Medical Physics as a Career

American Association of Physicists in Medicine (AAPM)

Public Education Committee

2003

February 9, 2005, version 1.0

What is a Medical Physicist?

A medical physicist is a professional who specializes in the application of the concepts and methods of physics to the diagnosis and treatment of human disease.

The Medical Physicist Bridges Physics and Medicine

Medical Physicist

Physics

Medicine

The Medical Physicist is Part of the Medical Team

Therapy

- Physician (Radiation Oncologist, Surgeon, …)
- Medical Physicist
- Medical Dosimetrist
- Physics Assistant
- Radiation Therapist

Imaging

- Physician (Radiologist, Cardiologist, …)
- Medical Physicist
- Physics Assistant
- Radiological Technologist

Medical Physicist Rewards

- Challenge of applying the principles of physics to medicine
- Satisfaction of developing new technology for medical use
- Contributing to the well-being of patients
- Receiving competitive compensation

What do we mean- a qualified medical physicist?

- An individual who is competent to practice independently in one or more of the subfields in medical physics.
  - Certification and continuing education (to demonstrate competence)
  - Trained to be familiar with the principles of physics used in the equipment and instruments
  - Familiar with government regulations and laws
  - Familiar with performance specifications of equipment
  - Familiar with physical limitations of instruments, calibration procedures, and computer algorithms

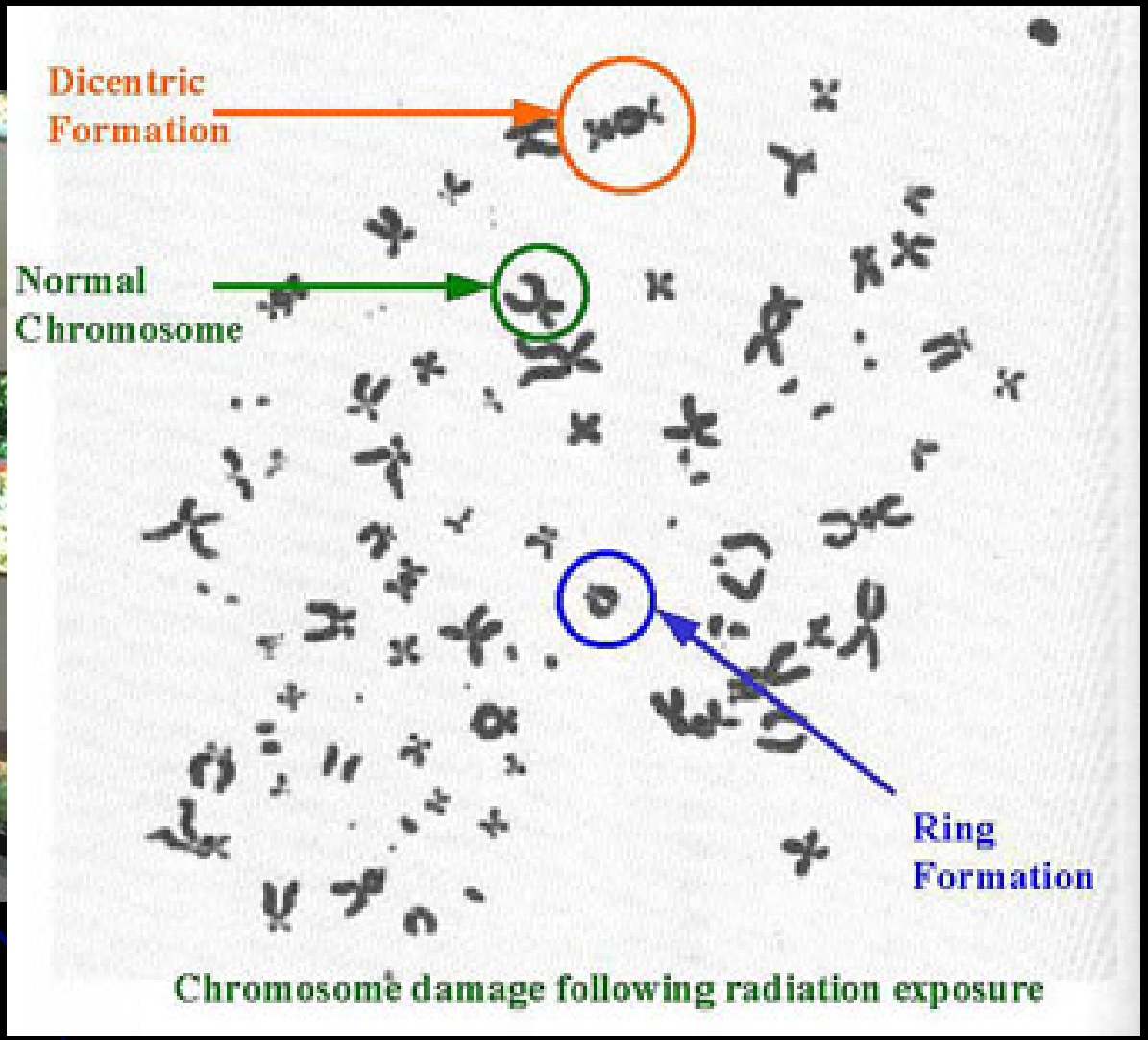
Medical Physics Disciplines (Subfields)

- Therapeutic Radiological Physics
- Diagnostic Imaging Physics
- Medical Nuclear Physics
- Medical Health Physics

Therapeutic Radiological Physics

- The therapeutic applications of x-ray, gamma ray, neutron, electron, and charged-particle beams, and radiation from sealed radionuclide sources.
- The equipment associated with their production, use, measurement, and evaluation.
- The quality of images resulting from their production and use.
- Medical health physics associated with this subfield.

Cell Killing By Ionizing Radiation

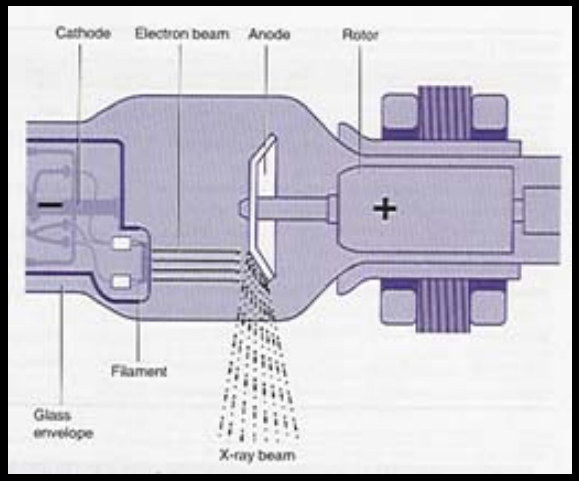


Diagnostic Radiological Physics

- The diagnostic applications of x-rays, gamma rays from sealed sources, ultrasonic radiation, and radio frequency radiation and magnetic fields
- The equipment association with their production, use, measurement and evaluation
- The quality of images resulting from their production and use
- Medical health physics associated with this subfield

Discovery of X-rays

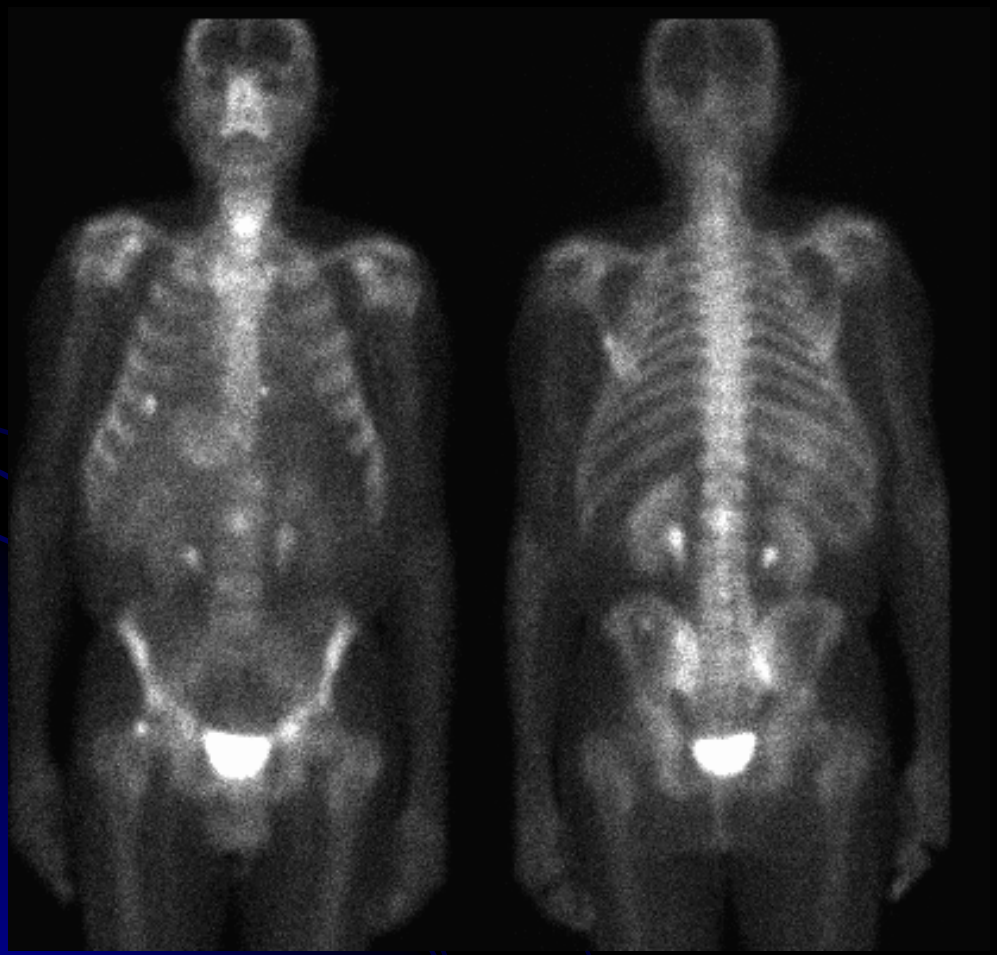
On 8 Nov 1895, Wilhelm Conrad Röntgen (accidentally) discovered an image cast from his cathode ray generator.



Medical Nuclear Physics

- The therapeutic and diagnostic applications of radionuclides in unsealed sources
- The equipment association with their production, use, measurement, and evaluation
- The quality of images resulting from their production and use
- Medical health physics associated with this subfield

Gamma Camera Scan



Liver metastasis from prostate carcinoma

IV administration of Tc99m

Accumulates in areas of increased blood flow due to active bone metabolism, oedema of inflammation or the angiogenesis associated with tumours

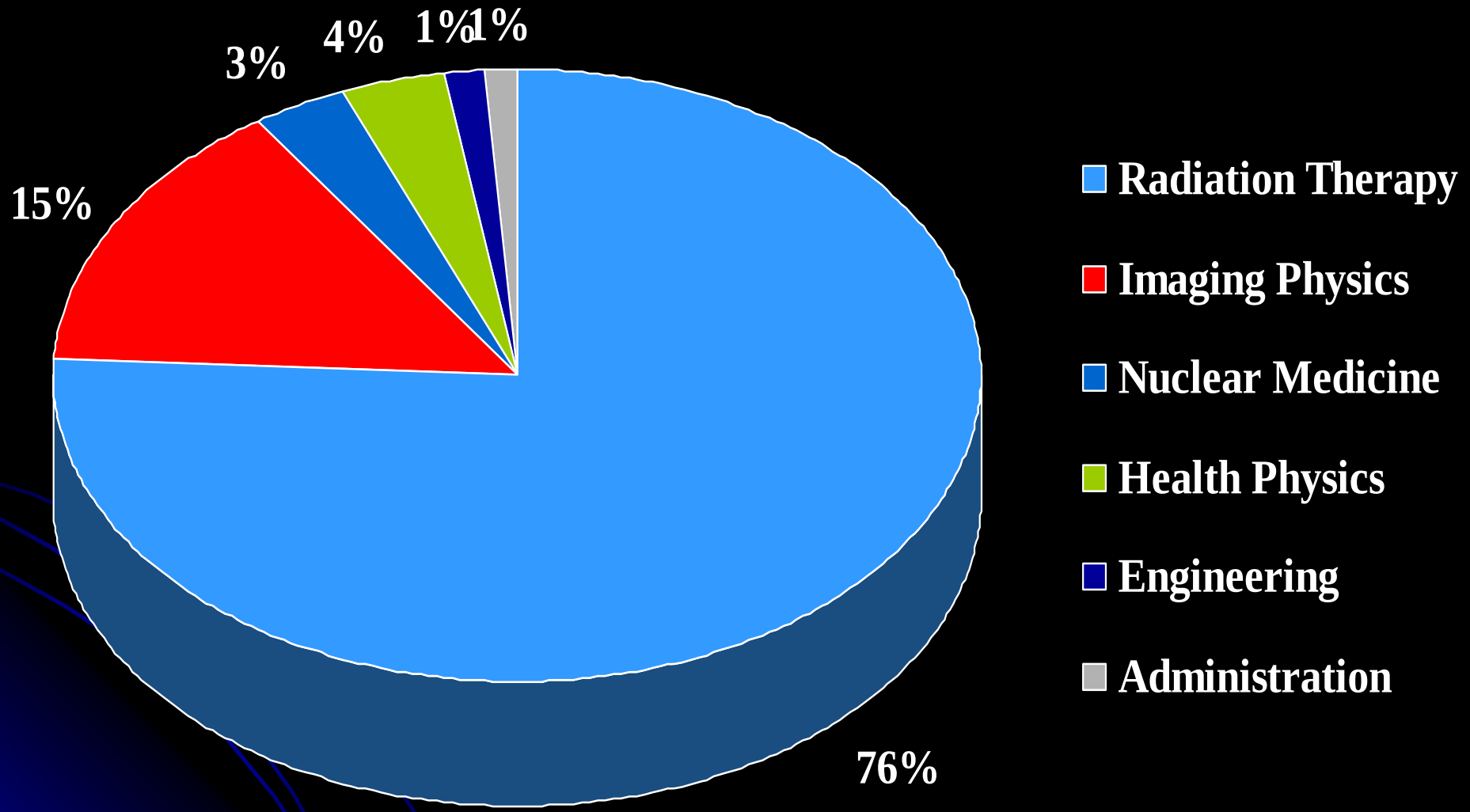
Medical Health Physics

- The safe use of x-ray, gamma ray, neutron, electron, and other charged particle beams or radionuclides in medicine (for diagnostic or therapeutic purposes).
- The instrumentation required to perform appropriate radiation surveys.
- The medical physicist often serves as radiation safety officer

Emergency Management of Radiation Casualties

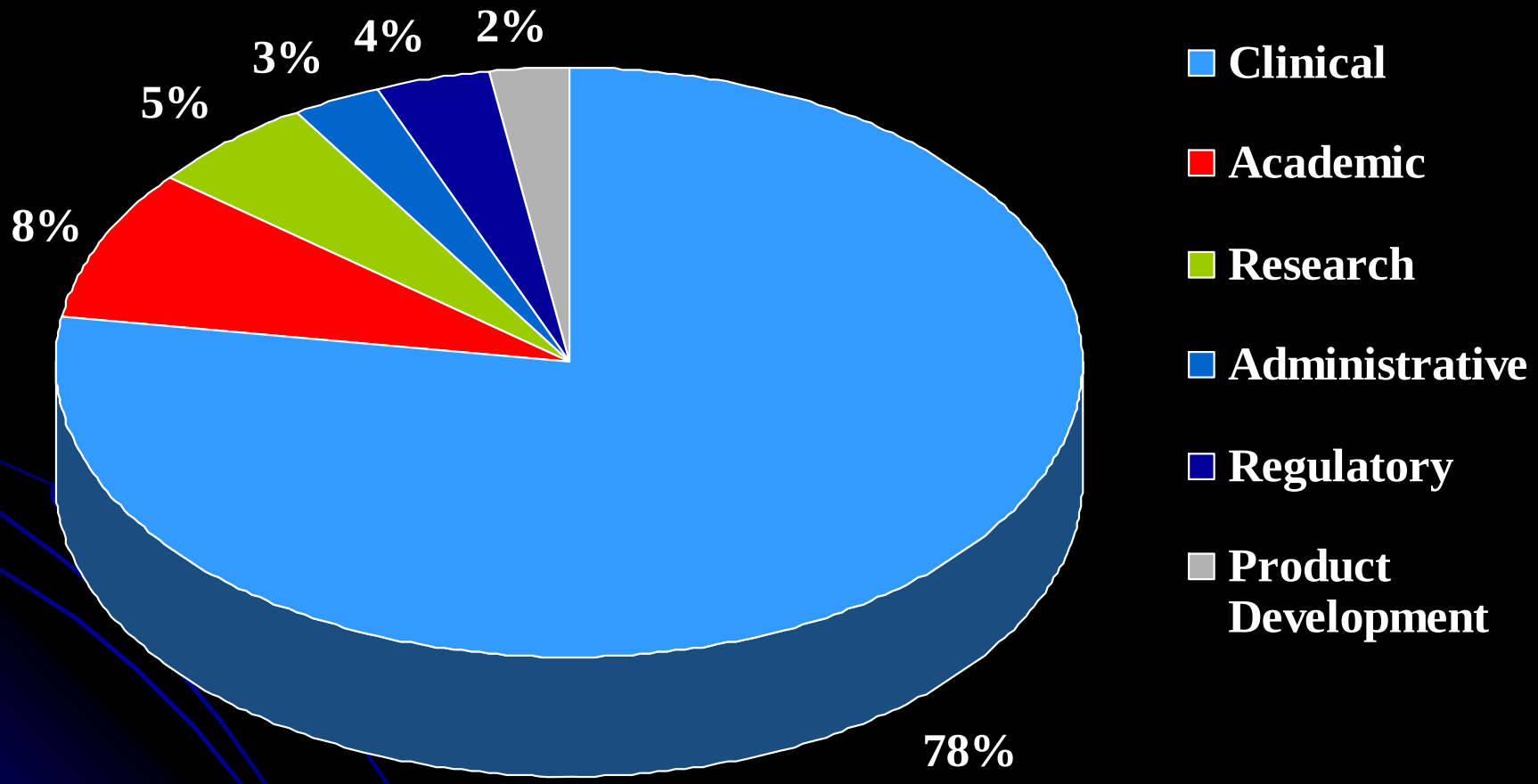
February 9, 2005, version 1.0

What is the Medical Physicist's Primary Discipline?



Source: 2002 AAPM Survey

What is the Medical Physicist's Primary Responsibility?



Source: 2002 AAPM Survey

General Areas of Responsibility of the Medical Physicist

- Clinical
- Research
- Education
- Regulatory Compliance

Clinical Responsibilities of the Medical Physicist

- Daily clinical support
- Equipment acquisitions
- Site planning
- Quality assurance
- Dose calculations
- Liaison between other medical professionals, manufacturers, and regulatory agencies

Research and Development Opportunities for the Medical Physicist

- Develop new therapeutic or diagnostic procedures
- Implement and/or integrate new equipment into clinical use
- Investigate or evaluate therapeutic or diagnostic outcomes/performance
- Basic scientific research

Educational Functions of the Medical Physicist

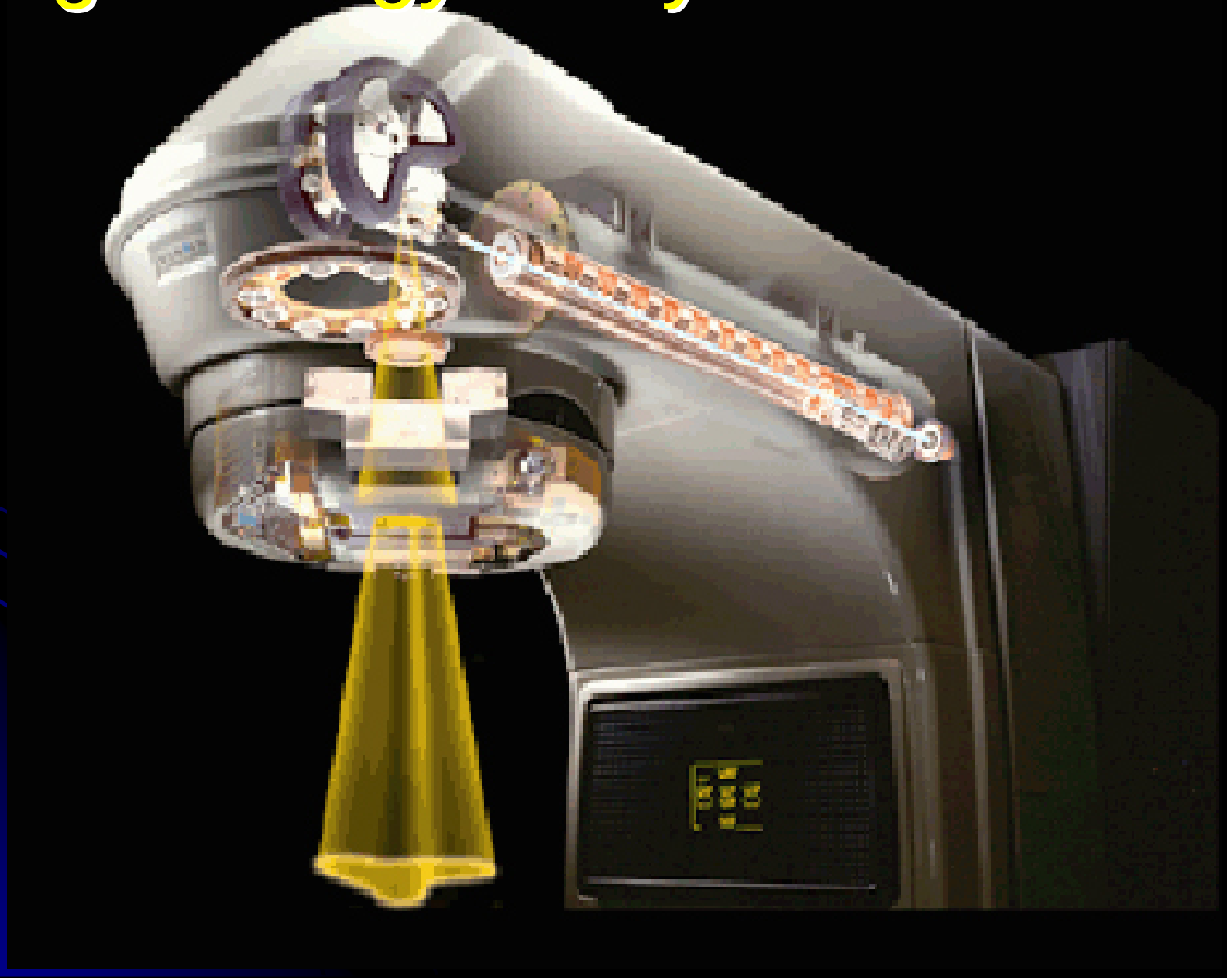
- Graduate programs in Medical Physics
- Residency programs
  - Medical Physics
  - Diagnostic Radiology
  - Radiation Oncology
  - Nuclear Medicine
  - Others (Cardiology, Gynecology, …)
- Allied Health Professionals
- Other training opportunities
  - AAPM annual meeting and summer school
  - ACMP seminars
  - Other professional society meetings

Therapeutic Radiological Physics

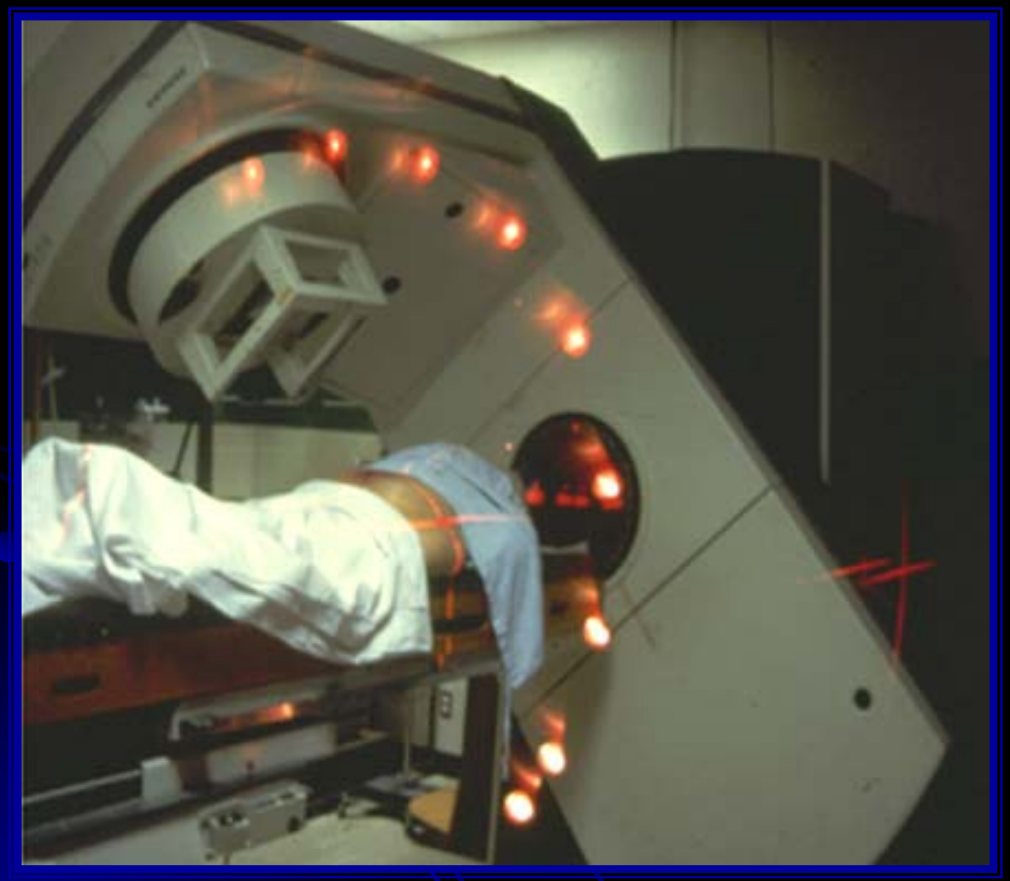
An Introduction

February 9, 2005, version 1.0

Modern Radiation Therapy Using High Energy X-rays and Electrons

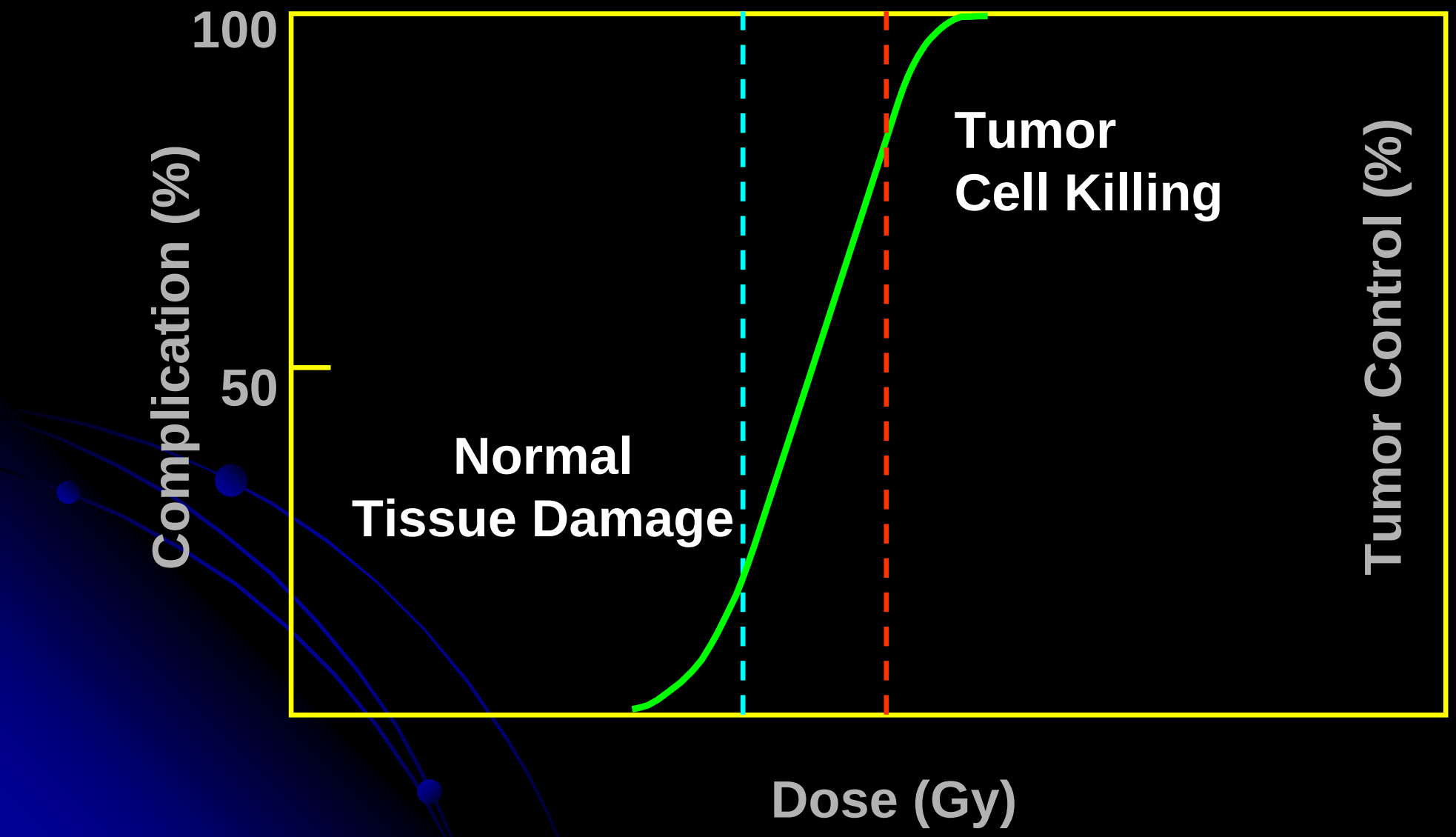


Isocentric Patient
Radiation Therapy

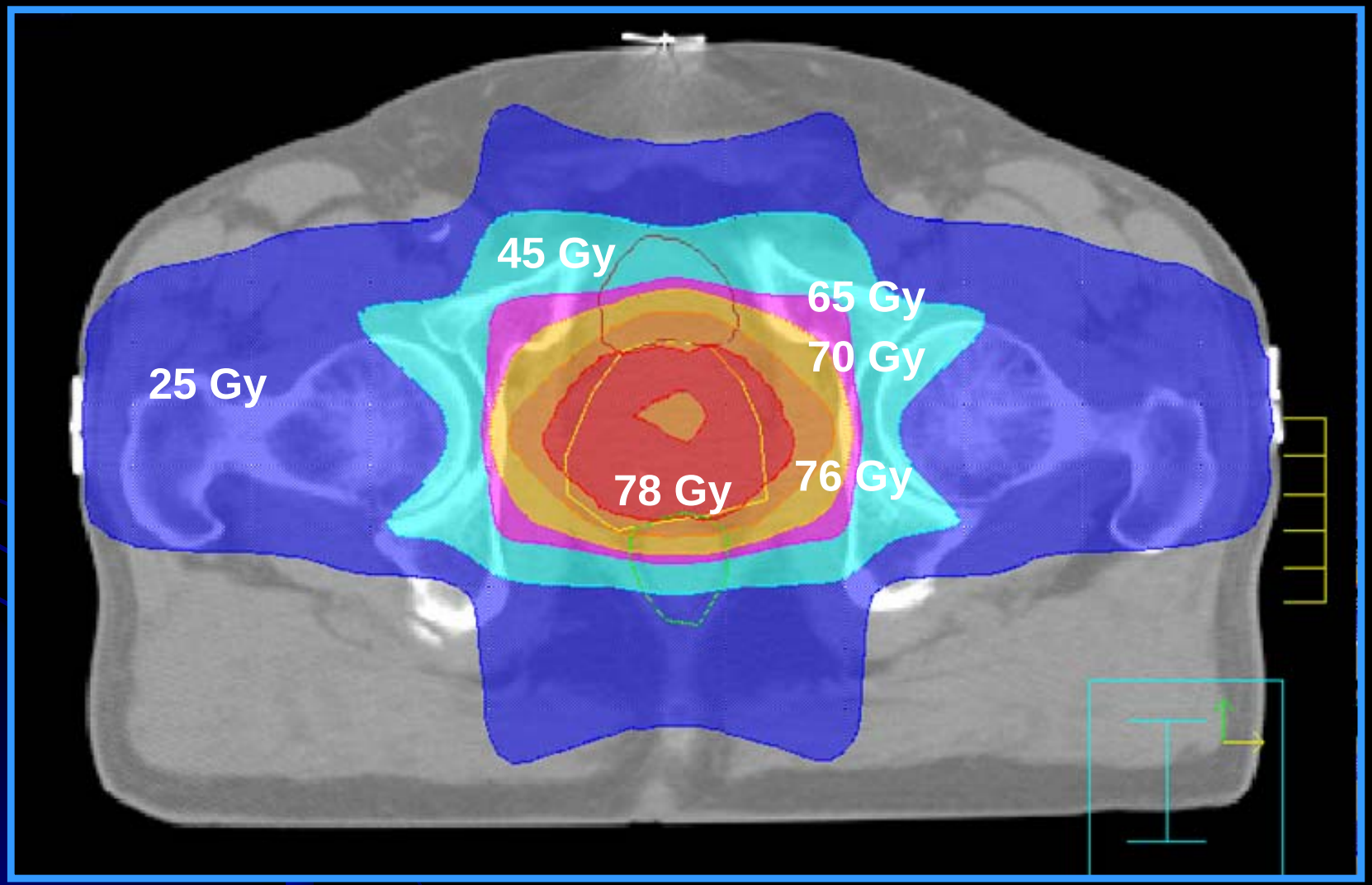


Therapeutic Gain

A compromise between tumor control and normal tissue complications

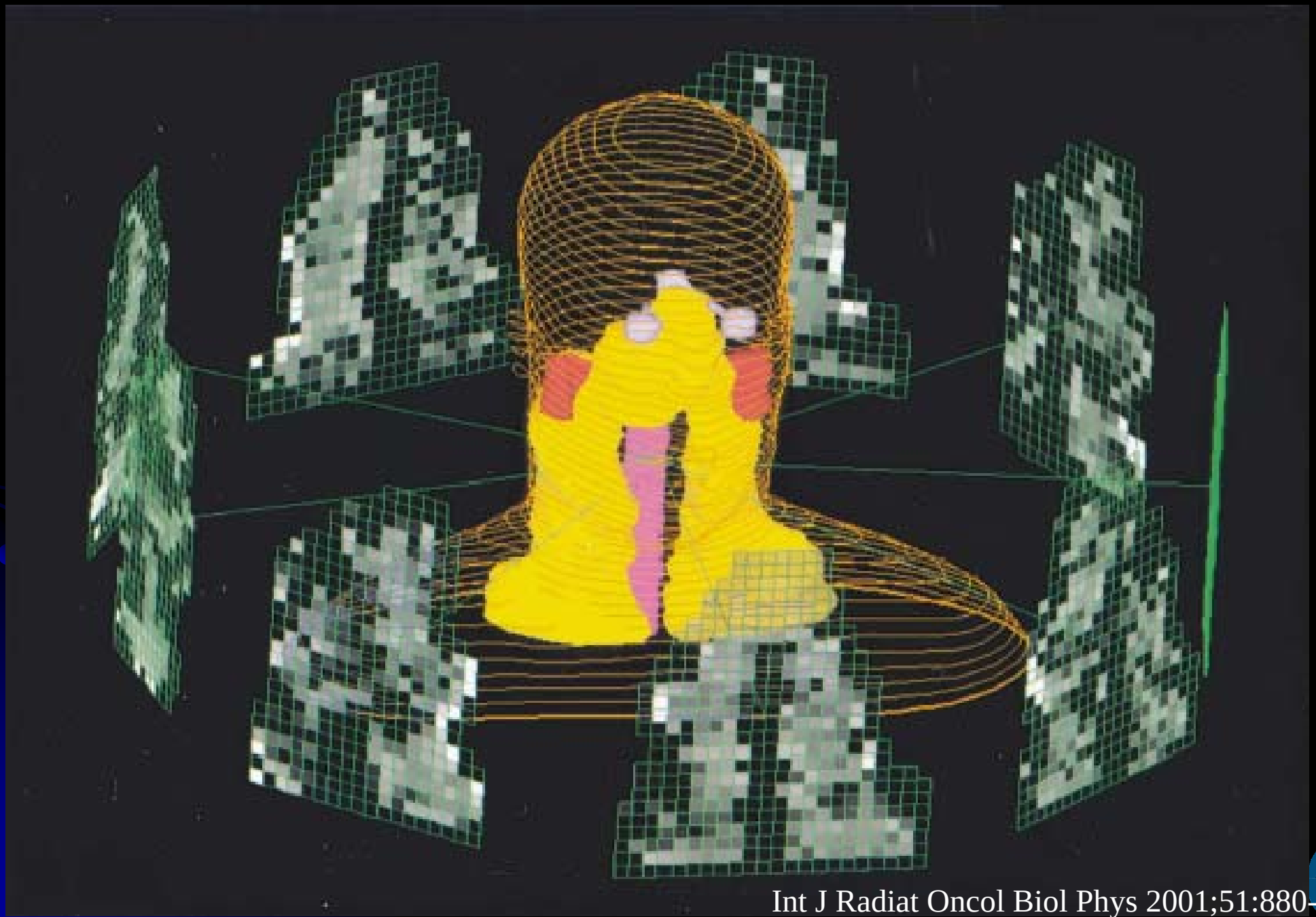


External Beam Radiation Therapy



3D Conformal Technique for Treating Prostate Cancer

9-Field Head & Neck IMRT Case



Int J Radiat Oncol Biol Phys 2001;51:880-914

Target Localization and Immobilization Using Ultrasound in Prostate Radiation Therapy

Example of Functions In Therapy Physics

- Clinical Medical Physics
  - → Dosimetry, radiation safety, quality assurance, *etc.*
- Research and Development
  - → Develop new therapeutic equipment or procedures, etc.
- Education
  - → Training of medical physicists, physicians, technologists, radiation therapists, and medical dosimetrists.

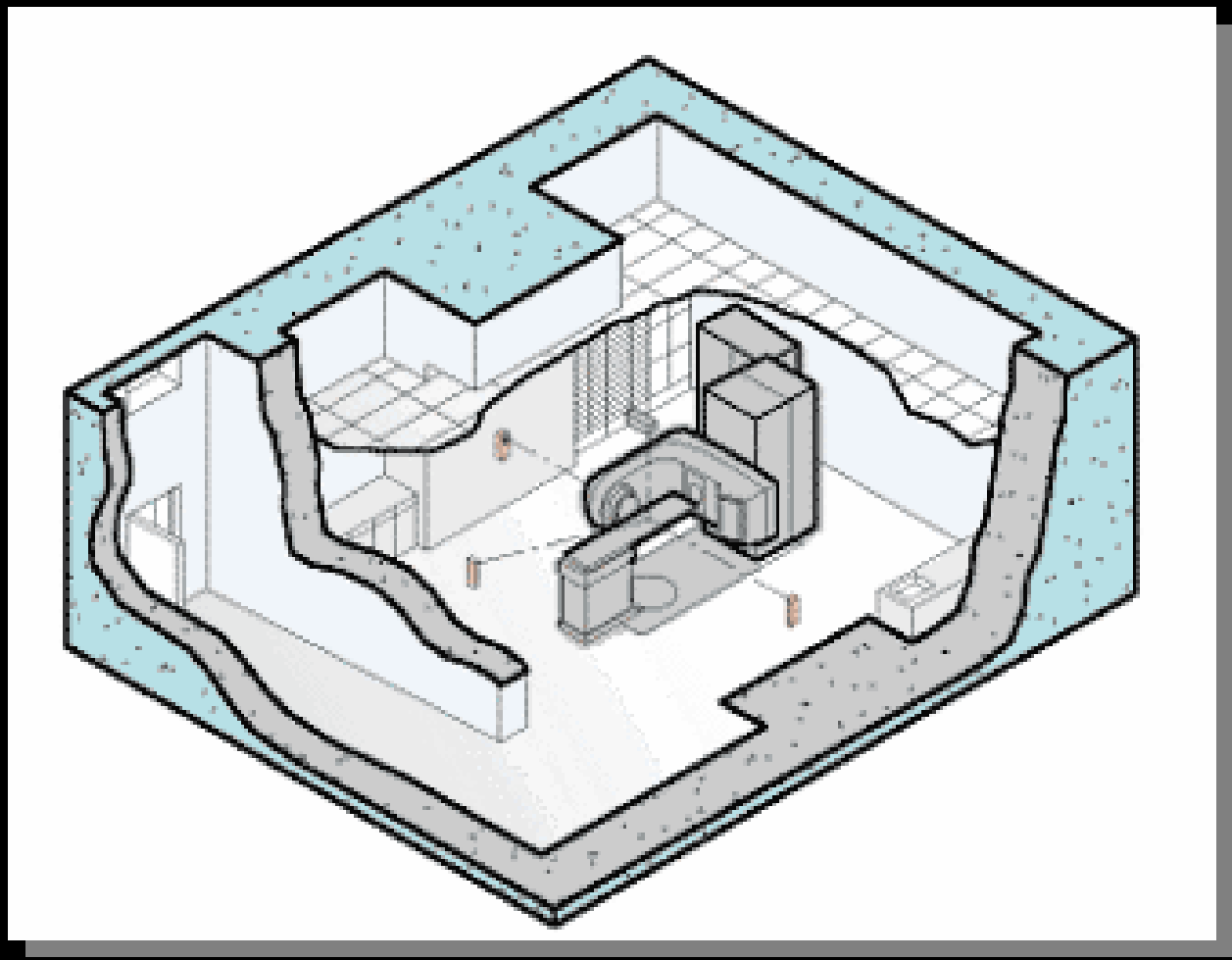
Contributed By: Dong (MD Anderson)

Therapy Responsibilities

- Equipment and facility specification and acquisition

$$B_x = \frac{Pd_{pri}^2}{WUT}$$

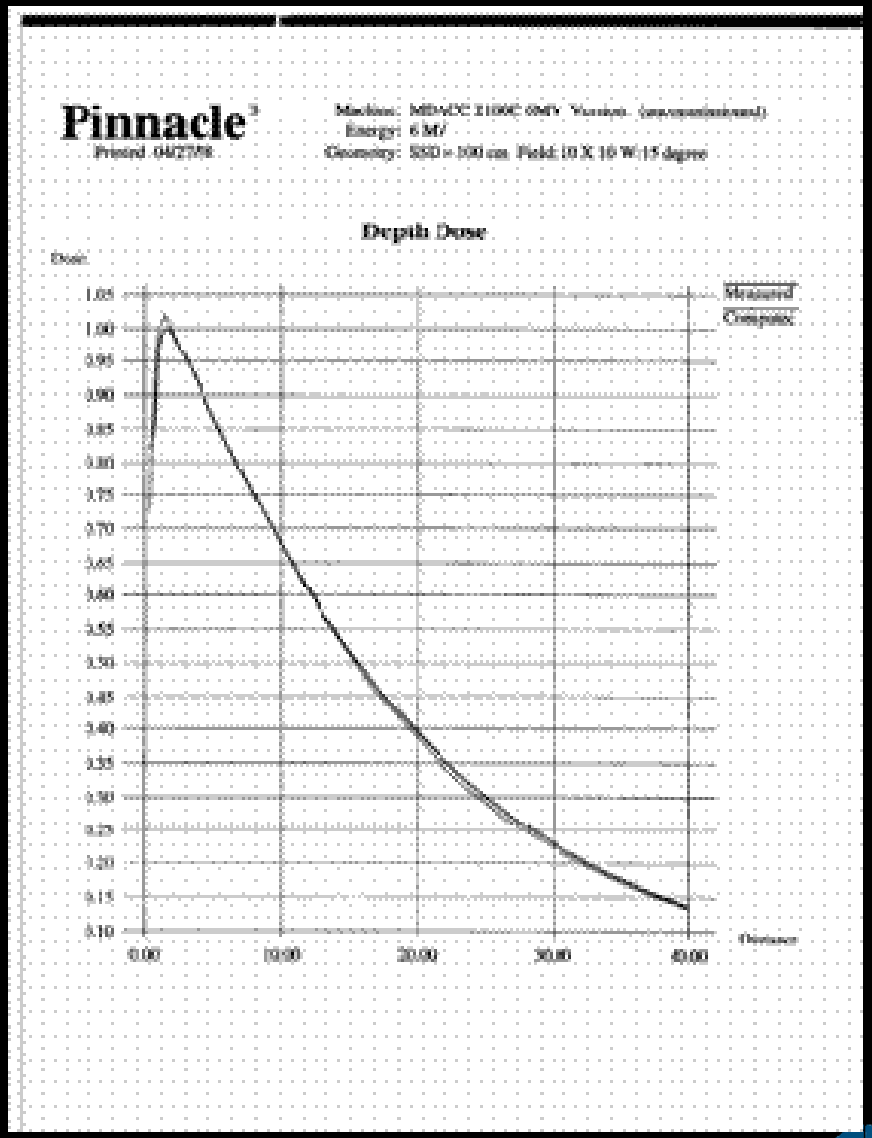
Shielding calculations



Contributed By: Dong (MD Anderson)

Therapy Responsibilities

- Equipment commissioning



Contributed By: Dong (MD Anderson)

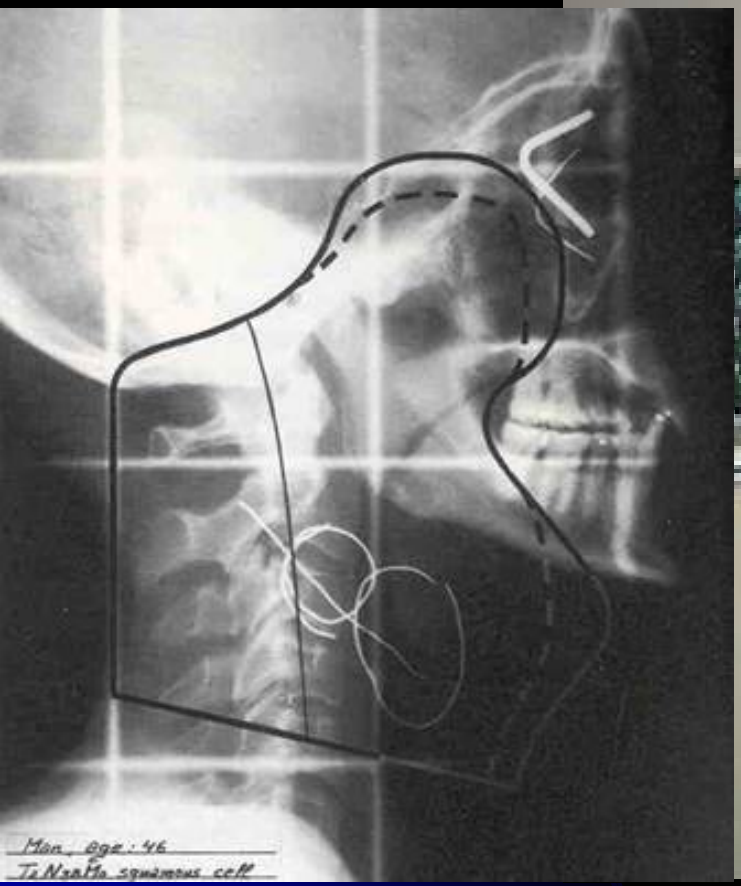
Therapy Responsibilities

- Calibration of radiation sources

Contributed By: Dong (MD Anderson)

Therapy Responsibilities

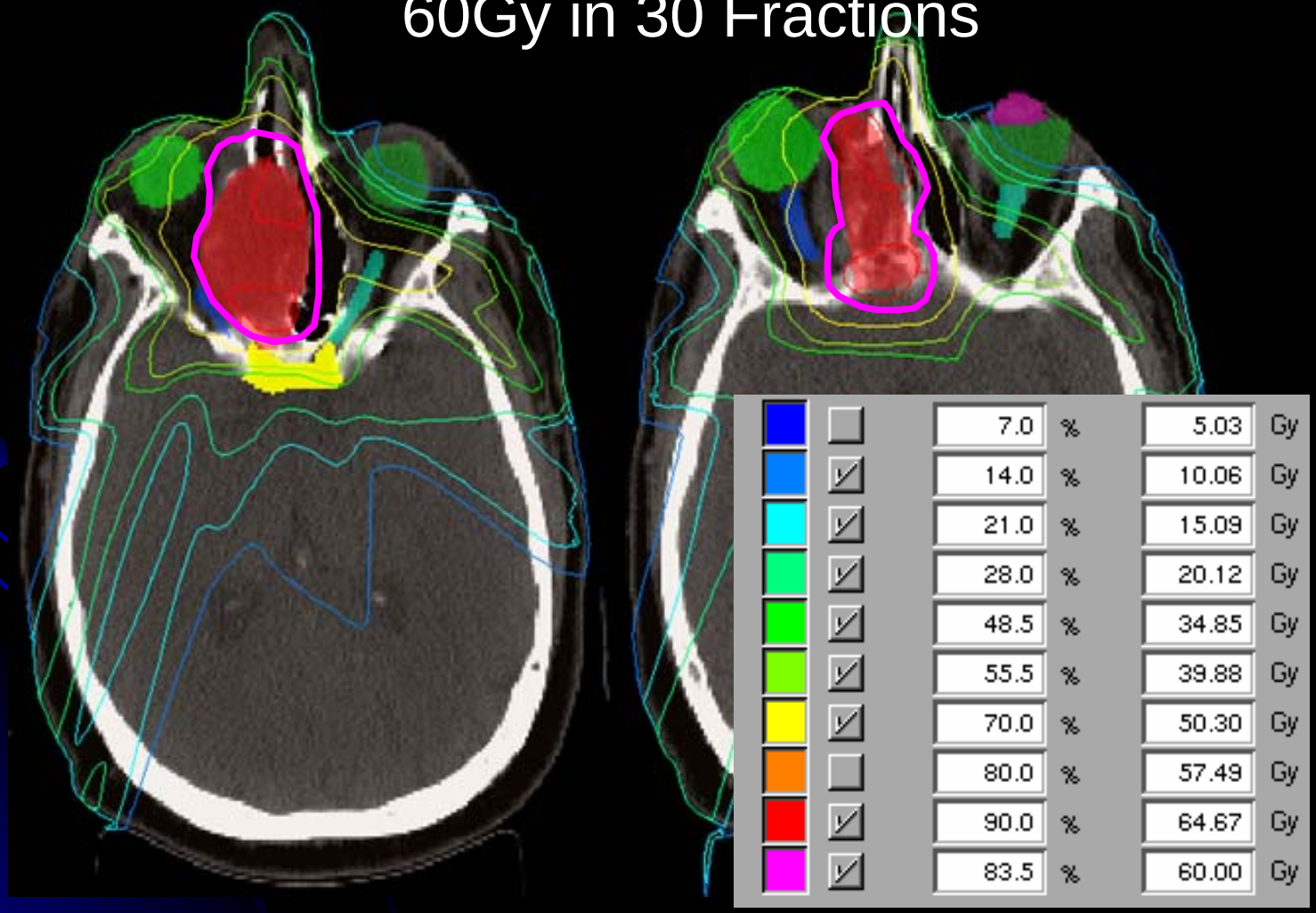
- Planning of patient procedures



Therapy Responsibilities

- Calculation of patient dose

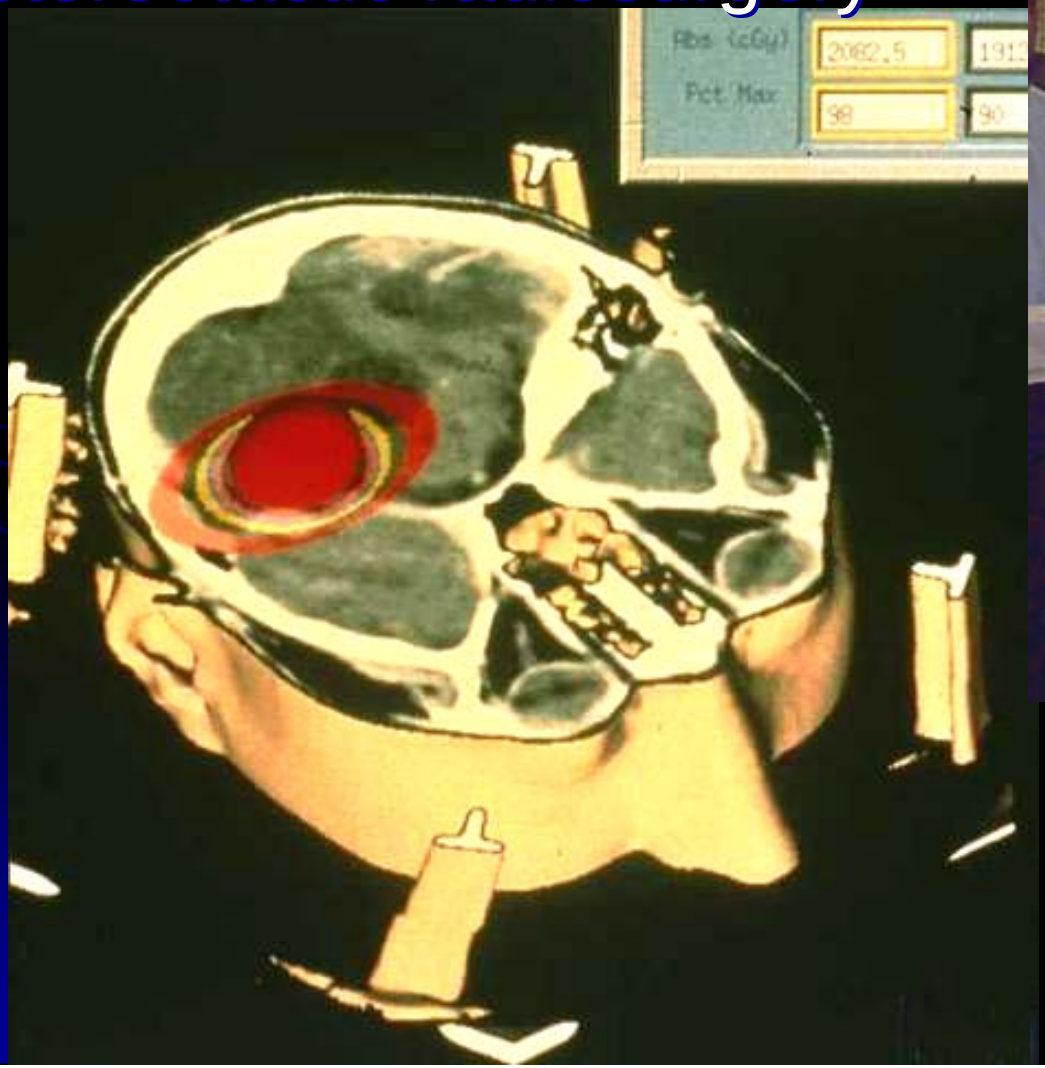
60Gy in 30 Fractions



Contributed By: Dong (MD Anderson)

Therapy Responsibilities

- Management of special procedure:
stereotactic radiosurgery



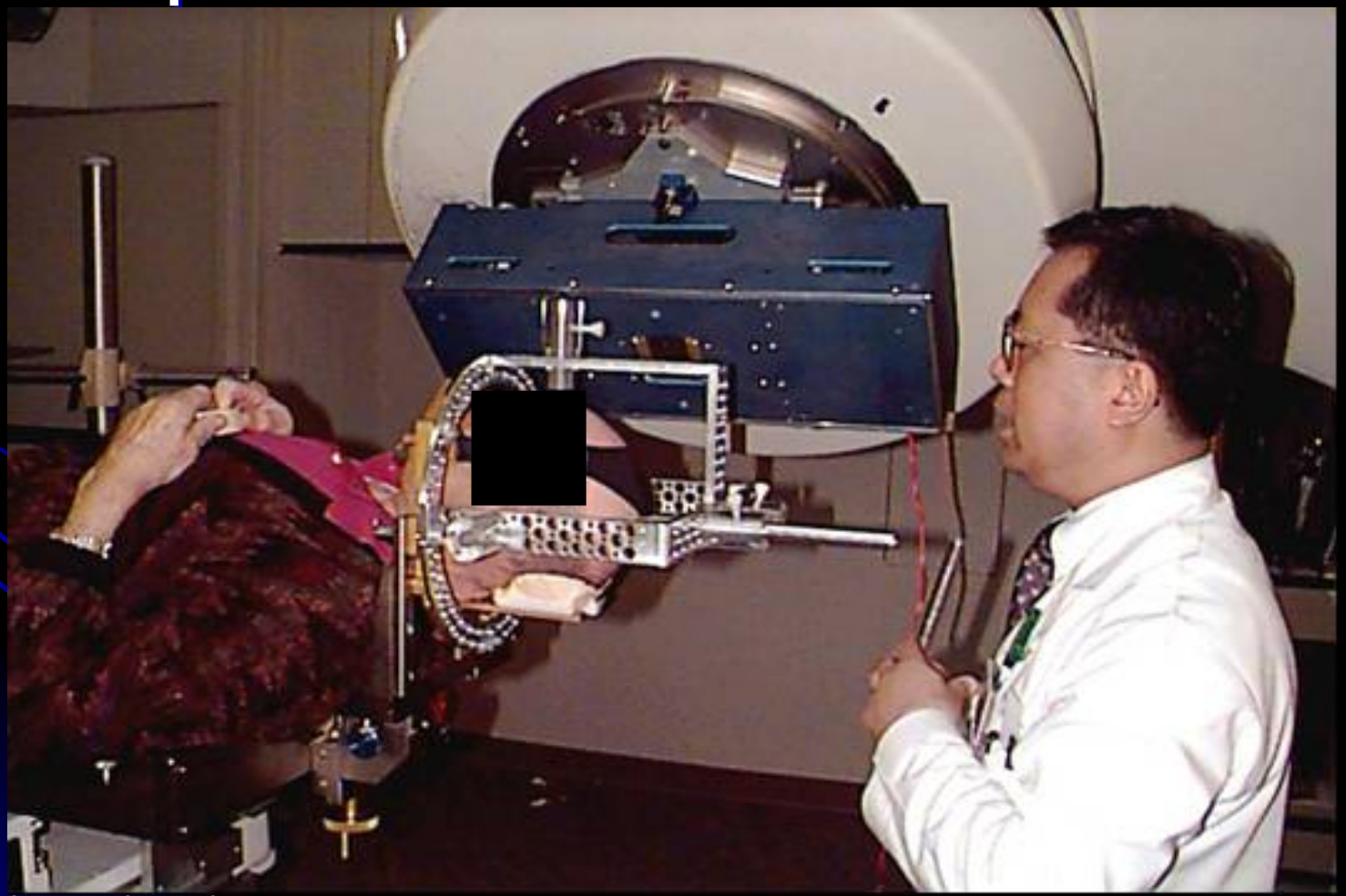
Therapy Responsibilities

- Calibration and quality assurance

Contributed By: Dong (MD Anderson)

Therapy Responsibilities

- Development of new devices and techniques



Contributed By: Dong (MD Anderson)

Therapy Responsibilities

- Radiation safety

Therapy Responsibilities

- Regulatory compliance (examples)

U.S. Nuclear Regulatory Commission

Diagnostic Radiological Physics

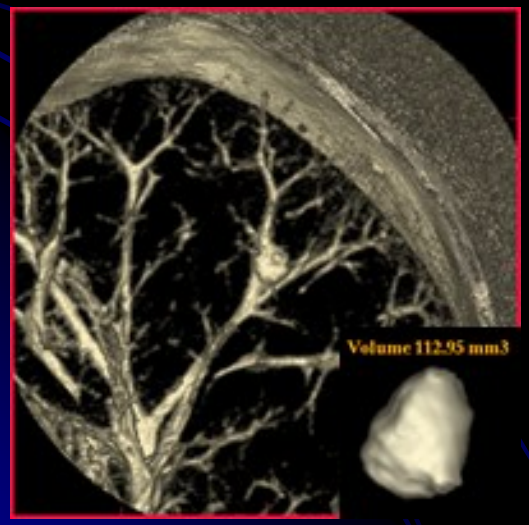
An Introduction

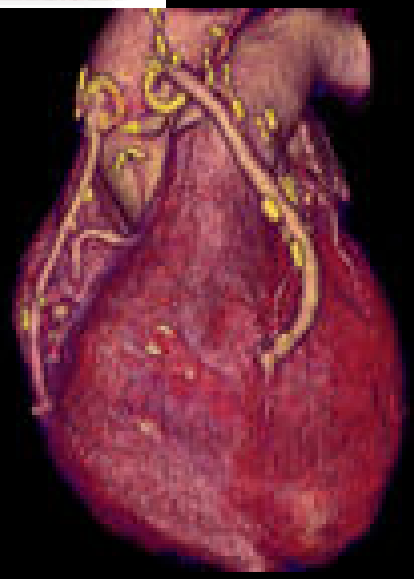
February 9, 2005, version 1.0

Components in Diagnostic Imaging

- Clinical images
- Imaging Physics and Principles
- Quality Control (QC) tests
- Radiation dose and effects in patients
- Shielding or sitting considerations

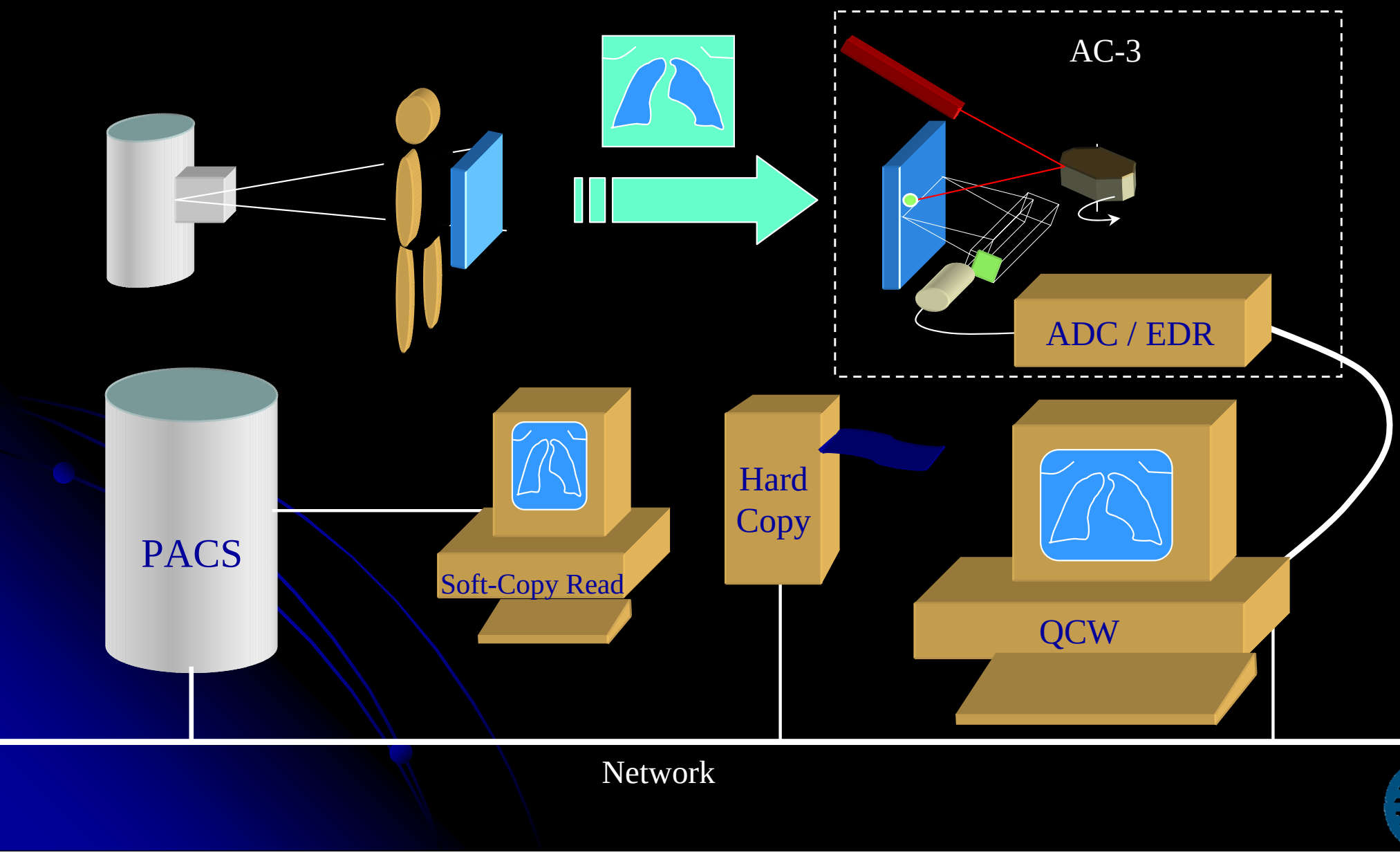
Diagnostic Use of X-rays



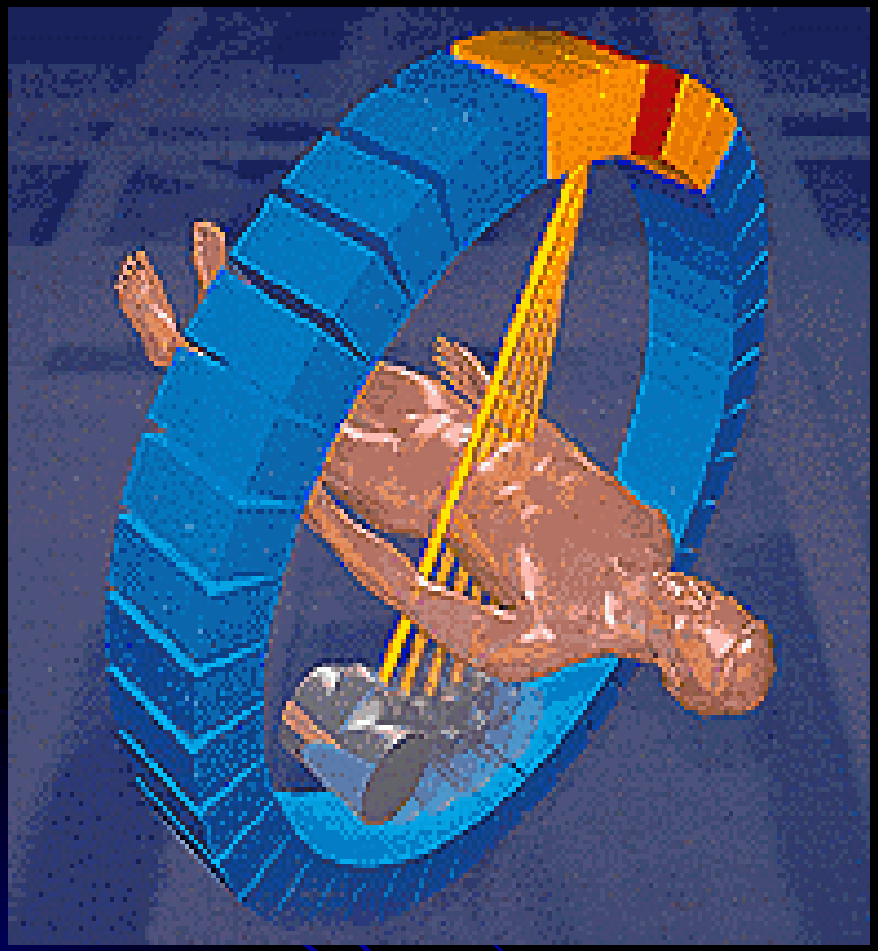


Angiography – Subtraction Imaging

Computed Radiography

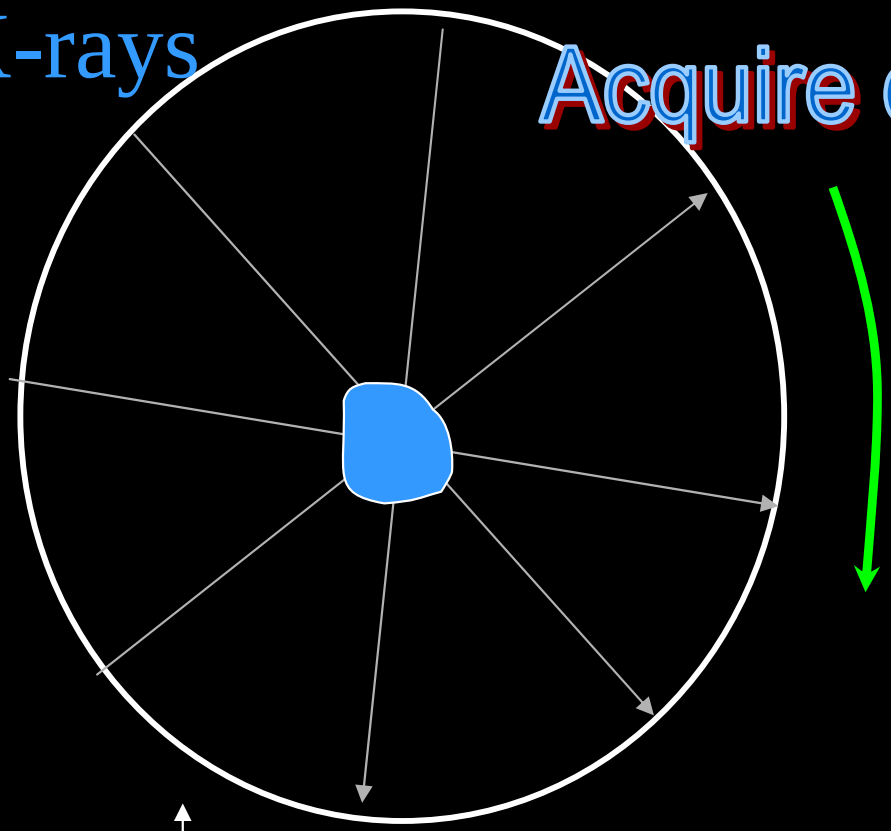


Computed Tomography Principle

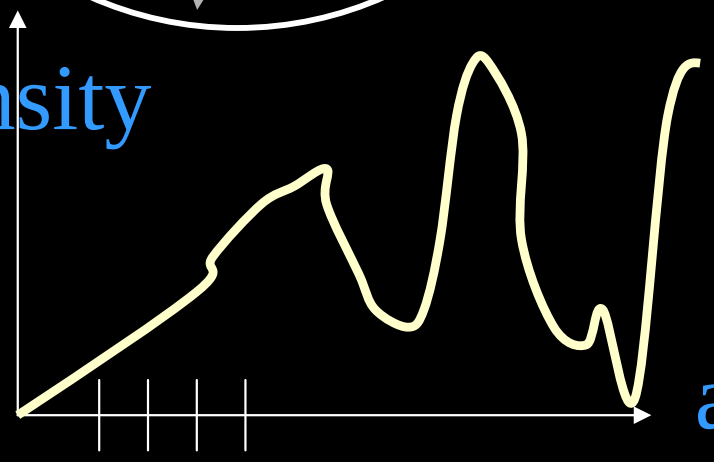


X-rays

Acquire data



intensity

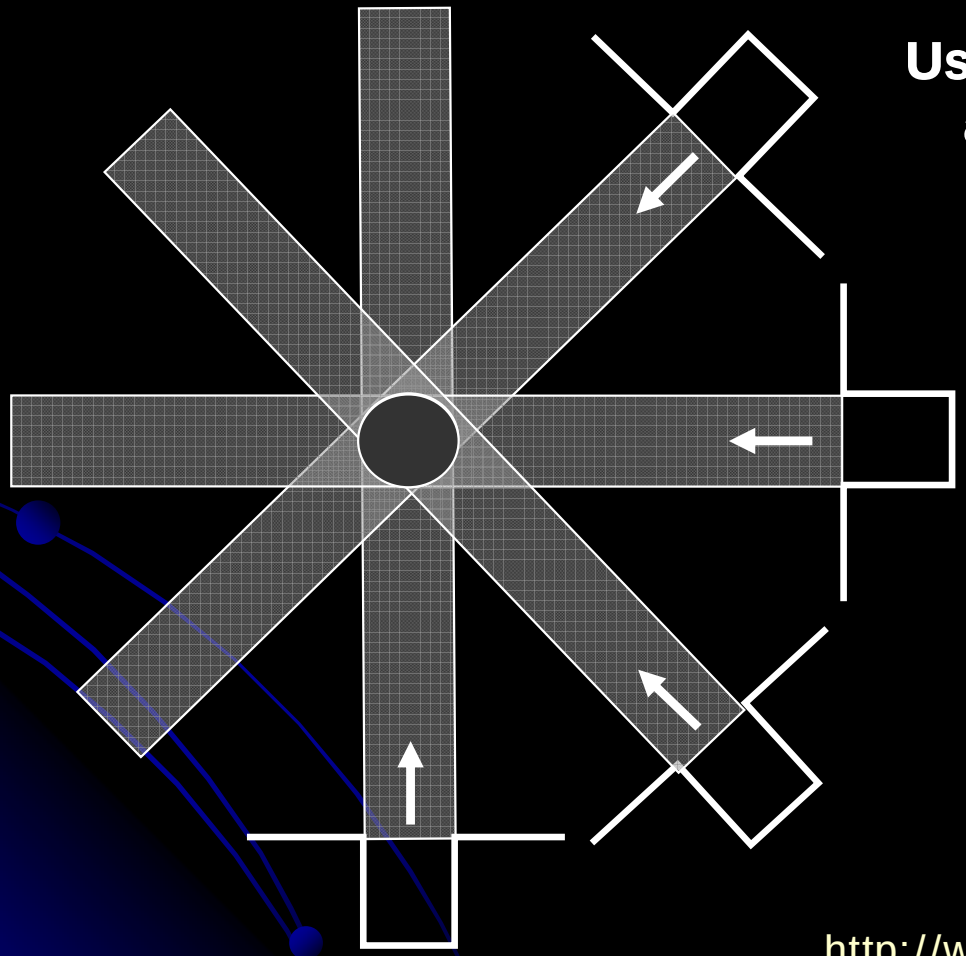


angle

Reconstruct image
with Fourier Transform

Computed Tomography (CT)

Back Projection



Use 1D projection as a template

Back projection of pixel brightness

PROJECTION RECONSTRUCTION

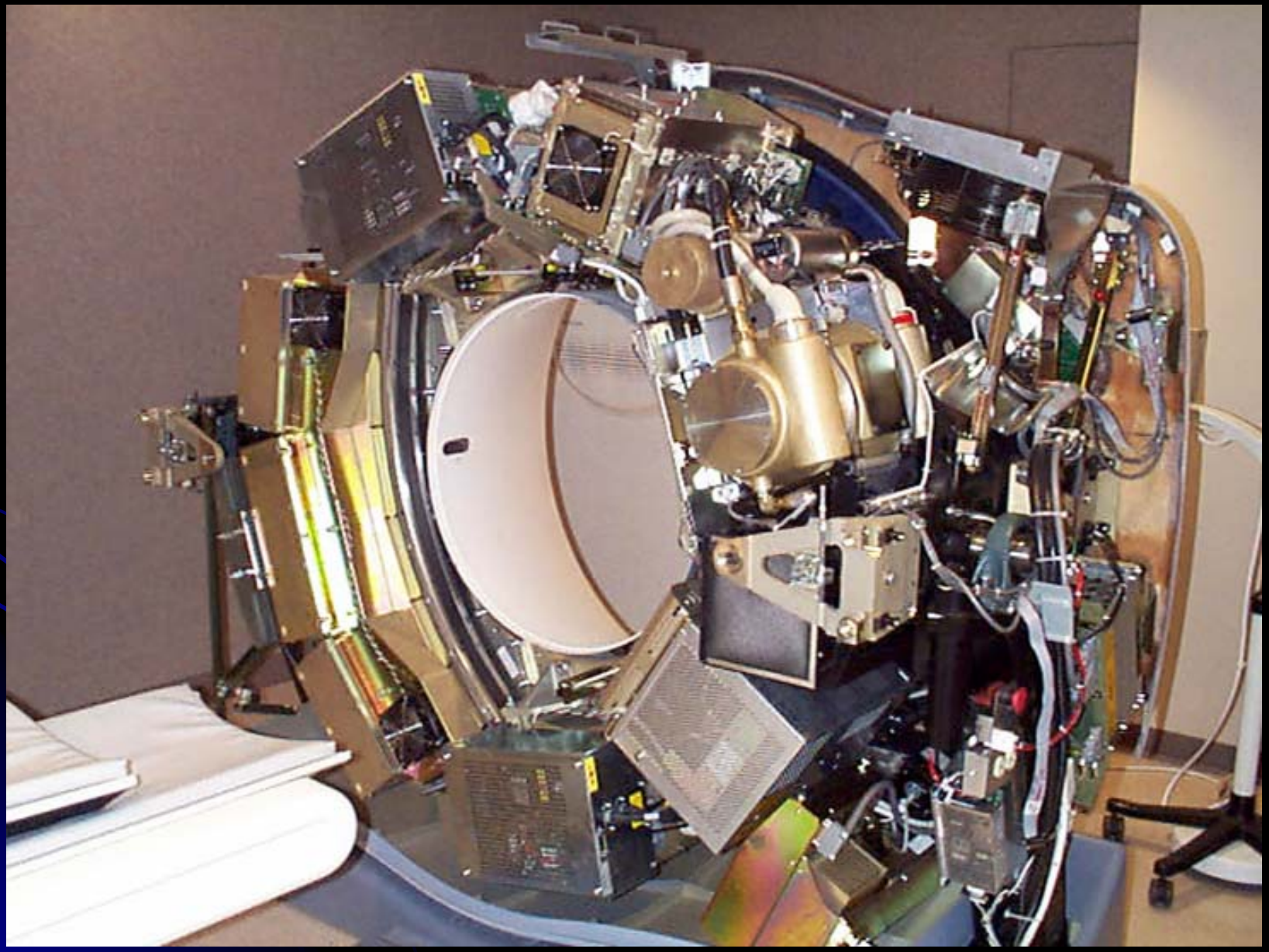
http://www.colorado.edu/physics/2000/index.pl

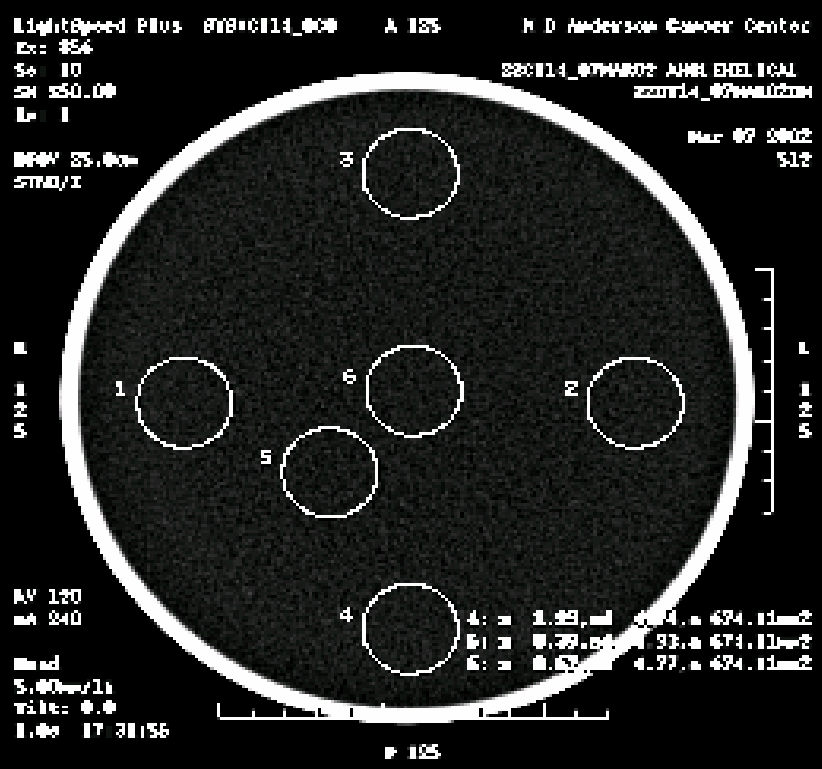
Example of a CT Image of Abdomen

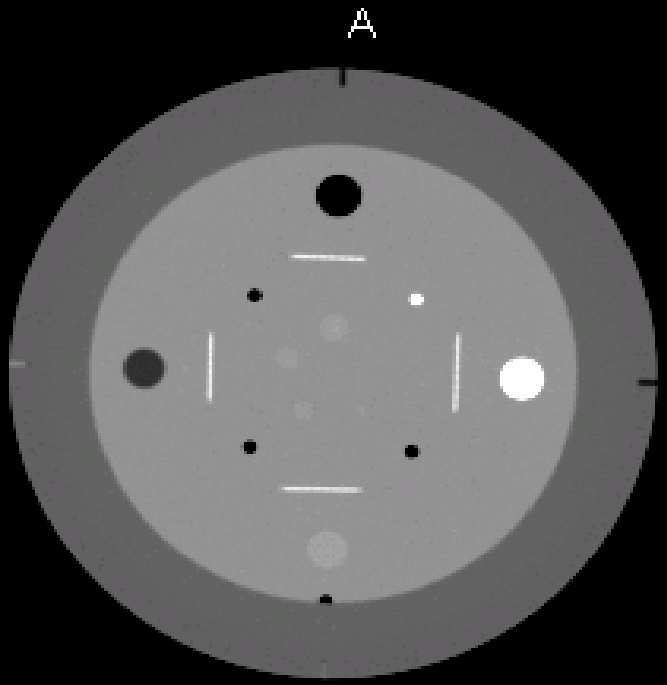
Axial image looking up from the feet.

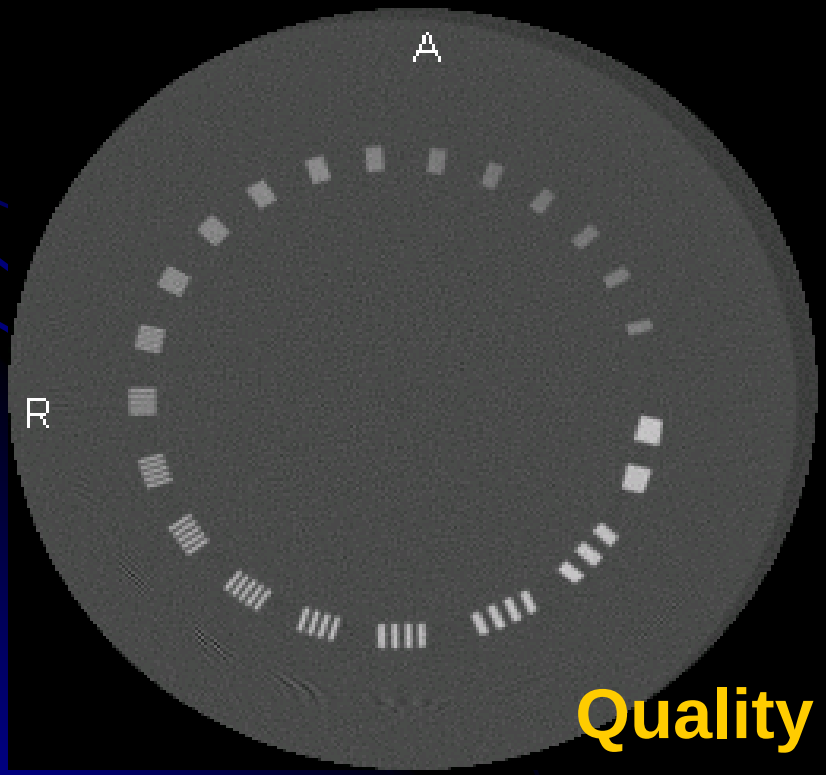
Liver metastasis from colon carcinoma

CT - Covers Off !!!





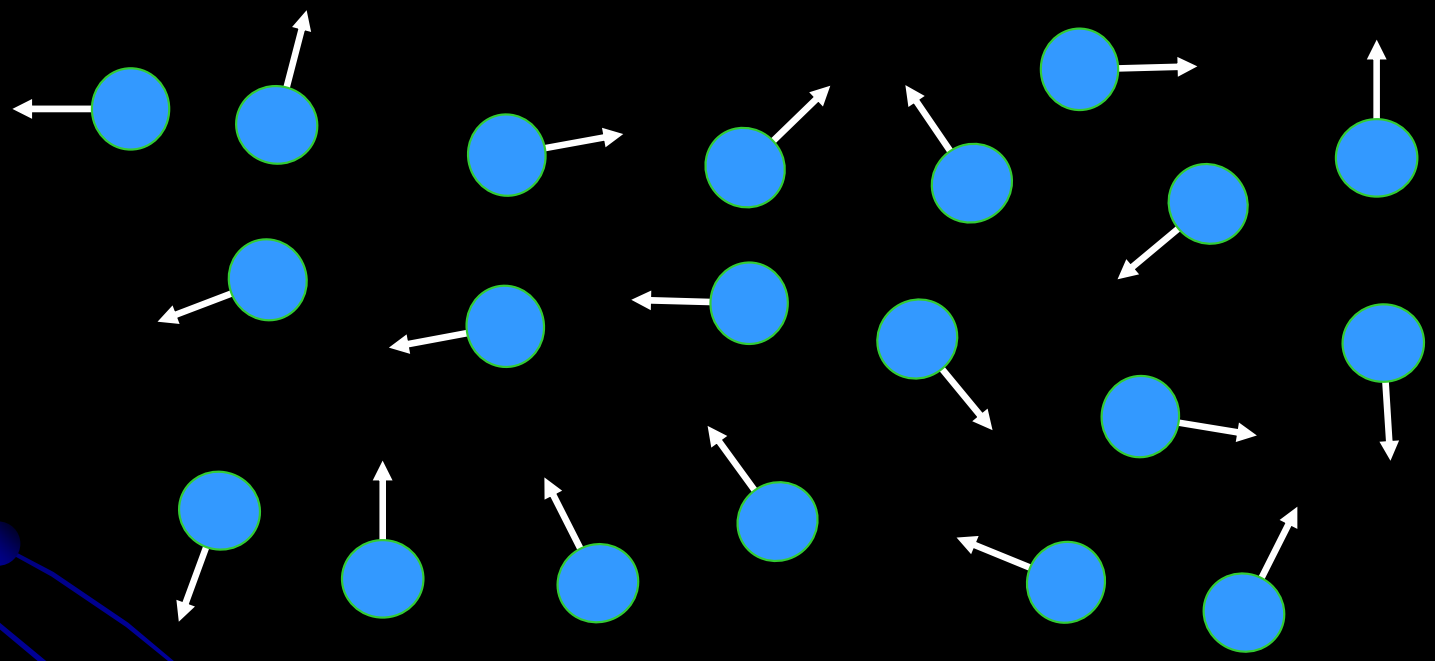




Quality Assurance of CT Scanner

Magnetic Resonance Imaging (MRI)

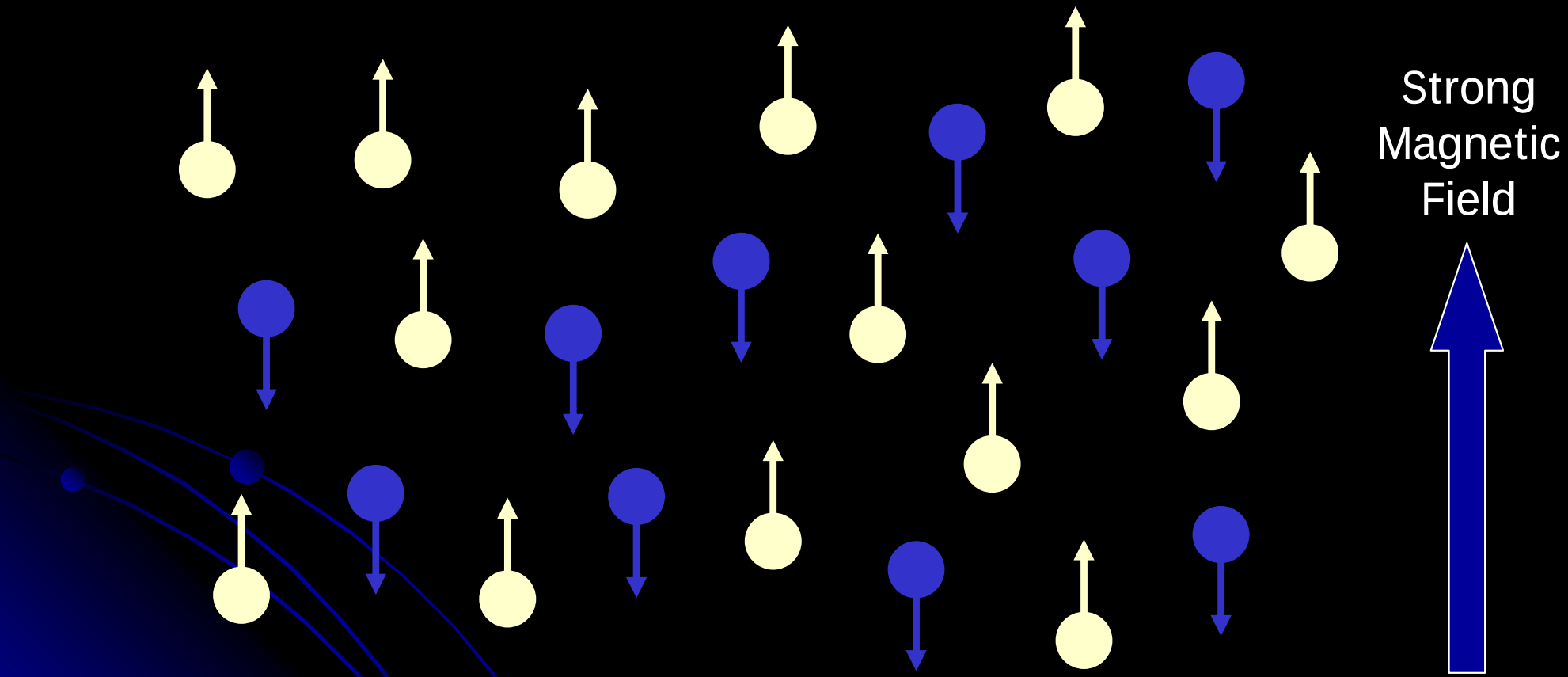
Zero External Magnetic Field



Point in random directions.

Magnetic Resonance Imaging (MRI)

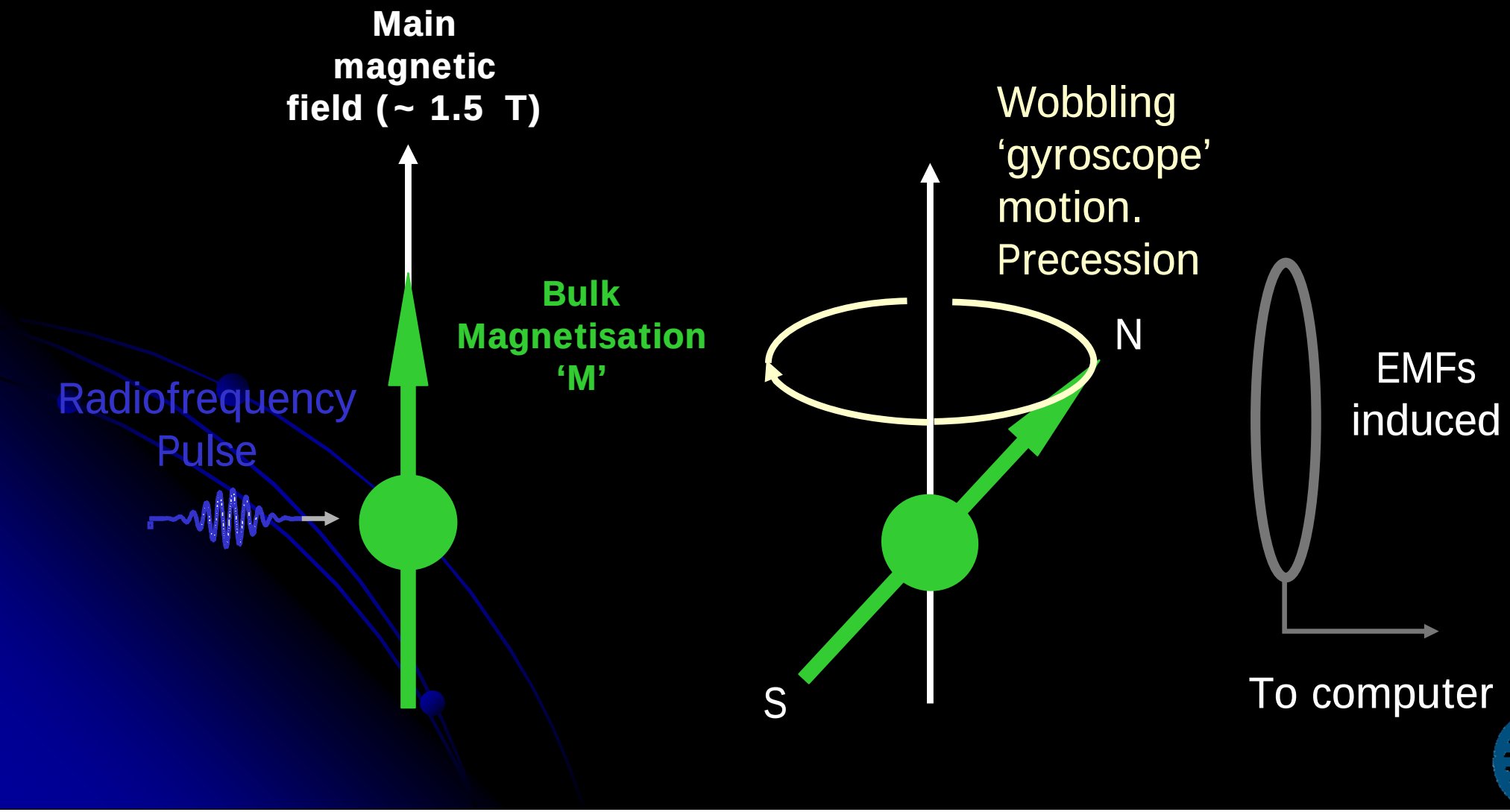
In Strong External Magnetic Field



Some line up. Some line down. Just the majority line up.
Out of 1 million ~ 500,002 UP – 499,998 DOWN.

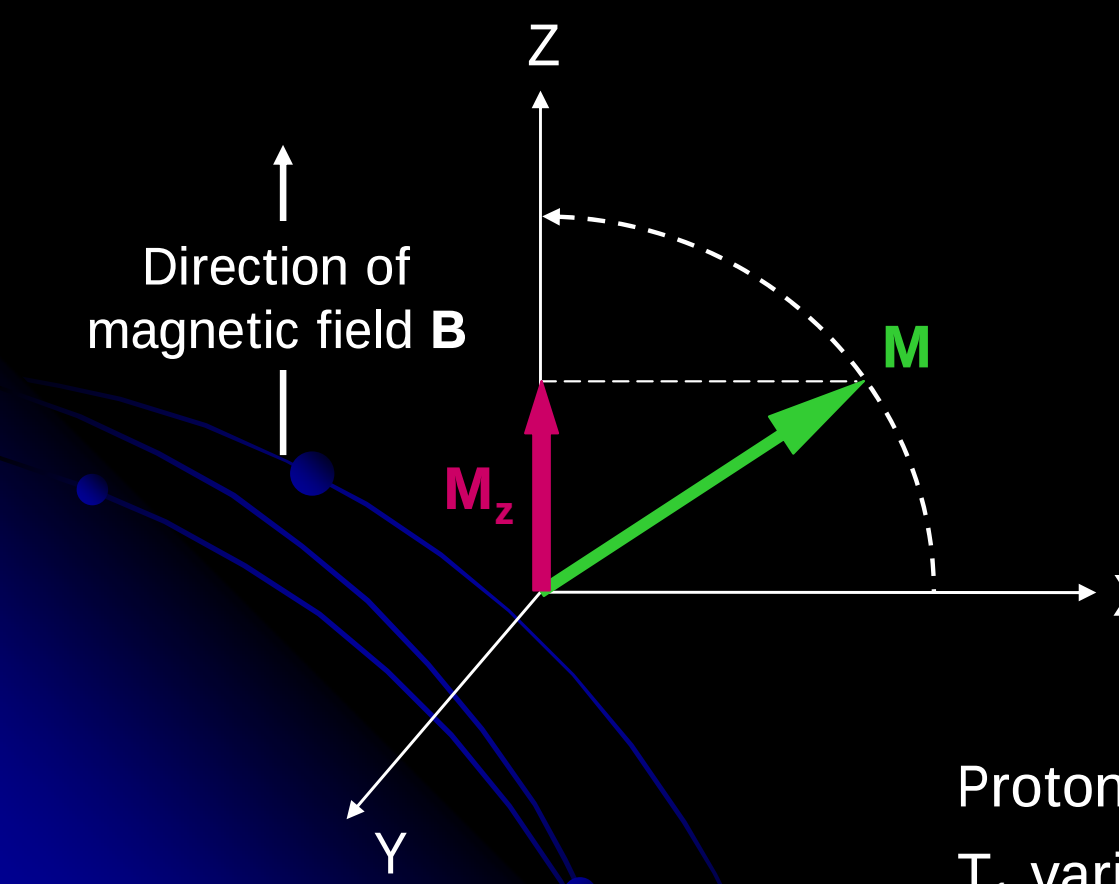
Magnetic Resonance Imaging (MRI)

Flipping Spins



Magnetic Resonance Imaging (MRI)

Nuclear Relaxation and Image Contrast



Spin-Lattice (or T_1) Relaxation.

Tipping back up of the bulk magnetisation (**M**). Re-aligns with **B**.

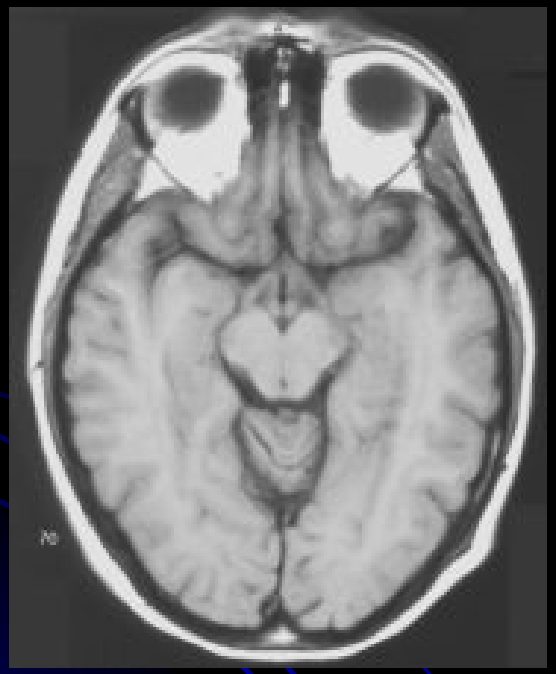
T_1 ~ 1 second for tissues.

Proton density variations < 10%

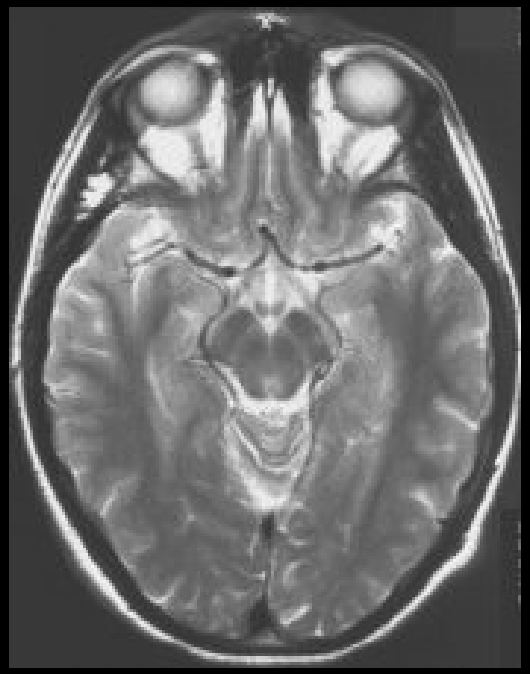
T_1 variations can be ~ 700%

Magnetic Resonance Imaging (MRI)

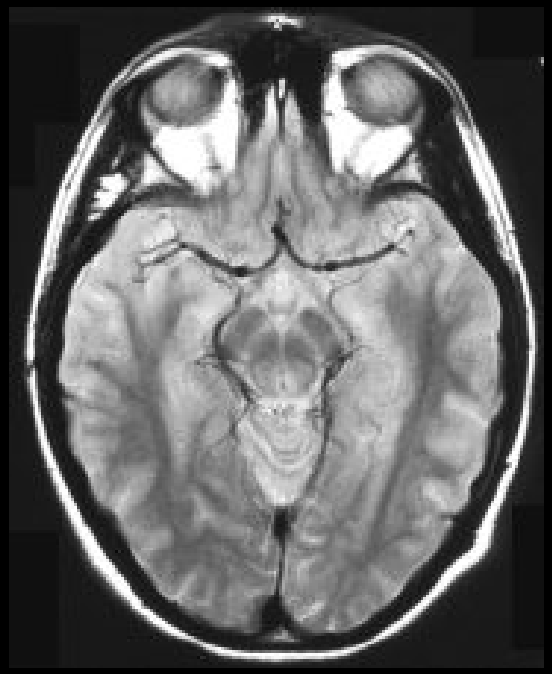
Axial Brain Images



T_1-weighted

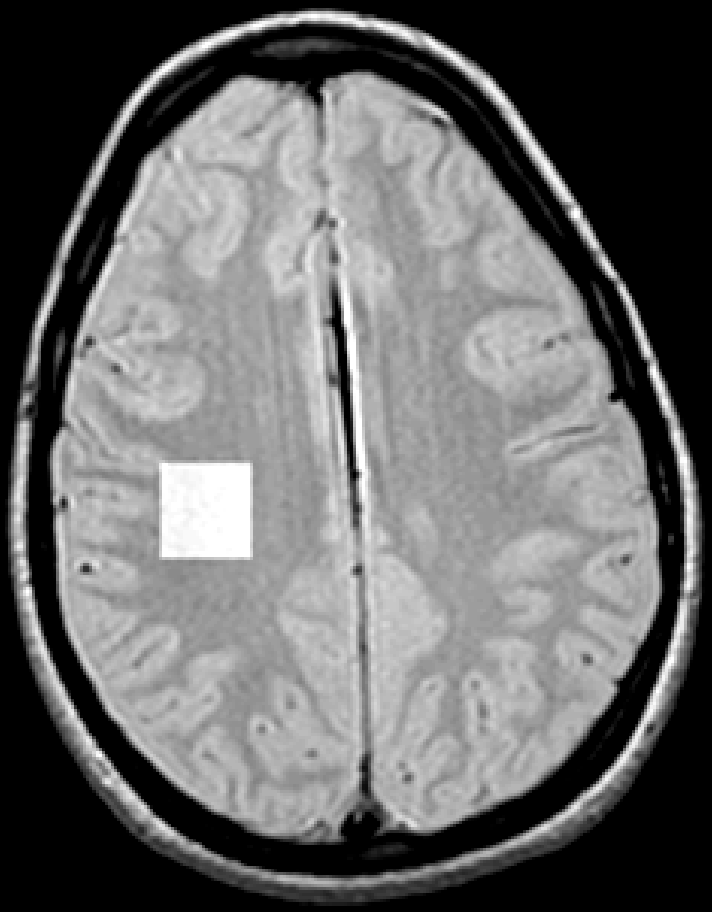


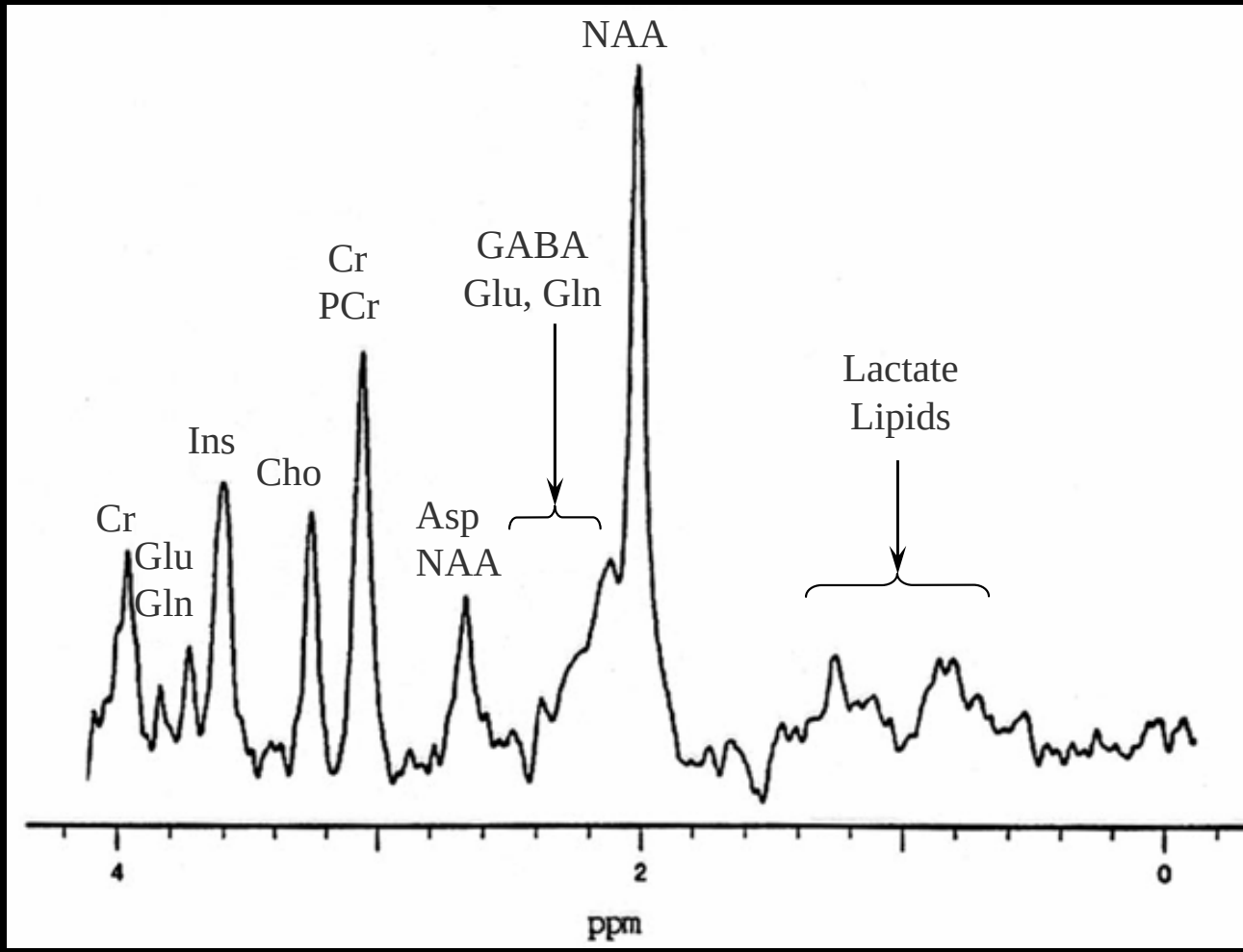
T_2-weighted



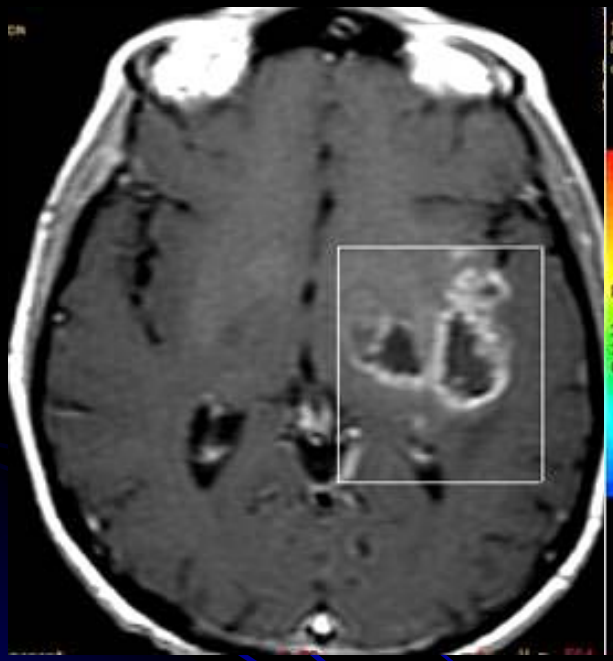
Proton density weighted

MR Spectroscopy

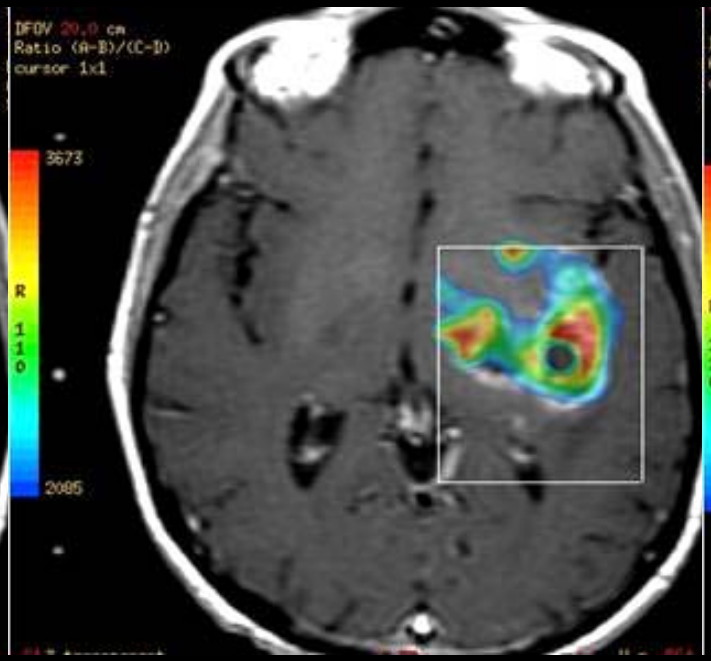




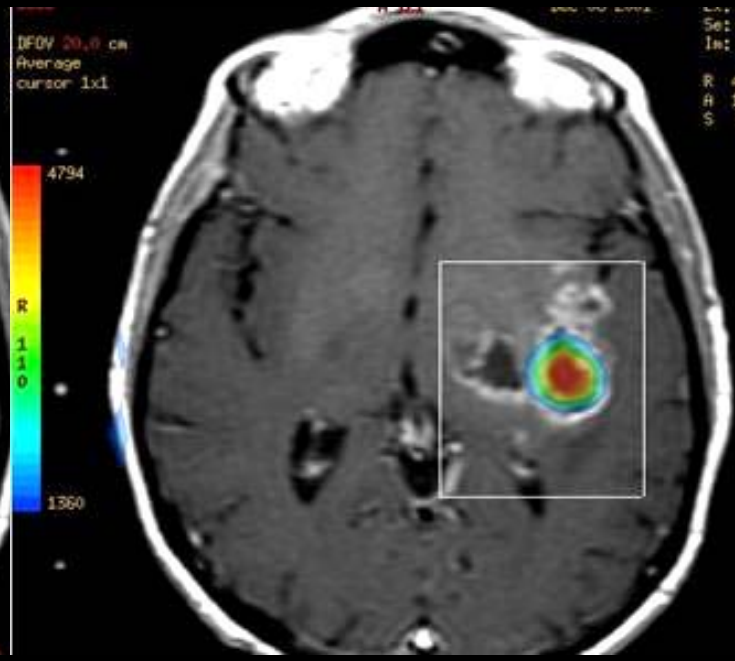
MR Spectroscopy



T1+C



Cho/Cr Map



Lipids

Medical Nuclear Physics

An Introduction

February 9, 2005, version 1.0

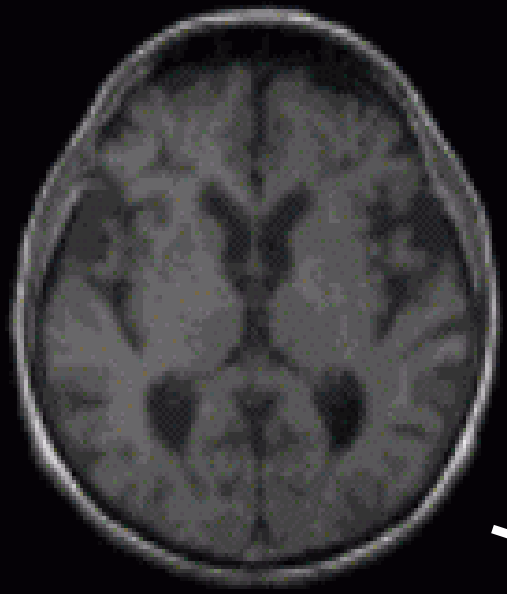
Medical Nuclear Physics

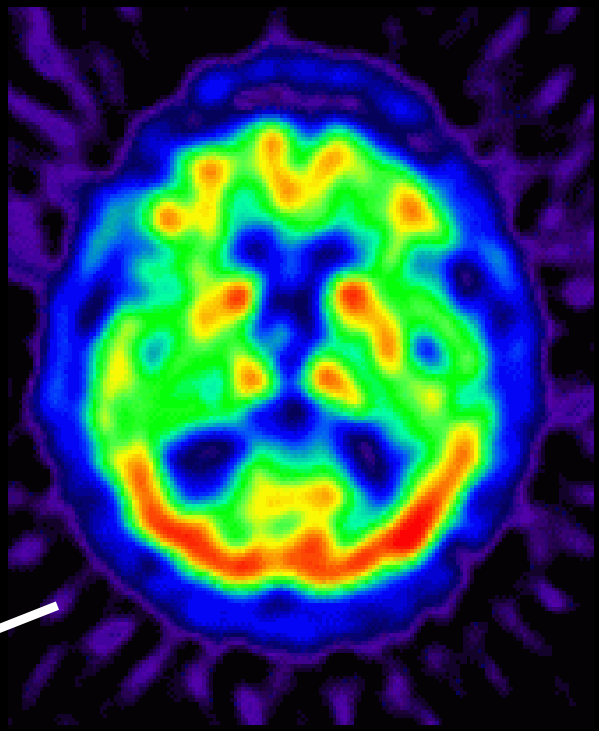
- Functional and morphological imaging
- Radionuclide therapies

Nuclear Medicine

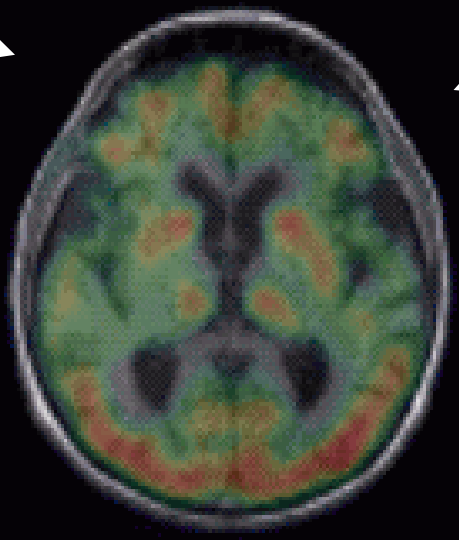
- Radioactive material attached to agent
  - Physical Half-life of radioactive material
  - Biological Half-life of radioactive material
  - $A_t = A_0 e^{-\lambda t}$
- Radiopharmaceutical administered to patient
- Wait for distribution
- Radioactivity yields images of function

Image Fusion: MRI and NMI





Fused slice



MRI (anatomy)

NMI (functional)

Positron Emission Tomography (PET)
β^+ Decay

Proton-rich radioisotopes e.g., ^{15}O, ^{11}C, ^{18}F

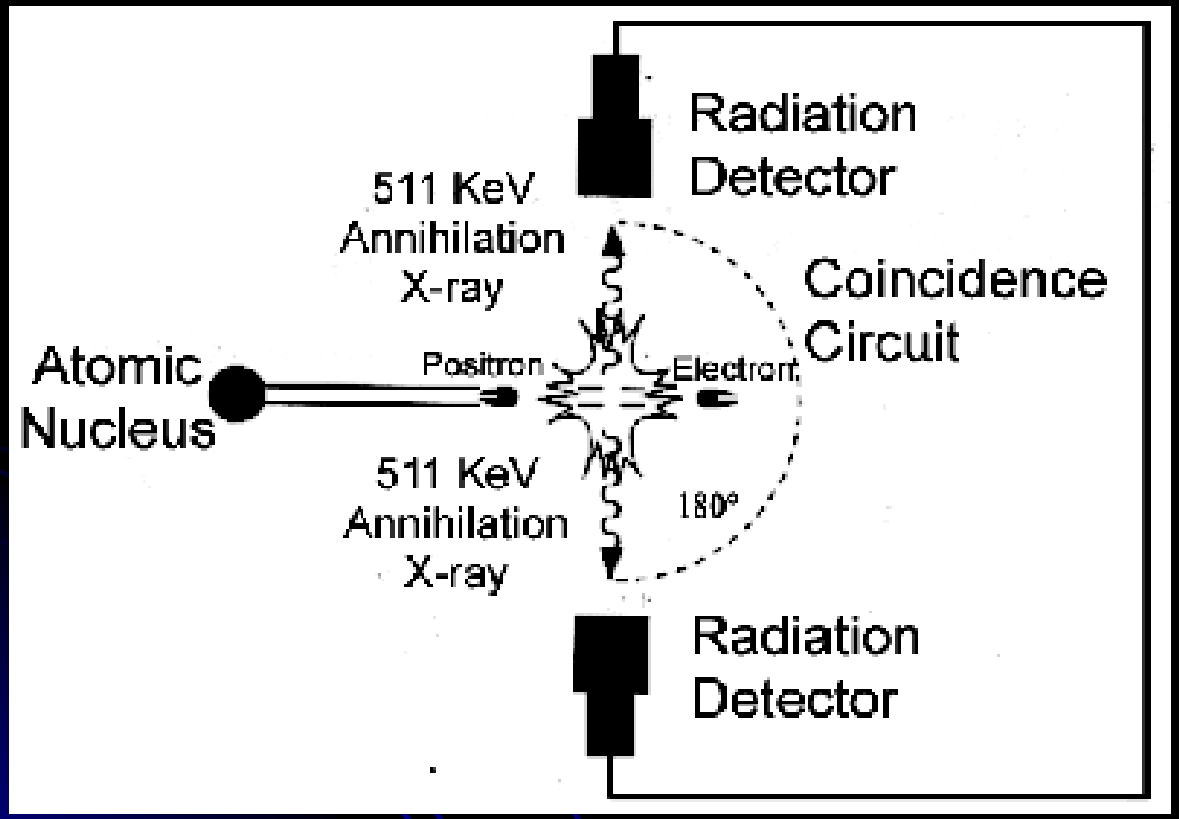
Produced by proton bombardment in a particle accelerator called a CYCLOTRON

Decay by: $p \rightarrow n \; e^+ \; \nu$

e^+ = positron. This is ANTI-MATTER.

^{18}F – ½ life ~ 110 minutes.
^{11}C – ½ life ~ 20 minutes. $\Rightarrow$ Get that cyclotron near the scanner!!
^{15}O – ½ life ~ 2 minutes!!

Positron Emission Tomography (PET)

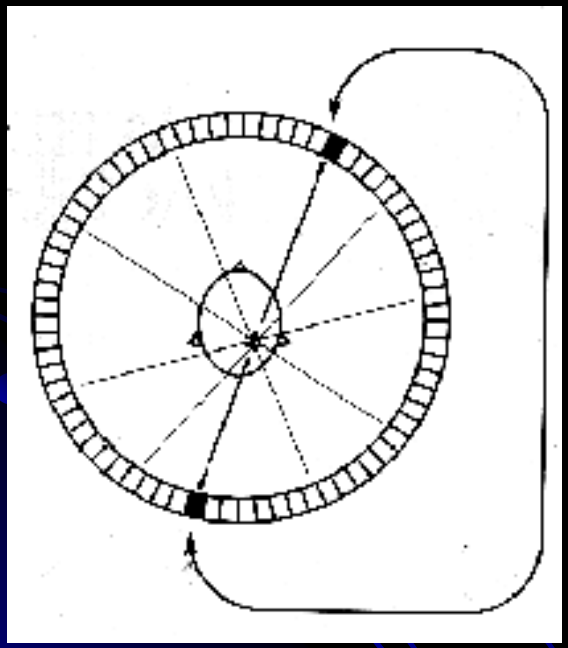


Rings of dense & segmented scintillation crystals (BGO) coupled to PMT's surround patient.

2 x 511 keV photons emitted back-to-back at annihilation.

~ 1mm

Positron Emission Tomography (PET)



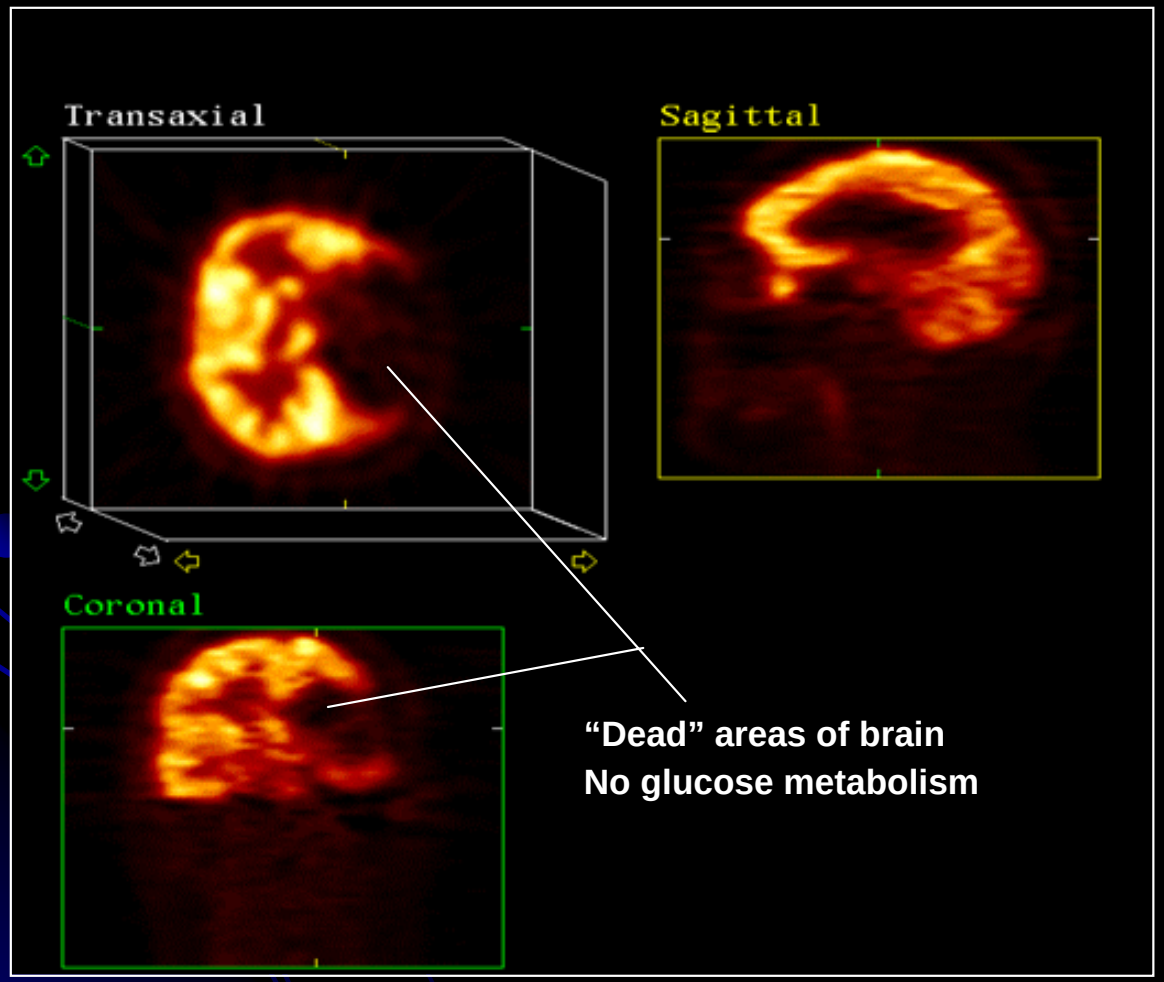
Determining LINE OF RESPONSE (LOR) :

- ☆ POSITION detecting of crystal.
- ☆ CO-INCIDENCE circuits determine if detector directly opposite detected same event (within ~ 2ns).
- ☆ ENERGY of photon determined.

Eliminates stray or scattered γ rays.

Image $\Rightarrow$ projection reconstruction along multiple LORs (like in CT).

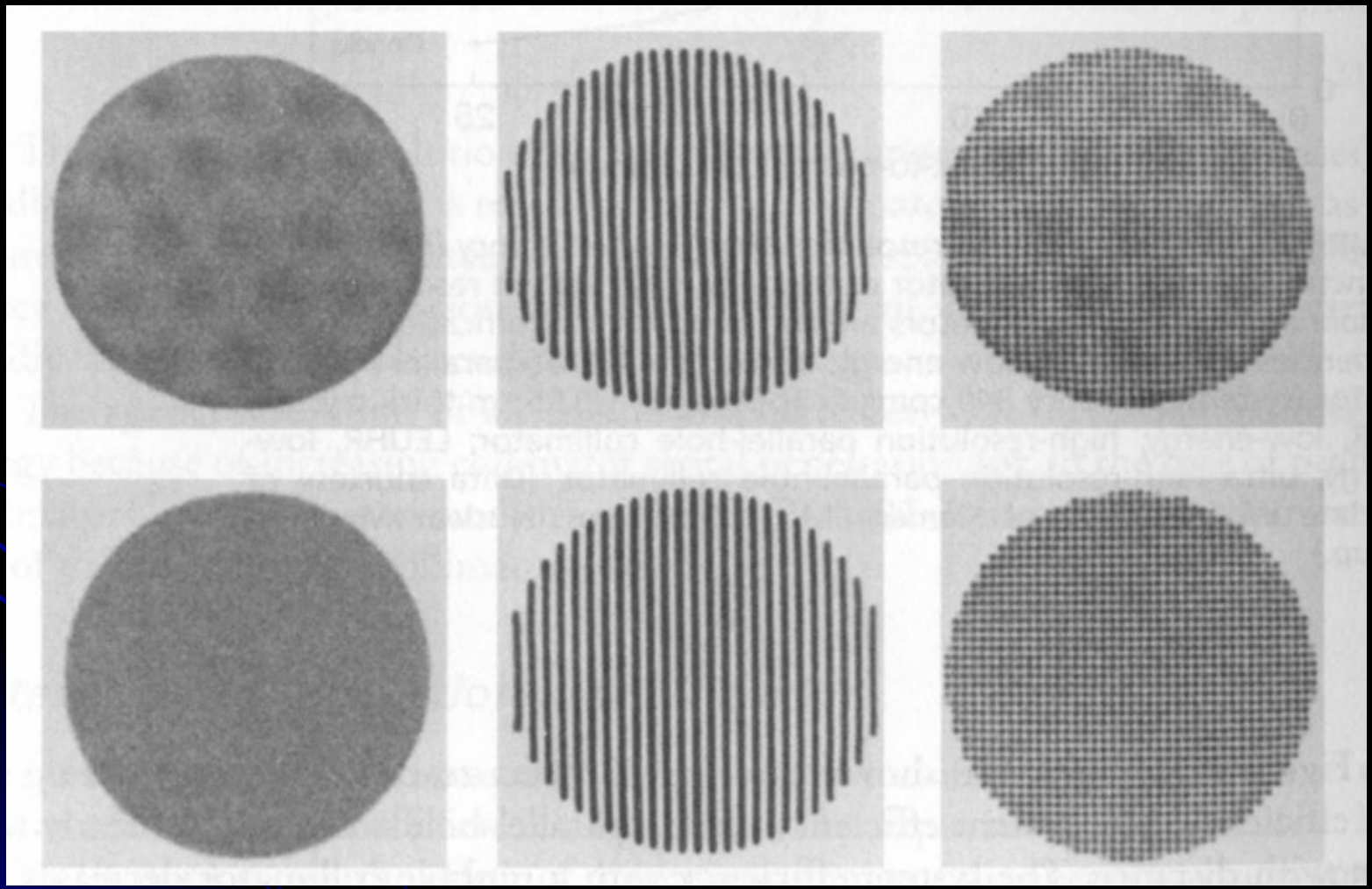
Image of Human Brain - Stroke



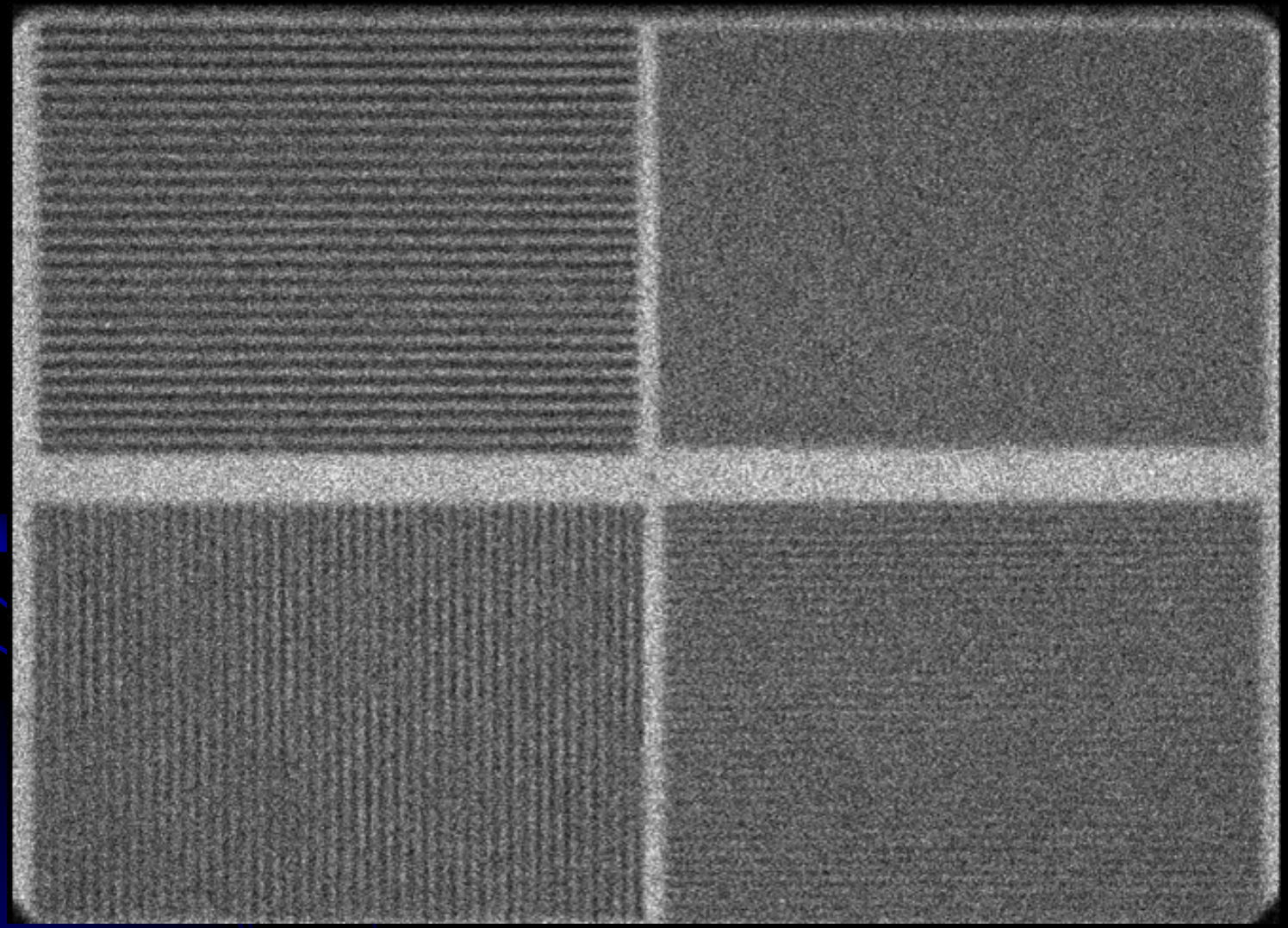
Glucose molecule labelled with Fluorine-18.

Intravenous administration.

Example of Quality Assurance Linearity Corrections



Nuclear Medicine QC Image



Medical Health Physics

An Introduction

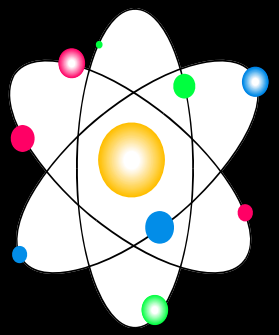
February 9, 2005, version 1.0

Radiation Doses and Dose Limits

Flight from Los Angeles to London	5 mrem
Annual public dose limit	100 mrem
Annual natural background	300 mrem
Fetal dose limit	500 mrem
Barium enema	870mrem
Annual radiation worker dose limit	5,000 mrem
Heart catheterization	45,000 mrem
Life saving actions guidance (NCRP-116)	50,000 mrem
Mild acute radiation syndrome	200,000 mrem
$LD_{50/60}$ for humans (bone marrow dose)	350,000 mrem
Radiation therapy (localized & fractionated)	6,000,000 mrem

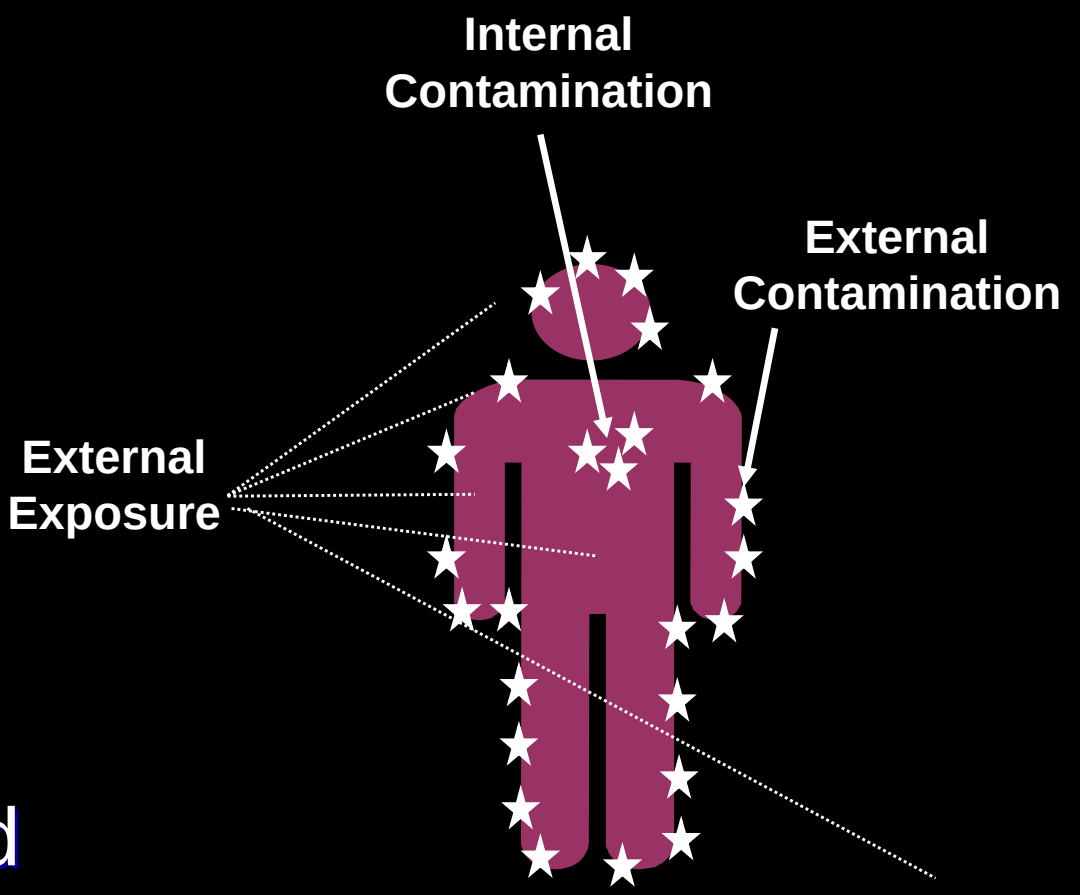
Radioactive Material

- *Radioactive material* consists of atoms with unstable nuclei
- The atoms spontaneously change (decay) to more stable forms and emit radiation
- A person who is *contaminated* has radioactive material on their skin or inside their body (e.g., inhalation, ingestion or wound contamination)



Types of Radiation Hazards

- ***External Exposure*** - whole-body or partial-body (no radiation hazard to EMS staff)
- ***Contaminated*** -
  - external radioactive material: on the skin
  - internal radioactive material: inhaled, swallowed, absorbed through skin or wounds



Causes of Radiation Exposure/Contamination

- **Accidents**
  - Nuclear reactor
  - Medical radiation therapy
  - Industrial irradiator
  - Lost/stolen medical or industrial radioactive sources
  - Transportation
- **Terrorist Event**
  - Radiological dispersal device (dirty bomb)
  - Low yield nuclear weapon

Example: Facility Preparation

- Activate hospital plan
  - Obtain radiation survey meters
  - Call for additional support: Staff from Nuclear Medicine, Radiation Oncology, Radiation Safety (Health Physics)
  - Plan for decontamination of uninjured persons
  - Establish triage area
- Plan to control contamination
  - Instruct staff to use universal precautions and double glove
  - Establish multiple receptacles for contaminated waste
  - Protect floor with covering if time allows

Example: Patient Management - Triage

Triage based on:

- Injuries
- Signs and symptoms - nausea, vomiting, fatigue, diarrhea
- History - Where were you when the bomb exploded?
- Contamination survey

Example: Facility Recovery

- Remove waste from the Emergency Department and triage area
- Survey facility for contamination
- Decontaminate as necessary
  - Normal cleaning routines (mop, strip waxed floors) typically very effective
  - Periodically reassess contamination
  - Replace furniture, floor tiles, etc. tha be adequately decontaminated

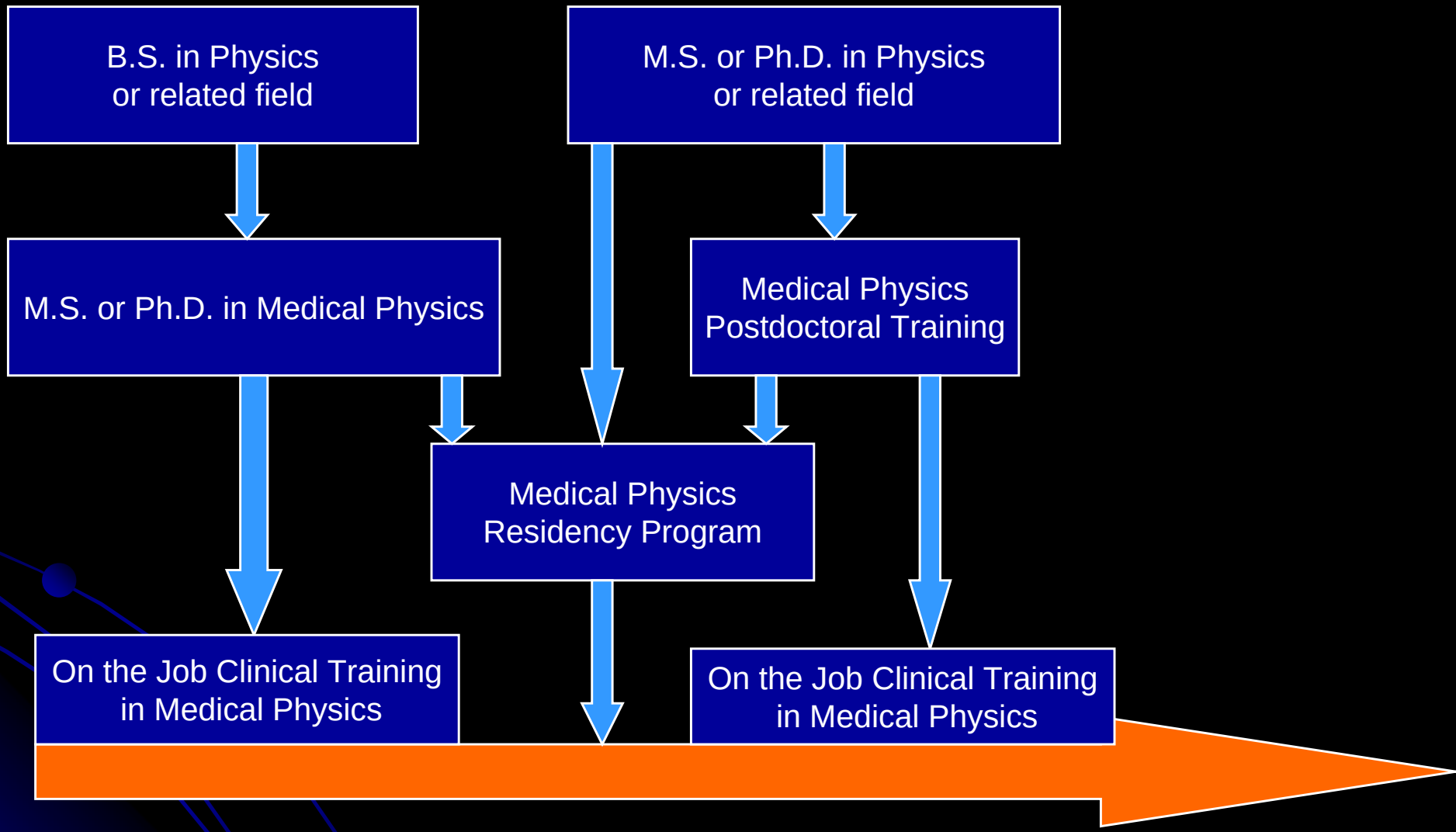
- Decontamination Goal: Less than twice normal background…higher levels may be acceptable

Educational Opportunities

Professional Training

- Academic Training
  - MS or PhD in medical physics, or
  - MS or PhD in physics or related discipline with post-graduate academic training in medical physics.
- Clinical Training
  - Residency in clinical medical physics, and/or
  - Supervised on-the-job training in clinical medical physics.

Pathways into Medical Physics



Practicing Medical Physicists

Contributed By: Dong (MD Anderson)

Example Graduate Program Requirements
(Univ. of Texas Graduate School of Biomedical Sciences, Houston)

- M.S. Program
  - 34 semester hours of didactic curricula
  - Diagnostic imaging physics clinical rotation
  - Radiation therapy physics clinical rotation
  - Thesis
- Ph.D. Program
  - M.S. Program requirements
  - 3 Research tutorials
  - Oral candidacy exam
  - Dissertation

Contributed By: Hogstrom (MD Anderson)

Example Medical Physics Curricula
(Univ. of Texas Graduate School of Biomedical Sciences, Houston)

Required Courses

- Mathematics for Medical Physics
- Electronics for Medical Physicists
- Radiation Detection, Instrumentation, and Data Analysis
- Intro Med Phys I: Basic Interactions
- Intro Med Phys II: Medical Imaging
- Intro Med Phys III: Therapy
- Intro Med Phys IV: Nuclear Medicine
- Medical Physics Seminars (3)

Contributed By: Hogstrom (MD Anderson)

Example Medical Physics Curricula
(Univ. of Texas Graduate School of Biomedical Sciences, Houston)

- Radiation Biology
- Radiation Protection
- Anatomy and Oncology for Medical Physicists
- Introductory Biochemistry (Ph.D. only)
- Ethical Dimensions of the Biomedical Sciences

<u>Electives</u>

- Physics and Applications of Electron Beam Transport
- Commissioning and QA of RT Planning Systems
- Digital Processing of Biomedical Images
- Principles of Magnetic Resonance Imaging
- Physics of Positron Emission Tomography

Contributed By: Hogstrom (MD Anderson)

CAMPEP-Accredited Graduate Education Programs

As of July 2003, there were 9 accredited programs:

- McGill University - Montreal
- University of Florida
- University of California - Los Angeles
- University of Kentucky Medical Center
- University of Oklahoma HSC
- University of Texas HSC - Houston
- University of Texas HSC - San Antonio
- University of Wisconsin
- Wayne State University

[For more info contact AAPM @ www.aapm.org or (301) 209-3350]

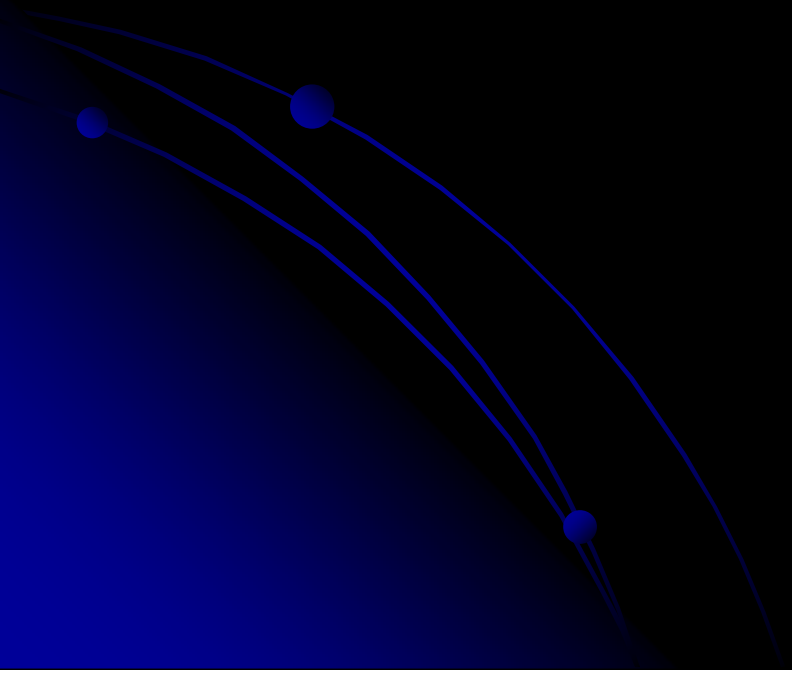
CAMPEP-Accredited Residency Education Programs

As of July 2003, there were 5 accredited programs:

- Radiation Therapy Physics
  - Fairview University Medical Center (Minneapolis)
  - McGill University (Montreal)
  - University of Florida (Gainesville)
  - Washington University School of Medicine (St. Louis)
- Diagnostic Imaging Physics
  - The University of Texas M. D. Anderson Cancer Center (Houston)

[For more info contact AAPM @ www.aapm.org or (301) 209-3350]

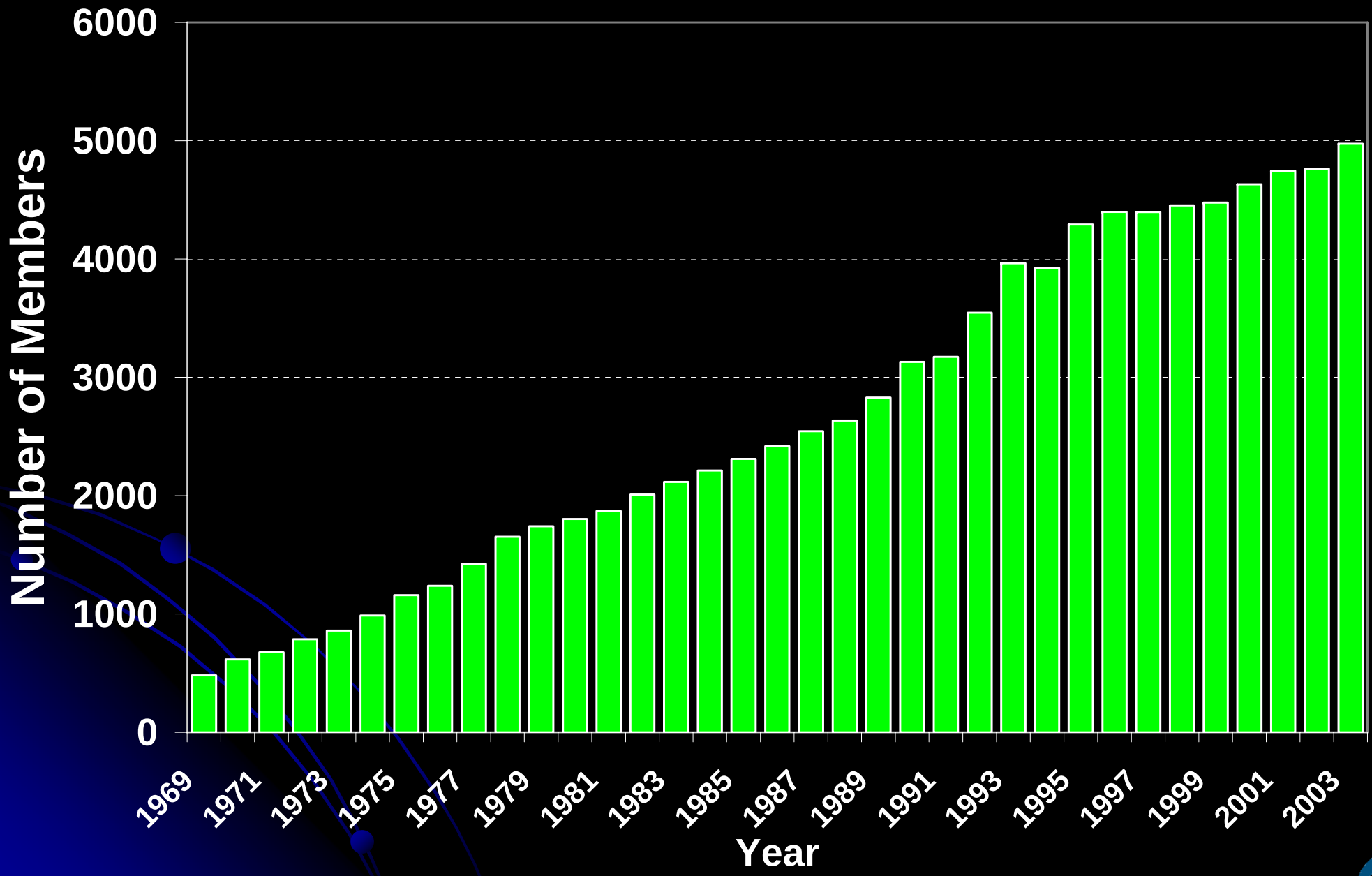
Professional Issues



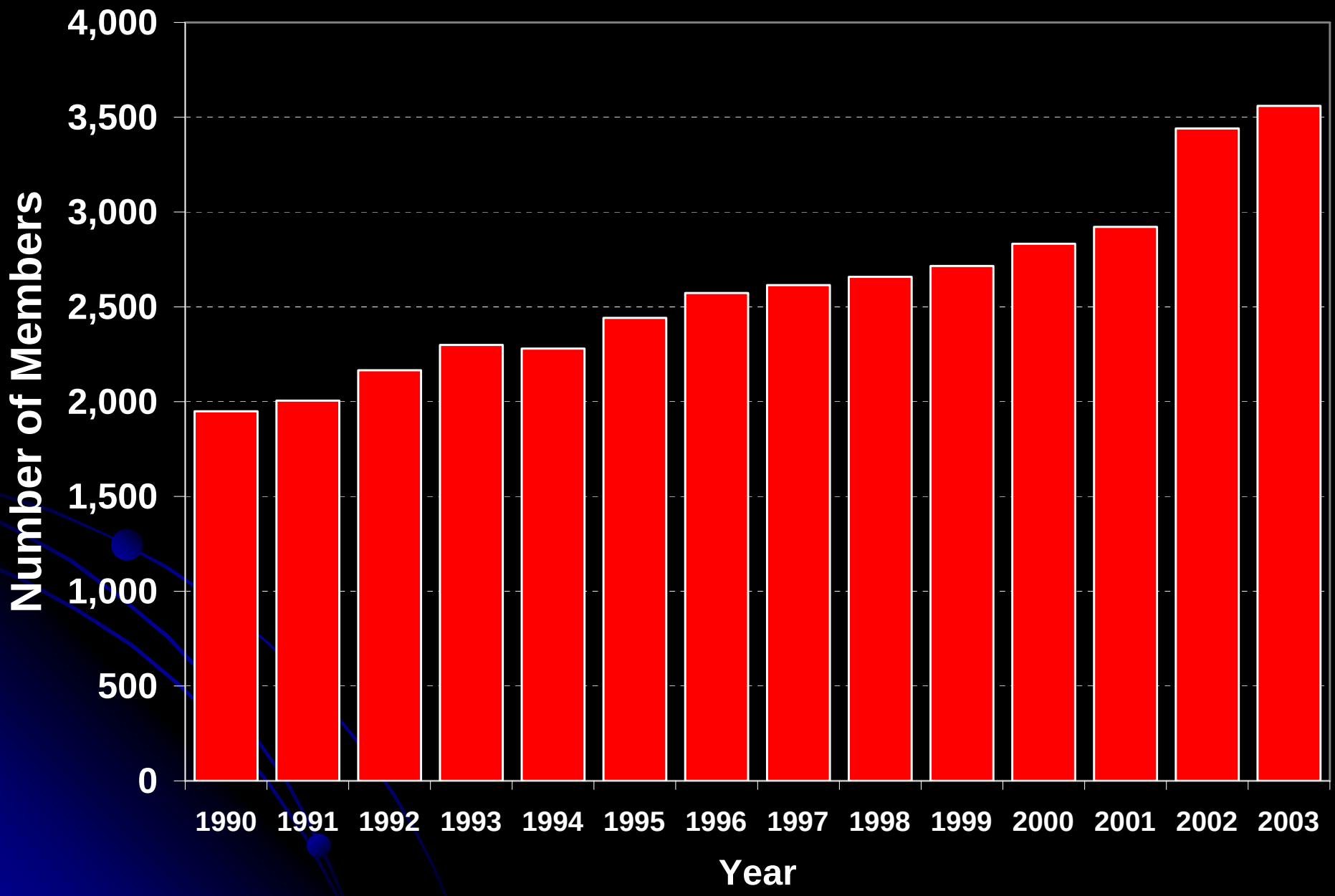
American Association of Physicists in Medicine (AAPM) Mission Statement

- To advance the practice of physics in medicine and biology by encouraging innovative research and development, disseminating scientific and technical information, fostering the education and professional development of medical physicists, and promoting the highest quality of medical services for patients.

Total AAPM Membership



Recent Full Members



Professional Credentials of Medical Physicists

- Education: M.S. (51%) or Ph.D. (49%) in medical physics, physics, nuclear engineering, or related discipline
- Certification: By specialty
- Licensure: State licensure or registration
- Hospital Credentials: Procedure specific privileges

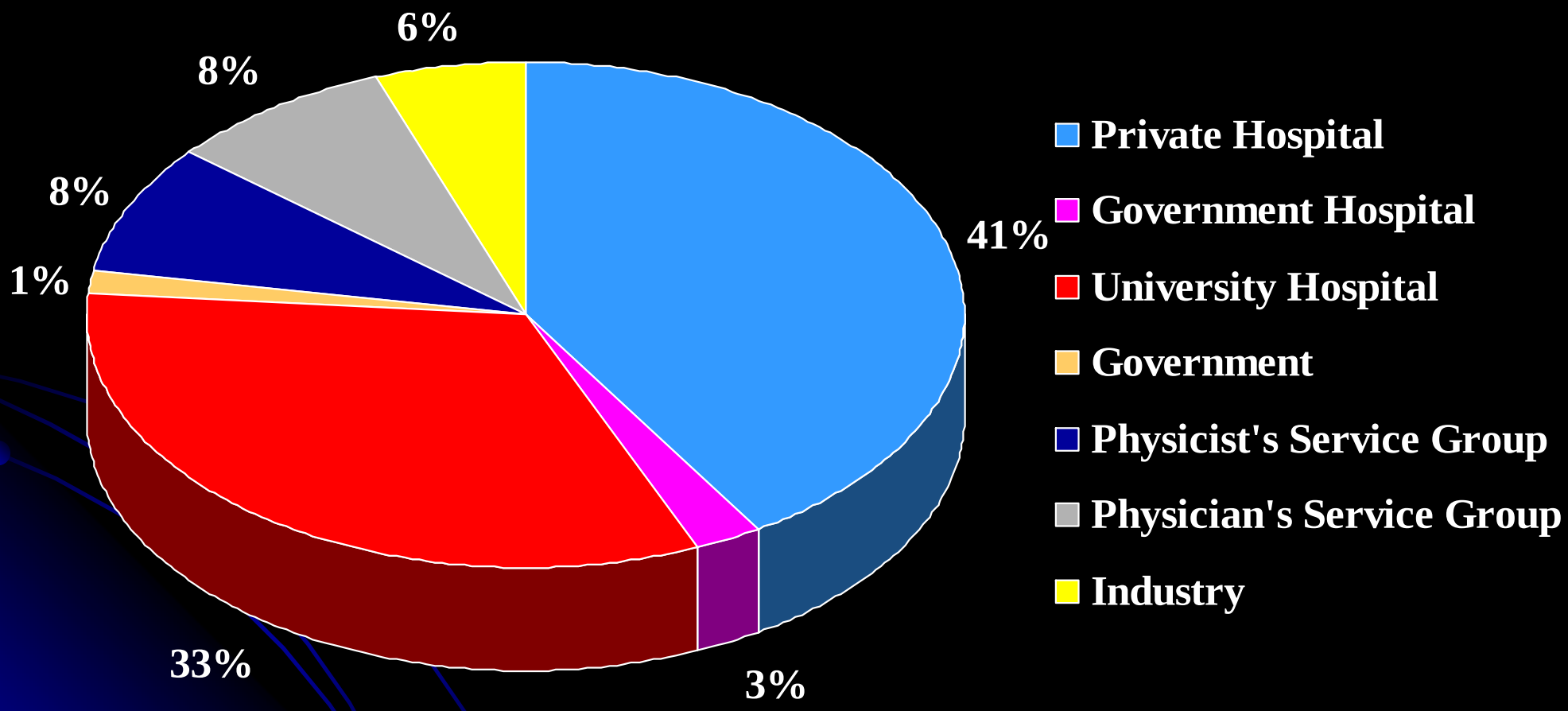
Professional Credentials

- Board Certifications
  - American Board of Radiology
  - American Board of Medical Physics
- Licensure and Registration
  - Texas (first in 1992), Florida, New York, and Hawaii
  - Licensure being pursued in California, and nationally
  - Many states require board certifications
  - Many states require registration
- Professional Society Memberships

Professional Societies

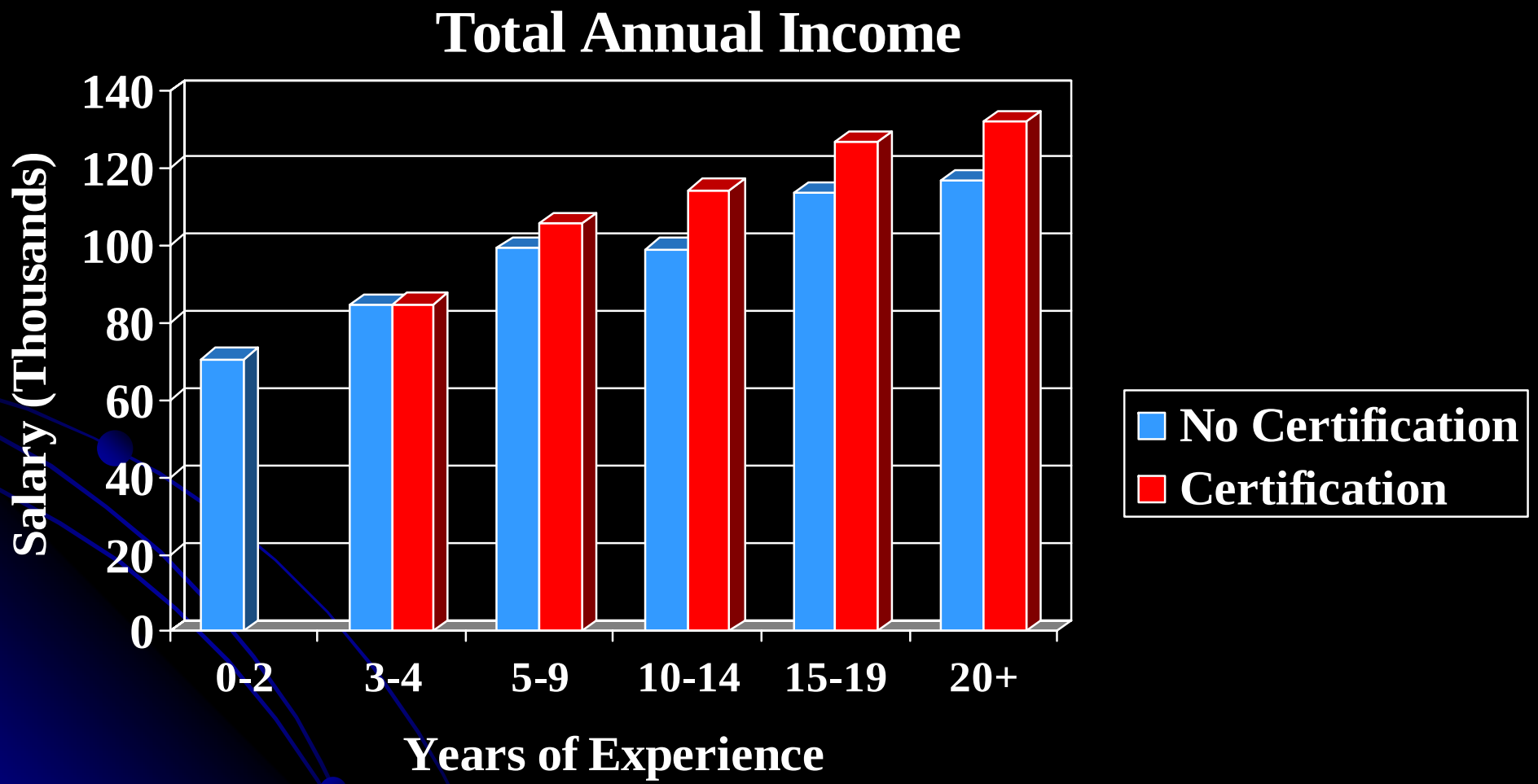
- Medical Physics Professional Societies
  - American Association of Physicists in Medicine
  - American College of Medical Physics
- Sister-Professional Societies
  - American Society of Therapeutic Radiology & Oncology
  - Radiological Society of North America
  - American College of Radiology
  - Society of Nuclear Medicine
  - International Society for Magnetic Resonance in Medicine
  - American Brachytherapy Society
  - Health Physics Society
  - …

Where are Medical Physicist's Primary Employment?



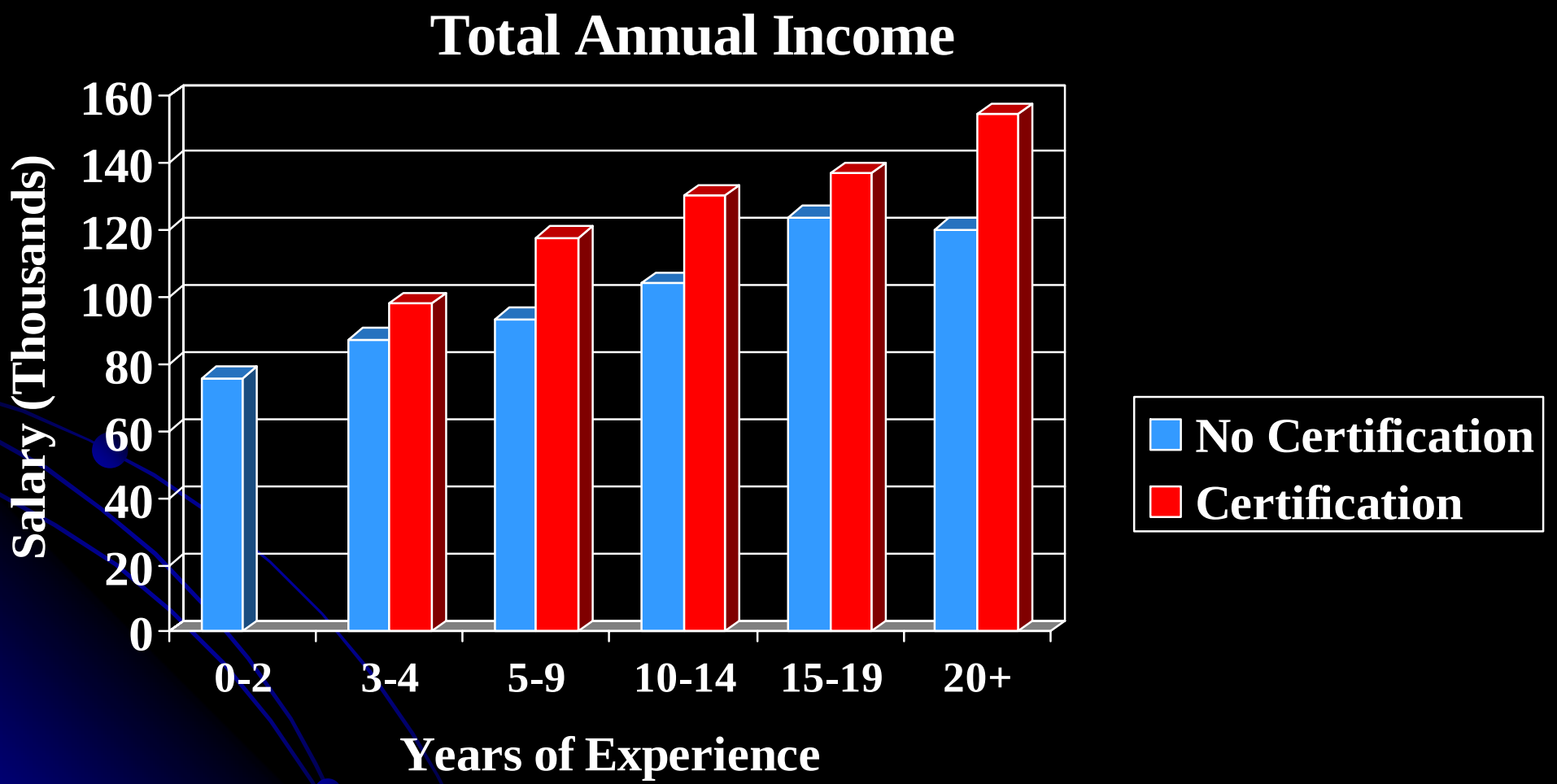
Source: 2002 AAPM Survey

Average Income (MS Degree)



Source: 2002 AAPM Survey

Average Income (PhD Degree)



Source: 2002 AAPM Survey

For More Information

http://www.aapm.org

American Association of Physicists in Medicine (AAPM) Public Education Committee 2003

February 9, 2005, version 2.0