual situation of Japanese MPs with regards to the accidents and (c) collaboration with IAEA to develop a training package for MPs in support of NRE. His presentation mainly described results of the survey on actual situation of Japanese MPs with regards to the accidents. One year after the accident, the survey was carried out for the members of Japan Society of Medical Physics (JSMP) to obtain information on activities and role of MPs for the accident. The survey consisted of simple questionnaire through internet. The principal results of his study are as follows:

The 43 % of respondents were involved in activities related to the accidents and the principal activities of MPs were:

1. Radioisotope contamination survey for residents,
2. Risk communication to the public and
3. Radioactivity measurements in environment.

The respondents thought that MPs should contribute to risk communication to the public and preparation of FAQ and/or material.

His study results showed that the main roles of MPs for the accidents are not only radiation measurements but also risk communication to the public. Even though the external dose estimation has shown the maximum dose of 19 mSv under a limited condition, still residents feared the effect of low dose radiation excessively. Some of the residents worried about the future health of their children and refusal to be exposed to X-ray in a medical examination. The study reports that the risk communication to the public was quite important and then MPs are expected to provide suitable scientific information with their expertise. He recommended for multidisciplinary training and/or text book including communications as well as radiation protection, biology and ecology etc. should be prepared for MPs to play an important role in a major NRE event.

In a presentation by Dr. Dhruv Kumar Nishad from Institute of Nuclear Medicine & Allied Sciences (DRDO), GoI on “alternative strategies for radioactivity decontamination” explained the radioactive contamination as unwanted radioactive materials on or inside the human body. Radioactive contamination usually spreads when radioactive material is released into the environment and leads to the exposure of living beings and non-living area. Removal of radioactive elements from an individual, object, or place is called decontamination. He emphasized that radioactive material from the body should be removed as soon as possible to lower the risk of harm from radiation exposure and reduce the chance of spreading contamination to others. At INMAS (DRDO) they have developed many novel, effective and economical approaches for radioactivity decontamination from skin, wound, body orfices and non living surfaces. Decontamination products developed by INMAS includes; Dermadecon (skin decontamination kit), Shuddhika (skin decon field kit); Remocon decontamination wipes, Peel off formulations, decontamination lotions and decontamination gel formulations. Apart from radioactivity decontamination many approaches for management of radioactive spill and contaminated biofluid/biowaste management has also been developed by his group. They have performed detailed safety and efficacy of these approaches and established through in vitro and in vivo studies and proven to have potential as the alternate strategies for radioactivity decontamination.

Dr N K Chaudhury from Biodosimetry Division, Institute of Nuclear Medicine and Allied Sciences, DRDO, GoI has presented his experience in ‘’Biodosimetry preparedness for radiological emergency in Indian context’’. He explained that radiation incidents or accidents depending upon the nuclear accident magnitude scale have long lasting impacts on society and country. The effective management requires availability of all necessary resources and even though a single country may not be able to manage. He mentioned that India with large population and expanding nuclear capability, management of radiation emergency therefore will be most difficult and complex even if all necessary infrastructures are in place. Biodosimetry laboratories have special role in post accident management. Medical management of exposed individuals will require information on absorbed radiation dose at the earliest. This diagnostic information will guide clinician for treatment, prediction of both short and long term health consequence absorbed radiation and counseling. In his viewpoint biodosimetry lab will estimate absorbed dose to individuals by using few ml of peripheral blood samples for processing and the method is dicentric chromosomal assay (Gold standard). Simultaneous assessment of clinical and hematological investigations will continue for initial treatment and confirmation of exact absorbed dose will guide clinicians for change of treatment protocol if required so that acute health effects are prevented. According to him large number of laboratories will be required and networking both within and internationally, therefore biodosimetry laboratory of Institute of Nuclear Medicine and Allied Sciences, has initiated a step in this direction for enhancement medical preparedness of radiation emergency.

A panel discussion on ‘’Role of healthcare professionals in radiological emergencies: What is done? What needs to be done?’’ marked the end of the scientific sessions. Prof R Ravichandran (Medical Physicist, India) moderated the panel discussion. Ramon de la Vega (IAEA), Hugh Wilkins (IPEM), Prof R Charry (Nuclear Scientist, Canada), Dr Nagesh N Bhatt (Biodosimetry expert, BARC, India) and Dr J K Bhagat (Nuclear Medicine Physician, India) were the panellists. From the discussions it is clear that in case of nuclear and radiological emergency, the role of trained medical physicists for effective and efficient mitigation of radiation hazards is indispensable.

The scientific proceedings of the conference have been published as the RUHS Journal of Health Sciences (RUHSJHS) supplementary abstract issue. (Available at: www.ruhsjhs.in). An e-souvenir of the conference was also released.

IV. CONFERENCE AWARDS AND CONCLUSION

A best oral presentation session which included 9 oral presentations and a best poster presentation session which included 12 poster presentations were an important part of the scientific programme. This was arranged to encourage and motivate students and young professionals to involve actively and contribute in academic and research work. Two prizes each comprising of certificate of appreciation and cash award was distributed to the winners

Best Poster Awards:
First Prize: Ms. Akanchha Tripathi, INMAS, DRDO, Delhi
Second Prize: Mr. Lalit Panwar, Defence Laboratory, DRDO, Jodhpur

Best Oral Awards:
First Prize: Mr. Sandeep Chaudhary, INMAS, DRDO, Delhi
Second Prize: Mr. Ram Milan Sahani, Defence Laboratory, DRDO, Jodhpur

Cultural and entertainment night was arranged on first two days of the conference where students as well as professional performers showcased the rich cultural heritage of Rajasthan. It was highly appreciated and thoroughly enjoyed by everyone.

The organizers highly appreciate the active participation, cooperation and support of the organizations IAEA, AFOMP, RUHS, AMPI, IOMP, AAPM, ICTP, MEFOMP, INS, AERB, NMPAI, IARP, INSA, ISRB, NPCIL-RAPP, BARC, INMAS-DRDO, DLJ-DRDO, IPEM and DAE-GOI and everyone involved in this conference.

ICONRADEM-2019 have enabled us to know the preparedness required for radiological/nuclear emergencies, the techniques of mitigation that already exist, the research going on across the globe to make better strategies to counter the radiation emergency effects, and the role of healthcare professionals, medical physicists, local public and administration in the face of an emergency. The role of the defense sector in managing any radiological or nuclear emergency and their research in this regard was also stressed upon.

The Medical Physicists have been very efficiently planning the radiation treatment for cancer patients, corroborating quality assurance of equipment and procedural protocols, researching on new diagnostic and treatment modalities, ensuring radiation protection and safety of patients and personnel in various streams of healthcare but have not yet taken the lead in field of radiological emergency mitigation and management. It is the need of the hour and we have tried our best to cover each and every aspect related to safety and emergency mitigation in this conference. We are confident that ICONRADEM-2019 will prove to be a milestone for the medical physics community and help us all in developing ourselves as radiation emergency experts. More such activities will be planned to nurture and promote the spirit of being an efficient radiological emergency expert to reach all medical physicists.

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2. T. Berris, et al., Nuclear and radiological emergencies: Building capacity in medical physics to support response. Physica Medica. 42. 93-98. 10.1016/j.ejmp.2017.09.117.
3. Berris T, Nusslin F, Meghzifene A et al., Nuclear and radiological emergencies: Building capacity in medical physics to support response. Physica Medica, European Journal of Medical Physics Oct 2017 42 93-98 https://www.physicamedica.com/article/S1120-1797(17)30436-2/abstract .

Corresponding author:

Author: Prof. Arun Chougule, Jaipur, India
Email: arunchougule11@gmail.com

Photos from ICONRADEM-2019

Dr Sudhir Bhandari Principal SMSMC Jaipur inaugurating the public awareness exhibition

Dr Pradeepkumar K S (BARC, Mumbai) and V K Jain (RAPP, NPCIL, Kota) demonstrating the emergency response and monitoring systems

Ramon de la Vega (IAEA, Austria)

Dr Brad Cassels (Australia)

HOW TO

EXPERIENCE ON PERFORMANCE MEASUREMENTS OF POSITRON EMISSION TOMOGRAPHS: NEMA NU2 – 2018

P Pasawang[1], T Sontrapornpol[1], A Krisanachinda[2]

[1]King Chulalongkorn Memorial Hospital, [2]Chulalongkorn University, Bangkok, Thailand

I.INTRODUCTION

The major role and responsibility of the clinically qualified medical physicist, CQMP in nuclear medicine[1] are the installation design, technical specification, acceptance and commissioning of equipment, including the establishment of criteria for acceptable performance. The others are the radiation safety and protection of patients, staff and general public, patient internal dosimetry, optimization of the physical aspects of the diagnostic procedure, quality management of the physical and technical aspects of nuclear medicine and collaboration with other clinical professionals. CQMPs have the leading role in preparation of equipment specification according to the needs of nuclear medicine facility. Following the installation of new equipment, CQMPs are responsible for specifying the basic standards to be applied for the acceptance and subsequent commissioning. They ensure that all units and systems function according to their technical specifications and guide on any deviation of equipment performance from acceptable criteria. In this study, after the installation and calibration of the positron emission tomographic system, the CQMPs perform the acceptance test using NEMA Standards Publication NU 2-2018[2]. The performance measurements of the PET system consist of the tomographic resolution, system sensitivity, the scatter fraction, count losses and randoms, the image quality and time- of- flight resolution.

II.MATERIALS AND METHODS

Positron Emission Tomograph system manufacturer Siemens Healthineers Model Biograph mCT 64 had been tested after the installation of the hardware and software, by the team of clinically qualified nuclear medicine medical physicists, local nuclear medicine technologists and Siemens service engineers. Performance measurement of the PET systems follows NEMA, National Electrical Manufacturers Association, Standards Publication NU-2 2018 which consist of

1. Spatial resolution

The purpose of the spatial resolution test is to measure the full width at half maximum (FWHM) and the full width at tenth maximum (FWTM) of the image reconstructed point spread function (PSF) of ^{18}F. The method starts from the preparation of a point source of ^{18}F at the activity of 2.22 MBq (60 µCi) at small quantity of less than or equal to 1 mm in a capillary tube and fix it in the FOV at six positions of (0,1,1/8FOV$_z$), (0,1,1/2 FOV$_z$), (0,10, 1/8 FOV$_z$), (0,10,1/2 FOV$_z$), (0,20,1/8 FOV$_z$), and (0,20,1/2 FOV$_z$). The acceptable offset on x, y axes is $\pm$2 mm for the source at 1cm offset, and $\pm$5 mm for the sources at offset 10 and 20 cm, and on z axis is $\pm$0.25 mm.

III RESULTS

NEMA NU-2 2018 Resolution Test

Image Size: Full (No Zoom)

Average Net Trues: 2,701,710.3 counts

Corrections applied: normalization, dead time, radial-arc-correction, decay-correction, frame-length-correction, FORE and Randoms-subtraction

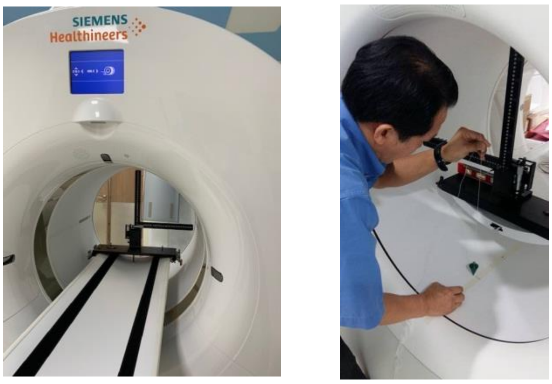


Figure 1: Position of point source in capillary tube for measurement of spatial resolution

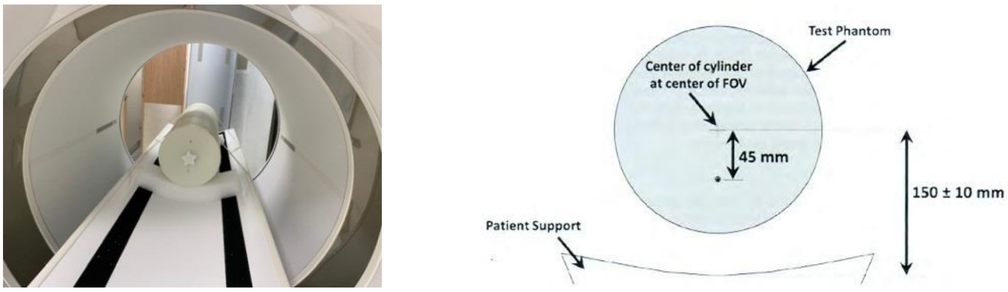
Table 1: The spatial resolution determined from the full width at half maximum (FWHM) and the full with at tenth msximum (FWTM) of ^{18}F activity 2.22 MBq(60 µCi)

Radial Distance	Direction	FWHM (mm)	FWTM (mm)	FWHM System Specification (mm)
1 cm	Radial	4.32	8.88	4.5
	Tangential	4.69	9.37	
	Axial	4.51	10.05	4.7
10 cm	Radial	5.61	10.81	5.2
	Tangential	4.92	9.50	
	Axial	6.18	12.67	6.1
20 cm	Radial	6.38	11.82	6.1
	Tangential	5.75	10.58	
	Axial	8.07	9.53	8.3

2. Scatter fraction, count loss and randoms

The purpose of this procedure is to measure the relative system sensitivity to scattered radiation. Scatter is expressed as the scatter fraction. SF, for the entire tomograph. Another purpose of this test is to measure the effects of system dead time and the generation of random events at several levels of source activity. The true event rate is the total coincident event rate minus the scattered event rate and minus the randoms event rate. The test phantom is a solid circular cylinder made of polyethylene with outside diameter of 203± 3 mm.and the length of 700± 5 mm. A 6.4mm hole is drilled parallel to the central axis of the cylinderat the radial distance at 45 mm

Source preparation and acquisition protocol The line source was filled with ^{18}F 1441.228 MBq (38.952 mCi), volume 5.5 cc, and inserted into the cylindrical scattered phantom. The phantom was centered in the transaxial field of view, and also in the axial field of view using a CT scout scan. The total number of acquired frames was 45.



A B

Figure 2 A) The scattered phantom during data acquisition B) Drawing of a scattered phantom and a hole for inserted 700 mm length of polyethylene line source.

Count rates and noise equivalent count rate (NECR). For each acquisition j, the system event rate can be calculated as the followings:

a. The total event rate $R_{TOT,j}$:

$$R_{TOT,j} = \frac{1}{T_{acq,j}} \sum_i C_{TOT,i,j}$$

b. The true event rate $R_{t,j}$:

$$R_{t,j} = \frac{1}{T_{acq,j}} \sum_i \left(C_{TOT,i,j} - C_{r+s,i,j}\right)$$

c. The random event rate $R_{r,j}$:

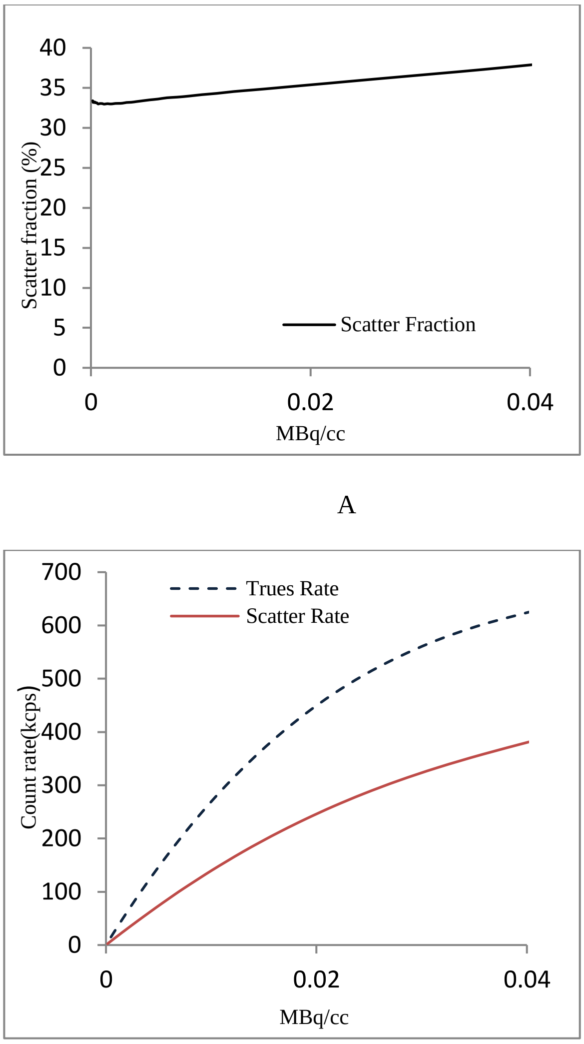
$$R_{r,j} = \frac{1}{T_{acq,j}} \sum_i C_{r,i,j}$$

d. and the scatter event rate $R_{s,j}$:

$$R_{s,j} = \frac{1}{T_{acq,j}} \sum_i \left(C_{r+s,i,j} - C_{r,i,j}\right)$$

The system scatter fraction can be determined from the equation

$$SF = \frac{\sum_i \sum_{j'} C_{r+s,i,j'}}{\sum_i \sum_{j'} C_{TOT,i,j'}}$$

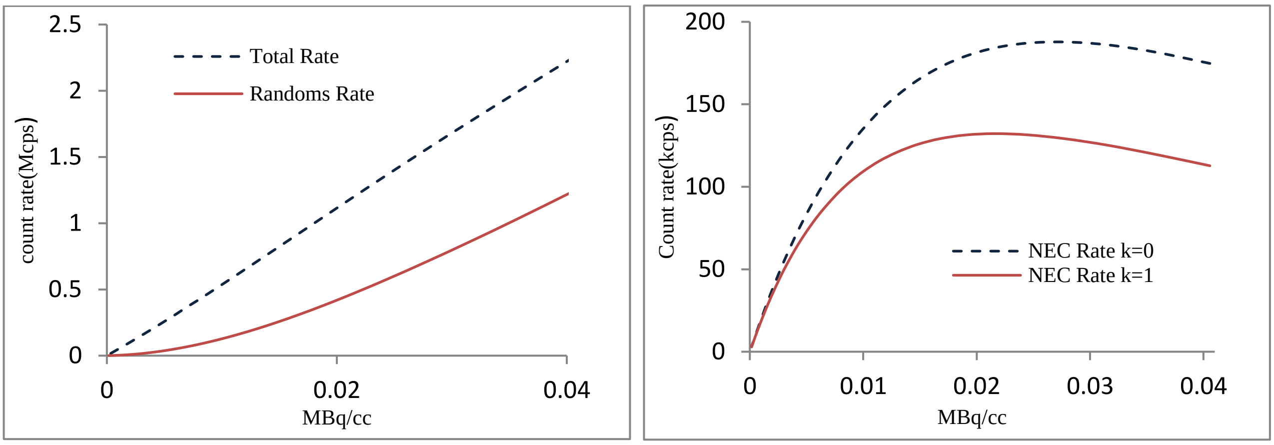


A

B

Figure 3 A) A graph plot between Scatter fraction and the average activity concentration (MBq/cc)

B) A graph plot between true and scatter counting rate (cps) and the average activity concentration (MBq/cc)



A B

Figure 4 A) The graph plot between Total and Randoms Rate and average concentration (MBq/cc)
B) The graph plot between Noise Equivalent Count Rate and average concentration (MBq/cc)

Table 2: Calculated and measured peak true count rate, peak NECR, and scatter fraction

Quantity	Value	System Specification
Calculated Peak Trues Rate, cps	657	610@< 40 kBq/cc
Calculated Effective Activity Concentration	53.9 kBq/cc	
Measured Peak Trues Rate, cps	627	
Measured Effective Activity Concentration	40.6 kBq/cc	
Calculated Peak NEC Rate, cps	188	180@< 28 kBq/cc
Calculated Effective Activity Concentration	27.2 kBq/cc	
Measured Peak NEC Rate, cps	188	
Measured Effective Activity Concentration	278 kBq/cc	
Scatter fraction (%)	33.3	37

3. Sensitivity

The purpose of the tomographic sensitivity relates the count rate measured by the PET scanner to the amount of radioactivity within the FOV. The sensitivity measurement is therefore to determine the rate of detected true coincidence events per unit of radioactivity concentration for a standard source configuration.

Source preparation and acquisition protocol

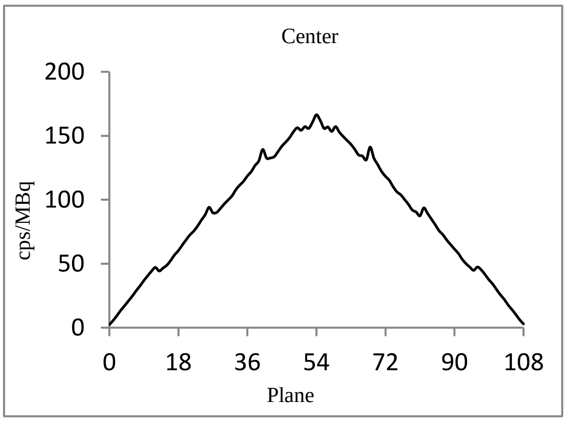
An innermost polyethylene tube at 700± 20 mm. length was filled with ^{18}F solution of 4. 421MBq (119 µCi). It was then inserted into the bore of the sensitivity phantom that consists of five concentric metal cylinders, and mounted on the scanning bed at the center of the transverse axial field of view. A series of acquisitions was then performed, each lasting 5 minutes (300 seconds). The aluminum sleeves were removed one at a time, and the phantom was scanned with 5, 4, 3, 2 and 1 cylinders. Each scan was also repeated at a distance of 10 cm from the center of the field of view.

Table 3: Sensitivity phantom of 5 sleeves at various inside and outside diameters. .

Sleeve No.	Inside Dia.(mm)	Outside Dia.(mm)	Length(mm)
1	3.9	6.4	700
2	7.0	9.5	700
3	10.2	12.7	700
4	13.4	15.9	700
5	16.6	19.1	700

Figure 5 Sensitivity phantom 5 layers of metallic cylinder inserted by polyethylene tube of 700± 20 mm filled with ^{18}F solution. Acquisitions of 5,4,3,2 and 1 layers at center and 10 offset of FOV

Results



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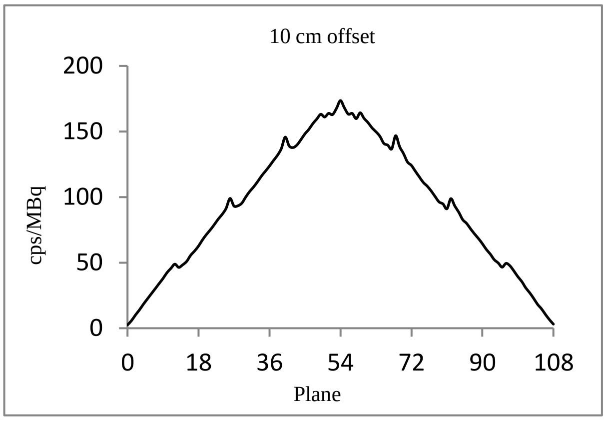
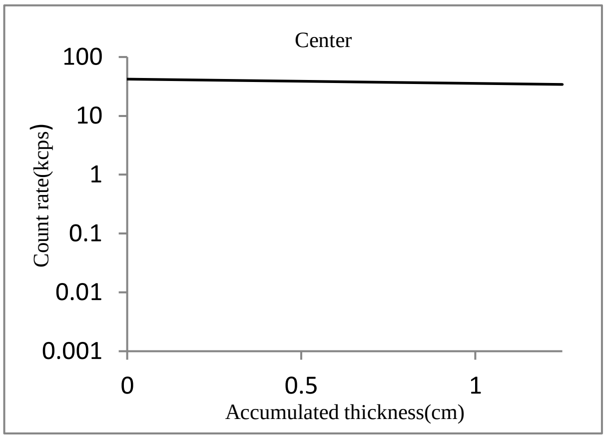


B

Figure 6 A) Axial sensitivity profile at center of FOV B) at 10 cm off center



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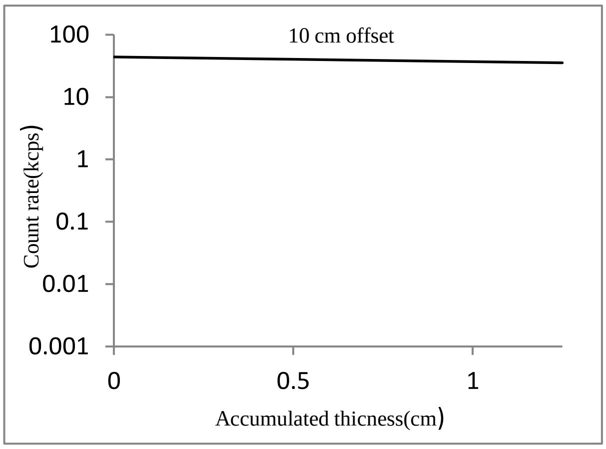

B

Figure 7 A) Semi Log graphs of sensitivity at center of FOV B) Sensitivity at 10 cm off center (right)

Table 4: System sensitivity of ^{18}F at center FOV and 10cm from center FOV

	Center (0 cm) (%Diff)	Offset (10 cm) (%Diff)	System Specification
System Sensitivity (STOT) (cps/MBq)	9616.4 (5.72%)	10040.5 (3.6%)	10200
Detector Efficiency (%)	0.96	1.0	
Effective mu (cm^{-1})	0.167	0.173	
Lower Level Discriminators (keV)	435	435	
Upper Level Discriminators (kev)	650	650	
Source Length (cm)	70.40	70.40	
Initial Activity (MBq, mCi)	4.20, 0.11	3.34, 0.09	
Average Net Trues (Counts)	9744189.2	8031871.2	

4. Image quality

The purpose of this measurement is to produce images simulating those obtained in a total body imaging study with both hot and cold lesions. Spheres of different diameters are imaged in a simulated body phantom with non-uniform attenuation; activity is also present outside the scanner. Image contrast and background variability ratios for both hot and cold spheres are used as measures of image quality. In addition, the accuracy of the attenuation and scatter corrections is determined from this measurement.

Methods

Data has been acquired and analyzed according to the NEMA NU 2-2018 Standard Publication, Section 7 (Image Quality). The NEMA NU 2-2018 protocol states the concentration of the background activity concentration in the phantom should be 5.8 kBq/cc, corresponding to an injected dose of 460 MBq for a total body study; however, a lower injected activity may be used if recommended by the manufacturer.

Twelve 37 mm diameter circular ROIs were drawn throughout the background at a distance of 15 mm from the edge of the phantom. The percent contrast (Q_H) in hot sphere can be calculated from

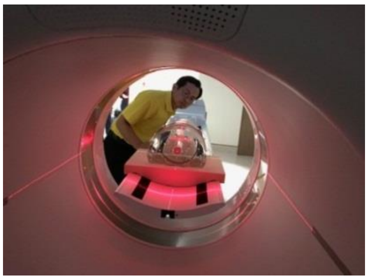

Figure 8 Setup for IEC/2001 body phantom and line source in scattered phantom for image quality acquisition

$$Q_H = \frac{(C_{hot} - C_{bg}) / C_{bg}}{(a_{hot} - a_{bg}) / a_{bg}} \times 100$$

where C_{hot} is the average counts in the ROI for each hot sphere, C_{bg} is the average counts of the twelve 37 mm in the background ROI, a_{hot} is the radioactivity concentration in the hot spheres and a_{bg} is the activity concentration in the background. The percent contrast in cold sphere (Q_C) can be calculated from

$$Q_C = \frac{(C_{bg} - C_{cold})}{C_{bg}} \times 100$$

where C_{cold} is the average of the counts in the ROI for each cold sphere. The percent background variability (N) can be calculated from

$$N = \left(SD/C_{bg}\right) \times 100$$

where SD is the standard deviation of the background ROI counts for sphere. To measure the residual error in scatter and attenuation corrections, the relative error (ΔClung) in percentage units for each slice can be calculated from

$$\Delta C_{lung} = \left(C_{lung} / C_{bg}\right) \times 100$$

where C_{lung} is the average counts in the ROI placed over the lung insert and ???

Acquisition Parameters

Emission Imaging Time	226 s
Axial step size	0 cm
Axial Imaging Distance Simulated	100 cm

Reconstruction Parameters

Correction Applied	NORM, DTIM, SCAT, DECAY, RAN
Reconstruction Method	PSF+TOF 3i21s, XYZ Gauss 5.00
Pixel size	4.07 mm
Imaging Matrix Size	200 x 200
Slice Thickness	3 mm

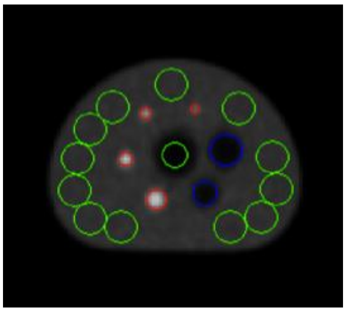

Figure 9 The torso phantom image and placement of ROIs for quantitative analysis

Result

Source-Background Ratio 4:1

Background Concentration	7.51 kBq/cc
Hot Sphere Concentration	32.40 kBq/cc 226 sec

Table 5: Image quality of IEC Phantom in terms of percent contrast of various sphere diameter and percent background variability

Sphere diameter (mm)	Contrast (%)	Background variability (%)
Hot 10	29.91	3.22
Hot 13	47.03	2.97
Hot 17	54.42	2.58
Hot 22	64.87	2.22
Cold 28	67.56	1.87
Cold 37	74.96	1.61
Average lung residual error (%)	14.28	

Source-Background Ratio 8:1

Background Concentration	5.8 kBq/cc
Hot Sphere Concentration	46.4 kBq/cc 226 sec

Table 6: Image quality of IEC Phantom in terms of percent contrast of various sphere diameter and percent background variability

Sphere diameter (mm)	Contrast (%)	Background variability (%)
Hot 10	45.87	3.14
Hot 13	62.87	2.80
Hot 17	68.54	2.39
Hot 22	77.54	2.07
Cold 28	68.28	1.75
Cold 37	75.88	1.44
Average lung residual error (%)	13.98	

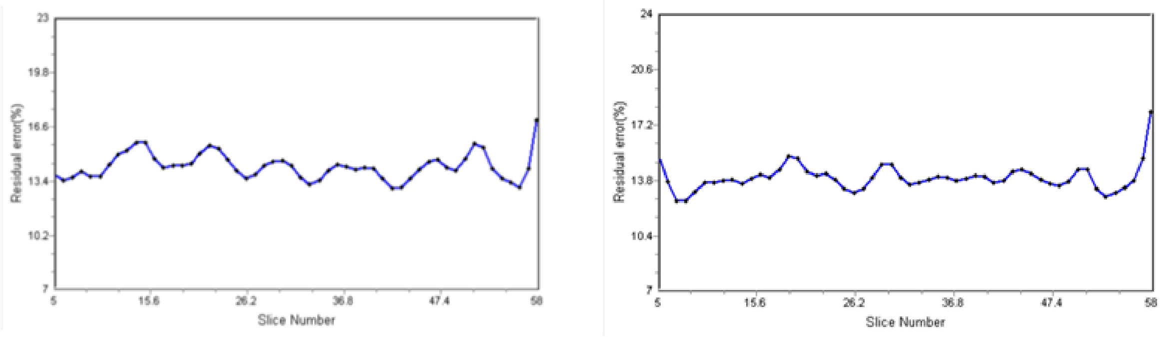

Figure 10 A) The slice number and lung residual error (average 14.28%) in Source-Background ratio 4:1
B) The slice number and lung residual error (average 13.98%) in Source-Background ratio 8:1

IV DISCUSSION AND CONCLUSION

The acceptance test of PET system is a series of measurement performed by the clinically qualified medical physicists in nuclear medicine to verify that the system conforms to vendor specification. The purposes of the tests are:

- To ensure that equipment performs to the manufacturer's specification prior of final payment for the equipment
- To establish the baseline performance of the equipment to which future quality tests will be compared
- To provide data that can give guidance in the determination of optimal operating parameters for routine use
- To ensure that the PET system meets regulatory requirement for radiation safety.

Before the acceptance test, all calibrations required as part of the installation and commissioning must be performed to ensure that the PET system is operating as expected. It should be verified that the daily QC had been passed and there are no problems apparent in the sonograms.

Acceptance test had been completed within three days of the test on spatial resolution, sensitivity, scatter fraction, count losses and randoms measurement and finally, the image quality. Time of flight resolution had been acquired to PET scanner operating in the TOF mode. Characterization of timing resolution is an important test that determines the capability of the system to estimate the difference in time of arrival of the two coincidence photons, and hence obtain information about the likely location of the annihilation along the LOR. The result of the test is in completed according to some errors in the correction files.

Tolerance levels:

Spatial resolution

Calculated FWHM should not exceed the specification given by the vendor. An appropriate tolerance criterion for FWHM is:

$$\mathrm{FWHM}_{\mathrm{observed}} < 1.05\ \mathrm{FWHM}_{\mathrm{expected}}$$

$$\mathrm{FWTM/FWHM} = 1.82\text{-}2.0$$

Sensitivity

The system sensitivity should be equal to or greater than the vendor's specification.

$$\mathrm{Sensitivity}_{\mathrm{measured}} > 0.95\ \mathrm{Sensitivity}_{\mathrm{expected}}$$

Scatter fraction, count losses and random measurement

Calculated scatter fraction, peak NEC and peak radio-activity concentration for peak NEC should meet or exceed the vendor's specification.

$$\mathrm{SF}_{\mathrm{observed}} < 1.05\ \mathrm{SF}_{\mathrm{expected}}$$

The NEC curve, NEC peak value and peak radioactive concentration should be reported for future comparison.

Image quality

There are no manufacturer specifications; the reference value should be set. A 5% tolerance criterion with respect to the baseline established values for all image quality parameters based on 3 measurements is recommended.

Timing resolution

Measured values of timing resolution, R_T, should not exceed the specification given by the vendor. The reference values, tolerances and action levels should be set. An appropriate tolerance criterion for timing FWHM is: $R_{T\ measured} < 1.05\ R_{T\ expected}$. Corrective action: The timing resolution is expected to be a highly constant parameter. If the tolerance criteria are exceeded, the results should be checked and the testing procedure repeated to confirm the finding. If the result is still outside the tolerance criteria, a recalibration of the system should be performed by appropriate service personnel.

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Development of a Deep Learning Model for Chest X-Ray Screening

W.H. Hsu[1], F.J. Tsai[2], G. Zhang[3], C.K. Chang[4], P.H. Hsieh[5], S.N. Yang[5], S.S. Sun[6], KenYK Liao[7], Eddie TC Huang[5,7,8,*]

[1] Division of Pulmonary and Critical Care Medicine, China Medical University Hospital and China Medical University, Taichung, Taiwan
[2] Department of Medical Research, China Medical University Hospital, Taichung, Taiwan
[3] Department of Radiation Oncology, Moffitt Cancer Center, Tampa, FL, USA
[4] Department of Medical Imaging, Chang Bing Show Chwan Memorial Hospital, Changhua, Taiwan
[5] Department of Biomedical Imaging and Radiological Science, China Medical University, Taichung, Taiwan
[6] Department of Nuclear Medicine and PET Center, China Medical University Hospital, Taichung, Taiwan
[7] Artificial Intelligence Center for Medical Diagnosis, China Medical University Hospital, Taichung, Taiwan
[8] Department of Bioinformatics and Medical Engineering, Asia University, Taichung, Taiwan

Abstract— **Developed in recent years, deep neural network becomes the best method for rapid analysis of advanced features and automation in medical image analysis. As a second clinical opinion provided by artificial intelligence (AI), it can reduce the physician's workload and reduce misjudgment. This study collected 365,892 chest X-ray images and clinical diagnosis reports through retrospective analysis, and compared five different input image sizes and images that generated by clinical labeling pre-processing in the classification model building and testing. An AI trained chest X-ray abnormal interpretation model by using DesNet121 neural network gave a test accuracy of 0.875. Deep neural network shows the potential of accountable methods to help lung classifications for normal and abnormal screening in clinics.**

Keywords— **Deep learning, Chest X-Ray**

I. INTRODUCTION

The 2016 pneumonia mortality statistics ranked the top three causes of death in Taiwan. Besides left and right atrium, ventricular enlargement, aortic aneurysm, calcification or exfoliation couldn’t be ignored in cardiomegaly diagnosis, which are frequently the disorders or diseases that cause heart failure (HF), often distinguished by severity level. Therefore understanding the complex interactions between the cardiopulmonary system is an indispensable part of the treatment of these patients [1]. Furthermore atherosclerosis is one of the major potential pathological processes leading to heart attack (coronary heart disease) and stroke (cerebrovascular disease) [2].

Because of its features and functions that reveal unforeseen pathological changes, non-invasive, low radiation doses, etc. [3], chest X-ray is the first choice for diagnosis pneumonia and other lung or heart diseases [4]. The most common diagnostic findings from chest X-ray images include pulmonary infiltration, abnormalities in catheter and heart size or contour [5]. Chest X-ray plays an important key role in clinical care and epidemiography research [6, 7]. However, detect and diagnose diseases in chest X-ray is a challenging mission that rely heavily on the clinical diagnostic experience of a professional radiology physician.

Beside X-ray in chest examination, another method is computed tomography (CT). CT also uses X-ray to penetrate the human body, and the signal data received by photodetectors being reconstructed to generate 3-dimensional (3D) images of the body. Today, CT data can provide accurate clinical diagnosis [8]. However, sometimes CT imaging needs to inject Iohexol to help highlight the disease site, which could cause serious allergy for some patients. Therefore, before the CT examination, patients must pass drug allergy test or risk assessment based on related medical history. Furthermore, patients who take CT examination are expected to receive much higher radiation dose than patients who take chest X-ray imaging, and the CT examination time is much longer. Because of these restrictions, chest X-ray is still the most used method in clinical examinations, including pneumonia and other lung and heart diseases [9]. Chest posterior-anterior (PA) X-ray imaging is the most often used chest X-ray photography technique.

The development of artificial intelligence (AI) had been frustrated in several generations until ImageNet classification competition in 2012 in which AlexNet top-5 error rate was 10% lower than previous year's champion [10]. Since then, convolutional neural network (CNN) has been received strong attention from researchers. AI is now widely applied, and its algorithms include deep learning, machine learning and natural language processing. In recent years’ machine learning has been used in automatic detection, extraction and classification of tumors [11-14]. The newest algorithm improvement of deep learning and very large database can surpass professional personnel in medical image missions, including diabetic retinopathy detection, skin cancer classification, arrhythmia detection and hemorrhage identification [15-18].

Automated diagnosis of thoracic diseases gets highly attention in recent years. Professor Lakhani used CNN of deep learning, and developed automatic classification of tuberculosis disease from chest X-ray [19]. Professor Huang used the algorithm to find features of CT images to detect and diagnose pulmonary nodules [20]. Moreover, some people used the data of Open-I study on the performance of various convolutional structures on difference of abnormal diseases [21]. Subsequently, Professor Wang released ChestX-ray-14, and it had further development in thorax diseases diagnosis. ChestX-ray-14 had a much larger amount of data than previous data of the same type, and they also benchmarked different CNN frame pre-trained on ImageNet [22]. Subsequently, based on this data set, some people developed a method, CheXNet, that was better than the previous algorithm in diagnosis of 14 kinds of chest diseases [23, 24]. However, the best accuracy of all the results was only about 80% so far, and obviously there is still room for improvement.

Traditional computer-aided methods use algorithms to assist disease diagnosis. Deep learning methods should be doing better. Professor Li compared deep learning and feature-based statistical learning in breast density assessments, which demonstrated that deep learning was better than feature-based statistical learning [25]. Anticipating the application of deep learning to the detection of breast density in the future, and applying the model to the prediction of breast cancer risk, it is expected once again to enhance the feasibility of using AI in the medical fields. Although chest X-ray and computed tomography are the major tools of diagnosis in thorax, according to the estimation of World Health Organization (WHO), there are two-third people couldn't get radiodiagnostic resources in the world [26]. Even through there are imaging devices available, there is a lack of experts who can interpret X-ray images, resulting in increased mortality from treatable diseases [27]. With expert-level automation, this research aimed at the evaluation of the effectiveness and feasibility of deep learning neural network applications in chest X-ray interpretation through the combination of AI and medical cross-domain. The technology developed in this research project was hoped to improve health care services in the future, and eventually provide diagnostic and treatment help in areas where the number of professional radiologists is limited, while giving the region the opportunity to learn medical imaging expertise.

II. MATERIALS AND METHODS

Data collection: This research retrospectively collected data from the Hospital of China Medical University, including a total of 365,892 subjects in two years between 1/1/2017 and 12/31/2018, for the model training and test. And a total of 1,883 data in January 2019 were used for the final model evaluation. The data for each case included one chest X-ray image and a corresponding radiology report. The original image was in Digital Imaging and Communications in Medicine (DICOM) format. There were no gender and age restrictions in the data collection. This research was approved by the Institutional Review Board (IRB: CMUH106-REC1-092).

Exploratory data analysis (EDA): The 365,892 radiology reports of chest X-ray were initially filtered through text mining to select key words include PA View or Chest PA. There were 80,246 chest X-ray and reports with PA View or Chest PA. At the same time, in the "Protocol Name" of Dicom Header in the image, the chest X-ray image of the Posterior to Anterior View (PA View) was selected by "Chest PA", and the unsuitable image data, such as AP View and KUB, were excluded. Comparing reports and images, a total of 44,430 chest X-ray were selected for the study, as shown in Table 1.

Table 1 Data selection

Data File Name	Number of reports	Report included ”PA View” or ”Chest PA”	Corresponding image with Protocol Name included ”PA View”
106_1	74549	20802	12638
106_2	81697	20762	6310
106_3	29758	4706	564
107_1	63927	11125	8479
107_2	30210	2843	1623
107_3	85751	20008	14816
Total	365892	80246	44430

Subsequently, the normal and abnormal X-ray images were classified by the radiologist. The normal data judgement was based on the report. There must be no additional findings. For example, like metal necklace, artificial implant and old fractures etc. would be classified as abnormal data. Finally, 9,322 chest X-ray data were classified as normal and 1,935 chest X-ray data as abnormal. These 11,257 data sets were used as the first preliminary test for mini database. Through Python language, the most used Scilit-Learn modules of KFold clustering was applied to divide the data into 10 equal parts with the same proportion. Among it, 7,867 were selected as training data sets, 2,257 for validation, and 1,132 as reference data for testing the merits of the model. Subsequently, the 1,883 cases collected in January in 2019 were filtered using the same analysis, resulted in the selection of 1,721 evaluation data for the final output models. This set of data was not applied in model training, but only used in the testing of the final model. The study flow chart is shown in Figure 1.

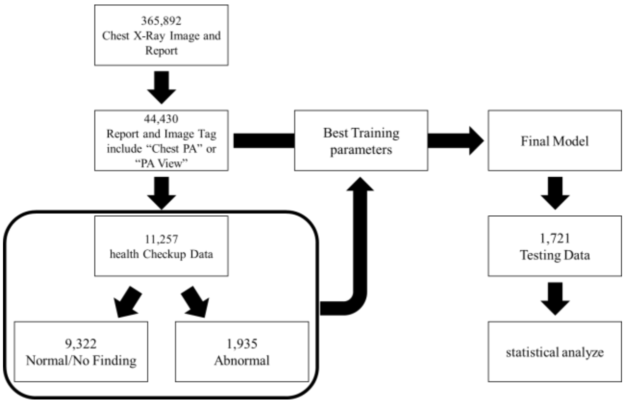


Fig. 1 Research process flow chart

Image Preprocessing: The Hospital of China Medical University has multiple institutions, including LIFI medical building, Children Hospital, rehabilitation medical building, MEIDE medical building, cancer center building and critical care center building. As a result, different brands of X-ray machines are used in the department of radiology in different buildings. The X-ray image machines are listed in Table 2. Because of the different equipment, different X-ray image sizes were common. Even with the same machine, different X-ray image sizes were also common because of different operations. In this study, all X-ray images were readjusted to the size of 224×224 or 299×299 pixels following the advice of Neural Networks model. In the same time, through DICOM header information, the contrast and brightness correction was also performed. The grey scale in X-ray images was converted to chromatic colors for the software analysis.

Table 2 X-ray machine brands in the hospital

Brand	Model
TOSHIBA	KXO-32R
TOSHIBA	KXO-50R
TOSHIBA	MRAD-A50S
TOSHIBA	MRAD-A80S
SHIMADZU	UD150L-RII
SHIMADZU	UD1506-RII

In addition to the purpose of image size standardization for the input, in the preliminary analysis, the annotation markers of the chest X-ray images were eliminated in the image resizing process. An annotation marker eliminated image is shown in Figure 2.

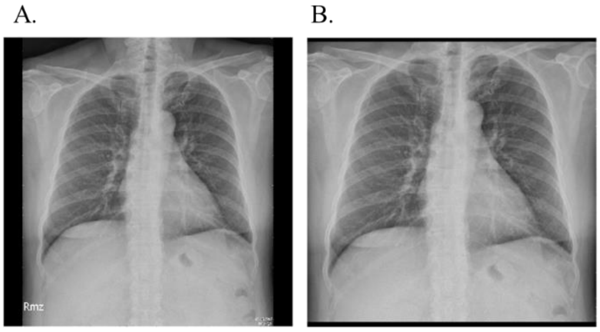


Fig. 2 A chest X-ray image after elimination of Annotation Marker. A. The original image, B. Image with cropping

Deep Learning Model: Convolutional neural networks are the result by learning how the human brain works. The nerve cells exist in a human brain. The nerve cell uses synapsis to connect and receive external signal and pass to next neurons. Every neuron has different ability of conversion and with the information transfer and collection, human brain has the ability of thinking and judgement. Because of the rise of deep learning in recent years, CNN offered a lot of help in image recognition. CNN can automatically learn and identify features. It is suitable for 2D images. The most important feature which makes people impressed is the capability of generalization of another image identification.

CNN has variety types and different functions. This research was based on the multiple types of CNN deep learning system, and used the published chest X-ray disease model by Rajpurkar et al. developed using DenseNet121 as a reference. The original data were pre-processed using different methods and verified by the corresponding radiologists before the input of imaging data. The clinical reports were used as a basis for learning and training. Finally, the advantages and disadvantages of each model resulted were compared, and an optimal chest X-ray abnormality interpretation model was finalized. The overall training process is shown in Figure 3.

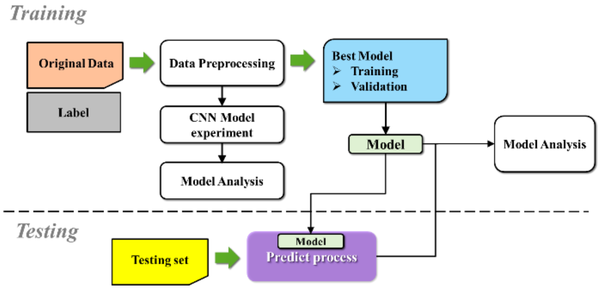


Fig. 3 Overall training process

Statistical Analyze: There were several criteria used for evaluating the pros and cons of the models: accuracy, area under curve (AUC), precision, recall (sensitivity), and F1 score. The confusion matrices were applied to calculate the actual true positive (TP), true negative (TN), false positive (FP) and false negative (FN) values of the models in the test data set.

III. RESULTS

First, 11,257 health check data were used for analysis. Under the same condition of neural network structure and hyper parameters, the most suitable model training method was evaluated by changing the different sizes of the image input and whether to perform an annotation marker removal image pre-processing process. For the 1,132 test set data, the input image was re-sized to 224×224, 224×224 with image pre-processing, 448×448, 512×512 and 672×672, respectively. Table 3 shows the results of accuracy, AUC, F1 Score, precision and sensitivity (Recall).

Table 3 Training result in different size of X-ray and image cropping

	224×224	224×224 with image cropping	448×448	512×512	672×672
Accuracy	0.712	0.602	0.635	0.570	0.649
AUC	0.711	0.681	0.688	0.700	0.708
F1 Score	0.402	0.351	0.375	0.384	0.404
Precision	0.315	0.245	0.267	0.256	0.287
Sensitivity/Recall	0.558	0.619	0.629	0.771	0.685

Confusion matrices and ROC curves on the test data for the five models are shown in Figures 4 and 5 respectively.

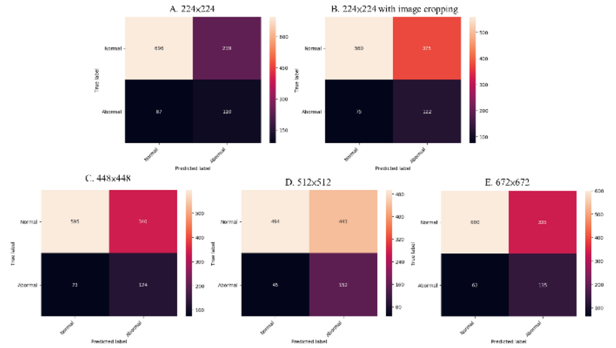


Fig. 4 Confusion matrix with different image size and image cropping

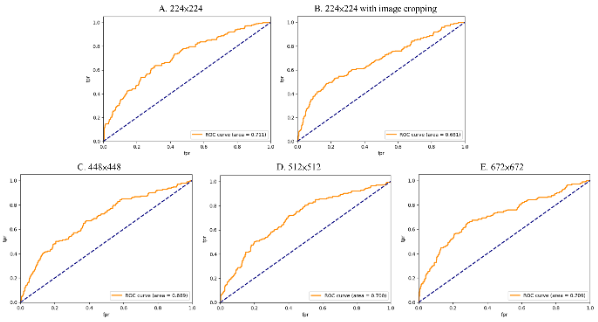
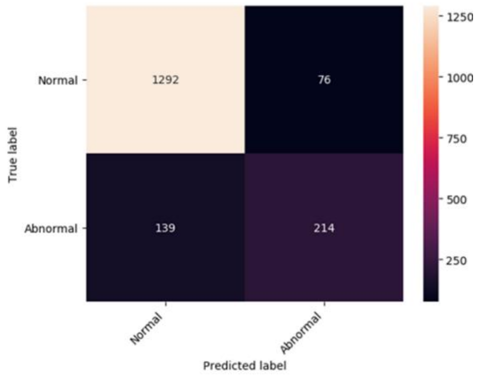


Fig. 5 ROC curves with different image sizes and image cropping

After the preliminary analysis, the 44,430 available data were screened and applied in the further training. The obtained final model was evaluated using the subsequent collection of 1,721 available data. The confusion matrix and ROC curve results of the evaluation are shown in Figure 6. The overall test accuracy rate reached 0.875, the AUC was 0.876, and the F1 Score, precision and sensitivity were 0.666, 0.738 and 0.606, respectively.


A. Confusion matrix of final model

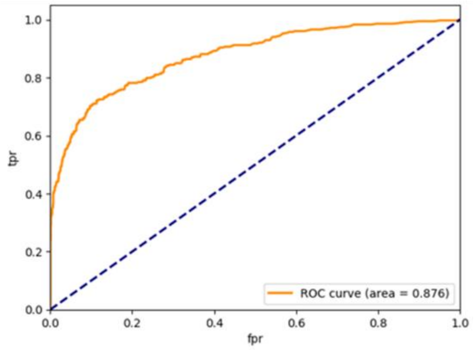

B. ROC curve of final model

Fig. 6 Confusion matrix and ROC curve of final model using the evaluation data set

IV. DISCUSSION

Comparison: Among the five models established using the 11,257 data of health check, the neural network architecture used was DenseNet121. The research found that the accuracy of model training results by changing the input image size was 71% optimal at image size of 224 × 224, and the training results at other image sizes did not improve. In addition, in the comparison of AUC, F1 Score, precision and sensitivity (Recall), all the results were better for the image size of 224 × 224 than the other input image sizes, with an exception of sensitivity. It shows that maintaining a training pattern that is closer to the original image size does not help the overall model optimization. If focused on AUC and the F1 Score, which takes into account both accuracy and sensitivity, the model with 224 × 224 image size still had higher scores. Further test based on this input image size was to remove the annotation markers in the input images. The results from Table 3 show that the model trained after the addition of the cutting process had a significant deterioration overall. The position of the neural network model reference was also visualized through the Gradient Class Activation Mapping (Grad-CAM) method. Figure 7 shows a case of normal chest X-ray images randomly selected from the test set. Image A is the original chest X-ray image, B is the color-highlighted image of Grad-CAM after image cropping and C is the Grad-CAM image without image cropping. In the Grad-CAM image, the closer the highlight color is to red, the higher the judgment value of the part affecting the neural network, which is the basis for the model to be "seen" by normal or abnormal interpretation. After the image cutting process, the test image displayed that the model focused on the black bar generated close to the abdominal cavity (Figure 7B). Therefore, the image characteristics of the processed chest X-ray were not correctly learned and thus misleading. The Grad-CAM results produced by the model trained without images cropping had strong visual representations in the bones, lungs, mediastinum, etc., which was more logically compatible with clinical interpretation (Figure 7C). Based on the observations of the two models, it was inferred that the black bars generated after image cropping might be one of the main causes of interpretation errors. It could be improved if the black bar was removed after the cropping. However, in this case, the image size must be resizing back to 224×224, which would introduce the image deformation. In addition, we also found that the image cutting method often cut off part of the lungs. As shown in the images of the red boxes in Figure 8, part of the apex of the lungs in the images was removed by this method. This is not allowed in clinical chest X-ray imaging standards. So we believed that this approach could make the neural network model erroneously learning. In summary, in the subsequent further model training, the pre-processing method of image cropping was abandoned.

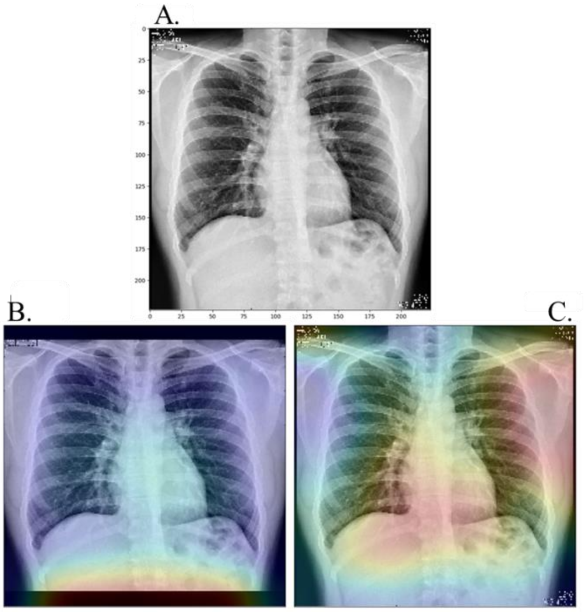


Fig. 7 An example of normal chest X-ray images. A. The original image, B. Grad-Cam image with cropping, C. Grad-Cam image without cropping

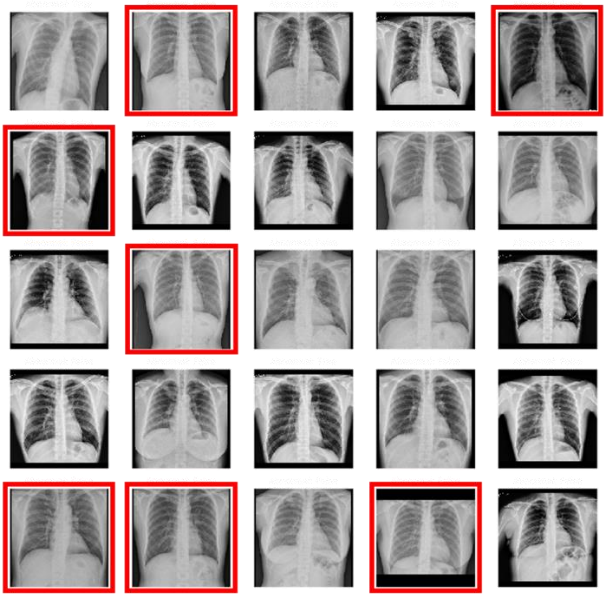


Fig. 8 Random sampling of chest X-ray images after image cropping. Part of the apex of the lungs were removed after cropping for the ones in red box

After preliminary training from the preliminary model, the decision was made to input image size 224x224 and not to crop image for final model training using all the subsequent training data. With the 44,430 chest X-ray data trained final model, the testing result using a month’s chest X-ray interpretations collected in 2019 was 0.875 in accuracy, 0.876 in AUC. Overfitting was not observed from the ROC curve. Usually, the accuracy of higher than 0.8 is considered outstanding result. However, the F1 Score and precision were 0.666 and 0.738 respectively. These values are lower than the conventionally recognized normal standard. From this point of view, this model still has some room for optimization and improvement.

Limitations of the Research: In this study, the most rigorous definition was applied in the normal image classification. When there was an obvious conflict between the clinical report and X-ray image: no finding or normal in the report but abnormal chest X-ray image, patient history was reviewed, as in the former literature, it has been proved that history of patients would affect the accuracy of radiologist interpret chest X-ray [28, 29] . Based on the text mining in patient's history, this kind of radiologist's reports was often found not exactly correct. It couldn't exclude the possibility of mistype report, or the physician determined that the symptoms were mild and thus gave a normal report. To correct these reports, data collection and the threshold of the need of the related cross discipline knowledge was really high. And it would be a difficult project to develop. The related methods of such corrections were not found in former literature. Therefore, those cases with questionable reports were excluded in this study.

V. CONCLUSIONS

In this paper, a chest X-ray assisted classification model using deep neural network is presented. This model is based on whether or not any abnormalities are mentioned in the radiology report. In addition, the performance of the DenseNet121 model under different input sizes and image cropping of the chest X-ray image was tested in this study. Finally, our own deep neural network classification model, which had a good performance in interpreting the abnormality of the chest X-ray film, was developed. This study further proved the feasibility of deep learning in the field of medical imaging classification.

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Contacts of the corresponding author:

Author: Tzung-Chi Huang, Ph.D.
Institute: Artificial Intelligence Center for Medical Diagnosis, China Medical University Hospital, 2, Yude Road, 40447, Taichung Taiwan
Email: tzungchi.huang@mail.cmu.edu.tw

BOOK REVIEW

BOOK REVIEW
THE PHYSICS & TECHNOLOGY OF RADIATION THERAPY, II EDITION BY PATRICK N. MCDERMOTT AND COLIN G. ORTON, MADISON, WI: MEDICAL PHYSICS PUBLISHING, 2018

Drs. McDermott and Orton have written an excellent timely textbook that can be used by graduate and undergraduate students of medical physics, radiation oncology residents and radiation therapy technology students. The authors are distinguished medical physicists. Dr. McDermott is the director of physics education at Beaumont Health Royal Oak Michigan. Dr. Orton is an emeritus professor in the radiation oncology department at Wayne State University. He directed the WSU Medical Physics Graduate Program for over 20 years.

The book should be the first book any medical physics student interested in radiation oncology physics should buy. It is “the physics book” for radiation oncology residents and a necessity for the radiation technology students.

The book begins with review of basic mathematics, Chapter 1, appropriate for the technology students and residents and continues with a review of basic physics in Chapter 2. These reviews are coherent and establish the formalism that follows. Chapters 3 and 4 introduce atomic theory, radioactivity and x-ray production. The interaction of radiation with matter follows in Chapter 6, with clear and concise explanation. Chapter 7 has a thorough discussion of radiation units and contains an explanation of the Monte Carlo technique. Residents have told me that they understood Monte Carlo Calculations for the first time, reading this book. Chapter 9 explains how the linear accelerator works, with an interesting side note on the cavity magnetron ???(I no longer feel guilty not understanding how it works), again with appropriate diagrams, figures and pictures. Chapters 12 through 14 cover monitor unit calculations, dose distributions and evaluation of patient dose distribution using modern concepts (TCP, NTCP), again the explanations are clear. IMRT, IMAT, and inverse planning are introduced in Chapter 15. The benefits of IMRT are demonstrated beautifully in Figure 15.3. The chapter ends with an explanation of physics plan validation.

There are chapters on electron beam dosimetry, brachytherapy and a very complete discussion of Radiation Protection (with contributions by Cheryl Schultz).

The chapter on Proton Therapy Physics stands out in its lucidity and completeness. This rapidly growing modality has a well-deserved description in this book. There are also chapters on Imaging in Radiation Therapy and Special Modalities. The chapter on Special Modalities discusses radiosurgery the gamma knife, and TBI. There is a chapter on Quality Assurance and Safety which introduces the role of regulatory bodies and QA of radiation therapy equipment.

Each chapter ends with a summary and problems; Appendix D has the answers to most problems.

Appendix A gives the listing of topics that need to be studied for the ABR Exam for radiation oncology residents indexed by topic to sections in the book. Similarly it gives the topics needed for the ARRT and Medical Dosimetrist Certification exams indexed to sections in the text. Appendix B contains dosimetry data for some common beams and isotopes. While Appendix D is Beam Data for a fictitious linear accelerator used in the problems.

This is an excellent book; the presentation of the book diagrams, figures, pictures (many in color), and selection of problems are clear and logical and make this book a classic. It is evident that the authors have taught this subject for a long time and were able to distill and explain concepts in a clear and interesting ways.

The authors have written a spellbinding textbook that belongs on the bookshelf of every medical physicist both as a reference and as guide.

Because the nature of our field, constant advances in technology, this book will certainly be eclipsed; but it surely belongs in the pantheon of great medical physics textbooks.

I wish I had this book when I was a student.

Summary: This is a great textbook for medical physics students, for radiation oncology residents, and for radiation oncology technology students.

PS: The publisher should publish the tables figures and pictures as a power point presentation. This exist for a number of texts (Sorensen and Phelps, Wolbarst, etc). This would help in teaching and I would be happy to buy it.

Reviewed by Thomas Lowinger

Thomas Lowinger is a somewhat retired medical physicist, presently consultant for Radiosurgery NY, a private clinic. He has taught medical physics for residents, physicists, and technology students in the NYC metropolitan area over the last 40 years..

AWARDS and ACHIEVEMENTS

KWAN HOONG NG - A RECEIPIENT OF THE ASIAN SCIENTIST 100 (2019 EDITION)

Professor Kwan Hoong Ng, the 2018 IOMP Marie Skłodowska Curie Awardee, has just been honoured by the Asian Scientist 100 (2019 edition) under 'Physics; category. The Asian Scientist 100 celebrates the successes of Asia's brightest researchers and innovators, highlighting their achievements across a range of scientific disciplines. Now in its fourth year, AS100 is a community of early-career and established scientists who have made significant contributions to their respective fields. The criteria to be acknowledged on the list, honorees must have won a national or international prize in the past year, or have been recognized for their significant achievements in scientific research or leadership in academia or industry.

The Asian Scientist Magazine, headquartered in Singapore, is an award-winning science and technology magazine that highlights R&D news stories from Asia to a global audience. The full list is given at https://www.asianscientist.com/as100

Dr Ng is a Professor at the Department of Biomedical Imaging, University of Malaya, Kuala Lumpur, Malaysia. He is certified by the American Board of Medical Physics. He is a Fellow of the Institute of Physics, UK, the International Organization for Medical Physics (IOMP), and the Academy of Sciences Malaysia. He is also a member of the Academy of Medicine Malaysia.

Dr Ng established the Master of Medical Physics Programme, University of Malaya in 1998. In 2002, he was responsible for obtaining the UK's Institute of Physics and Engineering in Medicine (IPEM) accreditation for the Master of Medical Physics programme, which remains the only programme so accredited outside the British Isles. Dr Ng has also contributed greatly to the teaching and training of radiology and clinical oncology residents.

Dr Ng has contributed extensively to the IOMP for over two decades. In 2013 the IOMP honoured him as one of the top 50 medical physicists for his outstanding contributions to the field. In 2016 he received the International Day of Medical Physics (IDMP) Award.

Dr Ng is active in breast density research and its clinical applications in predicting breast cancer. His other research contributions are in breast imaging, radiological protection, radiation dosimetry and medical physics education.

Dr Ng has authored/coauthored more than 250 peer-reviewed journal papers, 80 conference papers, 30 book chapters and co-edited eight books. He has presented more than 570 scientific papers, with over 300 of them being invited lectures. He is a member of the editorial and advisory board of more than 12 journals, and has served as one of the series editors for the "Series on Medical Physics and Biomedical Engineering" published by CRC Press (Taylor and Francis).

As a consultant and expert with the International Atomic Energy Agency (IAEA), he has participated in numerous expert missions, conference lectures, and in drafting and reviewing standards, guidelines, chapters and reports.

Dr Ng is the Founding President of the South East Asian Federation of Organizations for Medical Physics (SEAFOMP), serving from 2000-06 before being appointed as the President Emeritus in 2014. He instituted the John Cameron Memorial Lecture series. Further, he became one of the founding members of the Asia Oceania Federation of Organizations for Medical Physics (AFOMP), serving as its President from 2010-12. In 2014, he founded the ASEAN College of Medical Physics, which conducts regular medical physics education and training workshops.

In 2017, he started an international leadership and mentoring programme for medical physicists, collaborating with Prof. Robert Jeraj, Prof. Tomas Kron and Prof. Eva Bezak as fellow mentors.

Throughout his career, Dr Ng has been a passionate educator and communicator in various fields and he is often invited to build skills and capacity in South East Asia and many developing nations.

PROF. MARIO FORJAZ SECCA - A RECEIPIENT OF THE EGAS MONIZ PRIZE 2019

Professor Mario Forjaz Secca has been awarded with the Egas Moniz Prize - the first non-medical recipient of this special biennial prize of Neurorradiology, jointly attributed by the Portuguese Society of Neurorradiology, the Egas Moniz Museum House and the Portuguese College of Physicians.

This Prize is in honour of Prof. Egas Moniz who invented the technique of Radiologic Angiography, still today of utmost importance in Neurorradiology. In 2019 the prize was awarded during the 70th anniversary commemorations of the attribution of the Nobel Prize in Medicine and Physiology to Prof. Egas Moniz.

Dr Secca has been born in Mozambique, where he completed his school education. He graduated physics in Surrey University, UK and further received his Doctorate degree in the field of Solid State Physics.

Dr Secca worked both as medical physicists and as biomedical engineer in Lisbon, Portugal. He created at Universidade Nova de Lisboa one of the first two Biomedical Engineering undergraduate programs in Portugal. For 12 years since 2001 he was the coordinator of the integrated BSc and MSc program on the subject.

Since 2016 Dr Secca works back in home country Mozambique, both as Clinical Engineer and Medical Physicist at the Central Hospital of Maputo. He is also Invited Professor at Instituto Superior de Ciências da Saúde de Maputo (ISCISA).

Dr Secca is actively involved in the development of professional activities in Mozambique, and other countries in Africa (both for clinical engineering and medical physics). He has served from 2009 to 2018 as Chair of the IFMBE Working Group on Developing Countries. He has also served as Chair of the IFMBE Societies Committee, Chair of IFMBE Membership Committee, Chair of the IFMBE Secretaries Committee, and has been member of the IFMBE Administrative Council from 2012 to 2018. Additionally Dr Secca has been President of the Sociedade Portuguesa de Engenharia Biomédica, Education Commiittee member of the International Society of Magnetic Resonance in Medicine and Executive Board member of the European Society of Magnetic Resonance in Medicine and Biology.

Dr Secca has supervised and co-supervised many MSc and PhD theses. His strong involvement in the education activities has made him an active contributor to the Medical Physics Encyclopaedia – in the areas of Magnetic Resonance and General Physics. He has also taken part in various IUPESM activities and has been Co-President of the European MEDICON Conference 2019.

Over his long career Professor Mario Forjaz Secca has made significant contributions to the professional and educational development in many low and middle income countries and continues to actively support this development in Mozambique.

OBITUARY

OBITUARY:

Prof. Barry J Allen, PhD, DSc, AO

The International Organization for Medical Physics (IOMP) informs with great sadness that Prof. Barry J Allen, President of IOMP from 2006 to 2009 passed away on 21 November 2019 in his home in Australia.

Prof. Barry J Allen graduated MSc in nuclear physics at the University of Melbourne. After this he joined the Australian Atomic Energy Commission (AAEC) at Lucas Heights in 1963. His work was mainly associated with Radiotherapy research, but also with research in other areas of physics applied to medicine. He convened the Fourth International Symposium for Neutron Capture Therapy in Sydney in 1990. He designed the first human Body Protein Monitor (BPM) in Australia. He commenced the Targeted Alpha Therapy (TAT) project in 1994 at St George Hospital, and was the designer and Study Director of two world first trials of intralesional and systemic targeted alpha therapy for metastatic melanoma. He was Director of the Centre for Experimental Radiation Oncology at St George Hospital in Sydney. He has published over 330 papers in neutron and biomedical physics. In 2011 he co-authored the text book "Biomedical Physics in Radiotherapy for Cancer" with Drs. Eva Bezak and Loredana Marcu.

Prof. Barry J Allen has been awarded Fellowships by the Australian Institute of Physics (1972), the American Physical Society (1981), the Australasian College Physical Scientists & Engineers in Medicine (1992), the Institute of Physics (1999), the International Organization for Medical Physics (2013). Prof. Barry J Allen has been elected President of the International Society for Neutron Capture Therapy (1988), the Australasian College of Physical Scientists & Engineers in Medicine (1998) the International Organization for Medical Physics (2003).

Prof. Barry J Allen had very active international work on the global development of medical physics. He is one of the Founders of the Asia-Pacific Federation of Medical Physics (AFOMP), being its first Vice-President and second President. In this position one of his activities was the facilitation of the formation of the Vietnamese Association for Medical Physics. In 2003 he was President of the World Congress in Medical Physics and Biomedical Engineering in Sydney. In the same year he was elected Vice-President (President-Elect) of IOMP. He was President of IOMP in the period 2006 to 2009. During this period, among many other activities, he supported the formation of another Regional Organisation of IOMP – the Middle East Federation of Medical Physics (MEFOMP). From 2009 to 2012 Prof. Barry J Allen was President of the International Union of Physical & Engineering Sciences in Medicine (IUPESM). In this position, among many other activities, he was the inaugural Chair of the Health Technology Task Group, which aims at assisting developing countries in the implementation of appropriate medical technologies.

At the 50th Anniversary Conference on Medical Physics (Brighton, UK, 2013) Prof. Barry J Allen was included in the list of 50 outstanding medical physicists over the past 50 years.

In 2015 Prof. Barry J Allen was appointed an Officer in the Order of Australia award in the Queen's Birthday honours list. The citation read "for distinguished service to biomedical physics, particularly to radiation oncology and the development of innovative methods of cancer treatment, and to international professional scientific organisations".

We worked with Prof. Barry J Allen for a number of years and have met him and his wife Cynthia many times. Barry was an excellent person with great sense of humour, he was professional of the highest calibre and an outstanding leader. Prof. Barry J Allen will be missed by our whole professional community!

On behalf of the IOMP Executive Committee we are sending deepest condolences to the family of Prof. Barry J Allen.

On behalf of the IOMP Executive Committee we express heartfelt thanks to Prof. Barry J Allen for his enormous support for the development of medical physics – his legacy will be forever with our profession!

Prof. Slavik Tabakov, PhD, Dr h.c., FIPEM, FIOMP
IOMP Past-President, IUPESM Vice-President

Prof. Madan Rehani, PhD, FIOMP
IOMP President

PhD ABSTRACTS

MEDICAL PHYSICS INTERNATIONAL Journal, vol.7, No.3, 2019

DEVELOPMENT OF LOCAL RADIOLOGICAL REFERENCE LEVELS FOR MEDICAL RADIODIAGNOSTIC PRACTICES IN SOUTHWEST NIGERIA

J.A. Achuka

Covenant University Ota, Nigeria – Department of Physics

Abstract— **Background**: Radiation protection of patient undergoing diagnostic x-ray imaging has become an indispensable subject today due to significant increase in patient absorbed dose. The goal of diagnostic x-ray imaging is to use only the required radiation dose that will produce optimal image quality with minimal patient dose. However, this feat has been found difficult to achieve in practice due to diversities in x-ray equipment and examination protocols. Patient's dose from x-rays diagnosis varies significantly between countries, diagnostic centres, x-ray equipment, procedures and from one operator to the other. Dose reference levels (DRL) serve as the guidance level to curtail the superfluous dose and enhance patient safety. There are international, national and, local dose reference levels (DRL) worldwide. Nigeria has no indigenous DRL yet but adopts the International Atomic Energy Agency (IAEA) standards; hence, the need for national and local DRL development. Purpose: To develop local dose reference levels (DRL) for diagnostic x-ray examinations in Southwest Nigeria.

Methods: Thermoluminescence dosimeters (TLD) and computational methods were used to determine the patient skin equivalent dose. Consented adult human subjects of about 2500 from nine tertiary and secondary healthcare institutions with certified institutional consent were selected for the study. The quality control of the x-ray facilities was conducted using MagicMax universal quality control kits. Radiation risks assessment was determined using Personal Computer X-ray Monte Carlo (PCXMC) software and statistical analysis were conducted using Statistical Package for Social Science (SPSS) (version 23.0).

Results: The estimated DRL for radiography were 1.32 mGy, 1.94 mGy, 2.16 mGy, 4.94 mGy, 7.96 mGy, 1.27 mGy, and 1.38 mGy for chest PA, cervical spine (CS) AP, CS LAT, lumbar spine (LS) AP, LS LAT, upper extremity, and lower extremity, respectively. The computed tomography (CT) DRL for CTDIvol were 54.00 mGy, 47.50 mGy, 20.15 mGy, 20.45 mGy, and 13.45 mGy, respectively for head CT without contrast, head CT with contrast, abdomen CT without contrast, abdomen CT with contrast, and chest CT, respectively. The computed tomography DRL for DLP were 1504.38 mGy.cm, 2030.80 mGy.cm, 1214.52 mGy.cm, 1188.43 mGy.cm, and 723.43 mGy.cm for head CT without contrast, head CT with contrast, abdomen CT without contrast, abdomen CT with contrast, and chest CT, respectively. The DRL for fluoroscopy were 24.17 mGy for conventional x-ray machine for hysterosalpingography (HSG) examinations. The DRL for mean glandular dose for mammography was 1.97 mGy**.**

Conclusion: The DRL obtained in this study are comparable with those from other countries and showed the possibility of dose harmonization in southwest Nigeria. Adoption and implementation of DRL is therefore recommended in order to enhance patient safety.

Keywords — X-ray imaging, Dose reference levels, Radiography, Computed tomography, Fluoroscopy, Southwest Nigeria.

DESIGN OF A UNIVERSAL PHANTOM FOR QUALITY ASSURANCE IN DIAGNOSTIC RADIOLOGY X-RAY IMAGING

A Groenewald

Stellenbosch University – Faculty of Health Sciences

Abstract— **Background:** In medical X-ray imaging several diagnostic x-ray imaging modalities are applied to enable disease diagnosis, i.e. general projection radiography, fluoroscopy, mammography and Computed Tomography (CT) scanning. X-ray images must be of sufficient quality to enable accurate diagnosis. Image quality is quantified using suitable phantoms to ensure that equipment failure is detected before patient care is affected.

A variety of phantoms are commercially available. However, these are modality specific, expensive and often complicated to use. In resource limited institutions, like many in Africa including South Africa, three problems are identified in the field of diagnostic radiology X-ray image quality control (QC). These are cost, man power and expertise and time constraints. A gap thus exists in the market for a single universal image quality assurance (QA) phantom, capable of doing all required QC tests for all X-ray imaging modalities. A phantom, answering to this requirement, in addition must be user-friendly and cost- and time-efficient.

The aim of this study is to design, develop, manufacture, test and validate a universal image QA phantom (U-QA phantom) for diagnostic radiology X-ray imaging. The phantom must be compact, unique, universal (i.e. not modality specific), easy and quick to use and manufactured at a substantially reduced cost compared to the commercially available options.

Methods: Using literature studies on existing commercial phantoms for guidance, a prototype universal phantom was designed, manufactured and tested for all X-ray imaging modalities. From the prototype results, adjustments were made and the universal image quality phantom was developed and manufactured. The phantom is made from high density polyethylene and houses several inserts of different materials (Figure 1) to asses sensitometry, image uniformity, limiting resolution, image noise, i.e. signal-to-noise (SNR) and contrast-to-noise (CNR) ratios, geometry and measurement tools, standard signal, low contrast detectability, positioning and alignment, artefacts and visual image quality inspection. For CT scanning the phantom measures slice thickness and for mammography masses, fibres and micro-calcifications are evaluated.

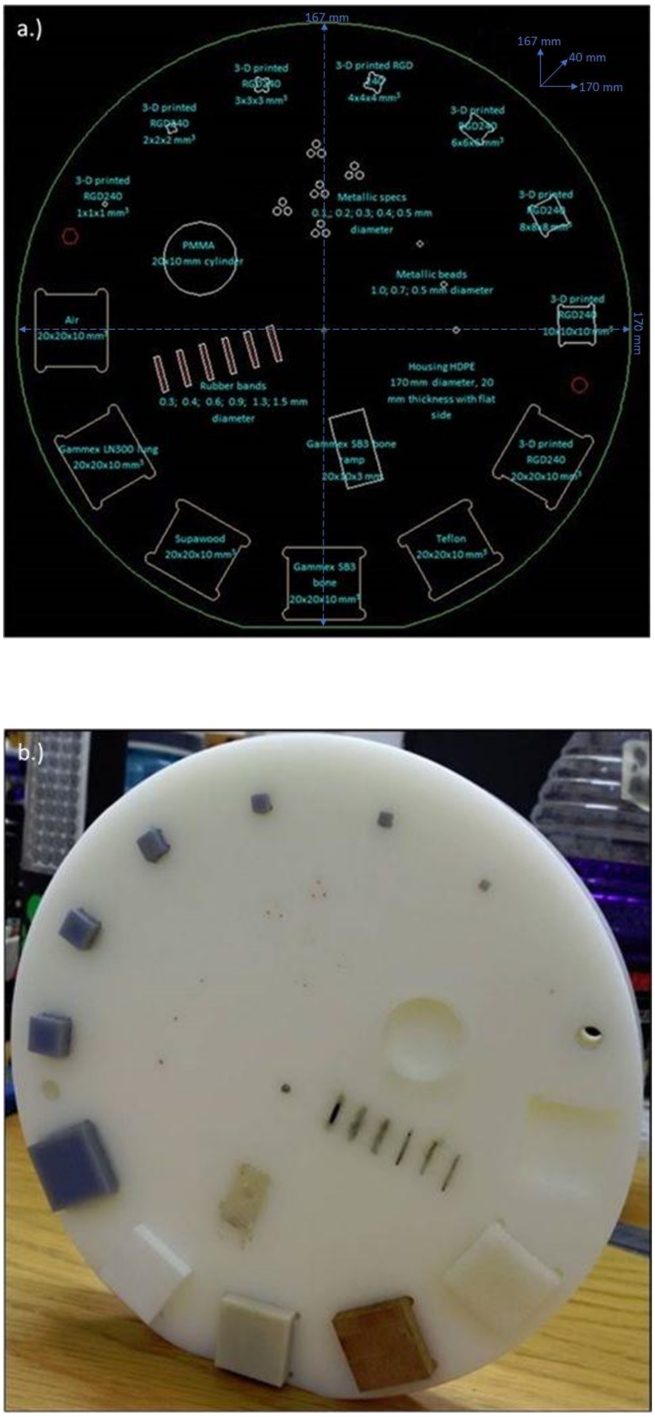


Fig. 1. A) The composition of the U-QA phantom showing the dimensions of the different inserts and the phantom. B) The bottom half of the U-QA phantom showing the different inserts in place.

Data analysis software was developed for analysis of obtained images and a complete step-by-step user's manual was prepared. Reproducibility testing was performed on the phantom, using Department of Health (DoH) specified limits. Independent validation of the phantom package (Figure 2) (i.e. phantom, software and manual) was done by three independent medical physicists. They compared the phantom to the commercial phantoms in general use in their institutes.

Fig. 2. The U-QA phantom package showing the phantom, user's manual and data analysis software in a travel case.

Results: The universal image QA phantom and accompanying data analysis software produced reproducible results for all imaging modalities, within the accepted DoH tolerance levels. The independent validation results proofed that the phantom package was easy to transport, light weight and compact, easy to set-up and use, versatile, cost effective and user friendly.

Conclusion: From the reproducibility testing and independent validation results it may be concluded that the universal image QA phantom, with accompanying data analysis software and user's manual, offers an acceptable single phantom solution for medical X-ray imaging. The universal phantom is a cost and time saver and as such could fill a gap in the existing market. In addition, the phantom could also be used by radiographers in resource limited institutions.

Keywords — QA/QC. Physics. Mammography. Fluoroscopy. CT. Conventional radiography. Image quality.

VALIDATION OF PLANNED RADIATION ABSORBED DOSE FOR BREAST CANCER TREATMENT USING RADIOMETRIC FILM DOSIMETER

T.B. Dery

Department of Physics – University of Cape Coast

Abstract— **Background:** GLOBOCAN estimates indicate that 4645 new cases were diagnosed and 1871 death occurred due to breast cancer in Ghana in 2018; making it the commonest female cancer and a major public health problem. According to the World Health Organization report, 40% of the cancer cure results from radiation therapy that uses high-energy particles to destroy cancer cells. The essential role of radiotherapy is to ensure the detection and treatment of breast cancers using appropriate doses. The unintended detriments in the treatment and the risk of secondary cancers are mostly associated with delivering much higher doses than the planned dose. To ensure the facilities in Ghana implement quality control measures, this study focused on using phantoms for the determination, and comparison of planned doses with actual doses delivered to the breast, during radiation treatment. To achieve this, the major limitation of the non-availability of phantoms was addressed by the construction of phantoms. **Methods:** Based on scanned images, two phantoms namely Adelaide phantoms "A" and "B" were constructed using perspex and locally procured materials to mimic the surrounding tissues of the human female thoracic cavity. Balloons, mango seed, cassava stick, and candle were radiologically assessed and used as surrogates for the lung, heart, spinal cord and glandular tissue of the breast respectively. Radiochromic EBT3 film dosimeter was used with the standard (anthropomorphic) and Adelaide phantoms to measure doses absorbed by the breast and non-target organs; the doses were delivered from cobalt-60 (^{60}Co) and linear accelerator (LINAC) systems of energies 1.25 MeV and 6 MV respectively. Monte Carlo N-Particle (MCNP) transport code was also used on a virtual phantom to compute the dose distribution from the cobalt machine. and validated with experimental measurement. **Results:** The deviations of delivered doses from planned doses when the standard anthropomorphic phantom, constructed phantoms "A" and "B" were used, ranged as follows, -0.05 – 0.03 Gy; -0.08 – 0.01 Gy; -0.14 – 0.01 Gy respectively, when the radiation was delivered by a Cobolt-60 machine. When the radiation was delivered by a linear accelerator system, the deviations were -0.05 – 0.03 Gy; -006 – 0.07 Gy; -0.06 – 0.04 Gy respectively. The spinal cord absorbed the lowest dose of 0.03±0.02 Gy and 0.05±0.01 Gy, while the left lung received the highest doses of 0.74±0.04 Gy and 0.78±0.01 Gy for Co-60 and linear accelerator system respectively.

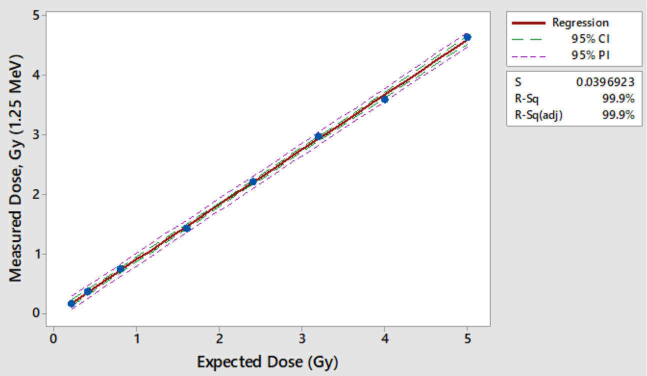


Fig. 1. Measured Dose versus Expected Dose for 1.25 MeV

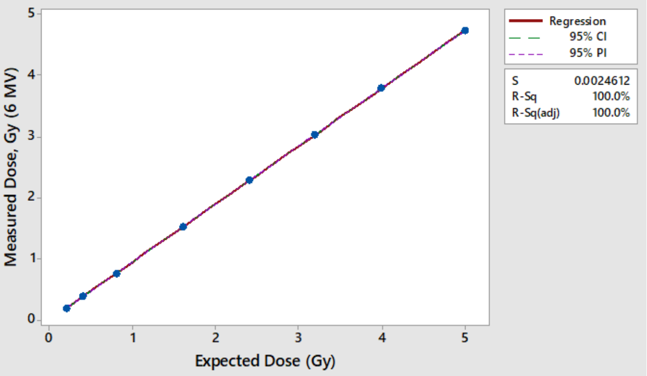


Fig. 2. Measured Dose versus Expected Dose for 6 MV

Based on the findings, it was clearly determined that the target organ received the expected dose within the acceptable tolerance level of 5%. Additionally, the non-target organs equally received a minimum radiation dose according to required standards and within dose constraints.

The MCNP generated a more fitting model for the relationship between dose and depth, and the absorbed doses simulated at many points were greater at the entrance surface, compared with the doses deeper within the phantom. The Monte Carlo simulation estimated for absorbed dose was below 5% of the acceptable tolerance.

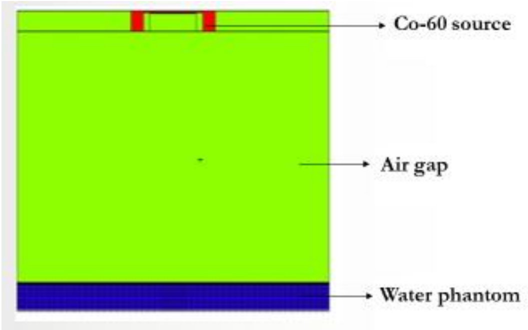


Fig. 3. Geometric view of MCNP simulation.

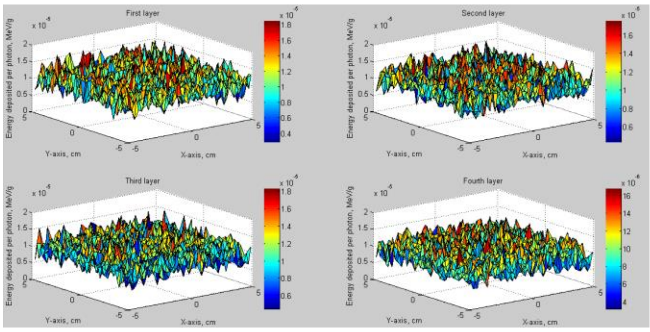


Fig. 4: Energy deposition at the depth within the virtual phantom.

The model computed the dose in each voxel in each layer by transporting several millions of particles based upon probability theory of interaction with the virtual phantom mimicking the patient. This is because radiotherapy involves finding the precise location of a tumour and optimizing the intensity of the radiation and the orientations of the beams shaped to match the plan delineation of the tumour.

Conclusion: A non-clinical significance differences of planned and delivered doses were achievable following appropriate quality control both with anthropomorphic and constructed phantoms. The study has demonstrated that local materials are potentially useful for the construction of phantoms, which can be good substitutes for standard commercial phantoms in ensuring the safety of patients under-going radiation treatment for breast cancer.

Keywords — Dosimetry. Cobalt-60. Monte Carlo. Phantom. Radiochromic film. Radiotherapy.

DESIGN AND SIMULATION OF WATER-COOLED ANTENNA FOR MICROWAVE TUMOUR ABLATION

S.O. Adeneye

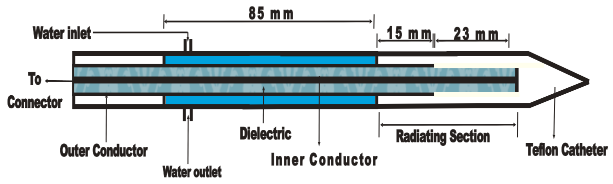
College of Medicine, University of Lagos.

Abstract— **Background**: Microwave ablation is a modern technique for treating cancerous tissues with the controlled application of heat. Some tumours are located in such a way that they cannot be successfully treated with conventional external radiation beam techniques. Microwave ablation is currently an alternative option being considered for the treatment of unresectable tumours. The aim of this study is to develop a water-cooled antenna that is able to remove the unwanted heat generated along the shaft of the antenna**. Methods**: Single slot, dual slot and monopole antennae were designed and compared with the newly designed water-cooled antenna (Figure 1). All the antennae were designed and simulated using Finite Element Method (FEM). For the open loop design, the water slot position, water slot length and the antenna slot length from the tip of the antennae were varied within the ranges $43 \leq z \leq 60$ mm, $1 \leq z \leq 10.5$ mm and $1 \leq z \leq 20$ mm at 1 mm, 0.5 mm and 0.5 mm intervals respectively. For the closed loop design the model was simulated at multiple discrete lengths of slots between 2.5 mm and 4.5 mm, using 0.1mm increments to determine the slot height. A ring-shaped slot 5.8 mm diameter was made from the outer conductor, 4mm in length from the tip. The slot position was varied between 4 and 30 mm from the radiating tip of the antenna. The most optimized antenna was constructed from 0.085′ RG-405/U semi rigid coaxial cable to match the prototype geometries in the simulation procedures. A solid-state microwave generator was used to produce 2.45 GHz frequency. A Syringe Pump (stackable syringe pump JZB – 1800c) was used to introduce cooling water into the pipe inserted along the shaft of the external conductor of the antenna. Bovine liver, muscle, lung, heart and breast samples purchased from a local government abattoir were ablated using input powers of 30, 50, 80 and 120 W for 5 and 10 min.

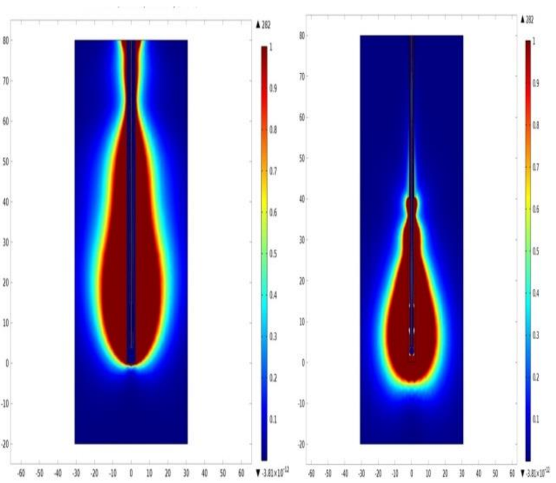
Results: From the simulation results (Figure 2), the best optimized design produced reflection coefficient -25.5dB, ablation length of 48.5 mm, ablation diameter 40.1 mm with 94 % power dissipation into the tissue. There were no significant difference in the simulation and the experimental results of the water-cooled antenna. In this study, water-cooled antenna of low reflection coefficient has been developed for microwave ablation of different tissues.

Conclusion: The study demonstrated that the inclusion of the cooling unit is capable of reducing backward heating along the shaft of the antenna (Figure 3). This study has demonstrated that microwave ablation using a cooling unit can be applied as one of the treatment modalities in the management of localized tumours.

Keywords — Cancer, Microwave Ablation, Tumour, Water-cooled, Antennae.

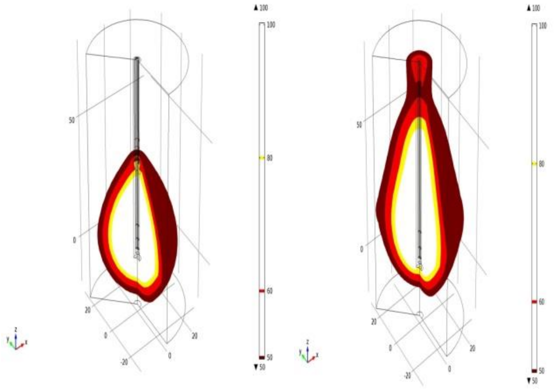


A. Figure 1: Radiating section of the monopole water-cooled antenna.



(a.) (b.)

Figure 27: Distribution of power dissipation density in tissue for closed loop antenna (a) without cooling unit (b) with cooling unit for 60 W 600 s.



(a.) (b.)

B. *Figure 3: Three dimensional view of the ablated region at 120 W 600 s. (a) with cooling and (b) without cooling unit.*

COMPENSATOR-BASED INTENSITY MODULATED RADIOTHERAPY WITH TELECOBALT MACHINE USING MISSING TISSUE APPROACH

Samuel Nii Adu Tagoe

University of Cape Coast, Cape Coast - Department of Physics, School of Physical Sciences, Colledge of Agriculture and Natural Sciences

Abstract— **Background:** Dose distribution within a patient has been found to be the most reliable and verifiable quantity that links treatment parameters of any radiotherapy treatment technique to treatment outcome. It is therefore imperative to chose irradiation geometries that will maximise radiation dose to the tumour volume while concurrently minimizing doses to normal tissues in close proximity to tumour volume during external beam radiation therapy (EBRT) to achieve favourable treatment outcome. Spatial distribution of radiation dose within a patient is influenced by skin topography at the point of beam entrance and tissue inhomogeneity within the irradiated region. The aforementioned factors coupled with the often complex shapes of tumours will require the modulation of the fluence distribution across beams from conventional teletherapy machines. This has culminated in the introduction of Intensity Modulated Radiotherapy (IMRT). Pre-requirements for modern day IMRT are capital intensity and may be out of reach of many developing countries.

Alternative approach of implementing IMRT with customized compensators with forward planning treatment planning system (TPS) and telecobalt machine to minimise cost is being presented.

Methods: Medium density materials such as: wax, Perspex, Alumimium, Brass and Copper were selected for the construction of compensators. Bolus with varying thicknesses placed on the surfaces of a tissue equivalent phantom were used to achieve beam intensity modulation during treatment simulation processes with the TPS (refer to fig. 1). The treatment plans generated with the TPS were replicated on the telecobalt machine with compensators placed on block trays and held at the accessory holder of the telecobalt machine to represent the bolus. Semi-empirical algorithm incorporating influences of treatment parameters (field size, treatment depth and applied bolus thickness) was developed and proposed for the conversion of an applied bolus thickness to a compensator material thickness such that the dose at any point within the phantom will be the same for the two irradiation geometries (with bolus and with compensator respectively). The semi-empirical algorithm was derived from the analyses of empirical data obtained through the implementation processes of a bolus and a compensator. A compensator sheet with grid lines was designed for recording bolus/compensator thicknesses across a radiation field, and this was utilized to account for beam divergence. Once the required shape of a compensator had been determined, the compensator was constructed from well known methods such as: cubic pile approach for compensators made from Perspex, Alumimium, Brass and Copper, and negative mould approach for a compensator constructed from wax. The efficacy of the proposed approach was verified to ensure clinical implementation.

Results: The semi-empirical algorithm derived for the convention of an applied bolus thickness, $\boldsymbol{X_b}$, along a particular ray line (or within a grid) to a compensator material thickness, $\boldsymbol{X_c}$, is given by:

$$\boldsymbol{X_c = X_b \times T \times f_r \times f_d} \quad \textbf{(1),}$$

where, $\boldsymbol{f_r}$ and $\boldsymbol{f_d}$ are correction factors introduced to account for the influences of field size and treatment depth respectively, and $\boldsymbol{T}$, is a thickness density ratio of a compensator material relative to that of the bolus (presumed to be water). Verification of the output of the proposed approach in a solid water with calibrated Gafchromic EBT2 films for compensators constructed from the various selected materials is presented in Table 1.

Correction factors for the stipulated treatment parameters in equation (1) were found through regression analyses of empirical data to be a fifth and a sixth degrees polynomial equations in terms of treatment depth and field size, respectively. The thickness density ratio for a particular compensator material could also be expressed as a fifth degree polynomial equation in terms of applied bolus thickness. The coefficients and the degrees of the polynomial equations were found to be dependent on the selected compensator material and the stipulated treatment parameters, respectively.

However, there were issues with abutting radiation fields, due to the fact that the TPS used does not allowed creation of bolus for an individual radiation field .

Dosimetric verifications of dose profiles measured in a solid water phantom with calibrated Gafchromic EBT2 films for various irradiation geometries having

compensators constructed based on the developed and proposed method were found to be comparable to that of the treatment planning system with deviations within ±3.00% (mean of ±(2.22 ± 0.68)%) (expressed as a percentage of the respective measured dose). This is within the tolerance of ± 5% recommended for dose delivery in external beam radiotherapy.

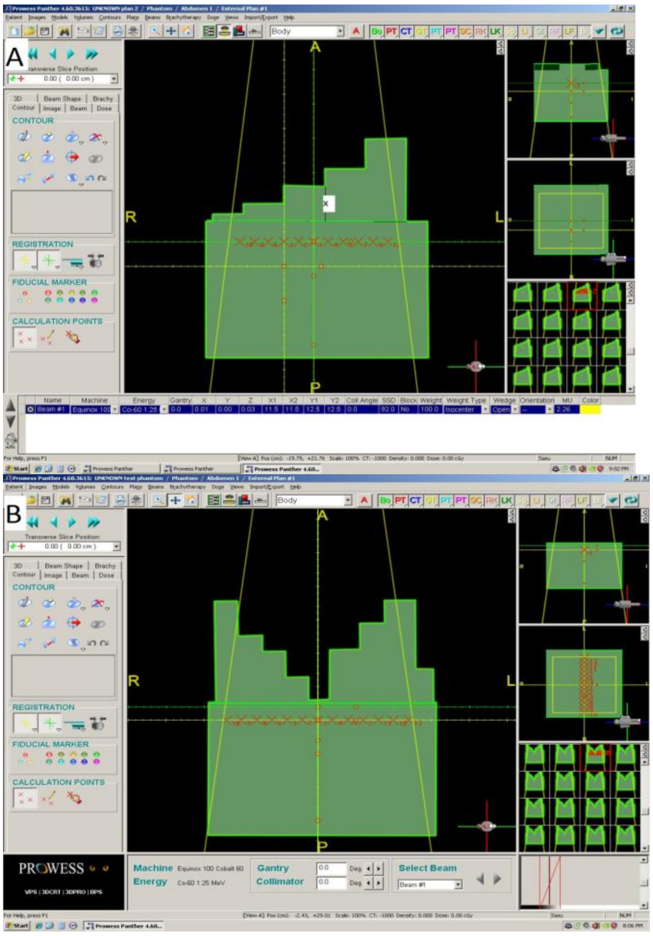


Fig. 1. TPS treatment planning window showing samples of bolus used to provide beam intensity modulations on the surface of a tissue equivalent phantom; A , for case scenario 1 and B, for case scenario 2 .

Table 1. Comparison of outputs of proposed and developed approach for selected compensator materials with those of the TPS .

Case scenario	**Compensator material**	**Range of % Diff. between meas. and Calc. doses (%)**	**Mean of % Diff. (%)**
1			
	Paraffin wax	-2.89 to 3.00	1.87 ± 0.87
	Perspex	-1.78 to 3.00	1.89 ± 0.76
	Alumimium	1.30 to 3.00	2.12 ± 0.74
	Copper	-2.14 to 3.00	2.32 ± 0.63
	Brass	-3.00 to 3.00	2.40 ± 0.54
2			
	Paraffin wax	-2.86 to 2.96	1.98 ± 0.67
	Perspex	-2.80 to 3.00	2.09 ± 0.50
	Alumimium	-3.00 to 3.00	2.52 ± 0.58
	Copper	-3.00 to 3.00	2.52 ± 0.50
	Brass	-3.00 to 3.00	2.51 ± 0.40

Conclusion: This signifies that the developed and proposed approach can be used to achieve beam intensity modulations with limited resources rendering encouraging results. This approach can be used for missing tissue compensation in the treatment of head and neck cancers, tangential breast irradiation, and total body irradiation with photon beams. It can also be used to account for tissue heterogeneities, especially in the treatment of lung cancers. The developed and proposed approach is therefore recommended for clinical application.

Keywords — Bolus. Compensator. Semi-empirical algorithm. Intensity modutaled radiotherapy. treatment parameters. treatment planning system.

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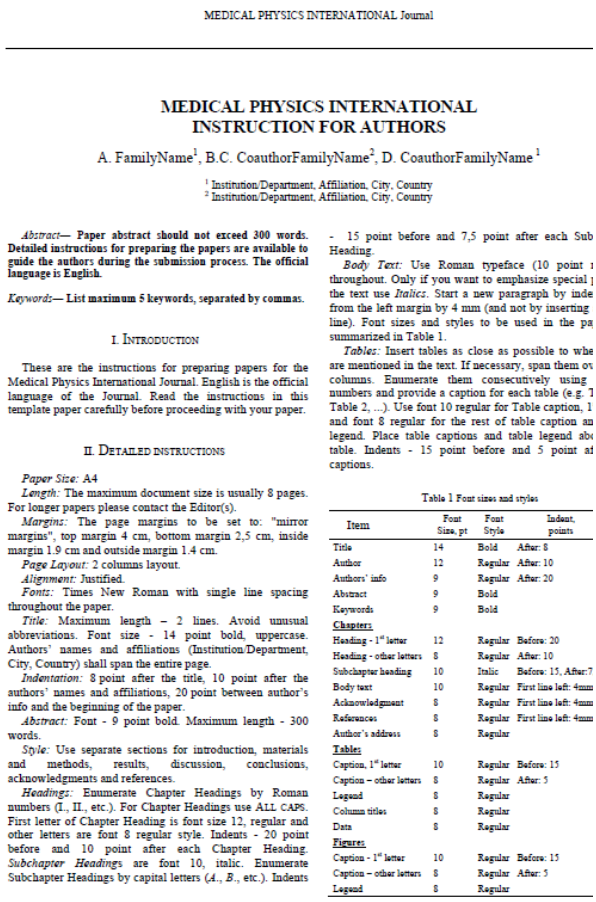

MEDICAL PHYSICS INTERNATIONAL Journal

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Item	Font Size, pt	Font Style	Indent, points
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Author	12	Regular	After: 10
Authors' info	9	Regular	After: 20
Abstract	9	Bold	
Keywords	9	Bold	
Chapters			
Heading - 1st letter	12	Regular	Before: 20
Heading - other letters	8	Regular	After: 10
Subchapter heading	10	Italic	Before: 15, After:7
Body text	10	Regular	First line left: 4mm
Acknowledgment	8	Regular	First line left: 4mm
References	8	Regular	First line left: 4mm
Author's address	8	Regular	
Tables			
Caption, 1st letter	10	Regular	Before: 15
Caption – other letters	8	Regular	After: 5
Legend	8	Regular	
Column titles	8	Regular	
Data	8	Regular	
Figures			
Caption - 1st letter	10	Regular	Before: 15
Caption – other letters	8	Regular	After: 5
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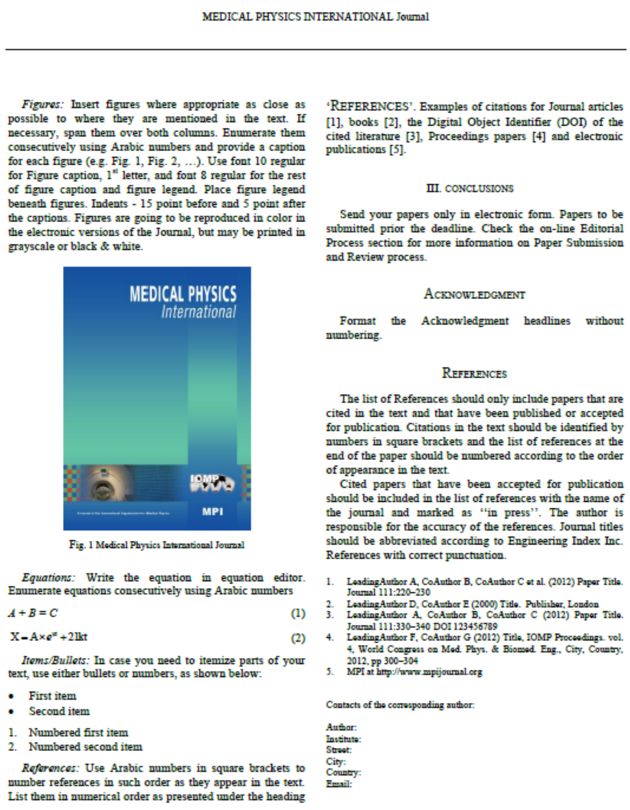

MEDICAL PHYSICS INTERNATIONAL Journal

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ANNEX

MEDICAL PHYSICS INTERNATIONAL Journal, vol.7, No.1, 2019

INTERNATIONAL SYMPOSIUM ON STANDARDS, APPLICATIONS AND QUALITY ASSURANCE IN MEDICAL RADIATION DOSIMETRY (IDOS 2019): HIGHLIGHTS OF AN IAEA MEETING

A Meghzifene[1], D Followill[2], Y K Dewaraja[3], P J Allisy[4], C Kessler[5] and D van der Merwe[1]

[1] IAEA, Vienna, Austria; [2] IROC, University of Texas MD Anderson Cancer Centre, USA, [3] Department of Radiology, University of Michigan, USA, [4] France, [5] BIPM, France

Abstract— **The IAEA in cooperation with several professional societies and international organizations, organized the International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS 2019) in Vienna on 18 to 21 June 2019. The major goal of IDOS 2019 was to provide a forum where advances in radiation dosimetry, at standards laboratories and hospitals, were reviewed and discussed. The Symposium also facilitated interactions between radiation metrologists, medical physicists, safety specialists and researchers in radiation dosimetry, and participation from all income settings was encouraged. The Symposium included topics related to dosimetry standards, medical dosimetry and radiation protection dosimetry with a specific focus on areas where research and development is needed. Very few international meetings facilitate interaction between radiation metrologists, clinical medical physicists and scientists engaged in the development of new standards, computational dosimetry, the traceability chain, codes of practices and cross-cutting research and in so doing, encourage collaborative opportunities in these fields. Participants submitted research contributions, which were reviewed by a scientific committee, and 110 talks and 84 posters were presented. The IDOS 2019 was attended by 424 participants from 77 Member States, including 54 observers.**

Keywords— **radiation dosimetry, dosimetry standards, primary standards, secondary standards, detectors, dosimetry audits, calorimeters.**

Introduction

Accurate measurements in radiation dosimetry are vital in a wide range of medical and industrial applications where the results are critical in reaching decisions relating to the health and safety of patients, radiation workers and members of the public. The development of primary standards followed by their dissemination to end-users, usually achieved through Secondary Standards Dosimetry Laboratories (SSDLS), ensures traceability of measurements to the international system of units (SI) [1, 2]. Dosimetry codes of practice (CoPs) are used jointly with the dosimetry standards, at SSDLs and clinics, to ensure implementation of accurate radiation dosimetry at the national level.

Due to its role in supporting the development of radiation dosimetry worldwide, the IAEA is well positioned to convene international meetings focused on this topic. Indeed, the IAEA has been supporting the development of radiation dosimetry for more than 50 years. During the sixties and seventies, IAEA support focused on the establishment of traceability of measurements and dosimetry audits to improve accuracy in radiotherapy dosimetry. It cooperated with the WHO (PAHO in Latin America) to launch the IAEA/WHO postal dose audits for radiotherapy dosimetry in 1969 [3], and to setup the IAEA/WHO Network of SSDLs in 1976 [4]. The IAEA support gradually evolved to include the development of internationally harmonized dosimetry CoPs in radiotherapy [5, 6], X-ray diagnostic radiology [7], and measurement guidelines for radioactivity measurement in nuclear medicine [8]. To support implementation of dosimetry CoPs and good practice in hospitals, the IAEA has also developed numerous guidelines in medical physics (such as treatment planning, in-vivo dosimetry) as well as education and training material.

The previous IAEA meeting on standards, applications and quality assurance dosimetry was held in Vienna in 2010. Since that time, major developments have resulted in changes in medical radiation dosimetry. The IAEA organized the International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS 2019) in Vienna on 18-21 June 2019 [9]. The IDOS 2019 was organized in cooperation with several professional societies and international organizations. Participants submitted research contributions, which were reviewed by a scientific committee and presented during IDOS 2019. A total of 424 participants from 77 Member States, including 54 observers, attended IDOS 2019. In addition to scientific sessions and panel discussions, the IDOS 2019 programme included educational courses and a technical exhibition from 21 manufacturers of radiation dosimetry and calibration equipment, irradiators, phantoms and dosimetry software. The major goal of IDOS 2019 was to provide a forum where advances in radiation dosimetry at standards laboratories and hospitals were reviewed and discussed. There are very few other international meetings where radiation metrologists, clinical medical physicists and scientists engaged in dosimetry, can share developments on new standards, computational dosimetry, the traceability chain and codes of practices, and discuss cross-cutting research and collaboration opportunities in these fields.

VI. INTERNATIONAL FRAMEWORK FOR RADIATION DOSIMETRY

The international framework for radiation dosimetry was presented, highlighting the background and the important roles of the International Bureau of Weights and Measures (BIPM), Primary Standards Dosimetry Laboratories (PSDLs), SSDLs and the International Committee for Weights and Measures - Mutual Recognition Arrangement (CIPM MRA) [2]. The background and functions of the international Consultative Committee for Ionizing Radiation (CCRI) [10] was also presented, stressing the importance of working collaboratively to support each other internationally in terms of the access and use of radiation sources for metrology. Through the CCRI, a review of the recommendations on key data was performed and published in the ICRU Report No. 90 [11] and an international consensus was achieved on the practical implementation of the changes in dosimetry standards worldwide [12].

Worldwide, there are only about twenty countries with PSDLs involved in radiation dosimetry. These PSDLS cannot meet the needs of all end-users for the calibration of their radiation dosimeters. In this context, the importance of the dissemination of standards to the end users through the IAEA/WHO SSDL Network was emphasized [13]. The IAEA/WHO SSDL Network is supported by the BIPM and several PSDLS to ensure that the SI is disseminated as widely as possible. The IAEA dosimetry laboratory is the central laboratory of the Network with calibration and measurements capabilities that have been reviewed by all regional metrology organizations. The quality management system has been approved by the Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB). Traceable standards are disseminated to SSDLs that have no access to BIPM and PSDLS. The IAEA has setup comparison programmes with SSDLs to help verify that the services provided by the SSDL members follow internationally accepted metrological standards [14]. The IAEA/WHO SSDL offers calibrations for radiotherapy (external beam and brachytherapy), radiology and radiation protection level instruments and issues approximately 100 certificates per year. About 20 comparisons are conducted annually. The IAEA dosimetry laboratory is also involved in capacity building and increasing the number of SSDLs worldwide.

VII. RADIATION DOSIMETRY STANDARDS

2.1.Developments at primary standards dosimetry laboratories

The BIPM and National Metrology Institutes (NMIs) are continuing to develop and improve their dosimetry standards. The National Physical Laboratory (NPL) reported on the development of an absorbed dose to water primary standard for radiopharmaceutical therapy [15]. This allows the determination of absorbed dose based on direct measurements rather than using tabulated nuclear data. The standard is based on a conventional extrapolation ionization chamber. The NPL also reported that a graphite calorimeter has been developed for use in clinical proton beams [16]. The doses obtained using the graphite calorimeter are consistent, within the uncertainties, when compared to the doses derived using TRS 398 [6], but with improved uncertainties.

The National Institute of Standards and Technology (NIST) developed a thick brass wall chamber to directly realize air kerma in photon fields from a megavoltage x-ray-based inspection system with energies ranging between 1 MeV and 6 MeV [17].

Air attenuation corrections for free air chambers are currently based on measurements, due to the large uncertainties historically associated with photon cross-sections and the estimation of the x-ray spectrum. Based on work at the National Research Council (NRC) [18], these calculated values are in closer agreement with the measured values if the renormalized photoelectric cross-sections for low-energy x-rays are used, as recommended by the ICRU Report No. 90 [19]. The result of this research can help establish confidence limits for Monte Carlo (MC) calculated air attenuation corrections for free air chambers.

Brazil reported on the results of characterizing Fricke dosimeters, as a primary standard for brachytherapy sources, to determine absorbed dose at the reference distance of 1 cm [20]. The results obtained are promising, demonstrating that Fricke dosimetry shows good potential as a primary standard for HDR ^{192}Ir sources.

2.2.Developments at secondary standards dosimetry laboratories

Primary standards are used by PSDLs to provide calibrations, usually to the SSDLs, which in turn calibrate the reference instruments of users. For x-ray dosimetry, SSDLs have to establish the reference beam qualities used for the calibration of their reference standards at PSDLs. Several SSDLs reported on their work to establish calibration capabilities for x-ray diagnostic radiology, including mammography [21, 22]. The SSDL of Poland presented an analysis of 18 ^{192}Ir air kerma calibration results over 6 years, using a traceable reference standard well-type ionization chamber (PTW 33004), which had a long-term stability of 0.3% [23]. Calibration of radiation protection instruments is generally performed using ^{241}Am, ^{137}Cs and ^{60}Co sources however, the response at 200 keV is not tested using this approach. However, backscattered Compton photons obtained from the ^{137}Cs source can be used to generate an appropriate field for this purpose [24].

2.3.Computational dosimetry

Confirmation of the mean energy to form an ion pair in dry air (W_{air}) value as published by the ICRU Report No. 90 [11] has been limited to electrons of energies up to 5 MeV. Preliminary data on a proposed aluminum calorimeter, as an alternative to graphite, in order to establish whether W_{air} varies as a function of electron energy, were presented. A consistent result of 33.82 ± 0.27 eV was calculated for clinical electron beams up to 22 MeV [#140]. Monte Carlo simulations of radiation transport are increasingly becoming accepted in the community to derive correction coefficients or to confirm, predict or interrogate experimental findings, however, several mathematical models of Compton scatter exist, for instance. Four theories, each using different approximations, were compared by calculating mass energy absorption coefficients for water and graphite, and major differences between the models were only found at energies at which the photoelectric effect dominates [309]. Preliminary results of the use of computational codes to study ionization quenching in scintillators [244], to develop a prompt gamma ray imaging system for particle beams [73] and to model alanine dosimeters in low energy x-ray beams [266], were also presented. The NPL presented results of calculated conversion and correction factors for a graphite calorimetry primary absorbed dose to water standard for ^{192}Ir high dose rate brachytherapy [104].

III. CODES OF PRACTICE IN RADIOTHERAPY DOSIMETRY

Radiation dosimetry CoPs constitute the final step in the dosimetry chain and are implemented by end-users. In radiotherapy, CoPs are used in conjunction with a reference quality ionization chamber, calibrated by a standards dosimetry laboratory, in order to determine a radiation dose under standard reference conditions. The CoPs TRS-398 [6] and TG-51 [25] are applicable for conventional radiotherapy, but they are not suitable for technologies that can only produce small fields. In some cases, accidents have occurred owing to the use of detectors, methods and procedures that are appropriate for large fields but not for small fields [26].

3.1. Small Field Dosimetry

In 2017, the IAEA and the American Association of Physicists in Medicine (AAPM) jointly published a CoP on the dosimetry of small static fields used in external beam radiotherapy (TRS-483) [27]. The CoP provides guidance for reference beam dosimetry of machine-specific reference fields, as well as relative dosimetry. In 2015, the IAEA initiated a coordinated research project (CRP E2.40.21) to test the implementation of the recommendations given in TRS-483. Investigators from eleven different countries were invited to participate in this initiative. Several different detectors were used and all technologies referred to in TRS-483 were investigated. The results of the group's investigations were presented during IDOS 2019. For equivalent square small field sizes of less than 1 cm, large differences in field output factors were found for most technologies because detectors were used that are not recommended for these small field sizes or no field output correction factors had been published [28]. The uncertainties arising from traceability for absolute dosimetry, machine setup parameters and the period since multileaf calibration on determining output factors for relative dosimetry ranged from (0.5 to 3)% [29]. Investigators also presented output correction factors for solid state detectors and ionization chambers (in different orientations) for which there is a lack of data [30]. Measurements of percentage depth dose in small fields showed that small volume ionization chambers exhibit an effective point of measurement of less than half the radius upstream. In addition, the polarity applied to small volume ion chambers and the type of solid state detector used, giving different results in the near surface region, was also presented [31].

The preliminary results of an IAEA pilot study of a new remote audit methodology for small field photon beams were presented [32]. The audit consisted of irradiating Gafchromic EBT-3 films and radiophotoluminescent glass dosimeters (GD-302M) and comparing the measured dose values to the dosimetry data calculated and provided from the local Treatment Planning System (TPS) that is used clinically. Data from 8 countries and 20 photon beams were analyzed. The results for field sizes greater than or equal to (2 x 2) cm^2 were all within 3% but (1 x 1) cm^2 or 1 cm diameter field sizes showed a much greater spread with many points falling outside this acceptance criterion.

An investigation dealing with the field size limitations of the RefleXion biology-guided radiotherapy (BgRT) system was presented [33]. This BgRT system delivers a 6 MV flattening-filter free (FFF) beam with a field width limit of (2 or 3) cm thus, the largest field size attainable that is the closest to a conventional (10 x 10) cm^2 field size is a (10 x 2) cm^2. Two approaches were presented to overcome this small reference field size challenge. The first approach was to generate a correction factor through MC calculations to account for the differences in field sizes. The second approach was to follow the TRS-483 formalism but with modifications due to the BgRT system not having a typical machine specific reference field or appropriate tabulated data for beam quality corrections. The two approaches were compared for six different detectors and found to be within 0.3% of each other. Ion chambers with a high atomic number central electrode, need to have a correction applied for perturbation effects.

The implementation of the plan class-specific reference (pcsr)-field concept for dynamic fields as described in the 2008 formalism [34], has proven difficult due to a lack of quantitative guidelines and guidelines. To help bridge this gap in knowledge, a multidimensional feature analysis and clustering analysis of numerous modulated treatments was conducted, aimed at determining if distinct plan clusters may help guide the creation of representative plans. A total of 627 clinical plans were investigated. The findings indicated that there were no intuitive plan clusters for a single technique and that it might be more useful to consider corrections on a class solution basis [35].

3.2.Update of TRS-398

Numerous developments have occurred since TRS-398 [6] was published in 2000, justifying the need for updating this CoP. From the Agency’s perspective, few users have requested clarifications on implementing the CoP since its publication but revised scientific data, and advances in machine and detector technologies have been the primary reason necessitating an update. The process to update the TRS-398 began in 2016 and took into account the feedback from end-users, new ion chambers, new radiotherapy technologies, updated data from ICRU Report No. 90 [19], and the lack of $N_{D,w}$ calibrations for dosimetry of kV x-rays. The updated dosimetric data (e.g. beam quality correction (k_Q) values) are still under development, based on the revised ICRU-90 stopping power values for graphite, water and air. For photons, the adopted values are those based on renormalized photoelectric cross sections for all materials. The main planned updates are summarized below [36].

- *High energy photon beams (up to 25 MV)*: In addition to new k_Q data, the main update is the introduction of an additional chamber-dependent correction k_{vol} for the dosimetry of flattening-filter free (FFF) photon beams, to account for the volume averaging effect whenever the beam profile across the detector is not homogeneous. The recommendations are consistent with the TRS-483 (25) code of practice, however, dosimetry for novel technologies that are not in widespread clinical use, e.g. MR-linacs, has not been included.
- *High energy electrons beams (from (3 to 25) MeV)*: No substantial changes have been introduced other than new k_Q data. The procedures for reference electron dosimetry were rationalized, to avoid the use of plastic phantoms and to harmonize the use of intermediate beam qualities for cross calibrations.
- *Kilovoltage x-ray beams*: Considering that a major change in the new ICRU Report No. 90 data is due to cross sections and coefficients for the photoelectric effect, a revision of the dosimetric data available for x-ray beams in TRS-398 was deemed necessary. New values of backscatter coefficients and ratios of mass energy-absorption coefficients for water to air (free-in-air and at 2 cm depth in water) have been calculated for various x-ray beam qualities (in terms of both kV and HVL), field size and focus-surface distance. A large database of these values has been developed that will be accessible through an IAEA web page. For the dosimetry standards, PTB confirmed that absorbed dose to water ($N_{D,w}$) calibrations for low-energy x-rays are based on air-kerma standards (N_K), which are then converted into $N_{D,w}$. In the case of medium-energies, absorbed dose to water standards are available in a few laboratories, however dissemination has been limited and the air kerma-based procedure still remains the most frequently used calibration modality. The TRS-398 CoP update will incorporate both methodologies.
- *Proton and heavier ion beams*: The updated edition of TRS-398 will include guidance and data for the determination of absorbed dose to water for the newer proton and light-ion beam delivery systems available in the clinic i.e. broad-beam delivery systems using scattered or uniformly scanned beams, as well as for pencil beam scanning systems using monoenergetic intensity-modulated scanned beams. Additionally, it has been noted that the two-voltage technique for the recombination correction in ionization chambers can lead to significant errors. The recommended correction procedures account for the beam behavior with respect to recombination, either as a continuous or as a pulsed beam.

- *k_Q value determination*: Owing to advances in simulation techniques, values of k_Q for a large number of ionization chambers have been determined with MC. For some chamber types however, values of k_Q for photon and electron beams have also been obtained experimentally at standards laboratories. The resulting MC and experimental sets of k_Q values for each chamber will be combined statistically to obtain consensus mean values and estimates of their relative standard uncertainty.

3.3.Update of TG-51

An addendum to TG-51 for high energy electrons is being prepared. The update will include new beam quality conversion factors and simplified calibration procedures such as removing the requirement for a measured gradient correction and the possibility of using a cylindrical ionization chamber for all energies [37]. It is expected that these changes will lead to fewer calibration errors being made.

IV. RADIATION DOSIMETRY

This section summarizes the highlights of several sessions that addressed topics related to measurement techniques in radiation dosimetry in radiotherapy, nuclear medicine, X-ray diagnostic radiology, radiation protection and experimental radiobiology.

4.1.Dosimetry for Radiotherapy

4.1.1.Out of field dosimetry

The European Radiation Dosimetry Group (EURADOS) presented results to assess out of field dosimetry for typical photon and proton treatment techniques used for pediatric radiotherapy of a brain tumour and treatment of the entire cranio-spinal axis [38]. Pediatric anthropomorphic phantoms (5 and 10-year-old) containing radiophotoluminescent (RPL) and two types of thermoluminescent (TL) dosimeters for x-ray doses, and bubble detectors and Polyallydiglycol carbonate (PADC) detectors for neutron doses, were used. The results show that TL detectors consistently record higher doses than RPL dosimeters and that overall, proton therapy reduces the out of field doses for these pediatric cases.

The results of calculated organ neutron doses from an 18 MV radiotherapy linac, using MC simulations were presented [39]. Detailed models of a female patient, linac and linac bunker were generated. An analysis of the effect of varying key linac components on the calculated neutron component of organ dose was also performed and the flattening filter composition caused the greatest change in neutron dose. The highest neutron doses were calculated to be next to the photon treatment field. This type of MC simulation of neutron dose calculations continues to increase our knowledge of out of field dosimetry for high energy photon beam treatments.

The evaluation of the doses for different organs at risk during Positron Emission Tomography / Computed Tomography (PET/CT) examinations for treatment planning, and kV planar and cone-beam CT (CBCT) image-guidance during head and neck radiotherapy was presented [40]. The average effective dose from PET/CT internal exposure was 4.31 ± 0.97 mSv in the range 2.19 – 5.89 mSv. From the analysis of 22 patients, the average CT dose index value was 55.80 mGy, the planar imaging delivered effective doses in the range 0.354 – 1.416 mSv and the average number of image guidance procedures during radiotherapy was 7.33 (2 to 10) per patient. This work demonstrated the need to be cognizant of the added radiation doses from imaging.

The efficacy of using Optically Stimulated Luminescence Dosimeters (OSLD) for in vivo out of field dosimetry by measuring entrance and exit doses was investigated [41]. A comparison was made of measurements using OSLDs and Thermo Luminescent Dosimeters (TLD) which were placed near the eyes of 10 head and neck patients. The doses measured with the OSLD were found to differ from the TLD doses, where the TLD were considered to be more accurate. The authors suggested that OSLD might not be the detector of choice for out of field measurements.

4.1.2.Dosimetry in the presence of magnetic fields

Magnetic-Resonance (MR)-linear accelerator (linac) guided radiotherapy allows real time organs-at-risk and target localization during treatment with enhanced soft tissue contrast and no additional radiation dose to the patient, increasing its potential in adaptive treatment strategies [42]. The number of these machines in clinical use is expected to grow over the next few years. Integrated systems with differing field strengths as well as magnetic field orientation (parallel or perpendicular) relative to the treatment beam, are being developed. A key issue regarding dosimetry in the presence of a magnetic field is the “electron return effect” (ERE), which is enhanced at solid/air interfaces. Dosimetric investigations have been made of the buildup effect, and detector type, design, response and orientation. Solid state detectors showed orientation effects of up to 20%. Magnetic field correction factors for Farmer-type chambers have been measured and calculated for different magnetic field strengths and field orientations [43, 44]. The ERE on ion chamber measurements has been studied, showing a general trend of increased signal with greater magnetic field strength, whose magnitude depends on the air cavity size.

The PTB presented the design of a new water calorimeter to be used for measuring the dose in a 6 MV beam from a 0.35 T MR-linac [45]. Special considerations were avoidance of ferro-magnetic materials, physical size (the MR-linac used had a bore diameter aperture of 70 cm), horizontal irradiation geometry and insulation. This device allowed for the direct calibration of various ionization chambers in parallel and perpendicular orientations with standard uncertainties of 0.6%. Further measurements are planned for a different MR-linac beam system. Similarly, a Canadian research team [46] presented the design of a MR-compatible water calorimeter that could be positioned using kV, CBCT or MR imaging. Finite Element Method (FEM) software and MC simulation of heat transfer were used to design the calorimeter. Based on the optimum design, a calorimeter was constructed, and its performance evaluated in a 7 MV beam from a 1.5 T MR-linac. The most difficult aspect of the construction was the thermal shielding needed to isolate any external temperature change influence.

The manufacturing details and use of a new ion chamber-shaped graphite calorimeter intended for use as an absolute clinical dosimeter for high energy photons in the presence of a magnetic field, was presented [47]. Magnetic field correction factors were calculated and measured. Within the uncertainty of the measurements, the graphite calorimeter agreed with the ion chamber measurements. There was more variability in the ion chamber measurements than observed with the calorimeter. Results from the study suggest that the calorimeter can be used in a solid phantom in the presence of a 1.5 T magnetic field without significant detector rotation or orientation corrections, with a combined relative standard uncertainty of 0.8%. Further measurements will be made in different magnetic field strengths and for other clinical dosimetry measurements.

A process to make FEM adjustments to ion chamber simulations was described in order to improve the agreement with dose measurements in the presence of a magnetic field [48]. The adjustment involved semi-empirical modification of the sensitive volume of the ion chamber using the FEM in order to correct for electric field lines that end in the guard as opposed to the collecting electrode. Monte Carlo calculations using EGSnrc and GEANT4 were compared. The deviations between the measurements and the calculations with the FEM modifications were within 1 % for all irradiation conditions [49]. The GEANT4 calculations will be extended to include simulation of the electric field.

The Australian Clinical Dosimetry Service has initiated development of an independent dosimetry audit for MR-linacs [50]. A 6 MV FFF beam was used with a 1 T inline MR-linac [51]. A multi-chamber comparison was performed for three ion chambers, a microdiamond detector, alanine and EBT3 film in solid water and liquid water. All measurements agreed to within 1% after magnetic field corrections were applied to the ion chambers. An end-to-end IMRT audit was also conducted using a commercial anthropomorphic phantom that was modified to enable visualization of the detector position and surface contour on the MRI images.

4.1.3.Protons and beyond

There are currently 73 proton therapy facilities and 11 carbon facilities in operation worldwide [52]. Significant technological developments have taken place for proton and light ion (atomic number < 10) beam generation systems over the past few years. The use of monoenergetic scanning beams is now widely available. This is in contrast with the technology used 20 years ago, when passively scattered proton beams were practically the only option available.

An introduction to the main topics to be included in the upcoming ICRU Report No. 93 was given [53]. The main recommendations in the new ICRU report is to discourage the use of gray (Gy)-relative biological effectiveness (RBE), and to rather include a descriptor to qualify dose. For dose reporting therefore, the absorbed dose, RBE-weighted dose and dose-weighted linear energy transfer (LET) should be recorded. In addition, reference dosimetry should be in accordance with the IAEA TRS-398 update.

A talk indicated that reference dosimetry for scanning proton beams [54] requires that the monitor units (MU) are typically calibrated in terms of number of particles since treatment planning systems calculate the number of protons per spot. This can be derived from the dose-area product (DAP), which can be performed with a cross-calibration of a parallel plate ionization chamber or a large-area ion chamber. For scanning beam calibration in the entrance region, it is important to account for the dose gradient if a Farmer chamber is used and the residual range (*R*res) is less than 15 cm. For calibration in the center of a spread-out Bragg peak (SOBP), the beam ripple should be taken into account. While limited data exists, experimental k_Q data was compared to MC calculations and agreed well.

The next presentation showed that for proton beams produced by cyclotrons and synchrotrons, the recombination behaves like a continuous beam. For proton beams produced by a synchrocyclotron, the recombination behaves more like a pulsed beam. Care should be taken when calculating k_{sat} with higher polarizing voltages. Two methods for calibrating monitor chambers in a synchrotron for particle therapy were described [55]. The first method determined absorbed dose to water at a shallow depth in a single energy layer scanned pencil beam using a PTW Roos chamber. For the second method, a single energy static spot was measured using a large-area ion chamber. The results of the two methods were compared over a range of energies and differences of up to 3.2% were observed. The chamber readings for the large-area ion chamber can be corrected to get agreement within 1%. Either method may be used with a combined standard uncertainty of about 2.6% (1σ), however, there are concerns over the homogeneity in response over the active volume of large area ion chambers [56].

The NPL described a comparison of the measured dose per MU at a water-equivalent depth of 2 cm of 6 user- and 7 reference-ion chambers, that was performed in passively scattered and scanning proton beams in 3 clinics [57]. Ion recombination was compared in a low-energy passive scattered beam using the two-voltage method, which underestimated the recombination. Clinical centers calculated recombination corrections differently, and standardization is recommended. There was agreement within 1.2% in proton beam calibration between the NPL and the clinical proton centers. Additional measurements in composite fields however, showed discrepancies up to 3.1%.

The NPL also described the use of a portable primary standard graphite calorimeter for proton beams (scanned and scattered) [58]. Monte Carlo calculations were performed to determine several correction factors for the graphite calorimeter as a function of energy and beam diameter. The correction for the presence of vacuum gaps was up to 0.8% in small fields, and within 0.1% for large proton fields. The dose averaging correction was within 0.3%. For the proposed primary and secondary standard test volumes, the corrections were found to be less than 0.1%. For the passive beams however, the dose averaging correction was much larger (2.6%).

An analysis of MC calculations was presented using GATE 8.1 and Geant4 to investigate the possibility of using a phantom containing an ionization chamber and alanine detectors for an end-to-end audit methodology for ion beam dosimetry [59]. Correction factors are necessary to account for stopping power ratios and relative effectiveness. Experimental data were compared to MC (GATE) and TPS dose calculations based on an independent MC dose engine. It was indicated that future work will focus on carbon therapy.

The next talk described absorbed dose to water measurements with ion chambers and a water calorimeter that were performed in a carbon ion beam in China [60]. The beam quality correction results obtained with different ionization chambers agree well within the uncertainty of measurement to the values provided in TRS-398.

The “Proton and Beyond” session ended with a talk looking at the effect of the revised key data from the ICRU Report No. 90 on the calculation of beam quality correction factors for the calibration of a carbon beam [61]. The ICRU Report No. 90 does not include stopping power values for several of the light ion fragments that make up part of the carbon therapy beam, and efforts were undertaken to calculate these values as well. The updated beam quality factors agreed better with experimental data for cylindrical chambers, especially where updated ^{60}Co perturbation factors were available. For plane-parallel chambers however, discrepancies up to 2% were found that require further investigation.

4.1.4.Dosimetry audits for new technologies

Dosimetry audits for advanced techniques and new technologies are necessary to assess quality and safety, to reduce delivered dose variability between institutions, to maintain and improve standards, and to support implementation of complex techniques [62]. Levels of audit begin with assessing beam calibration, expand to non-reference beams and assessing the TPS, and then end-to-end QA testing can be used to verify the whole treatment chain. Independent audits have been key to assessing new technology introduced into radiotherapy and they are often mandatory for credentialing to participate in multi-institutional clinical trials. In order to keep pace with the rapid pace of technological changes, new audit methodologies need to be devised and updated continually; however, this may be inefficient and costly if only on-site tools are developed. Prospective risk management strategies, such as Failure Modes and Effects Analysis (FMEA), could be considered which inform the development of dosimetry audits that focus only on the most critical processes. Other strategies could be the transmission of raw data to central repositories for analysis and the development of regional external audit groups with shared resources.

The details of an end-to-end head and neck IMRT audit that was conducted with on-site visits to 20 institutions in Portugal using the IAEA methodology (SHANE phantom) [63] were presented. The visit also included an audit of multi-leaf collimator (MLC) performance and machine calibration, as well as verification of TPS-calculated 2 cm x 2 cm field profiles and small field output factors. The MLC test showed all MLCs to be calibrated to within 0.5 mm at all institutions. All centers passed the output factor verification audit for field sizes greater than 3 cm x 3 cm, and calculated beam profiles were found to differ by up to 2 mm from measurements. Differences between the measured SHANE phantom doses and the TPS dose calculations were all within the 5% criterion for the PTV and 7% for the spinal cord OAR. Similarly, the initial results of a remote end-to-end prostate IMRT audit in Brazil were presented in which the local clinical protocol is applied to an anthropomorphic phantom and the results are centrally analyzed [64]. A phantom was designed and constructed with targets and organs at risk into which TLDs and film were placed. The results from the first 15 institutions irradiating this phantom were presented that showed the percent of institutions meeting acceptance for the planning target volume (PTV) TLD, organs at risk (OAR)

TLD and gamma index % to be 86.7, 66.7, and 80.0 %, respectively.

The National Research Council of Canada (NRC) described efforts to use alanine as a remote dosimeter for the validation of beam output [65]. Alanine has potential as a more accurate and precise dosimeter than other passive dosimeters used for mailed postal audits, including for high dose industrial applications. Comparisons between the NRC and the NPL were performed for absorbed doses of 15 to 1000 Gy. The comparisons of the two alanine systems were within 0.7%, with both laboratories claiming a standard combined uncertainty of within 0.7%.

An end-to-end dosimetry audit for proton therapy describing the use of alanine at five European proton centers [66] was described. A homogeneous plastic phantom and two anthropomorphic phantoms (pelvic and head and neck) have been modified to accommodate ion chambers, alanine and radiochromic EBT3 film. The phantoms were irradiated and the results from the three dosimeters were compared. The ion chamber and alanine results were within 3% of the calculated doses. A similar dosimetry audit methodology is being developed for carbon ion beams.

The IROC Houston QA Center's remote and on-site dosimetry comprehensive audit programme for proton therapy that monitors 42 proton centers [67] was presented. This audit programme includes remote annual monitoring of proton beam outputs using TLDs, performance of on-site dosimetry measurements and use of anthropomorphic phantoms for end-to-end audits. The overall anthropomorphic phantom pass rate is currently at 73%, with the lung phantom producing the lowest pass rate. Improvements in pass rate have been seen with MC TPS algorithms. Thirty-five site visits have been performed at 27 proton centers with the mean number of recommendations being four. Houston IROC has developed a robust audit programme for proton therapy that promotes more consistent and comparable proton treatment, which benefits participation in clinical trials.

The QA credentialing activities for 6 carbon ion facilities (8 different beam lines) in Japan that participate in multi-institutional clinical trials were described [68]. The QA activities include a questionnaire and an on-site peer review process. The site visit includes a dosimetry audit of the beam calibration for each line at two beam energies in a homogenous water phantom. The average discrepancy between measurements and TPS calculations for absorbed dose to water was 0.6% with an uncertainty of 1.4%. The maximum discrepancy was 2.7%.

4.2. Dosimetry for X-ray Diagnostic and Interventional Radiology

4.2.1.Patient dosimetry

There is a clear need for accurate dosimetry in medical exposures, in particular for the optimization process [69]. The European research project, Medical Low Dose Radiation Dose (MEDIRAD) is developing a patient-specific MC simulation with CT scanner-specific parameters in order to produce a voxel to voxel representation of the radiation dose distribution that corresponds to the CT image. This aims to provide accurate patient-specific organ doses from CT examinations. The MEDIRAD project aims also to develop a real-time tracking software for peak radiation skin dose in interventional radiology and to produce a staff radiation dose tracking system based on the physical location of the staff in the X-ray room. The latter, if successful, could potentially eliminate the need for personal dosimeters in the near future.

The scientific community in diagnostic imaging is moving towards personalized CT dosimetry. An interesting study focused on this subject and illustrated a four-step process starting with the actual patient CT scan, followed by the generation of a segmented 3D CT image, and the use of an "equivalent CT source" model in a MC calculation, to produce a 3D dose distribution that estimates the organ doses within 2 min following the patient's CT scan [70]. Semiconductor embedded probes in a CT phantom were used to compare the MC and measured doses, which agreed within the standard uncertainty of (5 to 10%) for three different manufacturer models.

Mammography examinations are very important from the radiation dose perspective because the procedure is routinely performed on healthy women without any clinical problems. Salomon, et. al. investigated the use of semiconductor dosimeters in dosimetry for mammography. Eight such detectors were calibrated at the IAEA for a range of mammography beam qualities [71]. Five dosimeters complied within the ±5 % stated by the IEC for air kerma.

Lau et al described the application of automated volumetric-breast-density measurement software for the MC calculation of mean glandular dose (MGD) and compared their results with those provided on the X-ray console by the manufacturer [72]. The comparison showed that manufacturers' calculations are lower than the MC results and thus underestimate patient's breast dose.

The development of a new breast model that identifies the distribution of glandular tissue within the breast, which is realistically neither uniform nor concentrated in the centre of the compressed breast, was presented [73]. This model is needed for more accurate patient-specific dosimetry.

Fedon et. al. estimated the entrance skin dose arising from angiography for four age-groups of children with heart disease [74]. Patient skin dose was either estimated using Dose-area-product (DAP) measurements and a conversion factor from the literature or determined using TLD and 4 different phantoms sizes. Comparison of DAP-derived doses with TLD-measured doses indicated that DAP estimated skin doses overestimate patient skin doses

4.2.2.Dosimetry as a tool for optimization and auditing

Tsapaki provided numerous examples of optimization in routine clinical radiology practice, highlighting the usefulness of dose management systems in the speedy evaluation of patient dose. The importance of engaging all staff in the optimization process, even though this may take time and requires patience, was emphasized [75].

The use of 1 mm bismuth shielding placed on the neck, was found to reduce thyroid, eye lens or other organ doses by as much as 60 % during CT of the cervical spine [76]. This was without loss of diagnostic information, although the images were slightly (1%) noisier. An experimental methodology to evaluate and reduce lung and thyroid organ doses in routine pediatric chest CT, using optimized clinical protocols, was presented [77]. Dose savings of 25% for the lung and 13% for the thyroid were achieved with acceptable CT image quality.

4.2.3.Monte Carlo for dosimetry in diagnostic and interventional radiology

Monte Carlo studies are an important component in modern x-ray dosimetry and contribute to reference dosimetry for diagnostic and interventional radiology through, for example the calculation of backscatter factors and mass attenuation coefficients [78]. Such calculations also allow the determination of dose conversion coefficients derived from anatomical phantoms and corrections for phantom material and phantom thickness. Monte Carlo is used in diagnostic radiology to investigate the components of the detection system, to determine physical factors such as the scatter-to-primary ratio and the backscatter ratio, to determine energy spectra such as the backscatter spectra and to estimate absorbed doses related to radiation protection aspects. Monte Carlo can also be used to interrogate the design of x-ray tubes.

4.3. Dosimetry for Nuclear Medicine

There are pros and cons of highly patient specific voxel level internal dosimetry compared with model based calculations that rely on S-values (dose per unit cumulated activity) generated for reference phantoms [79]. The trade-off between accuracy and speed, the available tools and the application should be considered when selecting one over the other. Although voxel-level dosimetry using Monte Carlo radiation transport is generally considered as the most accurate, phantoms used for the S-value calculation have evolved substantially since the mathematical phantoms of the 1960's (e.g. the Fisher-Snyder phantom used for MIRD 11 S-values). Recent S-values, such as those used by the ICRP, are based on voxel phantoms and hybrid phantoms combining the advantages of mathematical and voxel phantoms that are highly realistic and allow for more flexibility. Hence high accuracy can be achieved, even without the computationally demanding Monte Carlo based voxel-level calculation that rely on the patients' own images. When resources for voxel-level dosimetry are not available, the calculation can be made patient specific to some extent by using scale factors that depend on the organ masses specific to that patient. For homogeneous tissue, voxel-level dosimetry using dose point kernel convolution methods, can be in close agreement with Monte Carlo based calculations. When voxel size is large compared with the beta-particle range, dose estimation assuming local energy deposition can be sufficient for beta emitters that do not have associated gamma-rays (e.g. ^{90}Y). The presentation also included a discussion on the emphasis in diagnostic vs. therapeutic dosimetry in nuclear medicine. For diagnostics, the priority is for traceability whereas for therapy, it is on improving the accuracy of dosimetry.

4.3.1.Developments in nuclear medicine dosimetry

Dosimetry models are used to calculate the mean dose absorbed by the cell nucleus from Auger radionuclides in order to investigate the biological implications of subcellular localization of such electron emitters [80]. When there is no subcellular localization of activity, conventional electron dosimetry was sufficient. However, when activity is in the cell nucleus, conventional dosimetry strongly underestimated the absorbed dose.

The specific objectives of the of the Molecular Radiotherapy (MRT) project were described [81]. The MRT Dosimetry project focusses on the metrology needed for clinical implementation of dose estimation in MRT and builds on the previous MetroMRT project where the focus was on providing tools, protocols and guidance. One goal of the MRT Dosimetry project is to provide an open access database of reference images (phantom measurements and MC simulations), to be used as reference data for commissioning and quality control of SPECT/CT quantitative imaging. Other goals include improving accuracy and determining uncertainties associated with the various steps of the dose estimation chain as part of a multi-site dosimetry comparison.

Insight into clinical alpha particle dosimetry was given, highlighting its ultimate goal to link true microscopic 3D dose distributions to biological effect on both tumour and healthy tissues. The current lack of such data for patients is an obstacle for a wider clinical use of alpha-emitting radionuclide therapies [82]. The challenges of planar and SPECT/CT imaging of alpha emitters due to the low-count rates and multiple gamma-rays was discussed. Images and dosimetry results from their clinical trial on intraperitoneally administered ^{211}At-MX35 F(ab')2 for therapy of disseminated ovarian cancer was presented.

Iso-effective adaptive biological treatment planning in peptide receptor radionuclide therapy could be used to establish personalized prescriptions [83]. Bootstrapping techniques could be used to consider the influence of random error on dose estimations and inter-patient variation of the linear-quadratic (LQ) model adapted to radiopharmaceutical radiotherapy parameters. Their formulation could be also used to compare different therapeutic schemes or therapies with different radiopharmaceuticals or combined radiotherapy schemes.

The parametric optimization of a predictive mathematical model for the final thyroid mass determination, assuming heterogeneity of thyroid gland mass density, was presented [84]. The effect of actual mass density and changes during the treatment on the dose received by a thyroid was considered in contrast to previous models which assumed a constant density of 1 g/cc. On this basis, they optimized the parameters in the mathematical model predicting the smallest deviation between the measured and calculated volume of a Grave's diseased thyroid.

A methodology for patient specific dosimetry that enables the creation of 3D absorbed dose maps for patient specific dosimetry in radiosynovectomy with ^{153}Sm labelled Hydroxyapatite, was described [85]. Instead of assuming a voxel composition of water, 4 different tissue groups based on CT Hounsfield units were defined and tissue-dependent S values were determined. This method allows a qualitative assessment of the treated volume extension and it can be used by the clinical staff as a tool to establish a connection between total absorbed dose and therapeutic effect.

4.3.2.Dosimetry in therapeutic nuclear medicine

The importance and limitations of dosimetry in the therapy of neuro-endocrine tumors with radiolabeled peptides, initially with ^{90}Y-DOTATATE/DOTATOC and currently with ^{177}Lu-DOTA-octreotate, were highlighted [86]. Higher kidney toxicity has been observed with the 90Y labelled peptides compared with the ^{177}Lu labelled peptides where it has been limited to grade 1/II toxicity. Potentially, this is due to the lower range of the ^{177}Lu beta particles compared with the range of higher energy ^{90}Y beta particles. Initial studies were performed without co-infusion of amino acids for kidney protection and since this protocol was adopted, the reported incidences of higher level toxicity have been much lower. For the ^{90}Y labelled peptide, because of the difficulties of imaging ^{90}Y, dosimetry has been sometimes performed with ^{86}Y PET, but the short half-life is a challenge. For ^{177}Lu labelled peptides, direct planar or SPECT/CT-imaging based dosimetry has been performed after treatment cycles. Comparable tumor dose – response relationships have been demonstrated for the ^{90}Y and ^{177}Lu labelled therapies. These studies typically demonstrate ~ 30% inter-patient variation in kidney absorbed doses while the variation for lesions is much higher. Recent studies have demonstrated the potential of circulating NET transcript analysis (NETest) to predict efficacy of PRRT, hence there is possibility to identify patients needing higher activity/cycles

The value of post-therapy imaging-based dose estimates in radioembolization therapy (also known as selective internal radiation therapy) of hepatic malignancies was presented [87]. Post-therapy ^{90}Y imaging based dosimetry that can be performed immediately after the RE procedure is valuable for 1) dose verification to enable early intervention when needed, 2) absorbed dose documentation that is important when retreating with radiation, and to 3) establish tumor absorbed dose – response and liver dose – toxicity relationships that can be used in future treatment planning. For establishing dose – effect, ideally direct imaging of the delivered ^{90}Y distribution by PET or SPECT should be used because of potential differences between the predicted dose distributions from a pre-therapy imaging surrogate (e.g. ^{99m}Tc MAA) and the actual delivered dose distribution. Although imaging ^{90}Y by both PET and SPECT is challenging, there have been several recent advances that have substantially improved quantitative imaging capabilities. This includes using time-of-flight PET, and Monte Carlo based methods for correcting bremsstrahlung scatter in ^{90}Y SPECT. Evidence of dose – response has been demonstrated in multiple studies.

A pilot study was undertaken on performing a selective internal radiation therapy dose calculation that compares ^{99m}Tc MAA imaging based lung shunt fraction estimated with planar and SPECT/CT imaging [88]. In the 16 patients evaluated, the lung shunt fraction calculated based on planar imaging was almost two times higher than the value estimated by SPECT/CT imaging. They predict that this overestimation by planar imaging lead to unnecessary reduction of the administered activity (underdosing) and in some cases made the patient ineligible for therapy due to concerns of high lung absorbed doses. However, during discussion it was pointed out that lung dose limits were established many years ago based on planar imaging.

In 2017, under a collaboration between the National Cancer Institutes and the University Hospital, peptide receptor radionuclide therapy with both ^{177}Lu-DOTATATE and ^{177}Lu PSMA was introduced in Uruguay [89]. Dosimetry was performed for these therapies using planar imaging with scatter and attenuation correction coupled with MIRD methodology using the tools in OLINDA. The blood-based method was used for bone marrow dosimetry. Their dosimetry results are consistent with results in the literature. Future studies include SPECT/CT-based dosimetry and evaluation of dose – toxicity relationships.

A dosimetric analyses of critical organs (kidney, liver and spleen) of 81 patients with neuroendocrine tumors treated with ^{177}Lu-DOTATATE, was performed by coupling planar gamma camera imaging, performed at up to 9 imaging time points, with the tools in OLINDA/EXM [90]. The results demonstrate the large inter-patient variability and the estimates predict that up to 40 GBq can be administered before the renal toxicity 'limit' is reached. During the discussion there was a question on why a low-energy collimator was used for imaging ^{177}Lu, when studies have shown that the medium energy collimators are more suitable to reduce penetration effects. The response was that there was no access to a medium energy collimator. The potential for improving dose estimates by simple organ mass scaling available in OLINDA was also discussed.

The Indonesian experience with pre-therapy dosimetry for prostate cancer patients treated with ^{177}Lu - PSMA CC34 was presented [91]. The goal of the study was to establish a protocol for performing dosimetry in patients who will get ^{177}Lu PSMA TRT in the future. Previously, dosimetry has not been used in Radionuclide Therapy in Indonesia and this work was initiated with IAEA CRP E2.30.05. support. Under this protocol, 12 patients were imaged at 4h, 24h and 48h and conjugate-view imaging-based dose estimates were derived following the recommendations in MIRD 16. Results showed that kidney and liver receive the highest absorbed doses. They observed some bone uptake and they plan to further develop their methodology to include SPECT/CT imaging in order to investigate imaging-based bone marrow dosimetry.

4.3.3.Monte Carlo in nuclear medicine dosimetry

Monte Carlo has been used historically in several aspects of nuclear medicine [92]. The S-values that are tabulated for various phantoms and are routinely used in internal therapy dose estimation, are pre-calculated using Monte Carlo radiation transport in mathematical phantoms. More recently with the advances in computational power, voxel-level patient specific calculations coupling patient's own images with Monte Carlo dose estimation have become feasible, although such calculations are considered to still be too slow for routine clinical use. Because of the computational expense, Monte Carlo is only recommended when other voxel-level methods such as point kernel convolution and local energy deposition are insufficient due to tissue heterogeneities and complex geometries. Monte Carlo simulated data are widely used to test the performance of SPECT and PET imaging systems, reconstruction methods and compensation methods for image degrading physical effects. For this purpose, dedicated SPECT and PET codes such as SIMIND and SimSET, developed at single institutes, are used all over the world. In the early 2000s GATE (Geant4 Application for Emission Tomography), an opensource, freely distributed Monte Carlo simulation tool dedicated to emission tomography, was developed.

OpenDose: an Open Database of Reference Data for Nuclear Medicine dosimetry, is a free, open access data base that was launched very recently and is maintained by the collaborating researchers [93]. This is an international collaboration across 18 institutes and was initiated with the goals of generating, verifying and disseminating reference dosimetric data relevant to the nuclear medicine community. Five of the most popular MC software used in radiopharmaceutical dosimetry are included. One of the projects involves generating Specific Absorbed Fractions for different computational models and different monoenergetic radiation sources to cross check the results between different codes. The Specific Absorbed Fractions will be integrated over emission spectra to provide reference S values. Initially for this project, the focus will be on the ICRP 110 adult reference computational phantoms.

DOSIS, a patient-specific MC based dosimetry toolkit for nuclear medicine procedures, was developed for voxelized dosimetry in targeted radionuclide therapy using components from general purpose MC codes PENELOPE and FLUKA [94]. The activity and density distribution obtained from PET/CT and SPECT/CT can be coupled with the DOSIS toolbox to achieve highly patient specific dose estimates. The option to perform dose point kernel (DPK) convolution for homogeneous media is also available and work on the DPK model for non-homogeneous media is in progress. DOSIS was benchmarked with other validated MC codes and showed good agreement. The toolkit includes a Graphical user interface to facilitate the dosimetry calculation and work is also being done on implementing other features such as segmentation tools.

4.4.Dosimetry for Radiation Protection

4.4.1.Effective dose as an indicator of patient risk

The new ICRP proposals, for the use of effective dose as an indicator of harm with risk terms attributable to different effective dose ranges, were presented [95]. It was emphasized that the uncertainties associated with effective doses less than 100 mSv are very large and the corresponding risk is low. The age, sex and health status of individuals should be taken into account when considering risks, especially to patients. It was emphasized that one should not use effective dose calculations to extrapolate to future cancer risks as this was totally inappropriate for diagnostic radiology [96]. Attention was drawn to the WHO leaflets and booklet on communicating with parents and families of pediatric patients [97] and the benefits of justified diagnostic radiology procedures, were stressed.

An estimation of whole body PET/CT combined effective doses to 170 patients was made based on the ICRP Publication No. 106 [98] dose coefficients for the radionuclides and the ICRP Publication No. 102 [99] for the CT exposures [100]. For the ^{18}F-FDG patients the combined effective dose was 18 mSv and for the ^{68}Ga-DOTATATE patients the combined effective dose was 15 mSv.

Measurements of surface doses were made using TLDs placed in the centre of the exposed field on an anthropomorphic phantom for six common radiology examinations for a range of patient exposure parameters obtained from a national survey, which was used to produce the DRLs in Ukraine [101]. Phantom simulations were then used to estimate the equivalent dose to the 12 most radiosensitive organs exposed under similar conditions. The collective effective dose for the Ukraine population was then calculated from the average effective dose and the number of procedures carried out per year [102].

4.4.2.Occupational dosimetry

The ISO/TC 85/SC 2 standards for staff radiation protection in medicine were highlighted as a newly developed set of standards related to radiation protection for individuals [103]. In the medical field, the development of new standards meets the increasing need for guidelines and protocols. It includes standards for external and internal individual monitoring of the staff, for patient dosimetry and related protocols in clinical applications and for shielding systems.

Nuclear medicine services include the preparation and administration of radiopharmaceuticals to patients. Any manipulation of radiopharmaceuticals with syringes and vials will lead to high doses to the fingers. Measures to protect the fingers include the use of tungsten shields that support the vial and provide better protection than simple lead pots, and the use of syringe shields for preparation, drawing up, and performing injections. Obtaining accurate dose assessment from routine monitoring is difficult, as the dose gradients across the hands can be substantial and the maximum dose, which is usually at the fingertips, is underestimated by ring dosimeters worn at the bases of the fingers [104]. There is a need to have a clear strategy for extremity dose monitoring.

The efficiency of different models of lead glasses in protecting the eye lenses of interventional clinicians has been assessed in a variety of ways: with phantoms, during clinical practice and with computational simulations [105]. If the dosimeter is worn under the lead glasses, the measured dose is considered to be similar to that received by the eye lens, while if the unshielded dosimeter is worn outside the glasses, a correction factor may be applied to allow for the protection provided by the glasses. However, due to the complex radiation field to which interventional clinicians are exposed, there is the potential for both approaches to underestimate the dose to the eye lens. Data suggest that a reasonable estimate of the eye dose may be derived from personal dosimeter (Hp(10)) data [106]. A study of staff member dosimetry records from two nuclear medicine units showed that the estimated annual eye lens doses seemed to stay well below the new eye lens dose limit.

4.5.Dosimetry for Radiobiology Experiments

Dosimetry is an important component in many radiobiology experiments, allowing for repeatability and valid comparison of results [107]. However, radiation dosimetry is currently not standardized and output verification in several laboratories showed large variations, especially for the medium energy kV beams [108]. The NPL reported on the need for guidelines on the dosimetry of medium energy X-ray irradiators used in pre-clinical radiation research, since the setups used for in vitro samples differ significantly from reference conditions cited in dosimetry CoPs [109]. Datasets of correction factors were calculated that will be used to develop a set of recommendations to enable the radiobiology community to deliver more accurate and harmonized dosimetry.

Microdosimetry is important since mammalian cells have typical volumes 100 - 10 000 μm^3, whereas nanodosimetry is concerned with dose deposition in volumes comparable to DNA, where the double helix diameter is approximately 2.4 nm. Traditional dose formalisms, e.g. Medical Internal radiation Dose (MIRD), assume a uniform distribution of activity and an average dose deposition per disintegration. Track structure codes can provide finer details of the nature of electron energy deposition in cells and provide information on the differences in biological effects between different radioactive isotopes. New approaches are necessary for evaluating electron emission spectra at the cellular and sub-cellular level to enhance the understanding of dosimetry of targeted therapies. A study of different iodine isotopes was presented and concluded that ^{125}I was potentially the most effective radiobiologically, compared to ^{123}I or ^{131}I [110]. Quantitative descriptions of electron transport for energies lower than 50 keV in tissue equivalent media is complex but of relevance to the use of Auger emitters in radioimmunotherapy applications. Monte Carlo calculations using PENELOPE were conducted to compare range parameters with those determined theoretically or experimentally [111].

A commercially available inorganic scintillation detector with a diameter of 1.3 mm that was characterized with medium energy X-rays [112] was described. If cross-calibrated in the user’s beam quality, it can be used for real-time, relative measurements in small animal irradiators in beams larger than 3 mm equivalent square.

V. DETECTOR TECHNOLOGY UPDATES AND CHALLENGES

Various types of ion chambers are used in radiotherapy and there are different criteria that should be used to select the most appropriate device to achieve an accurate dose measurement [113]. Considerations include stabilization time, polarity corrections, stability in the traceability, effective point of measurement corrections, volume averaging effects, topology and modality. The evolution of new radiotherapy treatment beams has resulted in the development of new ion chambers, which require new correction factors to accurately measure dose, especially for small fields. Cylindrical chambers with graphite walls and aluminum central electrodes appear to be the most stable chamber type in terms of longevity. It remains the responsibility of the physicist to make sure that the equipment fits the need through measurements under various conditions. This will allow the user to understand the limitations of their dosimetry equipment.

In addition to reference and relative dosimetry, various other dosimeters and dosimetry systems are used when performing dosimetry audits in radiotherapy. Selection depends on the audit complexity, accuracy desired and the reproducibility. Considerations include accuracy requirements, what it will be used for, readout procedures and analysis methods. A comparison of ion chamber and passive detector reference field output measurements between different Quality Assurance (QA) groups showed excellent agreement [114]. As the complexity of the audit increases, the choice of dosimeter, such as radiochromic film and the associated analysis method, is more crucial for good results. It was shown that different results can be obtained from using different scanning protocols, evaluation criteria and software analysis packages [115]. Comparisons of results obtained from treatment plan analyses using different detectors (film, detector arrays, ion chambers) showed differences depending on the software used to compute the gamma index, the device used and how the device was used (composite vs field by field). As a result, comparisons between external audit groups is also a challenge.

Similarly, detectors used for QC measurements in diagnostic x-ray beams have evolved into automated, multi-functional devices that display several parameters following a single exposure. These non-invasive multimeters are however not corrected for energy response and can provide incorrect results particularly at low energies, e.g. mammography [116]. There are international standards for these devices (IEC 61674 and 61676). An additional challenge is the introduction of new imaging modalities, e.g. digital breast tomosynthesis and CBCT, for which there is, as yet, no consensus dosimetry guidance.

VI. NOVEL DOSIMETRY

Ion recombination issues are associated with an ultra-short high dose-per-pulse very high energy electron beam [117]. Measurements were performed with Roos type parallel plate chambers (PTW24001) in an experimental very high energy electron beam and in a 12 MeV linac beam were presented. The charge per pulse was varied along with the collecting potential. Various models were investigated to fit the measured data. There is no known acceptable model applicable to the whole data set for determining the ion recombination for the very high energy electron beams that use the ultra-short high dose-per-pulse. Findings indicated that the collecting potential needed for an accurate measurement of the collection efficiency far exceeded the ion chamber rating. These data can be used to provide a foundation for developing a new methodology to calculate the collection efficiency in these unique electron beams.

A study was conducted to assess the varying models of cross-section data used by different Monte Carlo codes on the uncertainty of microdosimetric quantities [118]. The EURADOS working group 6 launched an exercise to use various MC codes to calculate the energy distribution for three different ^{125}I source geometries (point, volume and surface configuration). The results for the point and volume sources were found to be within 2%, however, when the source was on the surface of the sphere, the deviations became significant. The origin of observed deviations is under investigation, specifically looking at the cross-section data tables used. For an ^{125}I point source in the centre of a well-defined liquid water sphere of diameter 10 micrometers, the ionization cluster size frequency distribution was calculated at different target positions and target diameters in the sphere, and large differences were observed.

Nanodosimetric track structure analysis was investigated for estimating RBE variation in a clinical proton beam. Simulations were performed using GEANT4-DNA [119]. The results showed encouraging data for the use of track characteristics predicting variations in RBE for lethal lesions in cells. The next step will be to confirm the simulations with radiobiological findings.

A study using novel photon counting pixelated detectors (cadmium telluride (CdTe) and silicon) that are capable of recording spectral information, to inform image processing algorithms to enhance CT imaging or directly correct for energy response in dose measurements [120] was described. A 0.5 mm thick CdTe chip showed promising results when irradiated with a ^{137}Cs source. Scintillator-enhanced silicon was analyzed as a high-resolution detector and may have an application in radiotherapy fields with high gradients. Promising results were demonstrated; however, further developments and testing are needed for clinical implementation.

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ADDENDUM TO:

EFFECTIVE PHYSICS KNOWLEDGE FOR DIAGNOSTIC RADIOLOGISTS

Clinically Focused Physics Education

Perry Sprawls, Ph.D.
Emory University, Atlanta
Sprawls Educational Foundation, www.sprawls.org

This is a presentation containing a collection of visuals used in courses on the general topic of medical physics education for medical professionals, especially radiologists and radiology residents.

They are provided here to be used by medical physicists for individual study, group discussions, or in class or conference presentations.

Clinical Medicine

Imaging


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Radiation Therapy

Physics

The Foundation Science

Sprawls

Effective and Safe Clinical Procedures

Imaging

Radiation Therapy

Require an extensive knowledge of

Applied Physics

and

The Associated Technology

Sprawls

Who needs a knowledge of Physics applied to clinical imaging?

Radiologists, Residents and Fellows

Technologists

Medical Physicists

Each provides unique challenges and opportunities.

Sprawls

Clinically Focused Physics Education

Classroom

Clinical Conference

Small Group

"Flying Solo"

Learning Facilitator "Teacher"

Individual and Peer Interactive Learning

Each type of learning activity has a unique value.

Sprawls

Clinically Focused Physics Education

Classroom

Clinical Conference

Small Group

"Flying Solo"

Learning Facilator "Teacher"

Individual and Peer Interactive Learning

The Goal..

Increase the **EFFECTIVENESS** of each type of learning activity with the **necessary resources** and **understanding of the process** by the Learning Facilators.

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The Barrier

Physics Education

Clinical Imaging

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Efficiency

Location, Resources, Human Effort, Cost

Limited Experience

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Why an Evolving Model?

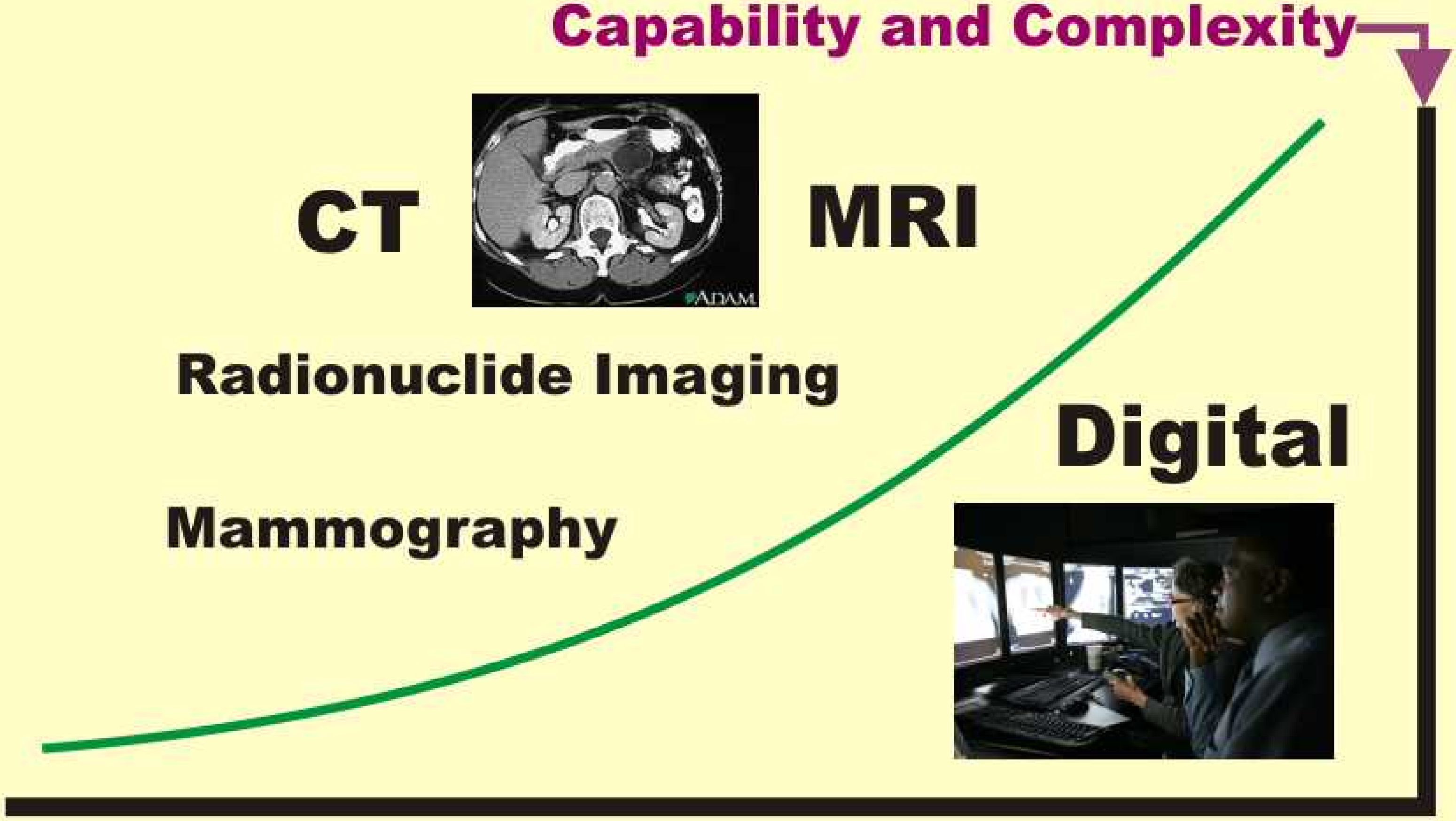
Three Dynamics....

1. Rapidly expanding **NEEDS** for physics knowledge.

2. Expanding availability of educational **RESOURCES.**

3. Better knowledge of the learning and teaching process.

Continuing Growth in the Need for Physics Knowledge



Capability and Complexity

CT

MRI

Radionuclide Imaging

Digital

Mammography

Time

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Digital Resources to Enrich Learning Activities

The Web

Connecting and Sharing

Textbooks Modules

Visuals

Clinical Images

Modules

References Teaching Files

Classroom

Clinical Conference

Small Group

"Flying Solo"

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Physics Learning Objectives for Radiologists

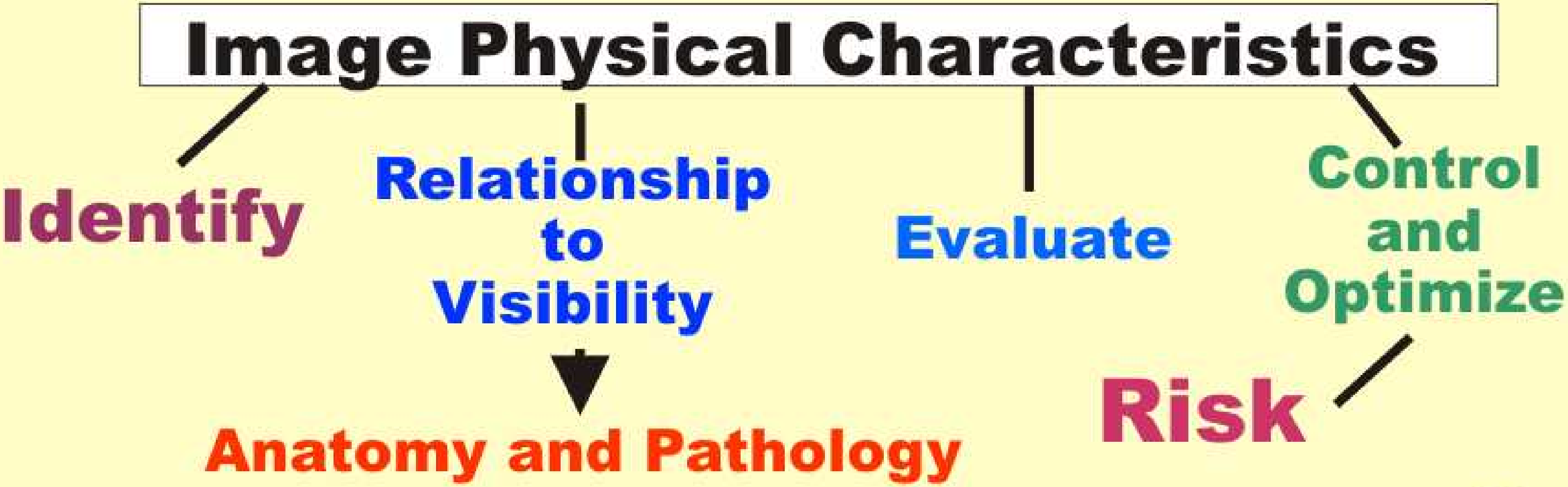

Image Physical Characteristics

Identify

Relationship to Visibility

Anatomy and Pathology

Evaluate

Control and Optimize

Risk

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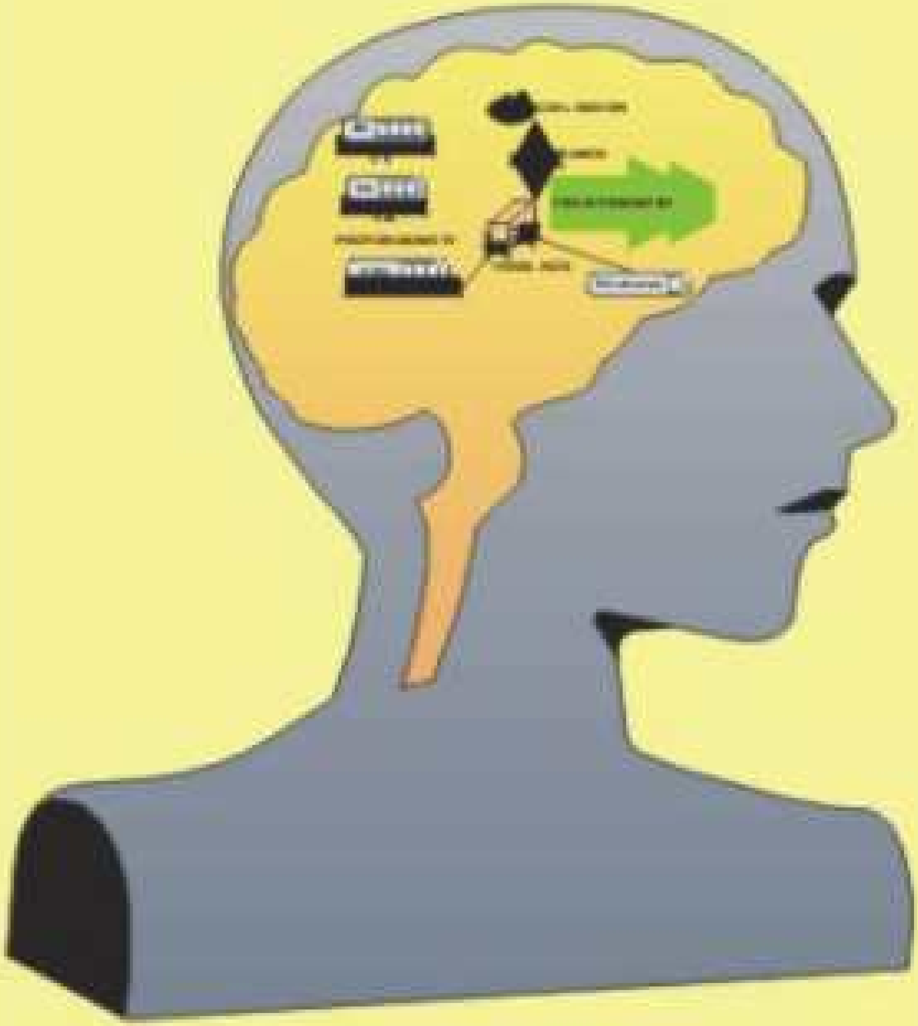
LEARNING is...



Building a knowledge structure in the mind

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Learning Physics is by..

Encounter and Experience

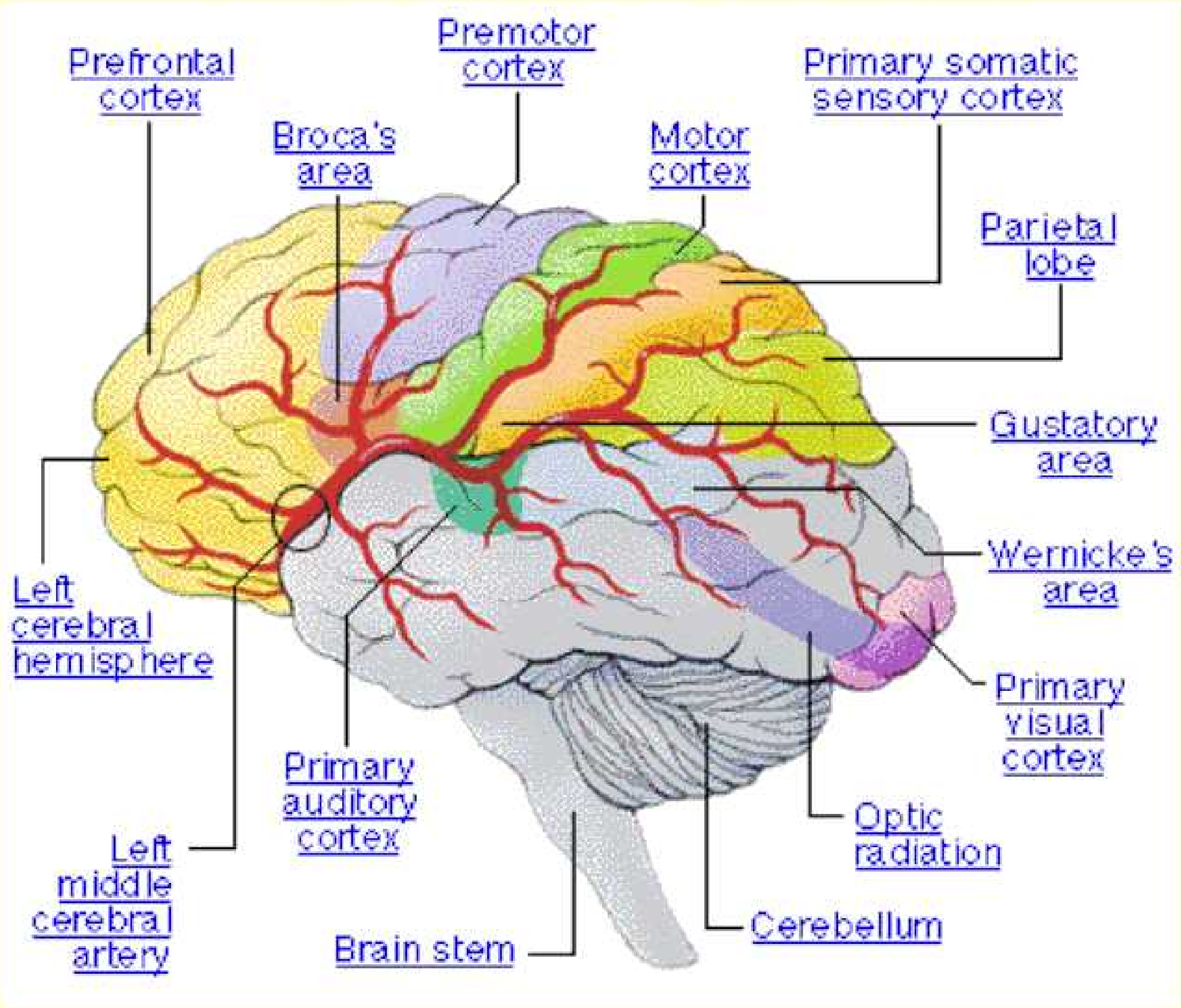
Physical Universe

Brain

Images: BYU and Howstuff works

Sprawls

The Brain...



Structure and Function

Image: AMA

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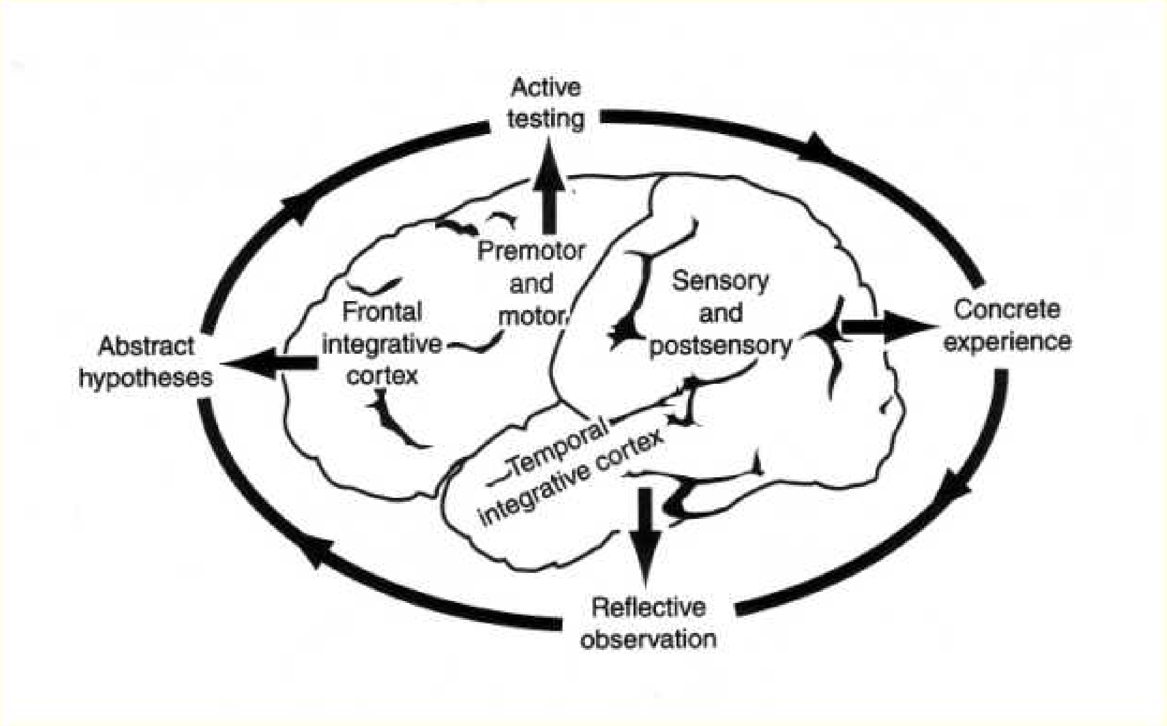
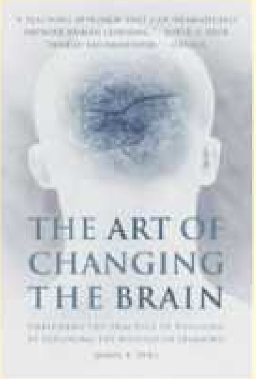
Zull's Model of Brain Function



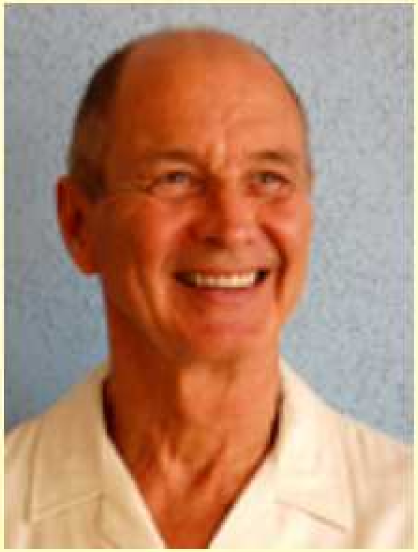
James Zull, Ph.D.
Professor of Biology
Professor of Biochemistry
Director of University Center for
Innovation in Teaching and
Education
Case Western Reserve

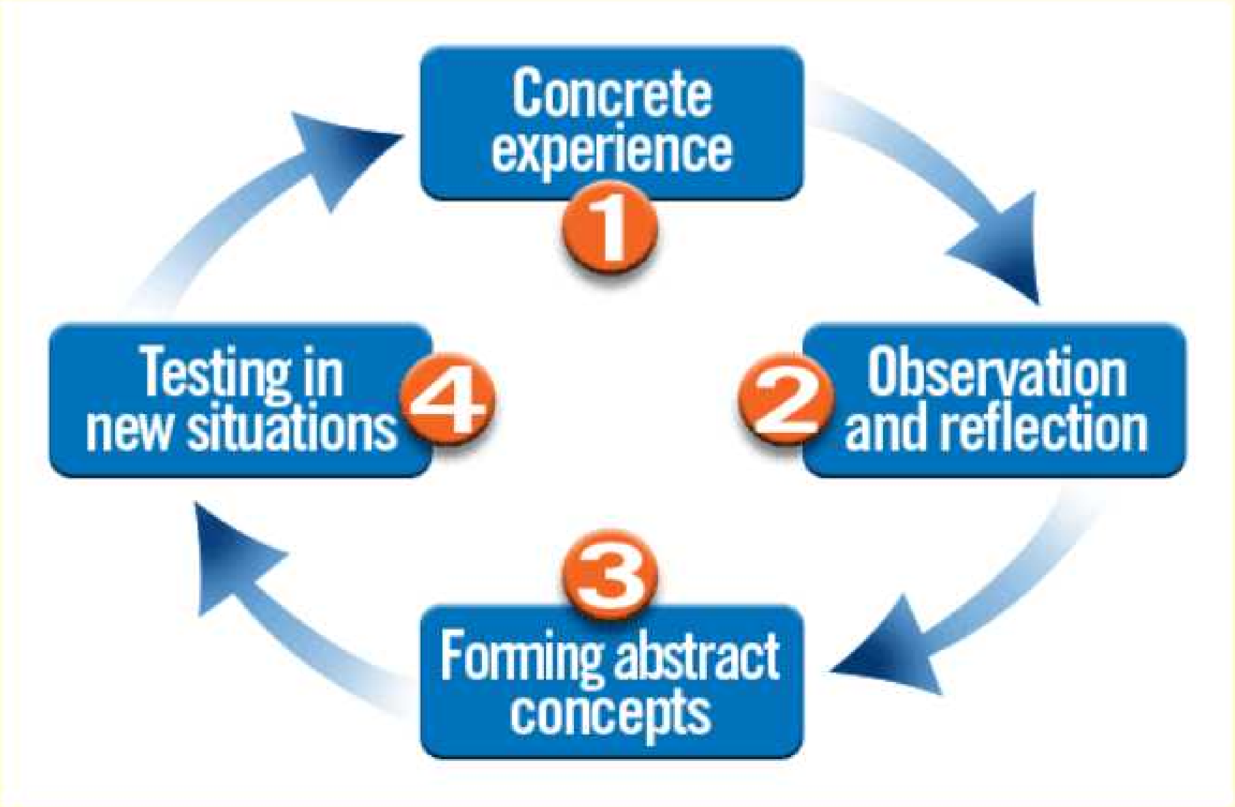
Reference:



THE ART OF
CHANGING
THE BRAIN

Kolb's Experiential Learning Model





1 Concrete experience

2 Observation and reflection

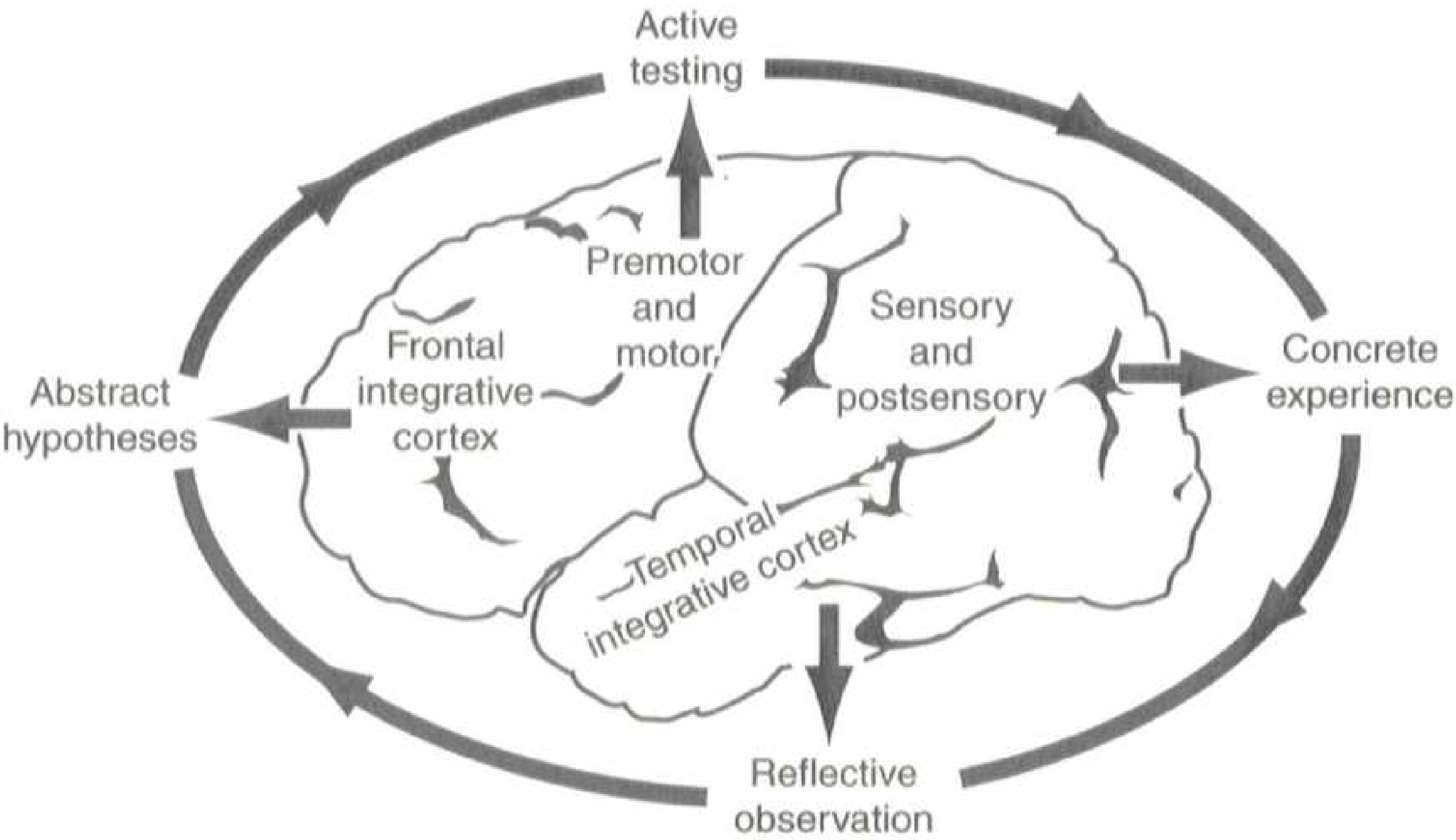
3 Forming abstract concepts

4 Testing in new situations

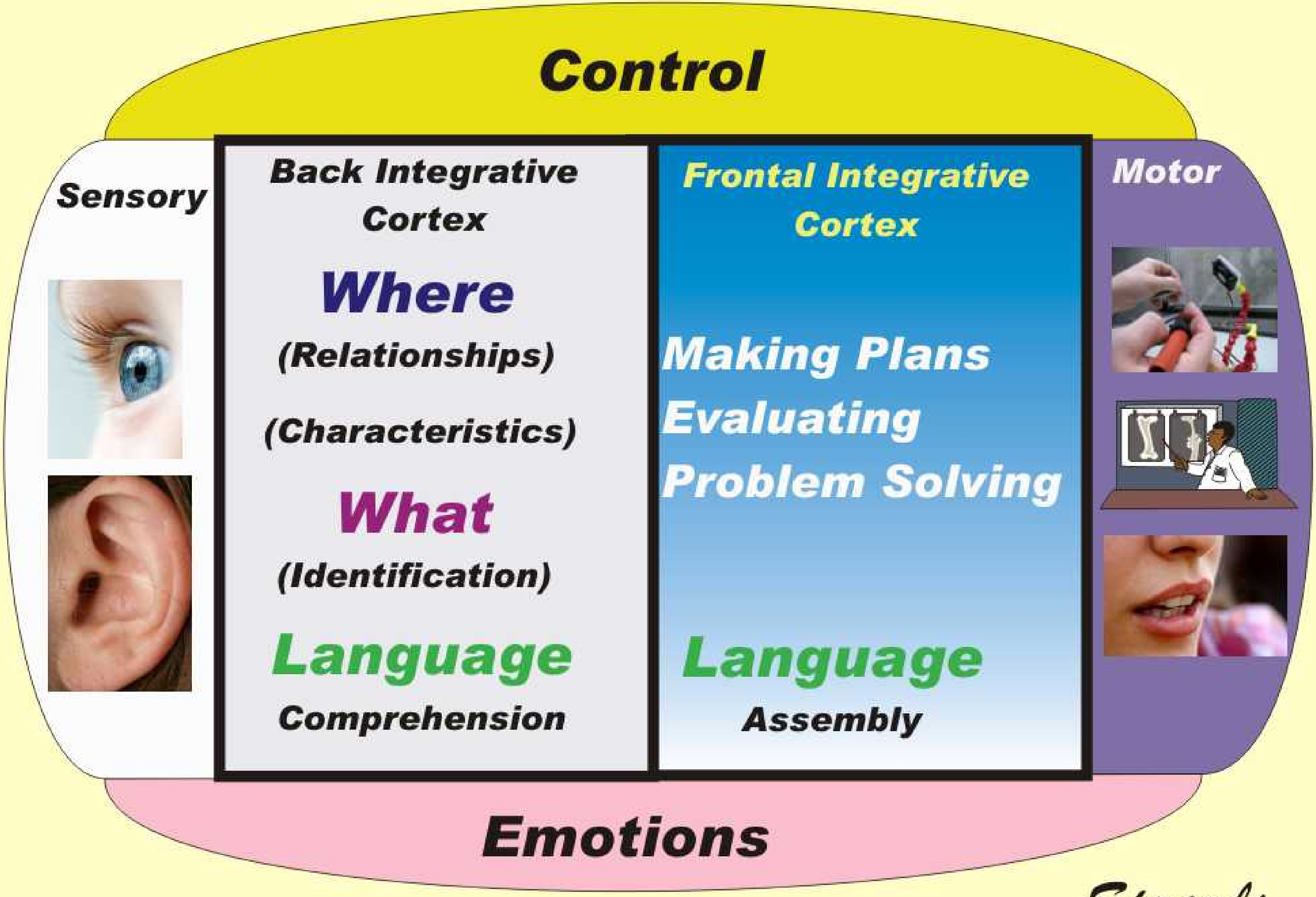
David A. Kolb, Ph.D.
Professor of Organizational Behavior
Case Western Reserve

Website: http://www.learningfromexperience.com

Zull's Model of Brain Function



Brain Functions for Learning Physics



Control

Sensory

Back Integrative Cortex

Where

(Relationships)

(Characteristics)

What

(Identification)

Language

Comprehension

Frontal Integrative Cortex

Making Plans

Evaluating

Problem Solving

Language

Assembly

Motor

Emotions

Sprawls

Brain Functions for Learning Physics

Control

Sensory

Back Integrative Cortex

Records of the Past

Reflection

Frontal Integrative Cortex

Preparation for the Future

Hypotheses

Motor

Emotions

Sprawls

Brain Functions for Learning Physics

Control

Sensory

Back Integrative Cortex

Records of the Past

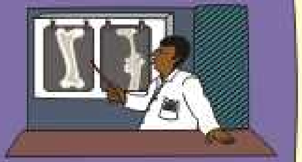
Knowing

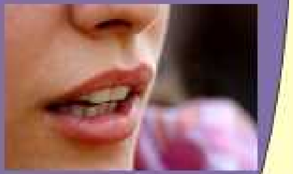
Frontal Integrative Cortex

Preparation for the Future

Doing

Motor

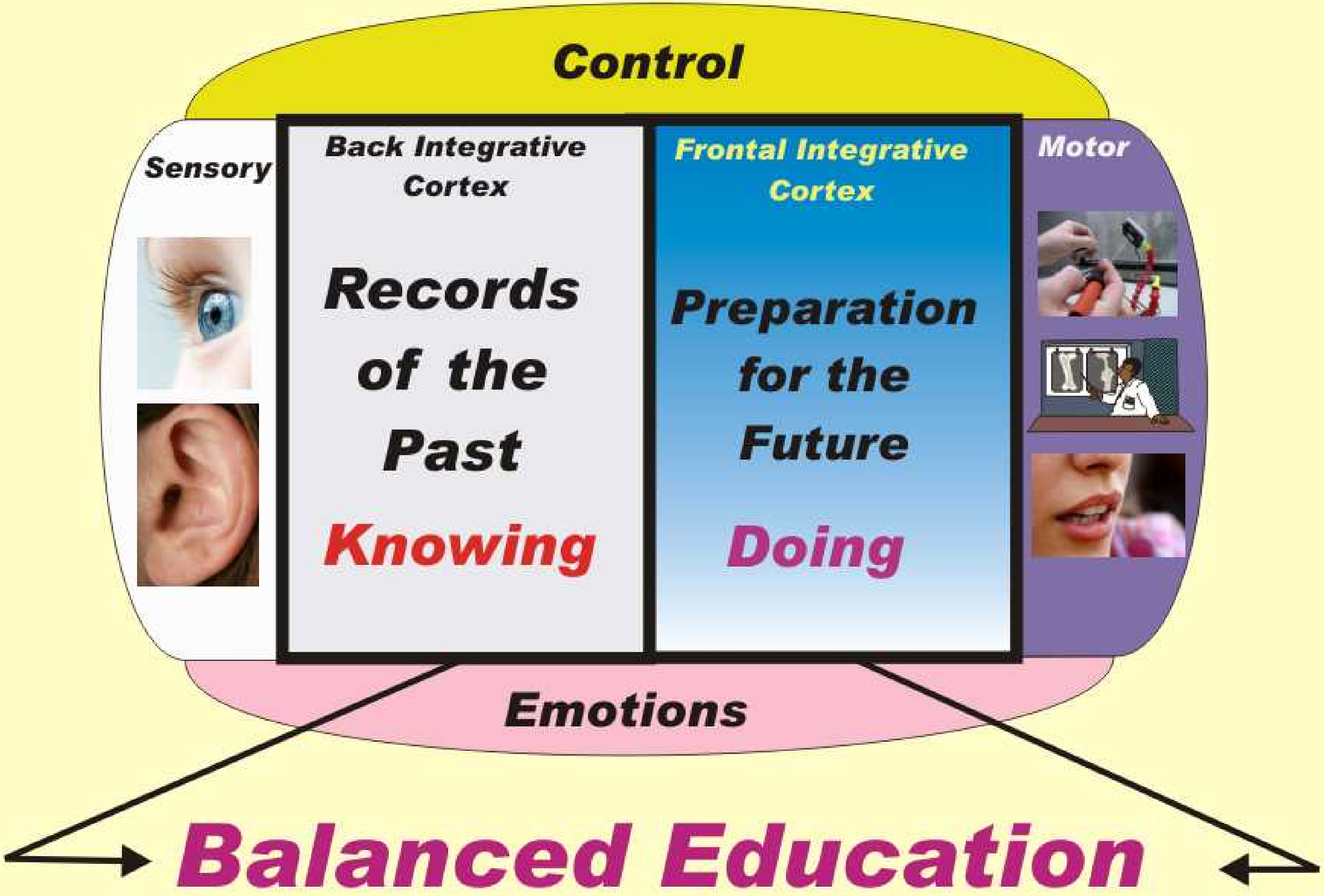




Emotions

Sprawls

Brain Functions for Learning Physics



Control

Sensory

Back Integrative Cortex

Records of the Past

Knowing

Frontal Integrative Cortex

Preparation for the Future

Doing

Motor

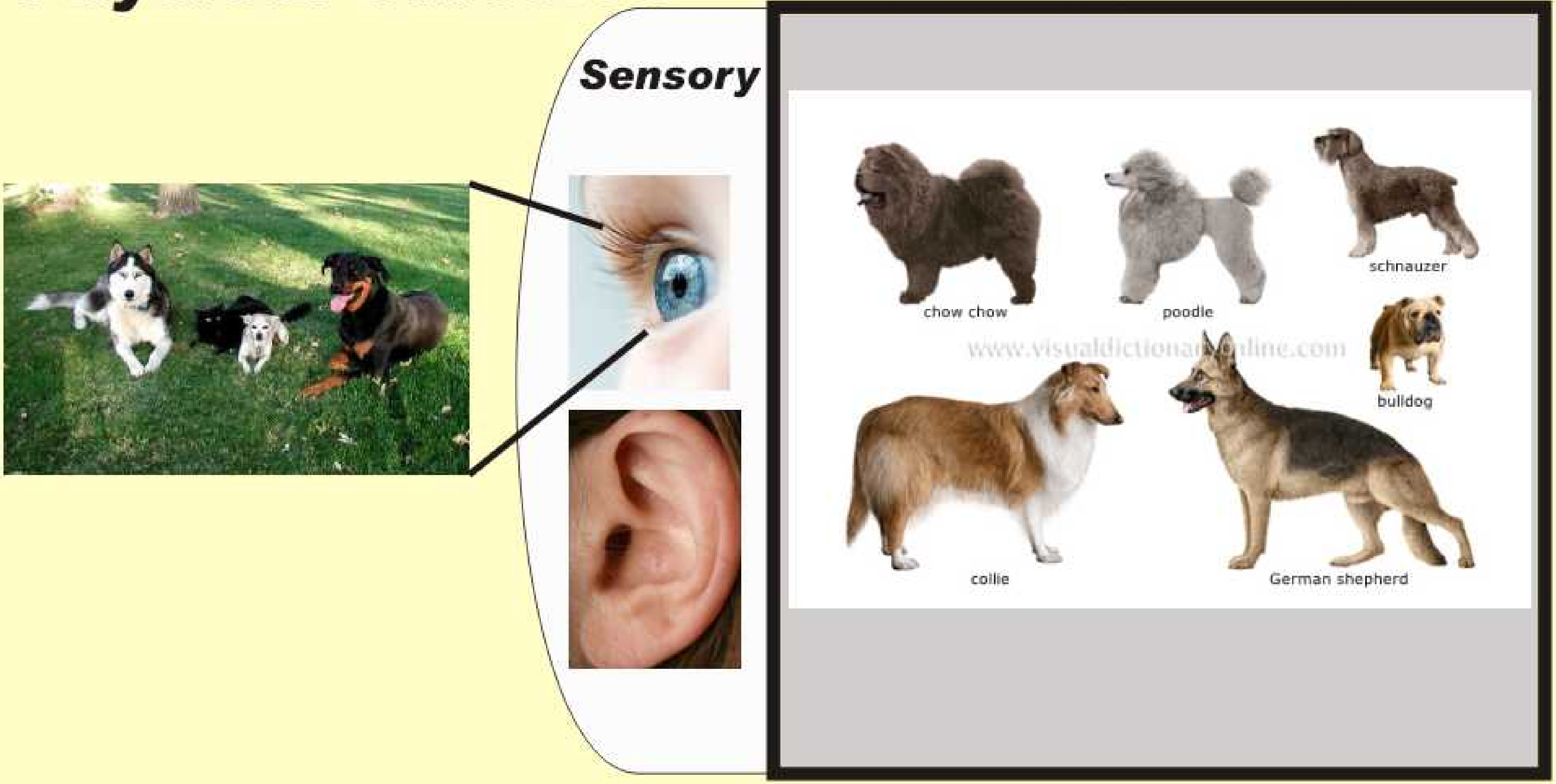
Emotions

Balanced Education

Sprawls

Forming Knowledge Structures

Physical Universe **Back Integrative Cortex**



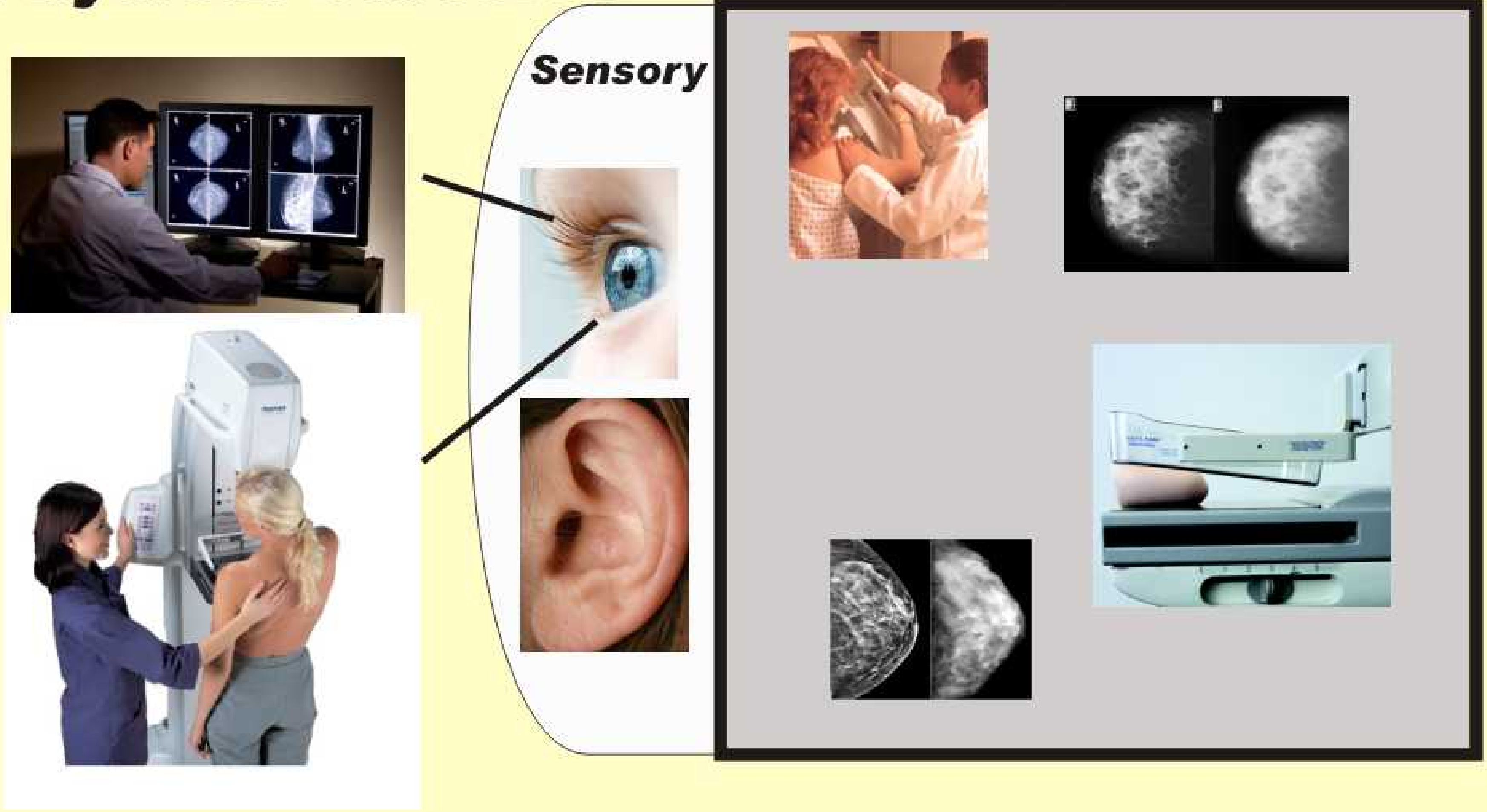
Visible Physical Objects

Sprawls

Forming Knowledge Structures

Physical Universe

Back Integrative Cortex



Visible Physical Objects

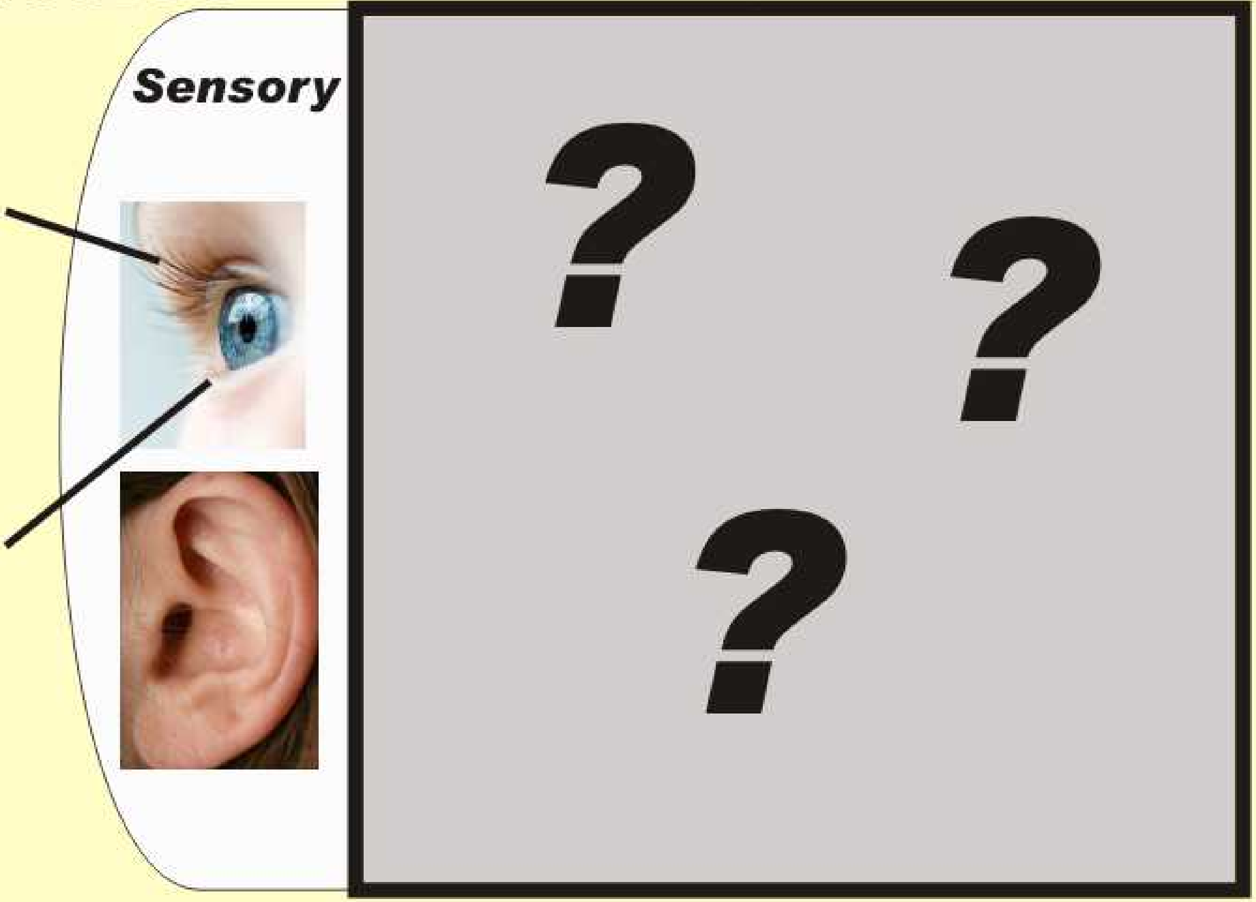
Sprawls

Forming Knowledge Structures

Physical Universe

Back Integrative Cortex

Radiation
Electrons
Magnetic
Atomic
Nuclear



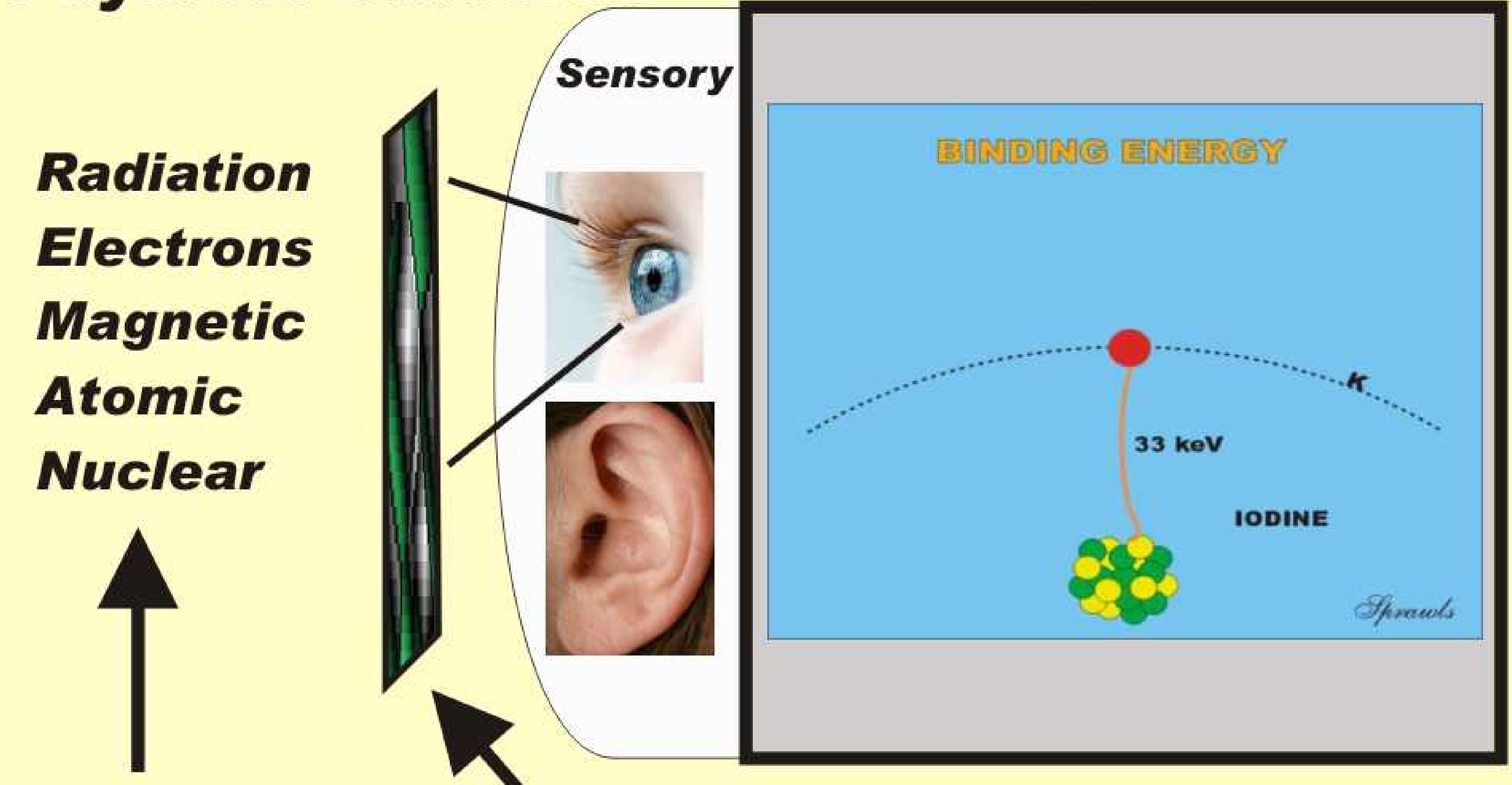
Invisible Physical Objects

Sprawls

Forming Knowledge Structures

Physical Universe

Back Integrative Cortex



Sensory

Radiation
Electrons
Magnetic
Atomic
Nuclear

Invisible

Visuals

Physical Objects

Sprawls

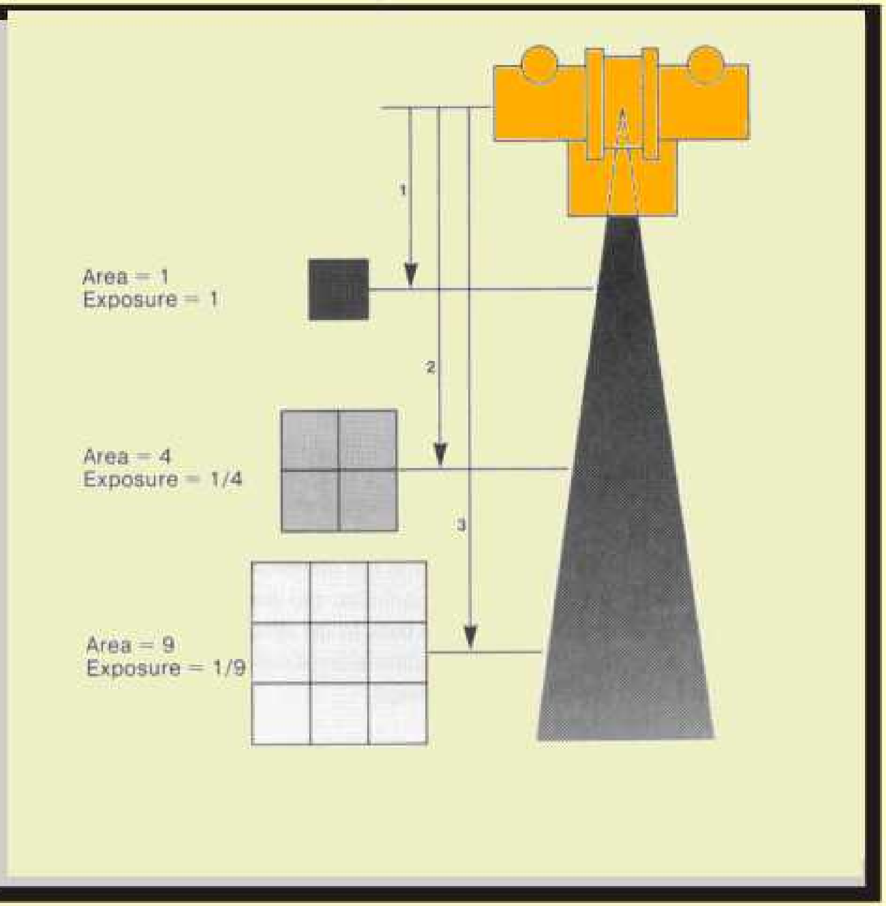
Forming Knowledge Structures

Physical Universe

Back Integrative Cortex

Inverse Square Effect

Sensory



Invisible

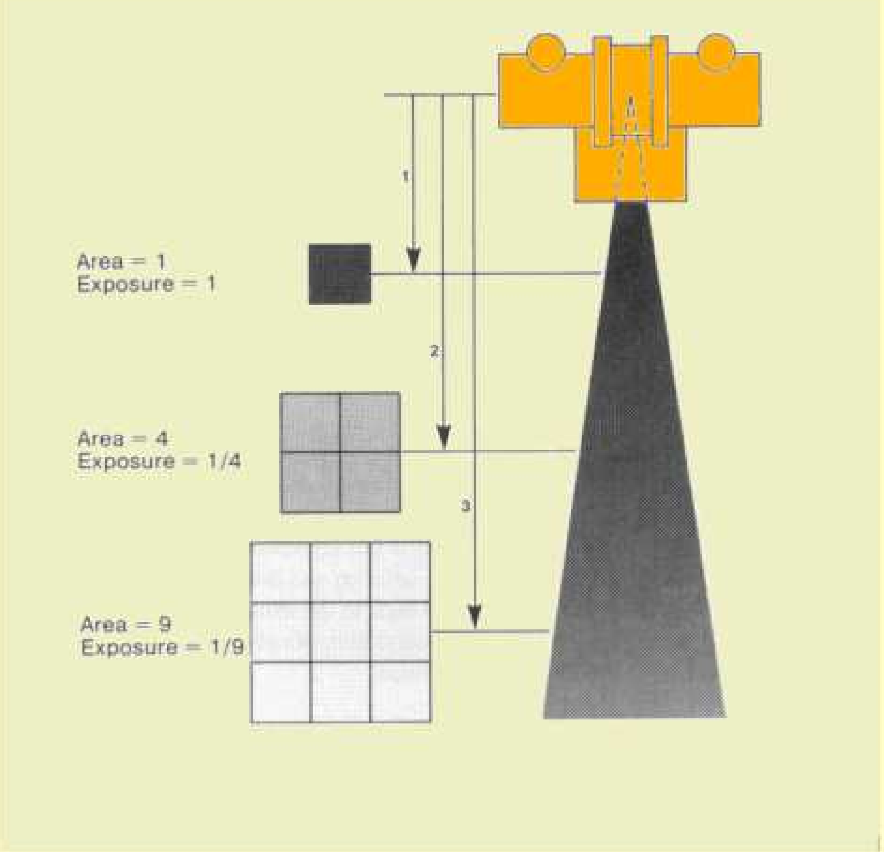
Concepts

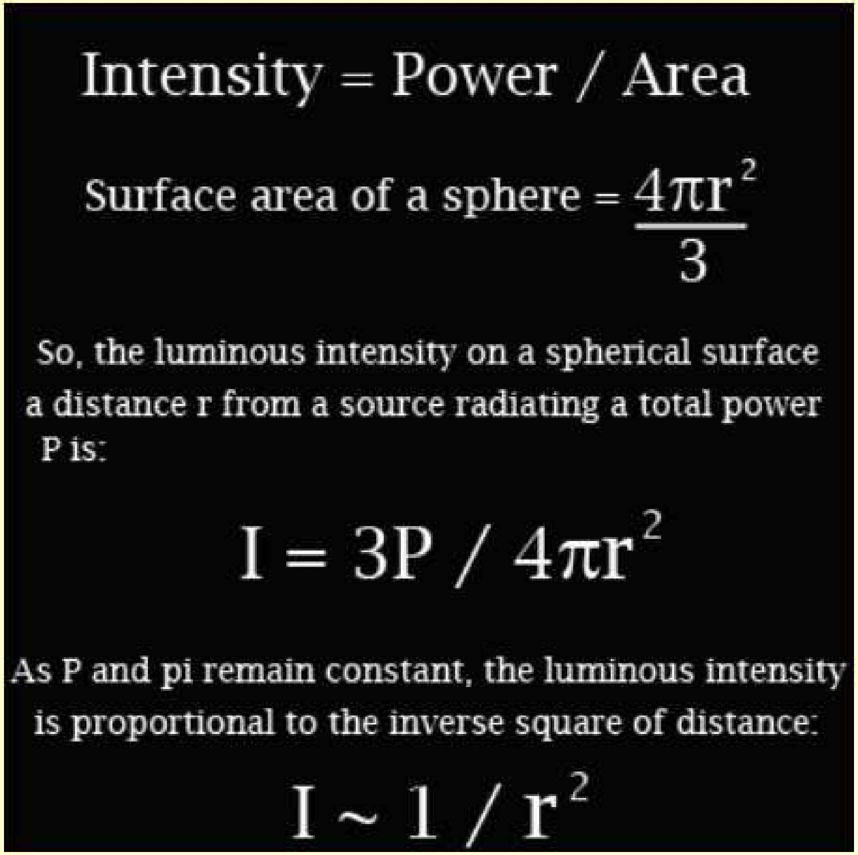
Ideas

Visuals

Sprawls

Forming Knowledge Structures





Intensity = Power / Area

Surface area of a sphere = $\frac{4\pi r^2}{3}$

So, the luminous intensity on a spherical surface a distance r from a source radiating a total power P is:

$$I = 3P / 4\pi r^2$$

As P and pi remain constant, the luminous intensity is proportional to the inverse square of distance:

$$I \sim 1 / r^2$$

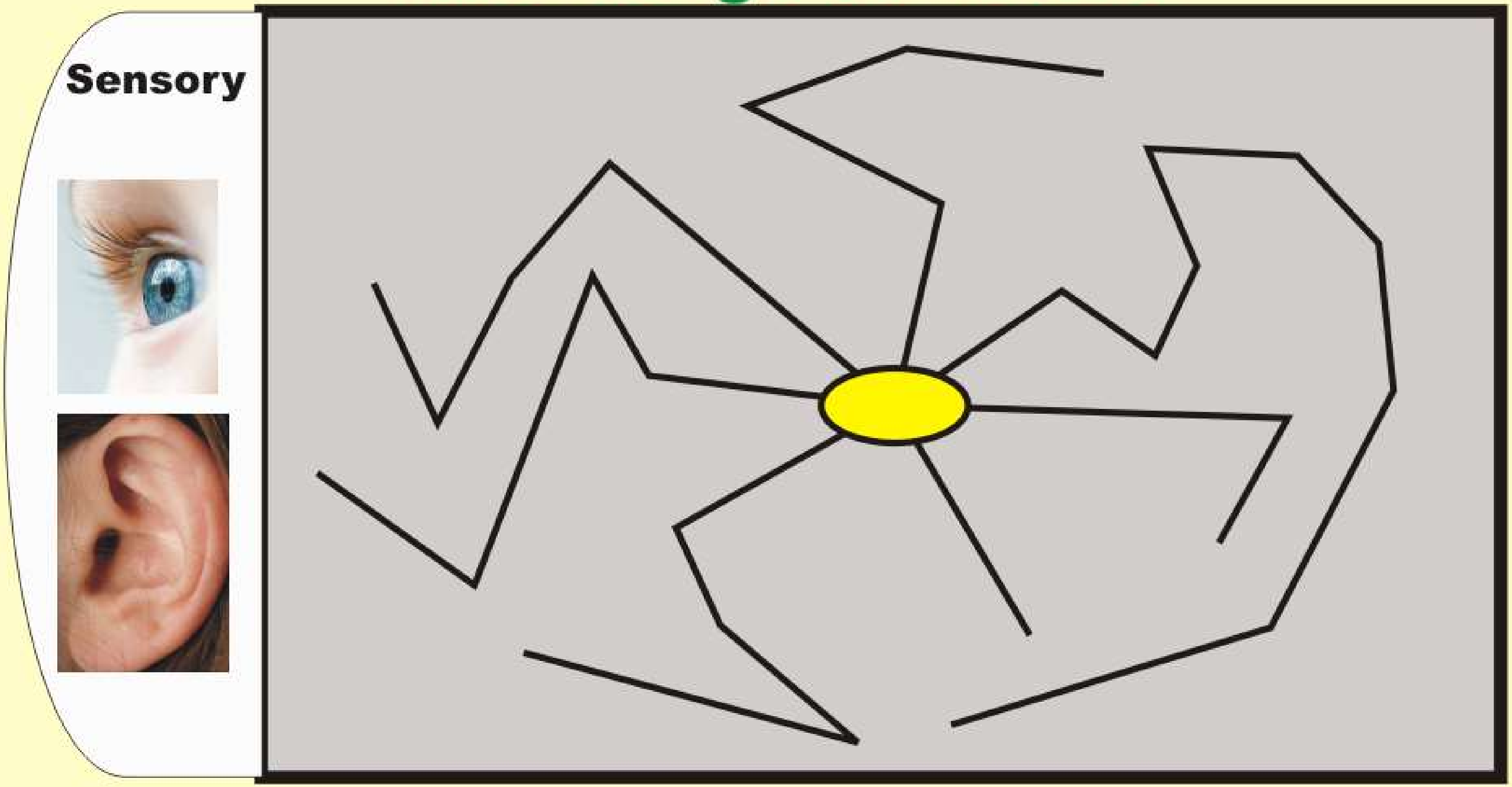
Visual

Verbal and Symbolic

Sprawls

Back Integrative Cortex

Integrating experience into existing knowledge structure

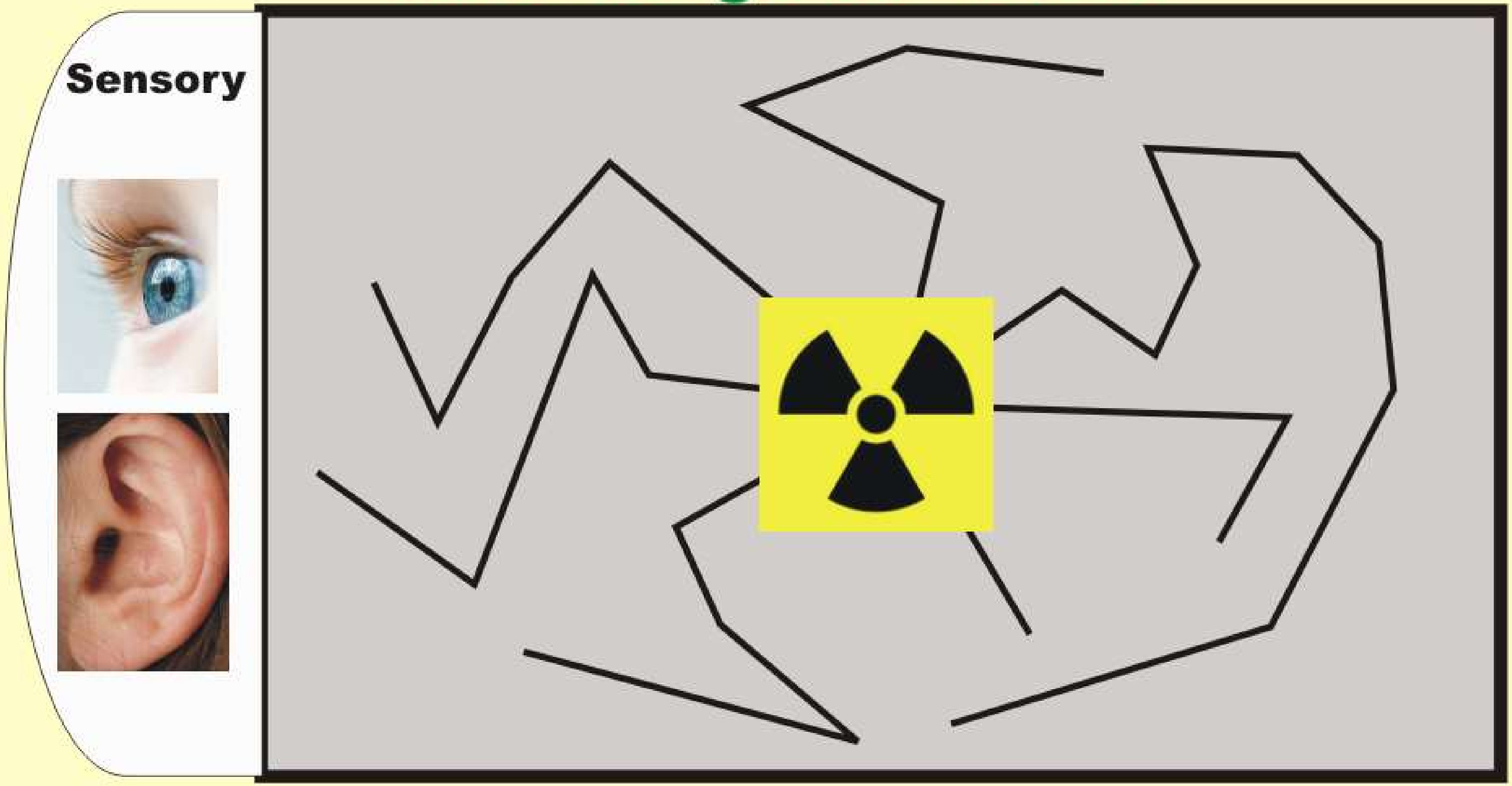


Meaning

Sprawls

Back Integrative Cortex

Integrating experience into existing knowledge structure



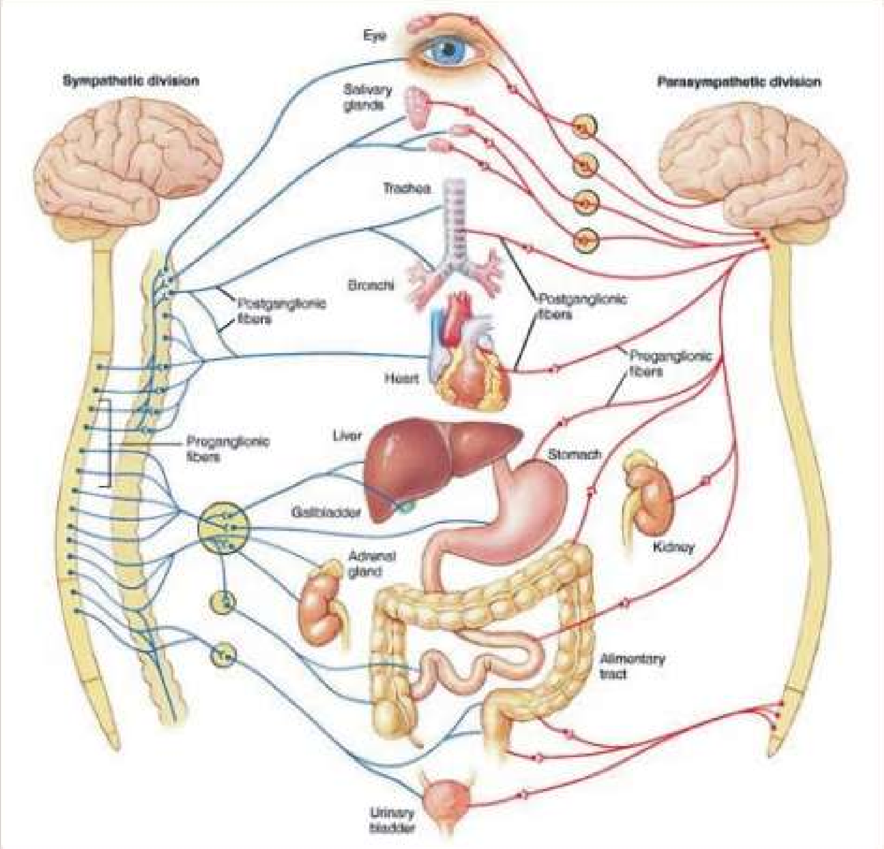
Meaning

Sprawls

Back Integrative Cortex

Integrating experience into existing knowledge structure

Sensory



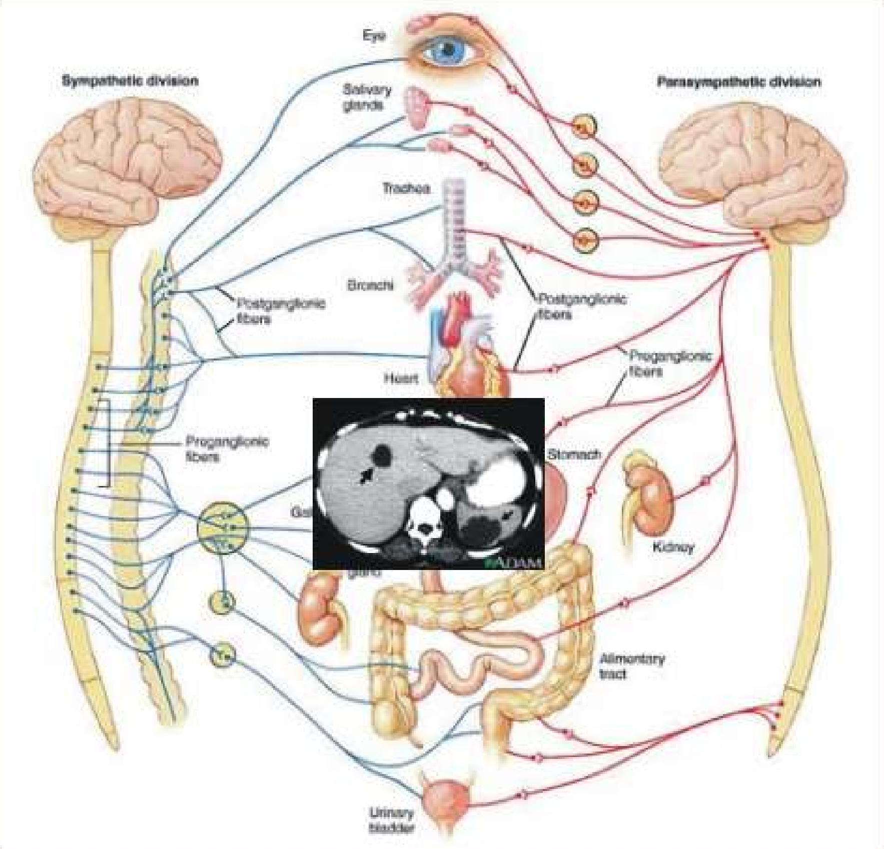
Medical Knowledge

Sprawls

Back Integrative Cortex

Integrating experience into existing knowledge structure

Sensory

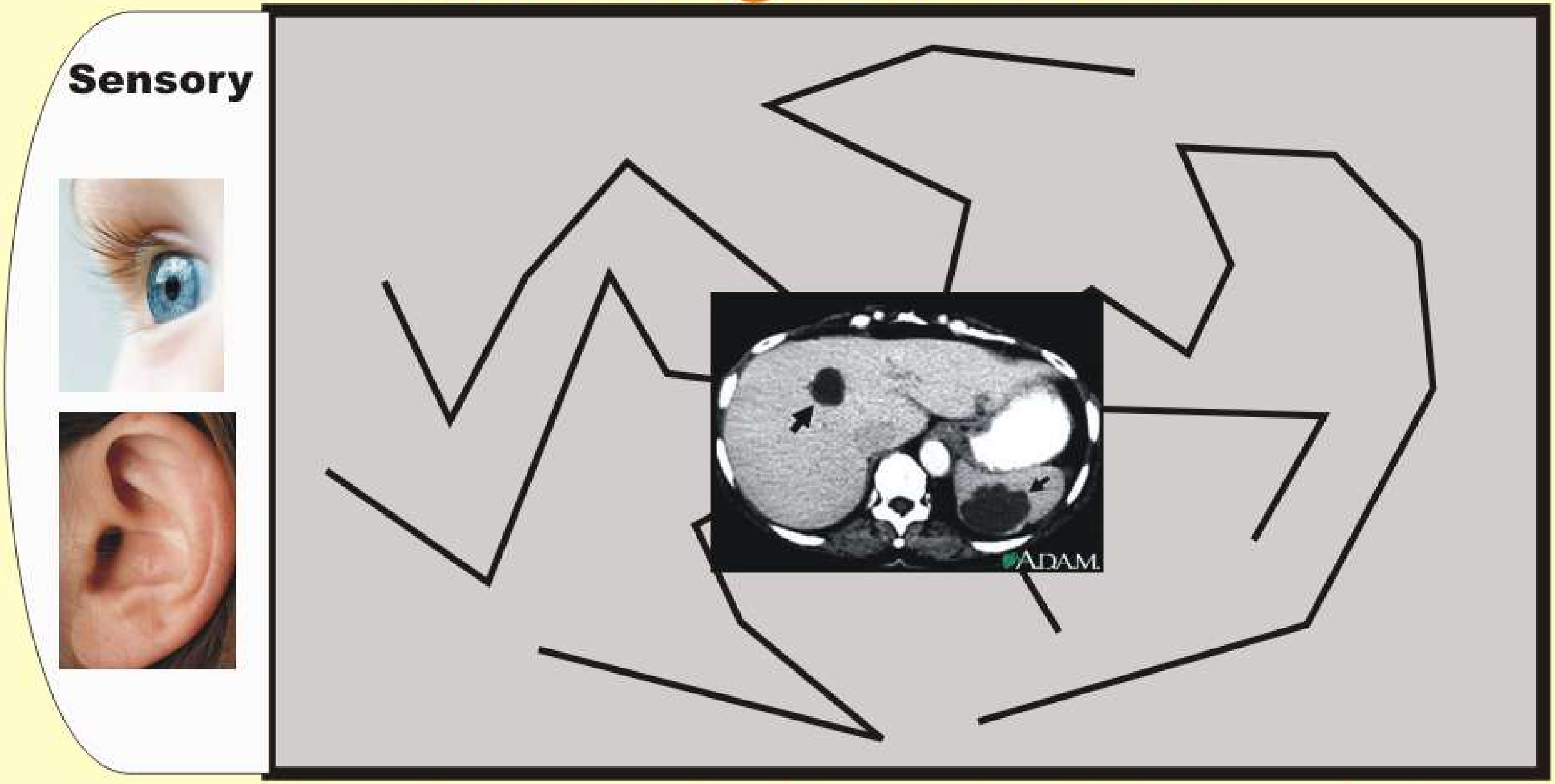


The image is the connection

Sprawls

Back Integrative Cortex

Integrating experience into existing knowledge structure



The image is the starting point for learning physics

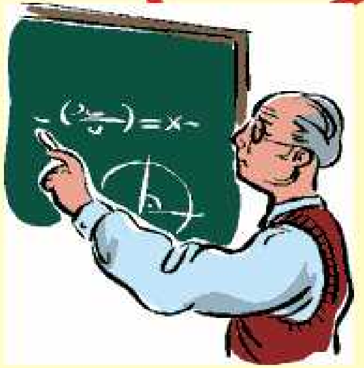
Sprawls

Forming Knowledge Structures

Physical Universe

Back Integrative Cortex

Inverse Square Effect



Sensory

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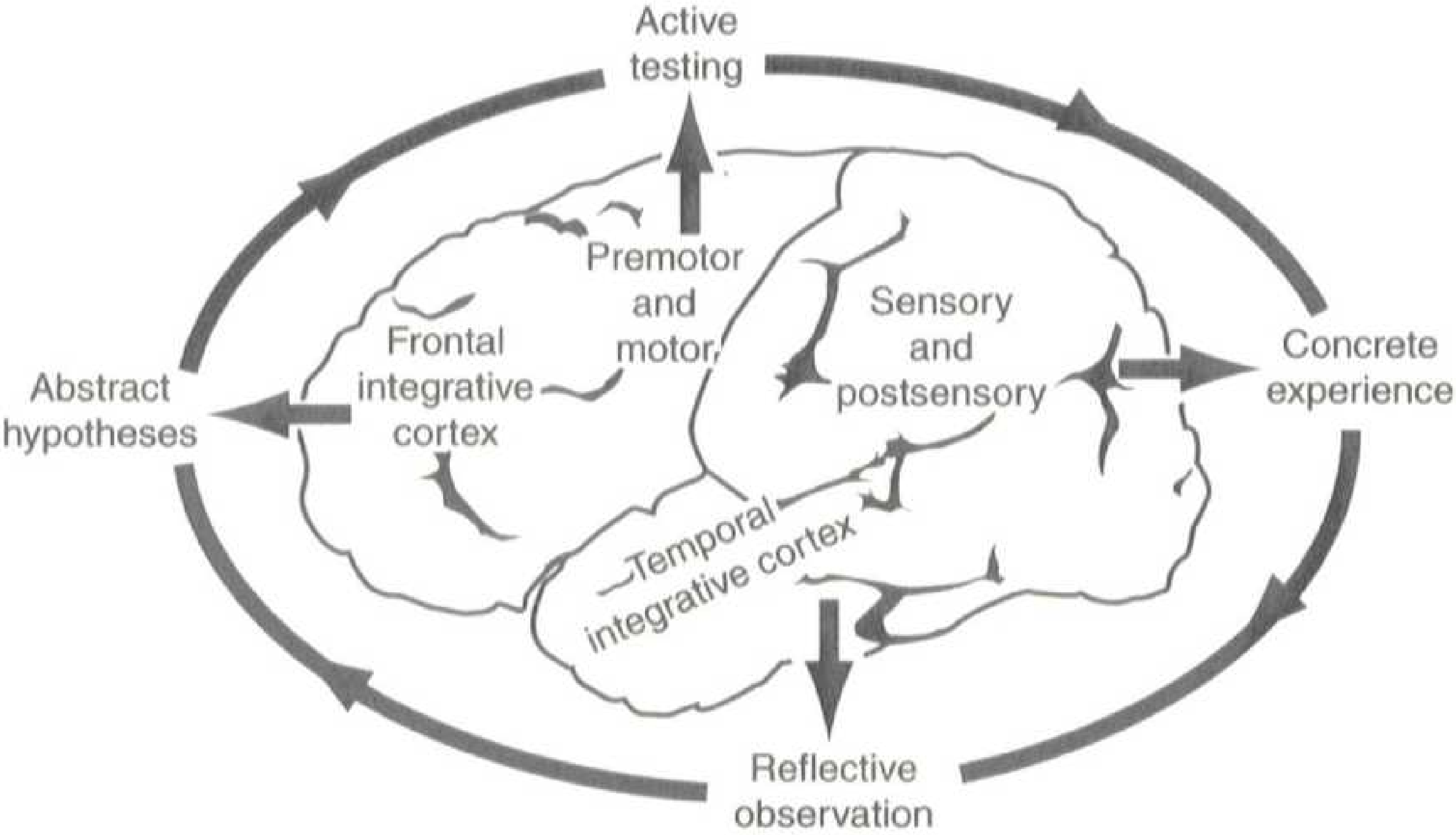
Verbal and Symbolic

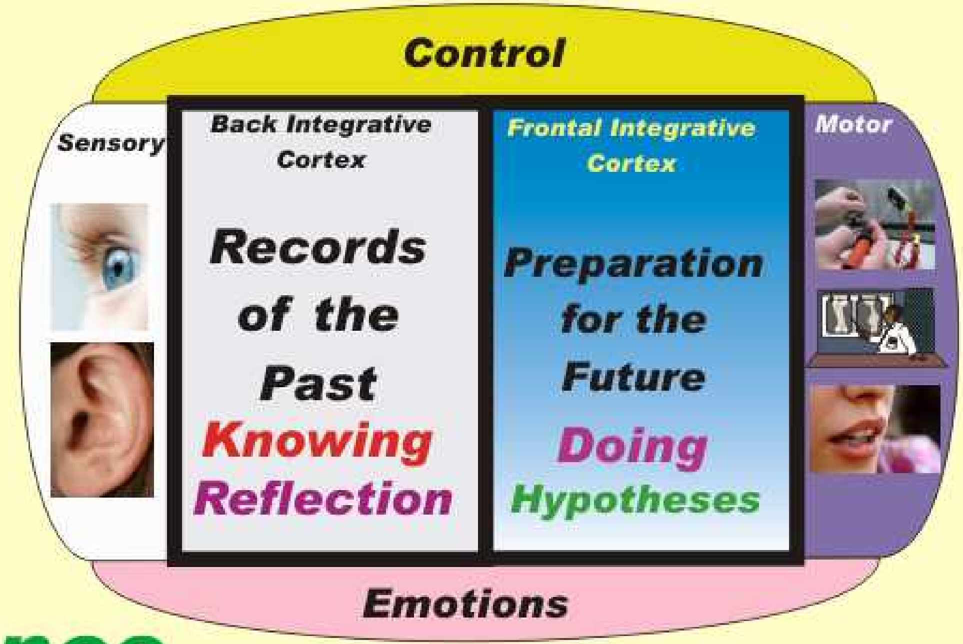
Sprawls

Zull's Model of Brain Function



Brain Functions for Learning Physics

Active Experimentation and Testing



Control

Sensory

Back Integrative Cortex

Records of the Past

Knowing

Reflection

Frontal Integrative Cortex

Preparation for the Future

Doing

Hypotheses

Motor

Emotions

Sense and Experience

Observe

Interact and Affect

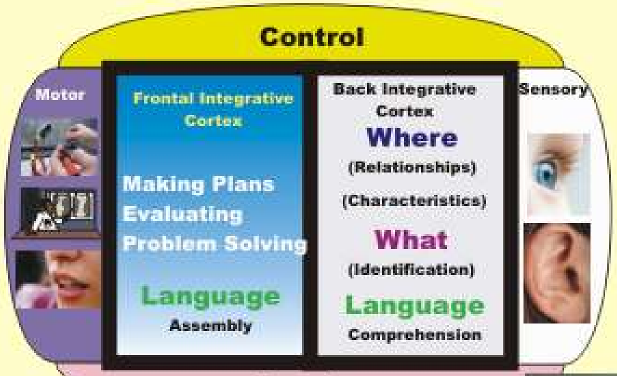
Physical Universe

Sprawls

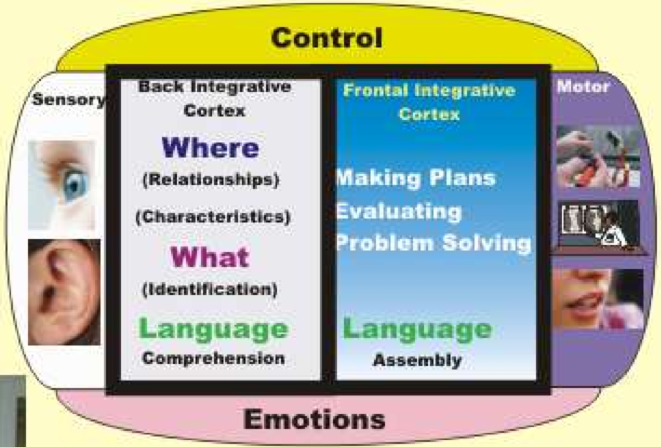
Brain Functions for Learning Physics

Two brains are better than one!

Collaborative Learning



Views
Perspectives
Experiences



Views
Perspectives
Experiences

Analysis and Evaluation

Image: UGA

Sprawls

Brain Functions for Learning Physics

Two brains are better than one!

Collaborative Learning

Control

Motor

Frontal Integrative Cortex

Making Plans
Evaluating
Problem Solving

Language
Assembly

Back Integrative Cortex

Where
(Relationships)
(Characteristics)

What
(Identification)

Language
Comprehension

Sensory

Emotions

Control

Sensory

Back Integrative Cortex

Where
(Relationships)
(Characteristics)

What
(Identification)

Language
Comprehension

Frontal Integrative Cortex

Making Plans
Evaluating
Problem Solving

Language
Assembly

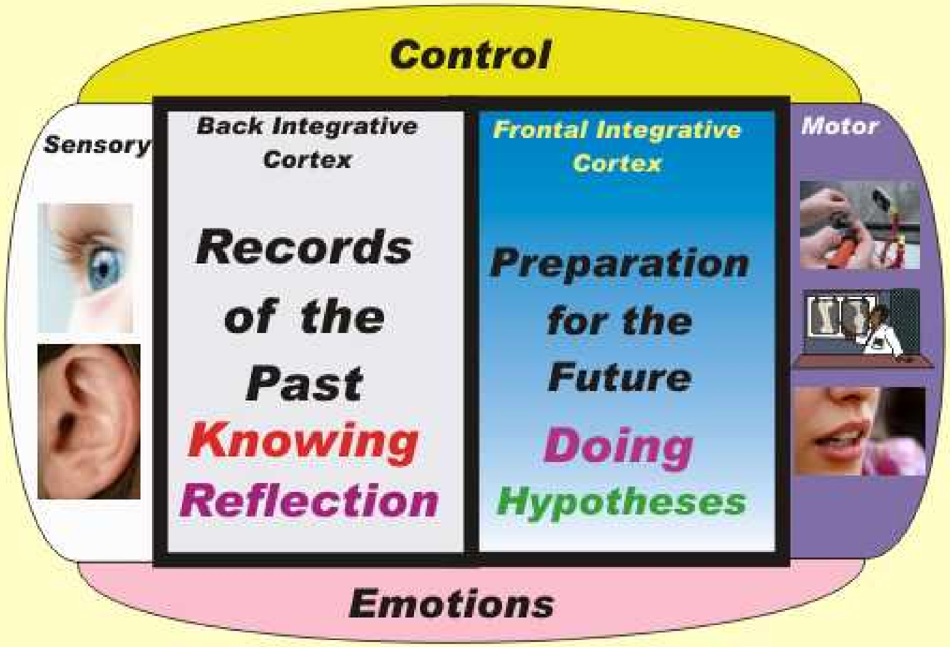
Motor

Emotions

Problem Solving
Analysis and Evaluation
Developing Plans

Sprawls

The Learning Environment



Control

Sensory

Back Integrative Cortex

Records of the Past

Knowing

Reflection

Frontal Integrative Cortex

Preparation for the Future

Doing

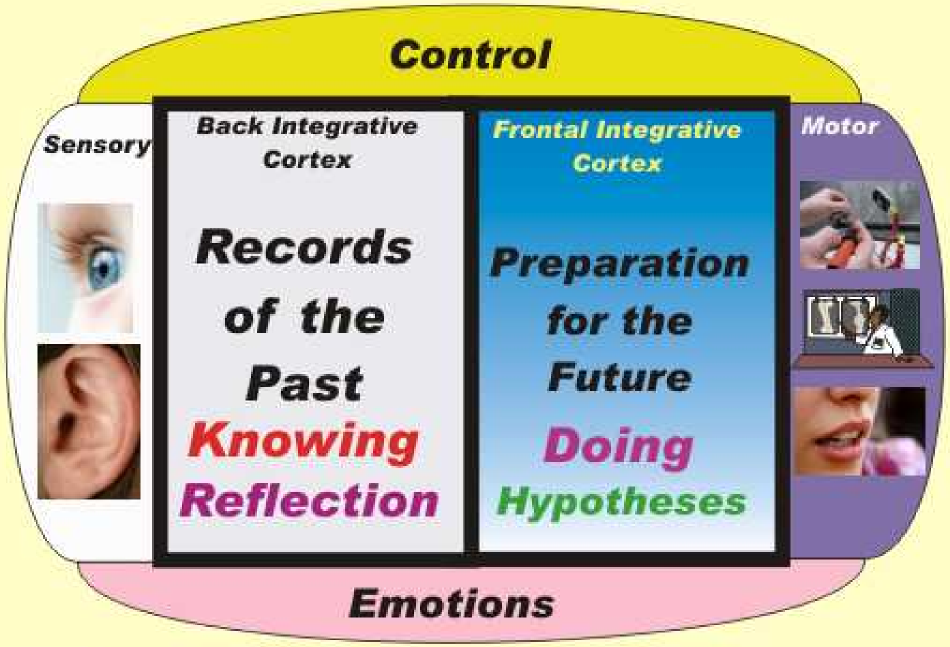
Hypotheses

Motor

Emotions

Sprawls

Rich Learning Environments



Control

Sensory

Back Integrative Cortex

Records of the Past

Knowing

Reflection

Frontal Integrative Cortex

Preparation for the Future

Doing

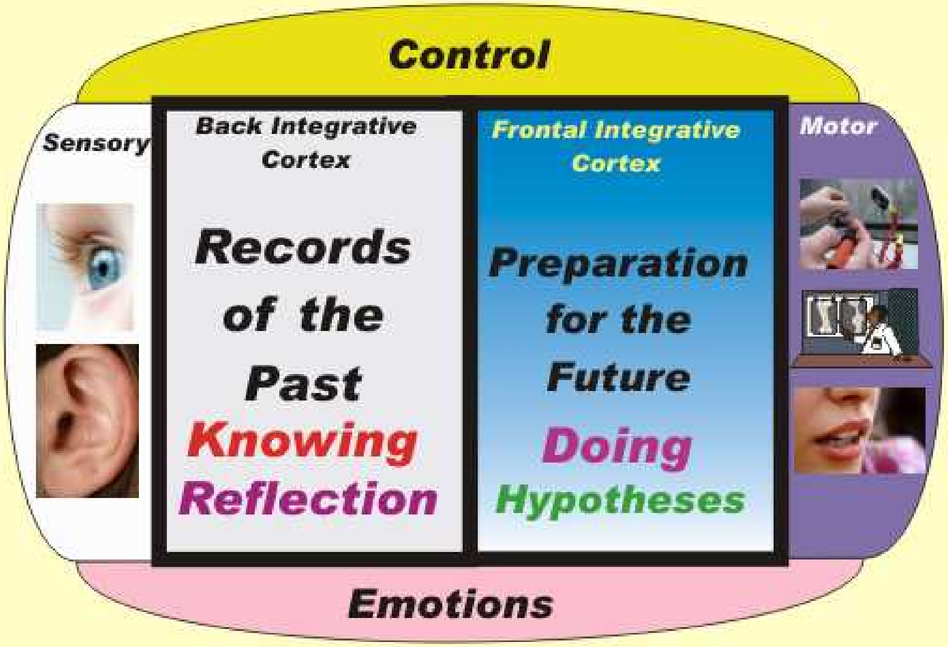
Hypotheses

Motor

Emotions

Sprawls

Challenging Learning Environments



Control

Sensory

Back Integrative Cortex

Records of the Past

Knowing

Reflection

Frontal Integrative Cortex

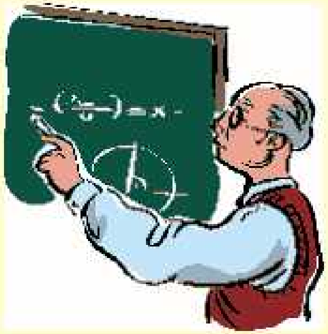
Preparation for the Future

Doing

Hypotheses

Motor

Emotions



Sprawls

Effective Learning

Rich Learning Environment

New and Different

Integrate into Existing Knowledge

——— Reflection ⟶

Sprawls

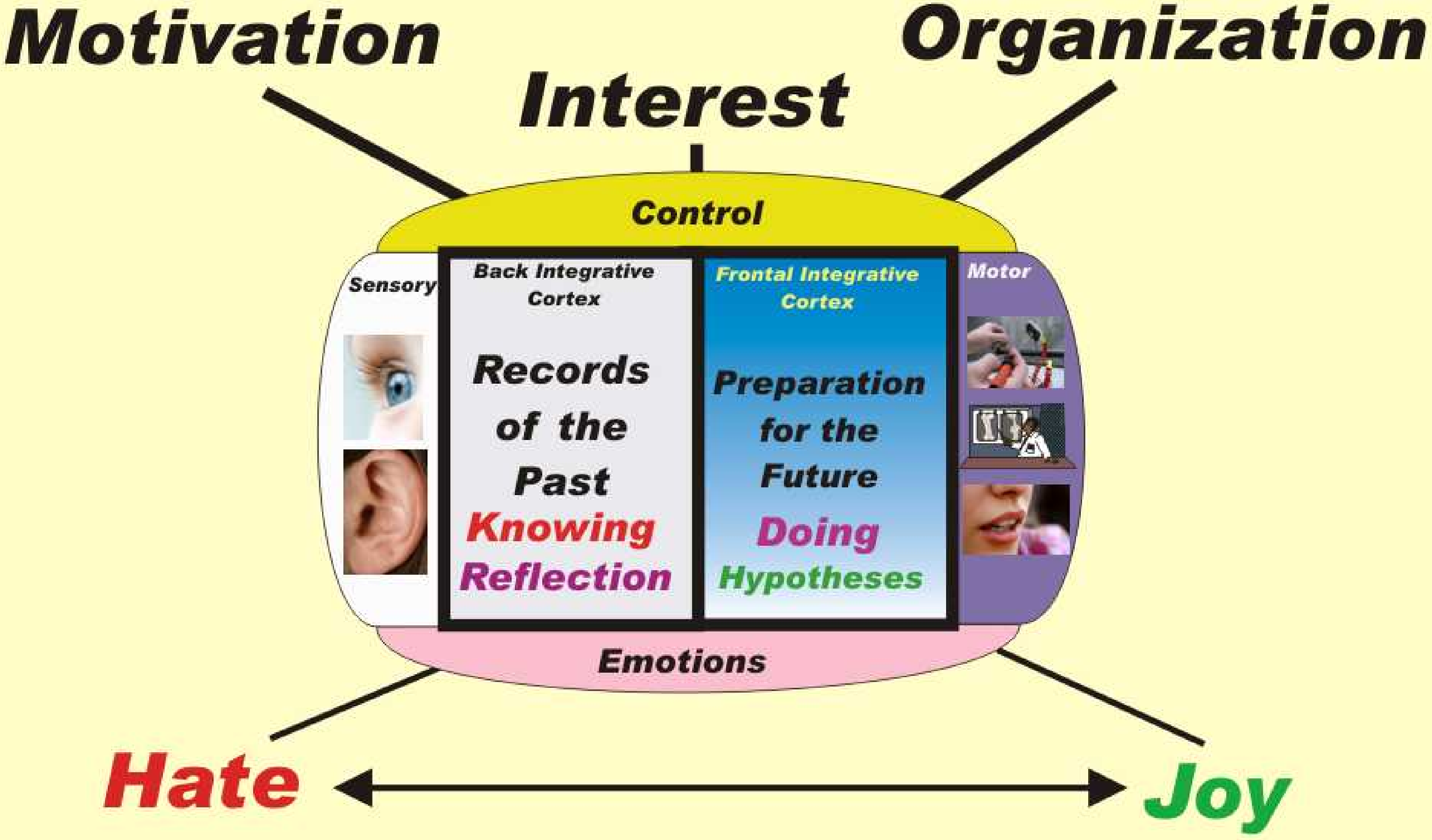
Effective Learning

Interact **Review** **Reflect**

Developing useful knowledge for the future

Sprawls

Brain Functions for Learning Physics



Motivation

Interest

Organization

Control

Sensory

Back Integrative Cortex

Records of the Past

Knowing

Reflection

Frontal Integrative Cortex

Preparation for the Future

Doing

Hypotheses

Motor

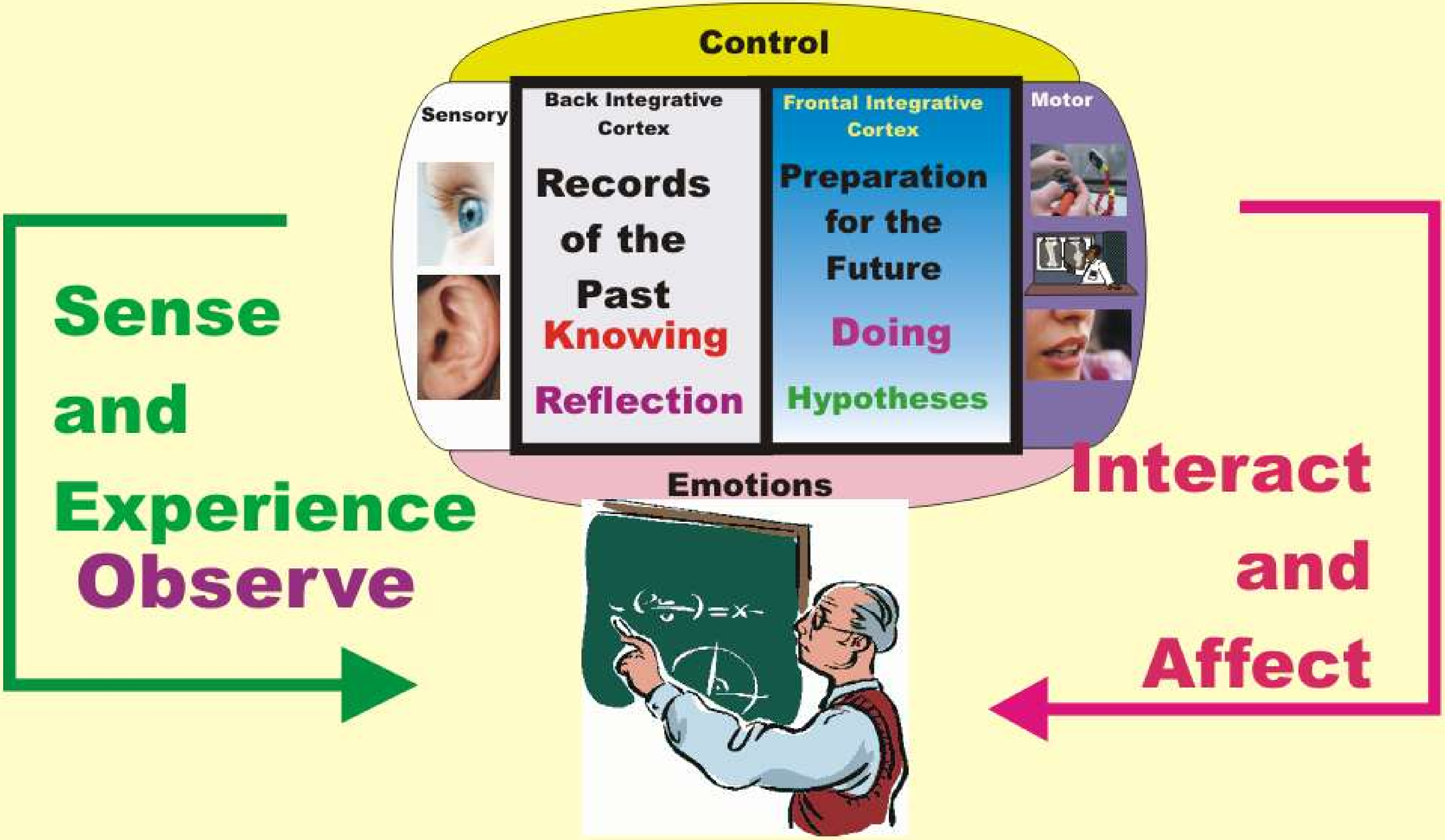
Emotions

Hate

Joy

Sprawls

Brain Functions for Learning About Learning Physics



Control

Sensory

Back Integrative Cortex

Records of the Past

Knowing

Reflection

Frontal Integrative Cortex

Preparation for the Future

Doing

Hypotheses

Motor

Emotions

Sense and Experience

Observe

Interact and Affect

Our Teaching

Sprawls

Robert Gagne (1916-2002)

Best known for his Nine Events of Instruction

The Gagne assumption is that different types of learning exist, and that different instructional conditions are most likely to bring about these different types of learning

Gagné was also well-known for his sophisticated stimulus-response theory of eight kinds of learning which differ in the quality and quantity of stimulus-response bonds involved. From the simplest to the most complex, these are:

signal learning (Pavlovian conditioning)
stimulus-response learning (operant conditioning)
chaining (complex operant conditioning)
verbal association
discrimination learning
concept learning
rule learning
and problem solving.

Sprawls

Gagne's Hierarchy of Learning

PROBLEM SOLVING

RULE LEARNING

CONCEPT LEARNING

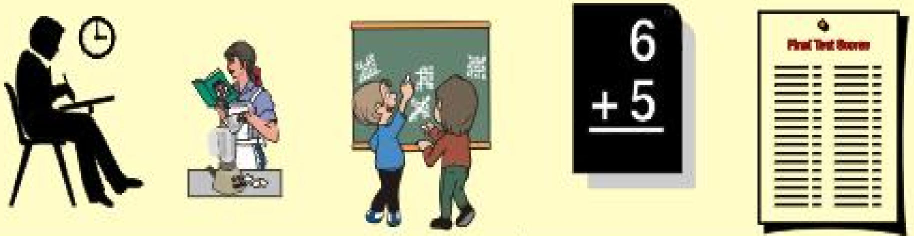
DISCRIMINATION LEARNING

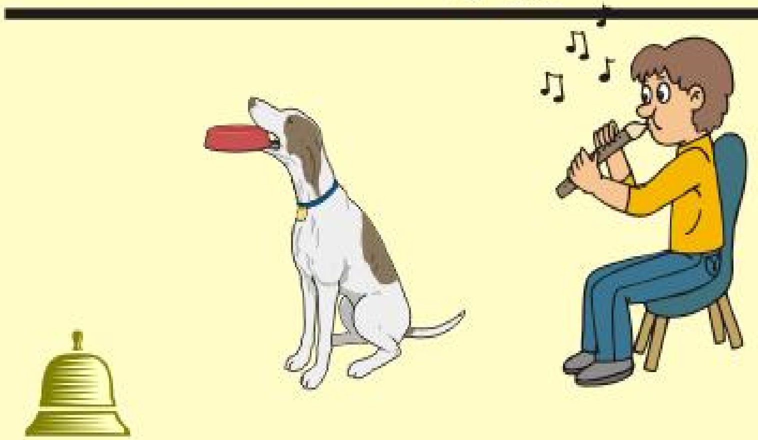
VERBAL ASSOCIATION

CHAINING

STIMULUS RESPONSE

SIGNAL LEARNING



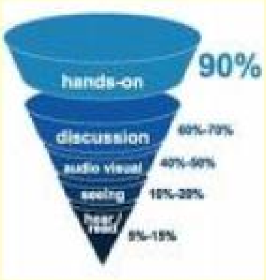


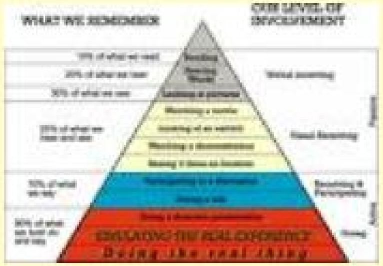
Sprawls

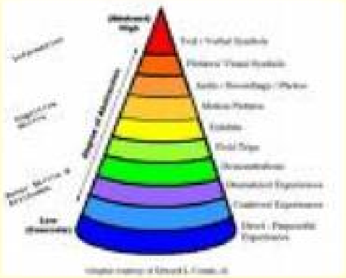
Edgar Dale (1900-1985)

Educationalist who developed the famous

Cone of Experience theory







Sprawls

Cone of Experience for Medical Imaging Education

VERBAL

SYMBOLS
EQUATIONS

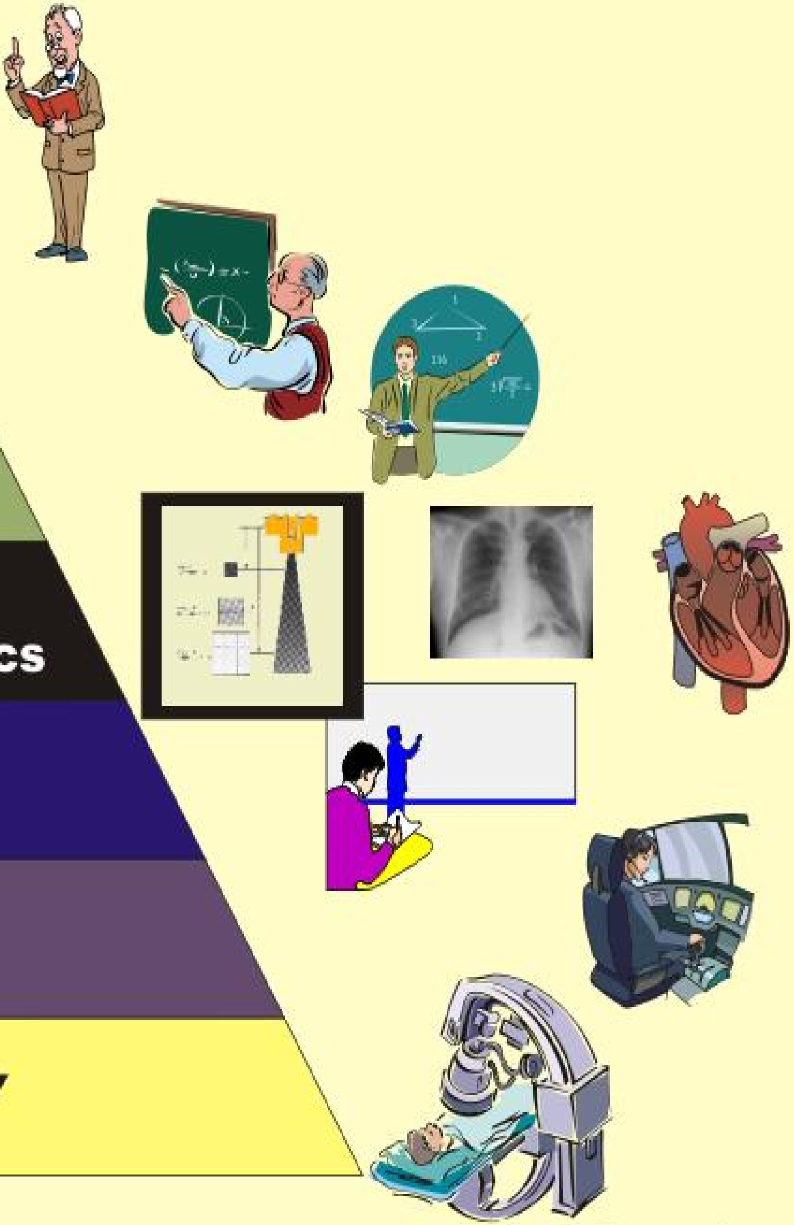
SKETCHES

VISUALS
Clinical Images and Graphics

VISUALS
With Expert Guidance

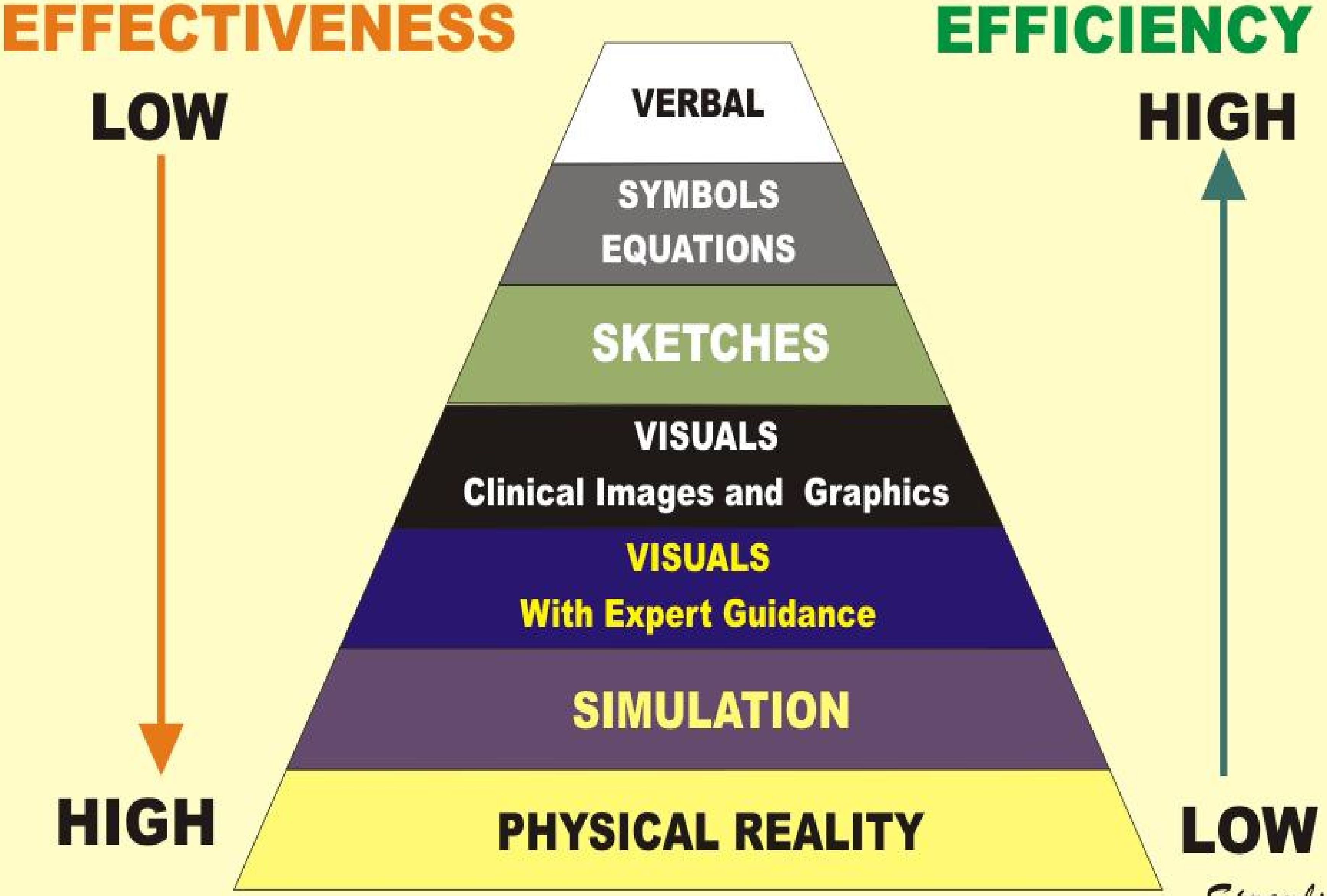
SIMULATION

PHYSICAL REALITY



Sprawls

Cone of Experience for Medical Imaging Education



EFFECTIVENESS

LOW

HIGH

EFFICIENCY

HIGH

LOW

VERBAL

SYMBOLS
EQUATIONS

SKETCHES

VISUALS
Clinical Images and Graphics

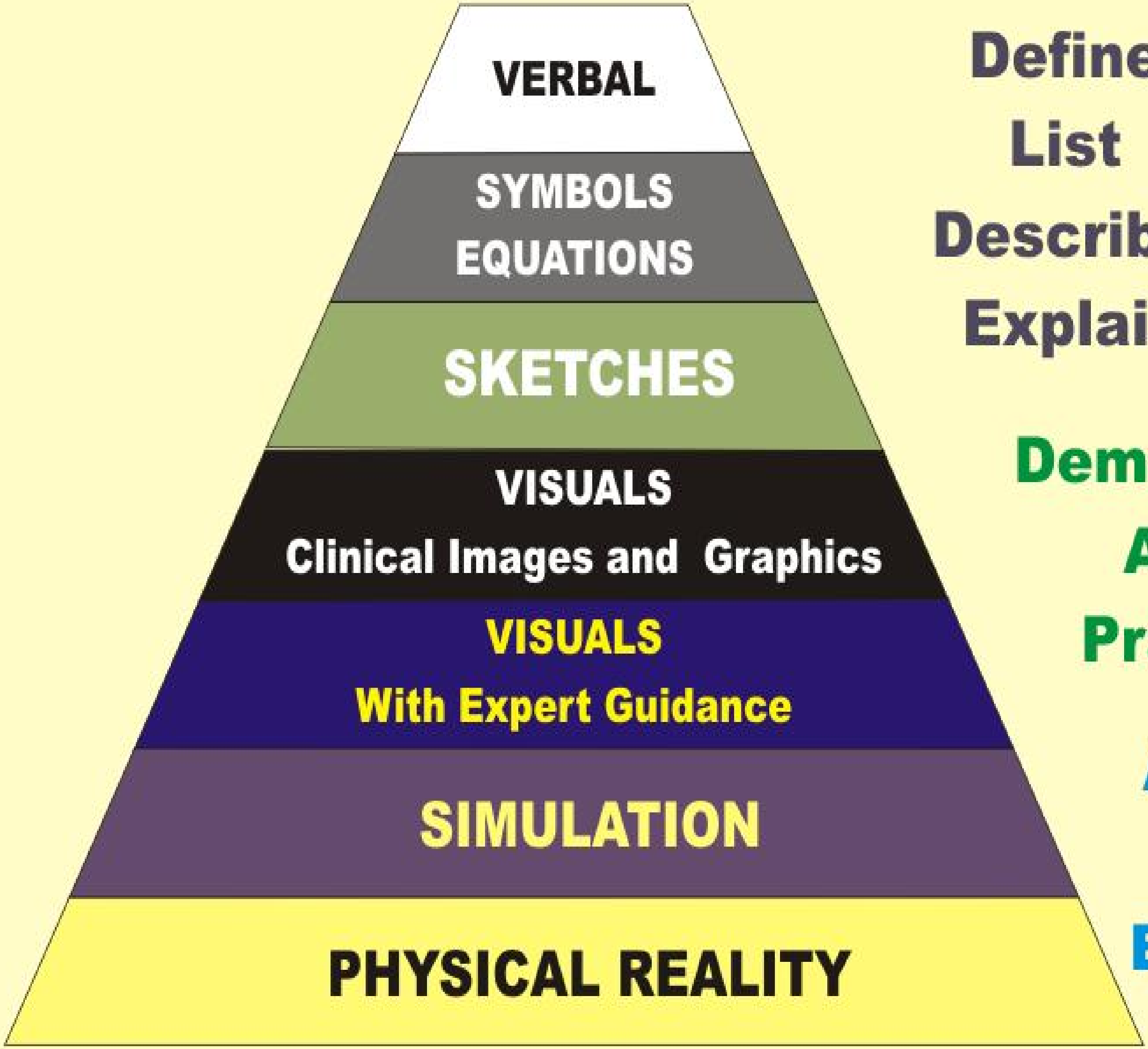
VISUALS
With Expert Guidance

SIMULATION

PHYSICAL REALITY

Sprawls

Cone of Experience for Medical Imaging Education



VERBAL

SYMBOLS
EQUATIONS

SKETCHES

VISUALS
Clinical Images and Graphics

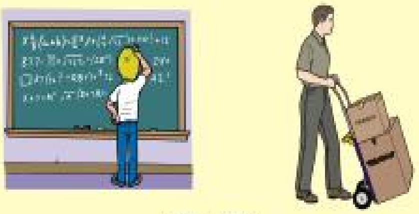
VISUALS
With Expert Guidance

SIMULATION

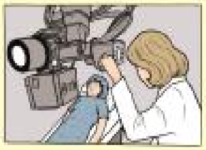
PHYSICAL REALITY

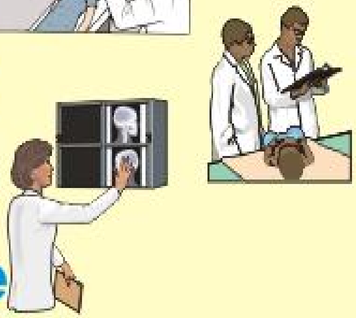
LEARNING OUTCOMES

Define
List
Describe
Explain



Demonstrate
Apply
Practice

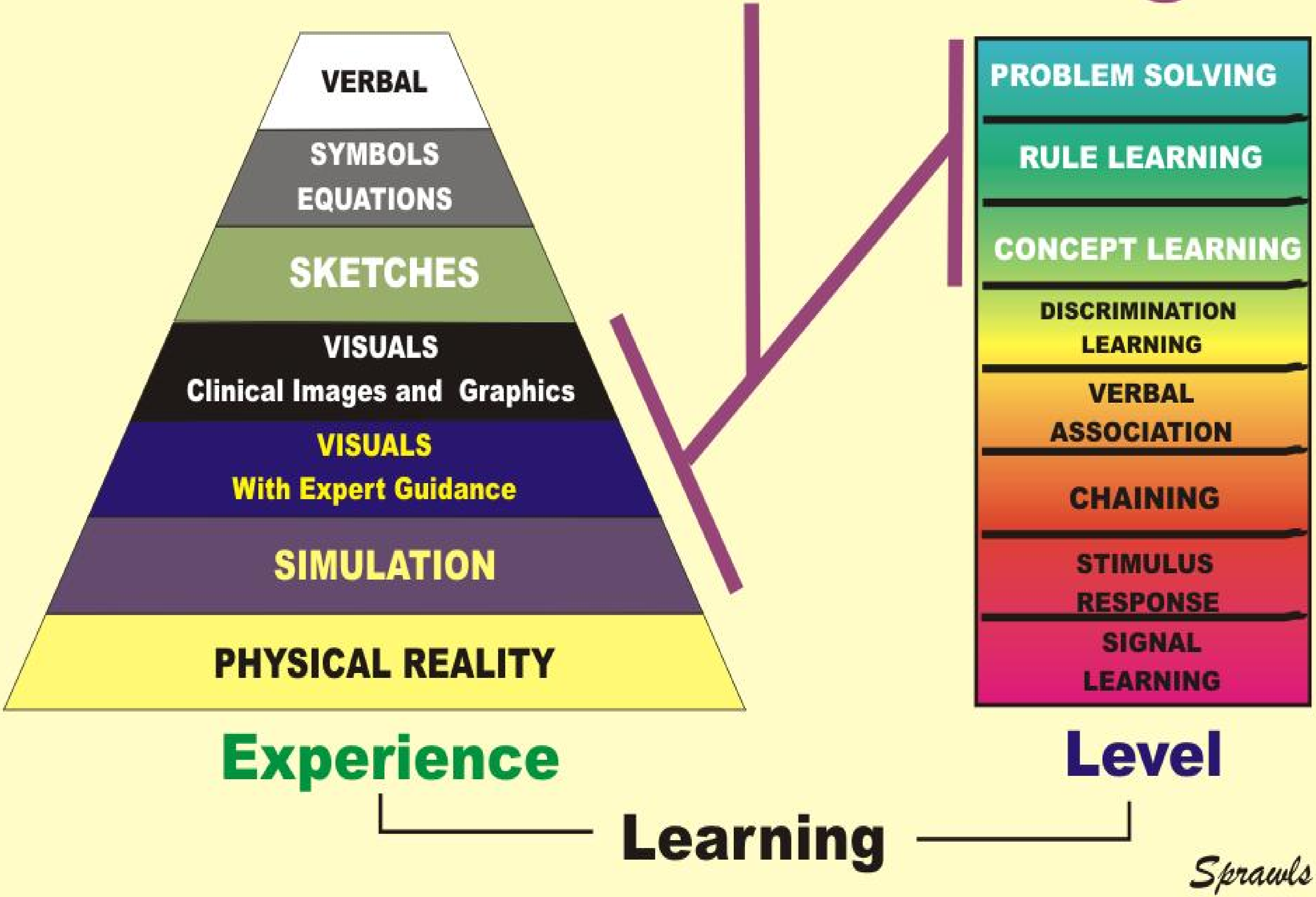




Analyze
Create
Evaluate

Sprawls

Effective Learning



VERBAL

SYMBOLS
EQUATIONS

SKETCHES

VISUALS
Clinical Images and Graphics

VISUALS
With Expert Guidance

SIMULATION

PHYSICAL REALITY

PROBLEM SOLVING

RULE LEARNING

CONCEPT LEARNING

DISCRIMINATION
LEARNING

VERBAL
ASSOCIATION

CHAINING

STIMULUS
RESPONSE

SIGNAL
LEARNING

Experience

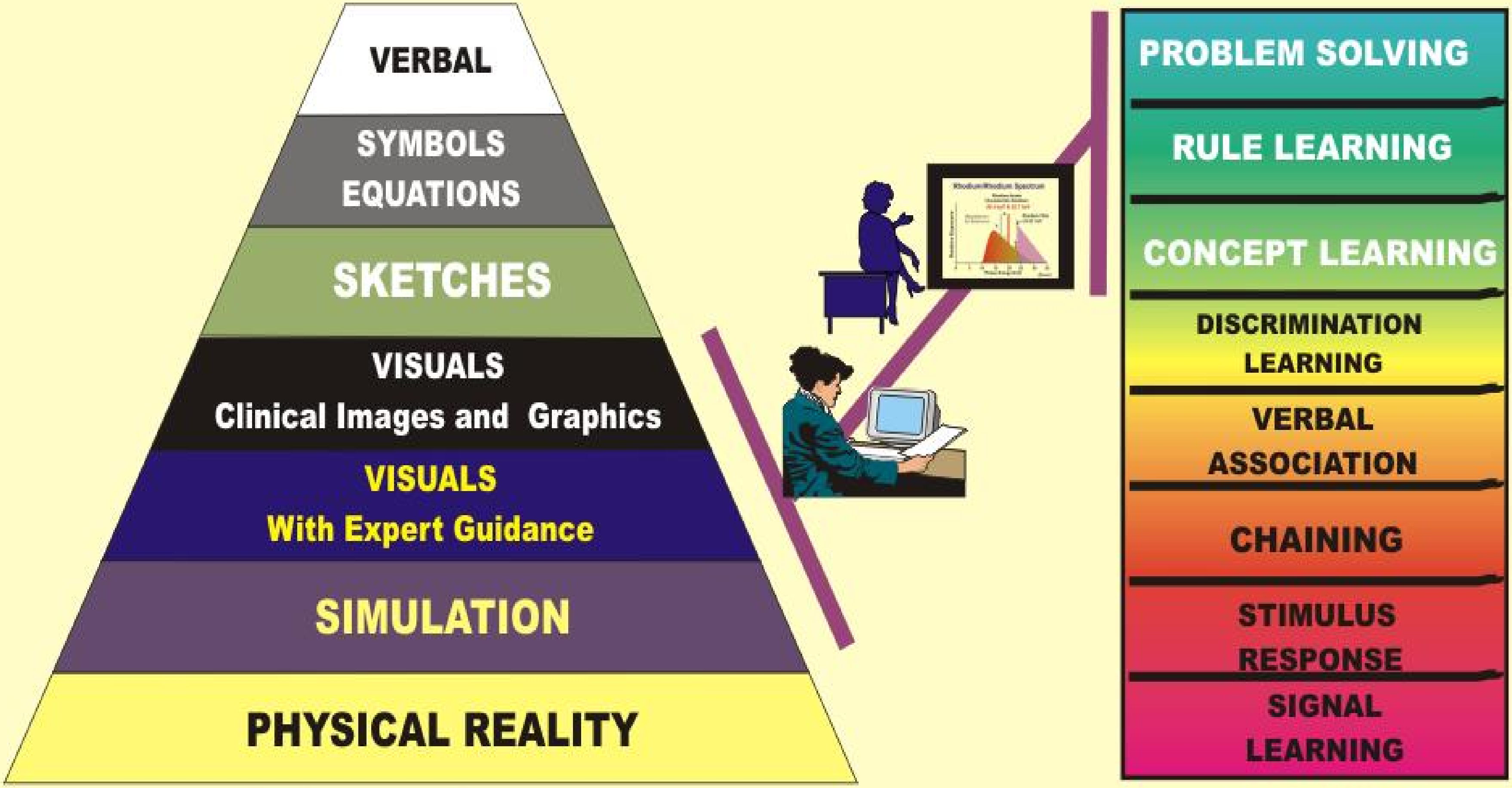
Level

Learning

Sprawls

Technology Enhanced

Learning and Teaching



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STIMULUS RESPONSE

SIGNAL LEARNING

Experience

Level

Learning

Sprawls

Clinically Focused Physics Education

Classroom

Clinical Conference

Small Group

"Flying Solo"

Highly Efficient

For General Physics and Related Topics

Highly Effective

Clinically Rich Learning Activities

Visuals Images Online Modules

Resources and References

Sprawls

Physics Education

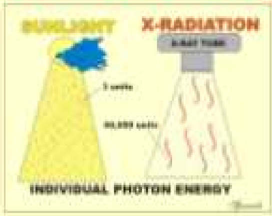
General Basics

Images

- Contrast
- Detail
- Noise
- Artifacts
- Spatial

Characteristics and Comparison of Modalities

Radiation



- Radiation for Imaging
- Quantities and Units
- X-Ray Production
- Radioactivity
- Interactions

Digital Image Structure and Characteristics

Clinical

- X-Ray Image Formation
- Radiographic Receptors
- Radiographic Detail
- Fluoroscopic Systems
- CT Image Formation
- CT Image Quality and Dose Optimization
- Radionuclide Imaging, SPECT, PET
- MRI
- Ultrasound

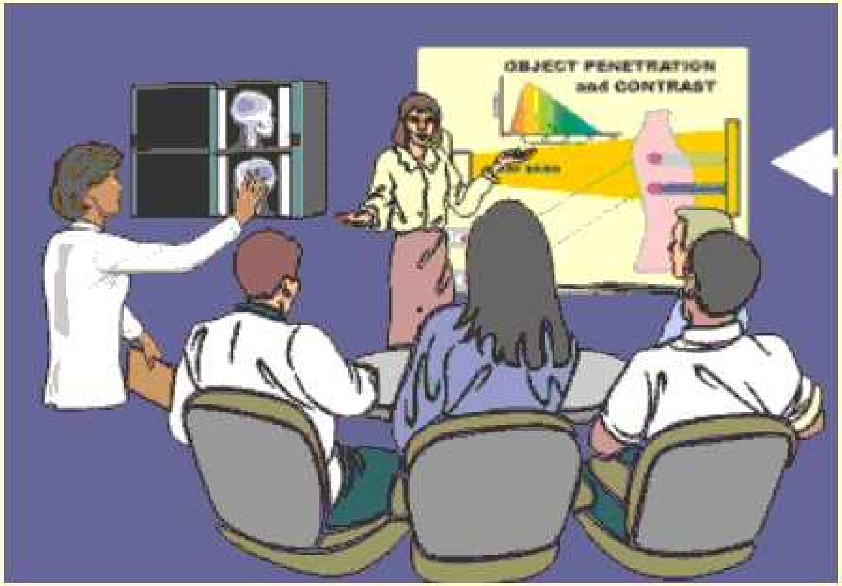
Radiation Safety

- Biological Effects
- Personnel Protection
- Patient Dose Management

Sprawls

Rich Classroom and Conference Learning Activities

Learning Facilitator
"Teacher"



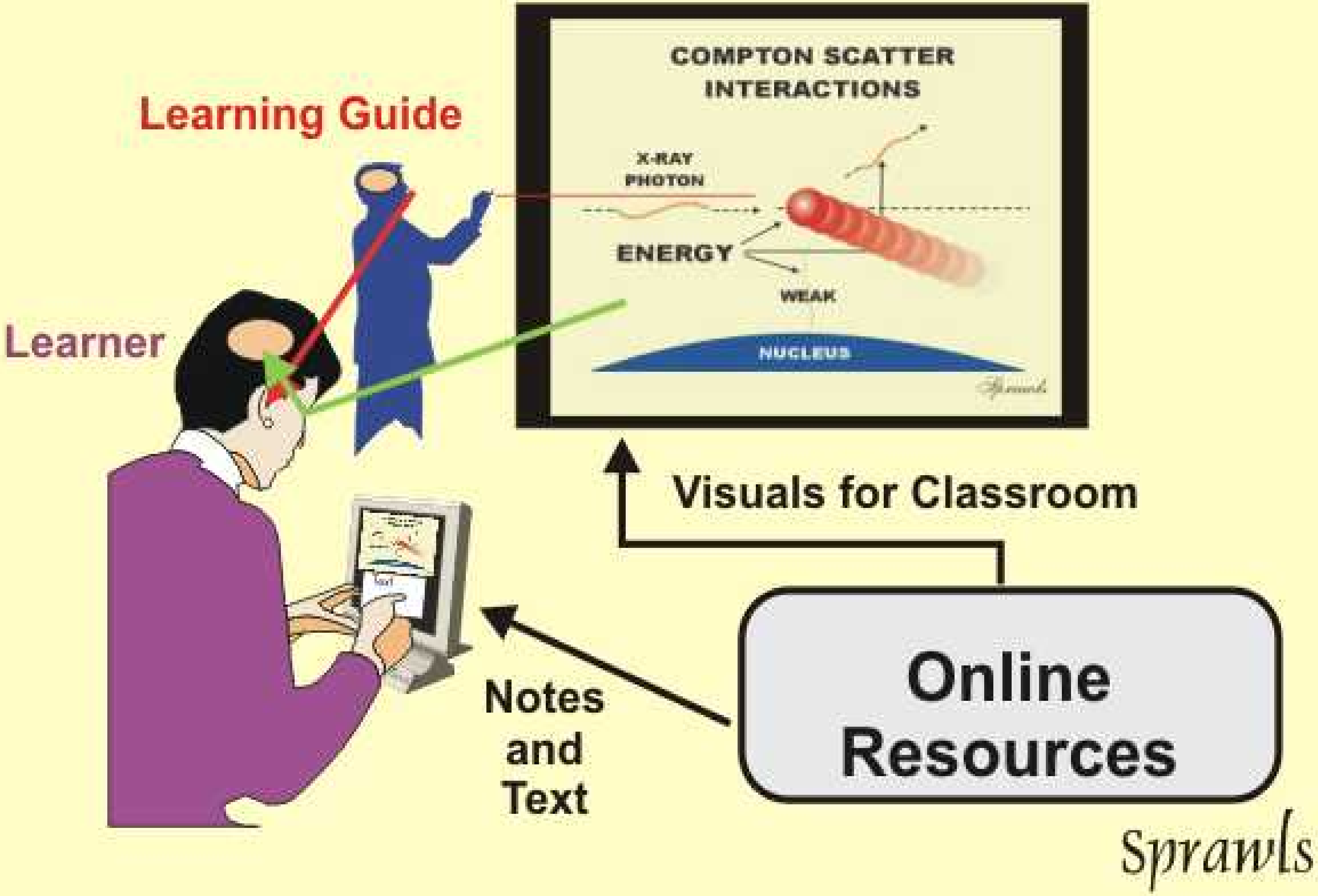
Visuals

Representations
of
Reality

- **Organize and Guide the Learning Activity**
- **Share Experience and Knowledge**
- **Explain and Interpret What is Viewed**
- **Motivate and Engage Learners**

Sprawls

Technology Enhanced Learning



Learning Guide

Learner

Visuals for Classroom

Online Resources

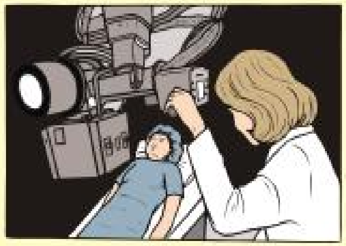
Notes and Text

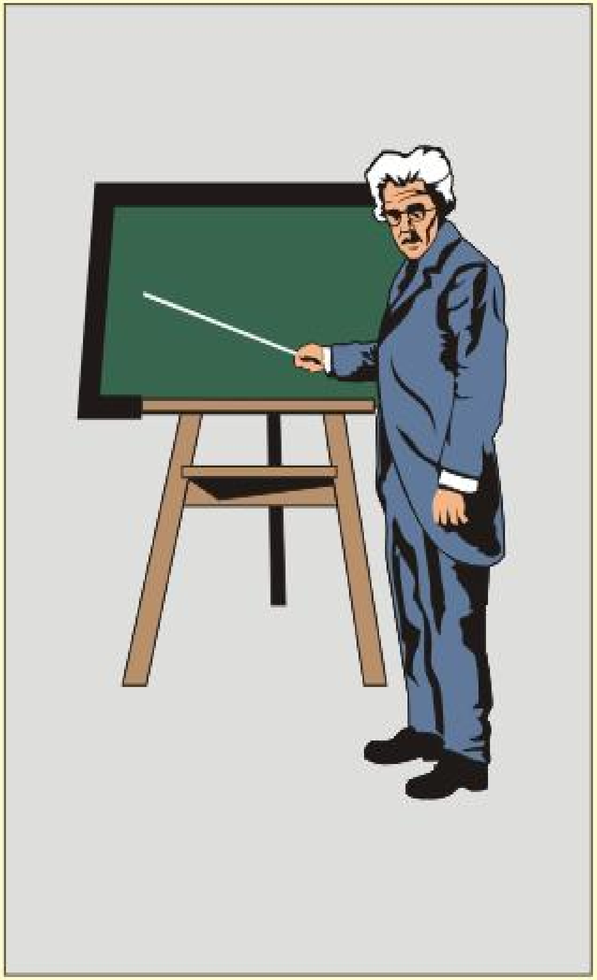
Sprawls

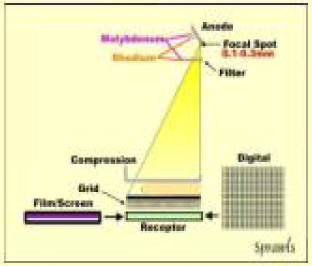
THE LEARNERS

WINDOW
or
BARRIER

PHYSICAL UNIVERSE



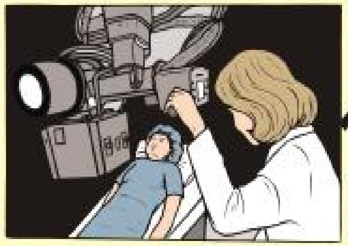




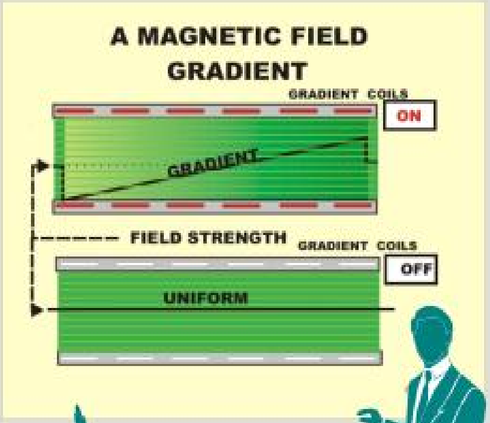
Sprawls

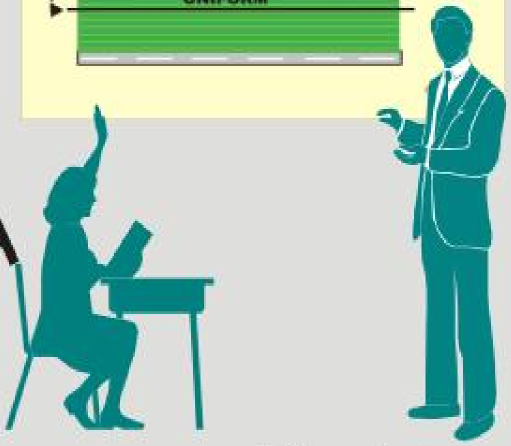
WINDOW
or
BARRIER

THE LEARNERS



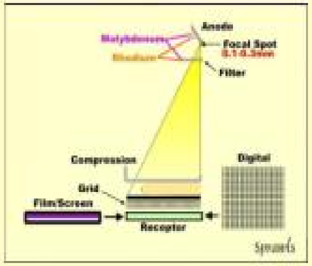
Visuals





Physicists

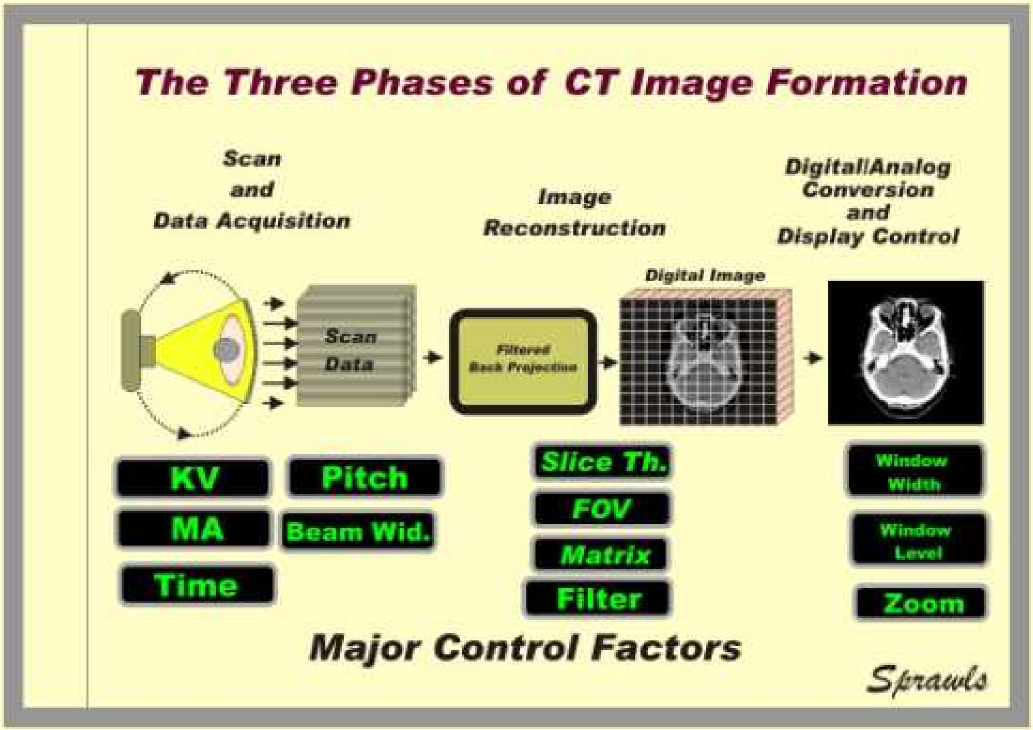
PHYSICAL UNIVERSE



Sprawls

Visuals
for
Learning and Teaching

The Imaging Process



The Three Phases of CT Image Formation

Scan and Data Acquisition

Image Reconstruction

Digital/Analog Conversion and Display Control

KV
MA
Time
Pitch
Beam Wid.
Slice Th.
FOV
Matrix
Filter
Window Width
Window Level
Zoom

Major Control Factors

Sprawls

Clinical Images

Sprawls

Clinically Focused Physics Education

Classroom

Clinical Conference

Small Group

"Flying Solo"

Highly Efficient

For
General Physics
and
Related Topics

Highly Effective

Clinically Rich Learning Activities

Visuals Images Online Modules

Resources and References

Sprawls

Radiology resident analyzing a mammogram under the direction of radiologist Dr. Debra Monticciolo who discusses image characteristic and related physics. The monitor in the rear is displaying the mammography physics module.

They then use the module to study topics in more depth or lookup specific information. The resident will continue to use the module to study physics during his mammography clinical clinical rotation.

Mammography Physics and Technology

for effective clinical imaging

Perry Sprawls, Ph.D.

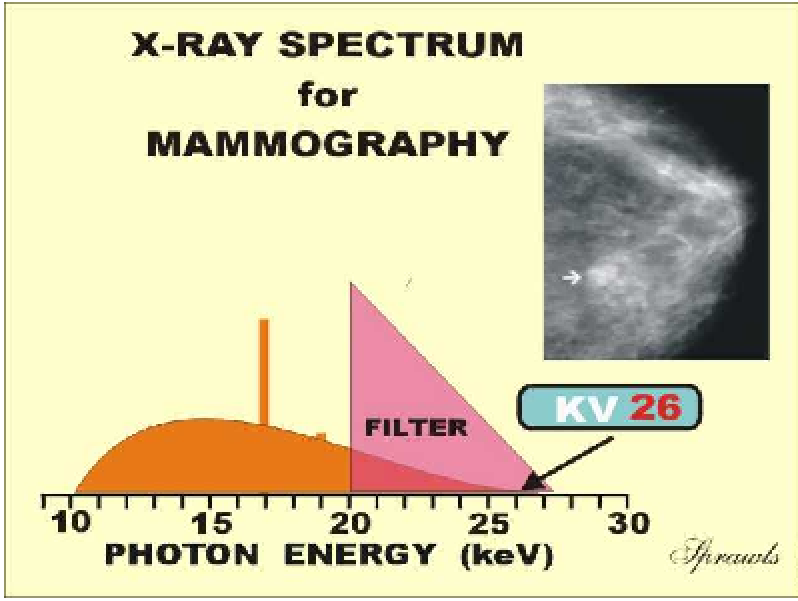
To step through module, CLICK HERE.

To go to a specific topic click on it below

Imaging Objectives	Rhodium Anode	Blurring and Visibility of Detail
Visibility of Pathology	KV Values for Mammography	Focal Spot Blurring
Image Quality Characteristics	Scattered Radiation and Contrast	Receptor Blurring
Not a Perfect Image	Image Exposure Histogram	Composite Blurring
Mammography Technology	Receptor & Display Systems	Magnification Mammography
Imaging Technique Factors	Film Contrast Transfer	Mean Glandular Dose
Contrast Sensitivity	Film Contrast Factors	
Physical Contrast Compared	Film Design for Mammography	
Factors Affecting Contrast Sensitivity	Controlling Receptor (Film) Exposure	
X-Ray Penetration and Contrast	Film Processing	
Optimum X-Ray Spectrum	Variations in Receptor Sensitivity	

Module available on www.sprawls.org/resources

KV Values for Mammography



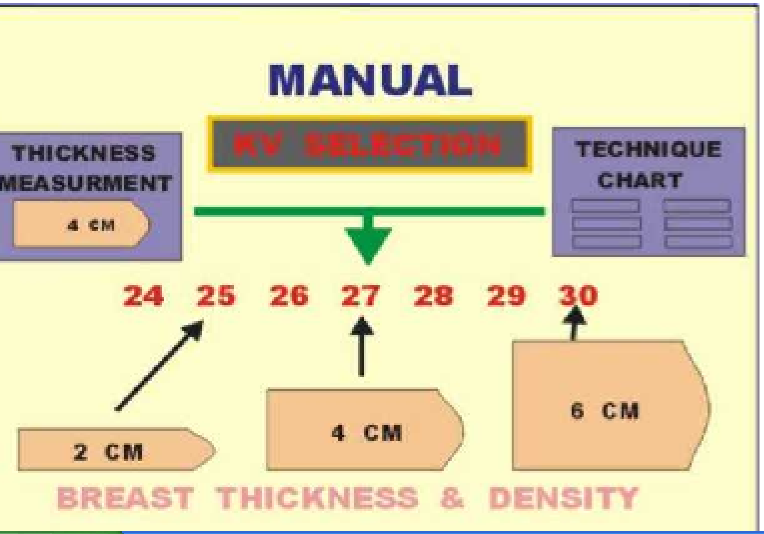
e x-ray beam spectrum is one of the most critical factors that must be justed to optimize a procedure with respect to contrast sensitivity and dose.

e can think of it as a three-step procedure:

1. Select the appropriate anode (moly or rhodium)
2. Select the appropriate filter (moly or rhodium)
3. Select the appropriate KV (In the range 24 kV to 32 kV)

reasing the KV has two effects on the x-ray beam. It increases the efficiency d output for a specific MAS value and it shifts the photon energy spectrum ward so that the beam becomes more penetrating.

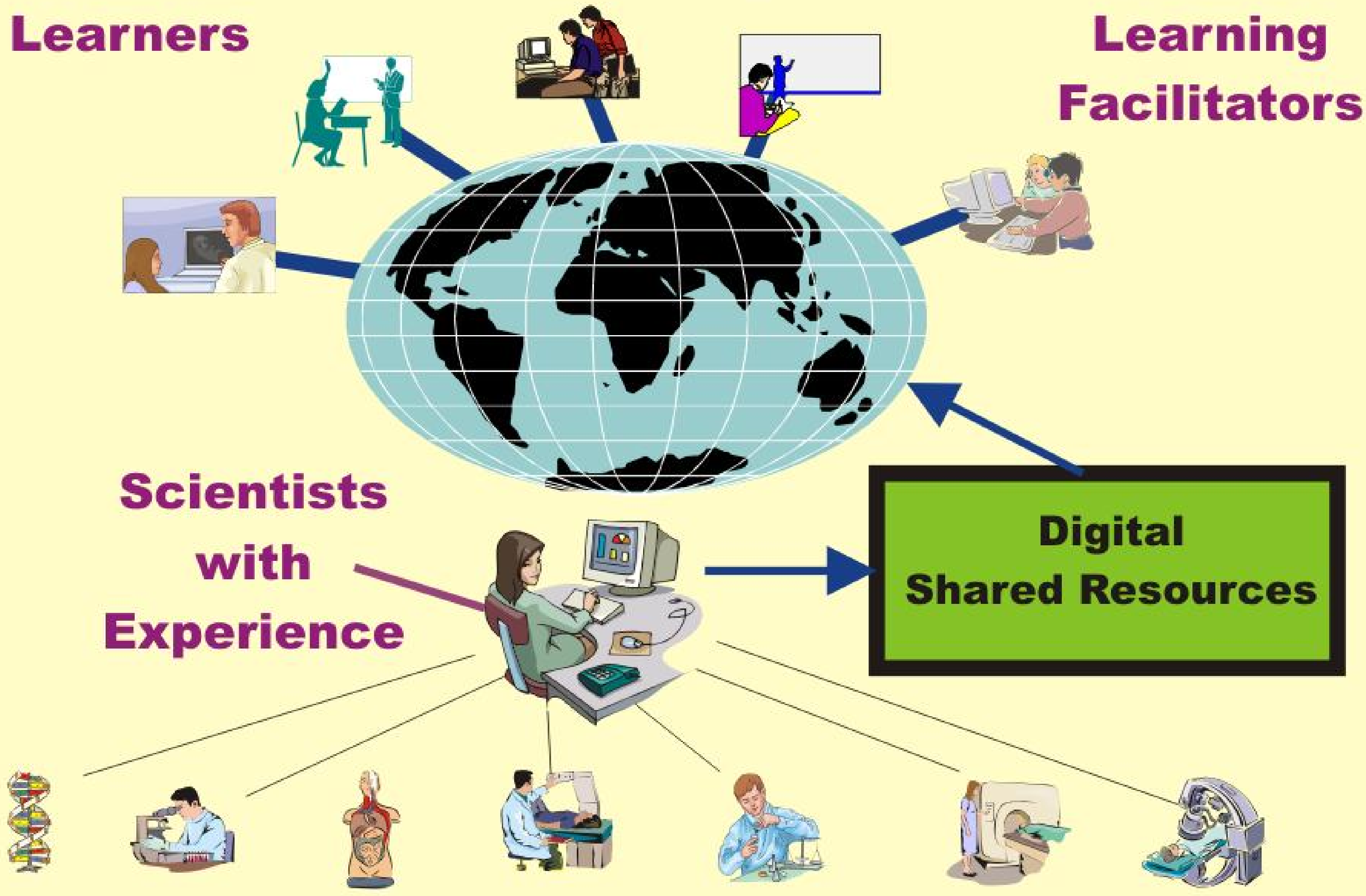
hile a more penetrating beam does reduce contrast sensitivity it is necessary en imaging thicker and more dense breast. Therefore compressed breast thickness is the principal factor that determines the optimum V.



Mammography systems have indicators that display the thickness of the compressed breast. This along with a general assessment of breast density is used to manually select an optimum KV either from experience or an established technique chart.

The general goal is to increase the KV as necessary to keep the exposure time, MAS, and dose to the breast within reasonable limits as breast thickness increases.

Enriched Learning Environments



Learners

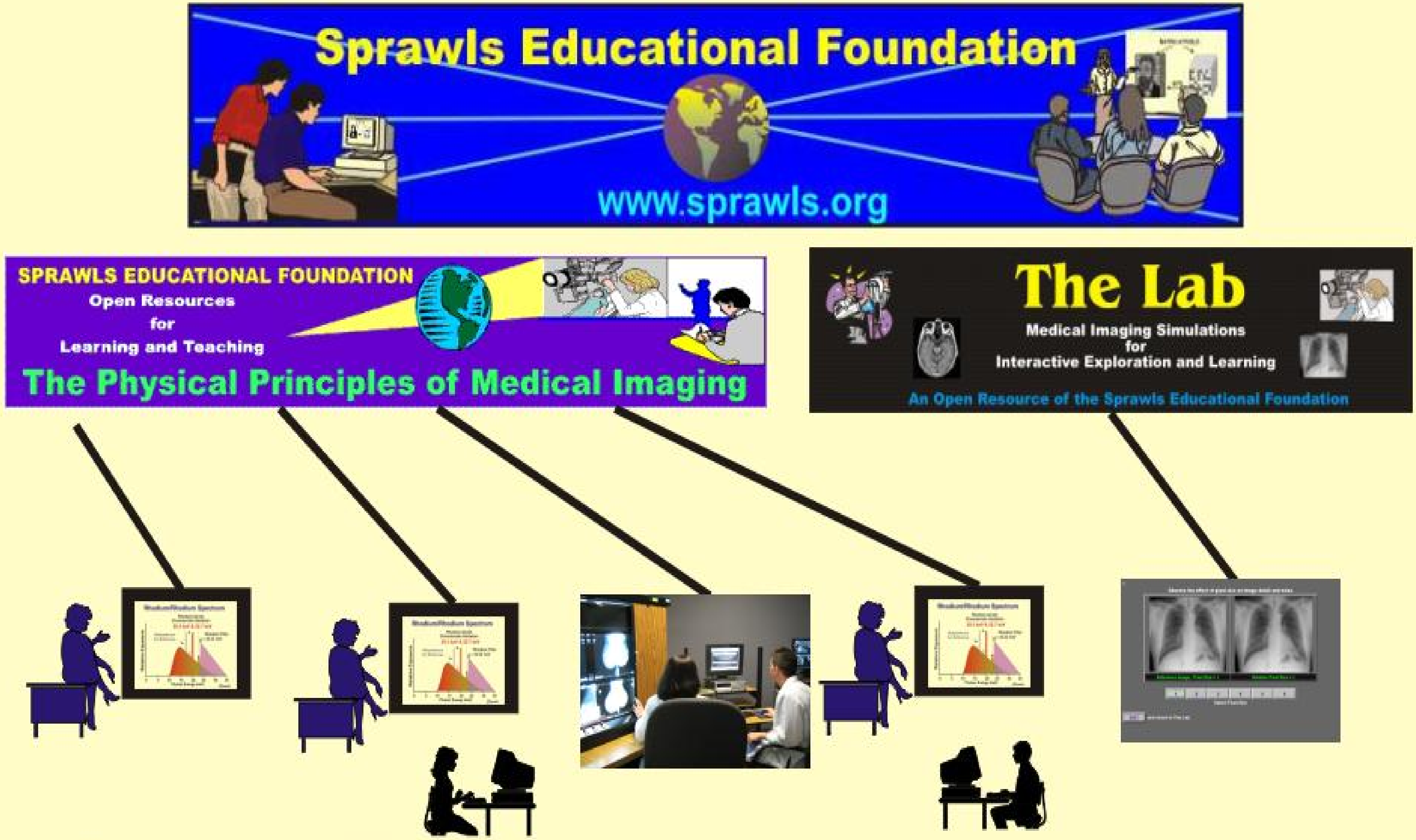
Learning Facilitators

Scientists with Experience

Digital Shared Resources

The Physical Universe

Sprawls



Sprawls Educational Foundation

www.sprawls.org

SPRAWLS EDUCATIONAL FOUNDATION

Open Resources
for
Learning and Teaching

The Physical Principles of Medical Imaging

The Lab

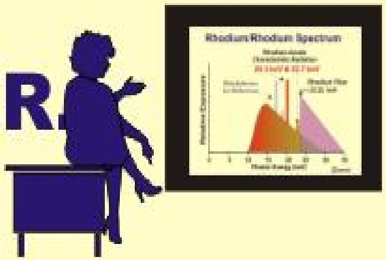
Medical Imaging Simulations
for
Interactive Exploration and Learning

An Open Resource of the Sprawls Educational Foundation

In Partnership with Other Medical Physics Teachers to be More Effective and Efficient in Providing Medical Imaging Education

The Values We Hold

The PHYSICIST is the TEACHER.



TECHNOLOGY is the TOOL that can be used for effective and efficient teaching.

Technology should be used to enhance human performance of both learners (residents, students, etc.) And teachers

Sprawls

Clinically Focused Physics Education

Perry Sprawls, Ph.D.
Emory University, Atlanta
Sprawls Educational Foundation, www.sprawls.org

This is a presentation containing a collection of visuals used in courses on the general topic of medical physics education for medical professionals, especially radiologists and radiology residents.

They are provided here to be used by medical physicists for individual study, group discussions, or in class or conference presentations.

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