Radiation Safety Institute of Canada
Institut de radioprotection du Canada

May 13, 2021

Radiation Safety Issues in PET/CT

Followed by Salem Dance Company

Good Science in Plain Language®

Webinar Functionality

- Audio and video
  - Will be from the presenters only
  - Use computer or telephone (call in)
  - Computer seems to give the best sound quality
- Use the “Chat” feature to enter comments
- Use the “Questions” feature to ask questions
- Posted on webinar page
  - Video, Q&A answers, copy of the slides
- Follow up email will be sent
  - Topics covered, time of attendance
- It may be possible to change your Zoom view if the controls are hiding the closed captioning.

Overview

- What is ionizing radiation?
  - Beta/positron
  - X-ray
  - Gamma
- Regulation of ionizing radiation
- What is PET/CT?
- Dose
- Resources for Radiation Protection for PET/CT
- Canada Safe Imaging

Radiation Safety Institute of Canada
Institut de radioprotection du Canada

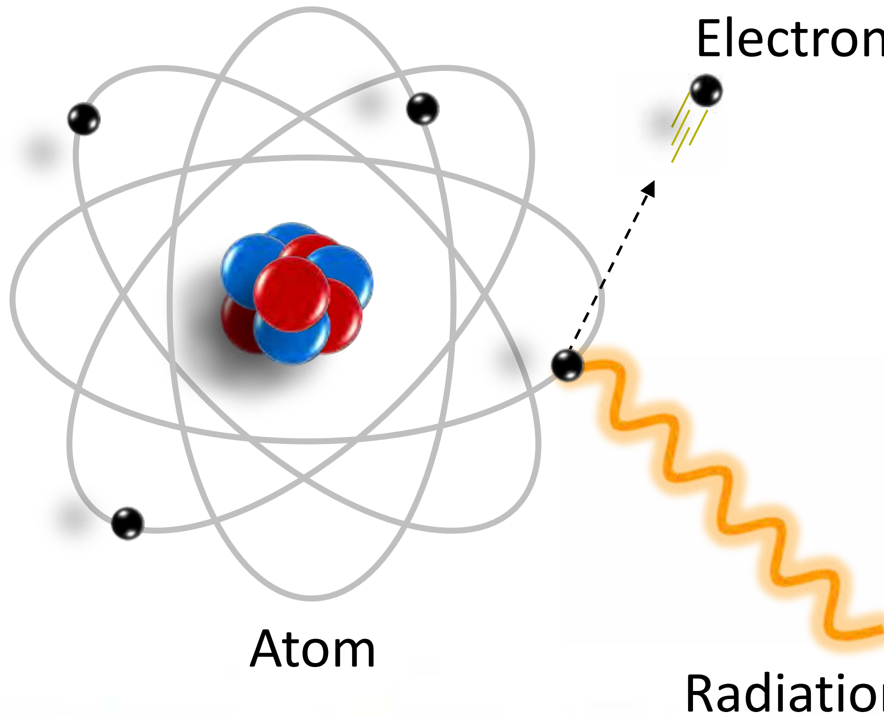
Radiation and Energy

- Radiation can be interpreted as a form of energy.
- Radiation will interact differently with matter depending upon how much energy it has.

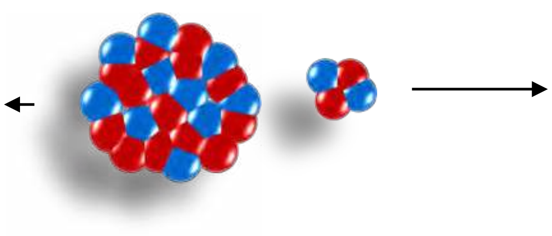
Ionizing Radiation

When radiation strikes matter, it interacts with the atoms of the matter.

Radiation with enough energy can knock **electrons** out of orbit from the atoms it strikes.

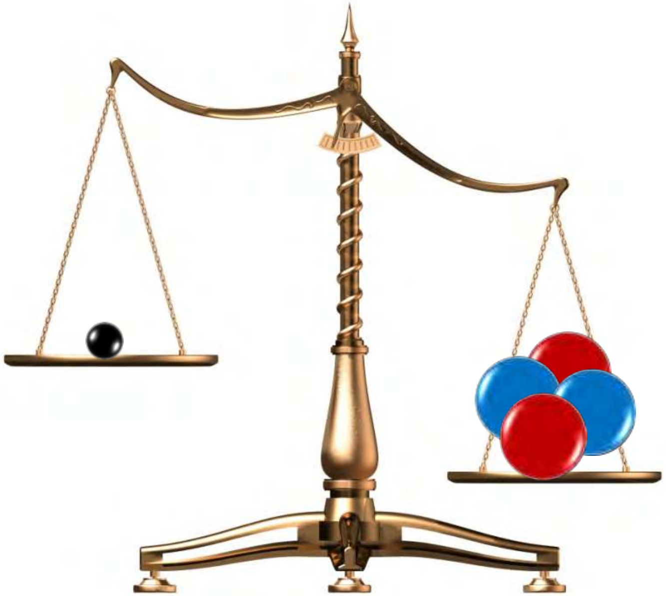


Where does ionizing radiation come from?

Radioactive atoms	Man-made devices
	

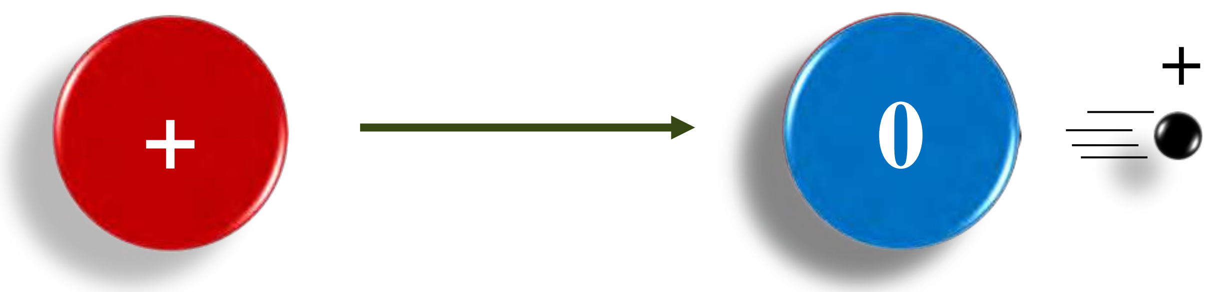
Beta Radiation

- Electrons or positrons.
  - Emitted from the nucleus of a radioactive atom.
  - Positrons –
  - Electrons +
- Very small mass.
  - Approximately 2,000 times smaller than proton or neutron.



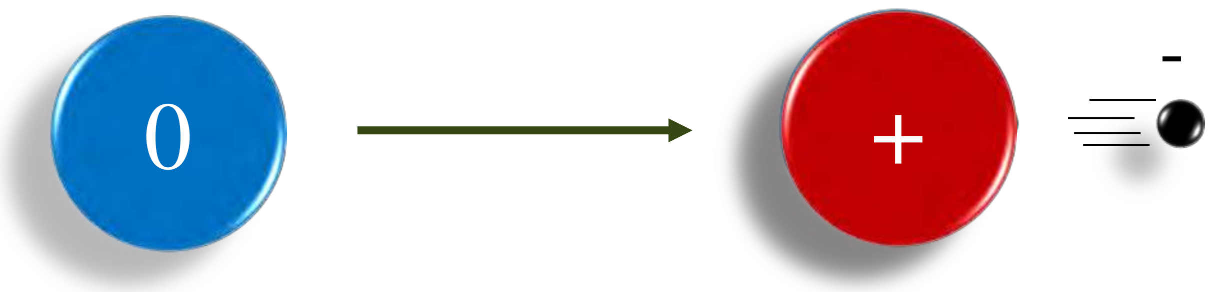
Beta Radiation

Beta particles are emitted from the nucleus of a radioactive atom when a **proton** transforms into a **neutron**…



Positron Emission

…Or when a **neutron** transforms into a **proton**.



Negative Beta Emission

PET Radiopharmaceuticals

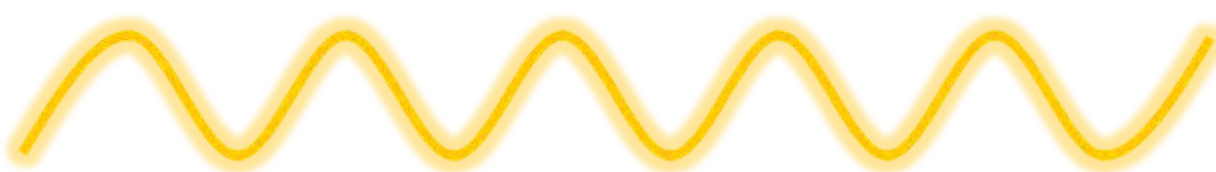
Nuclide	Half-life	Tracer	Application
O-15	2 mins	Water	Cerebral blood flow
C-11	20 mins	Methionine	Tumour protein synthesis
N-13	10 mins	Ammonia	Myocardial blood flow
F-18	110 mins	FDG	Glucose metabolism
Ga-68	68 min	DOTANOC	Neuroendocrine imaging
Rb-82	72 secs	Rb-82	Myocardial perfusion

IAEA

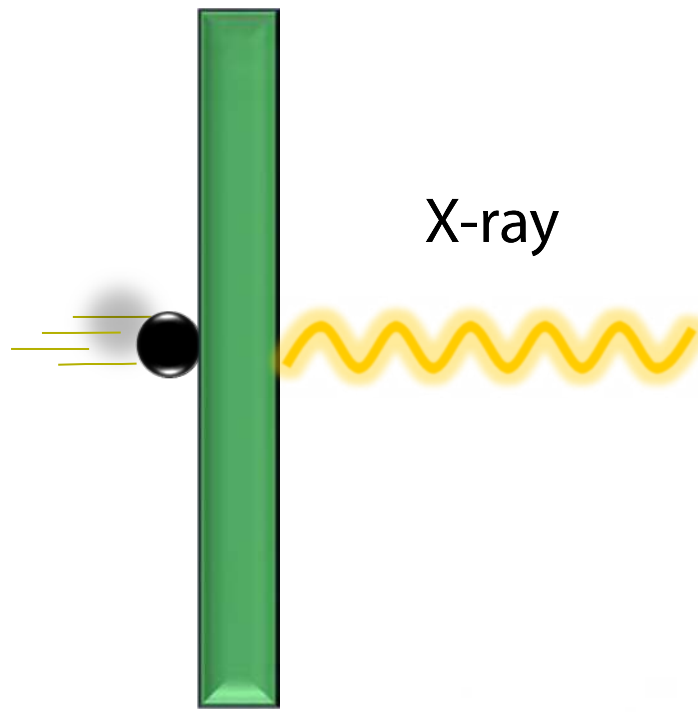
Bremsstrahlung Radiation

- When beta particles pass through matter, x-rays can be produced.
  - This is called bremsstrahlung, meaning “braking radiation”
- The higher the atomic number, the more bremsstrahlung produced.

Gamma Radiation



X-Rays



Radiation Penetrating Power

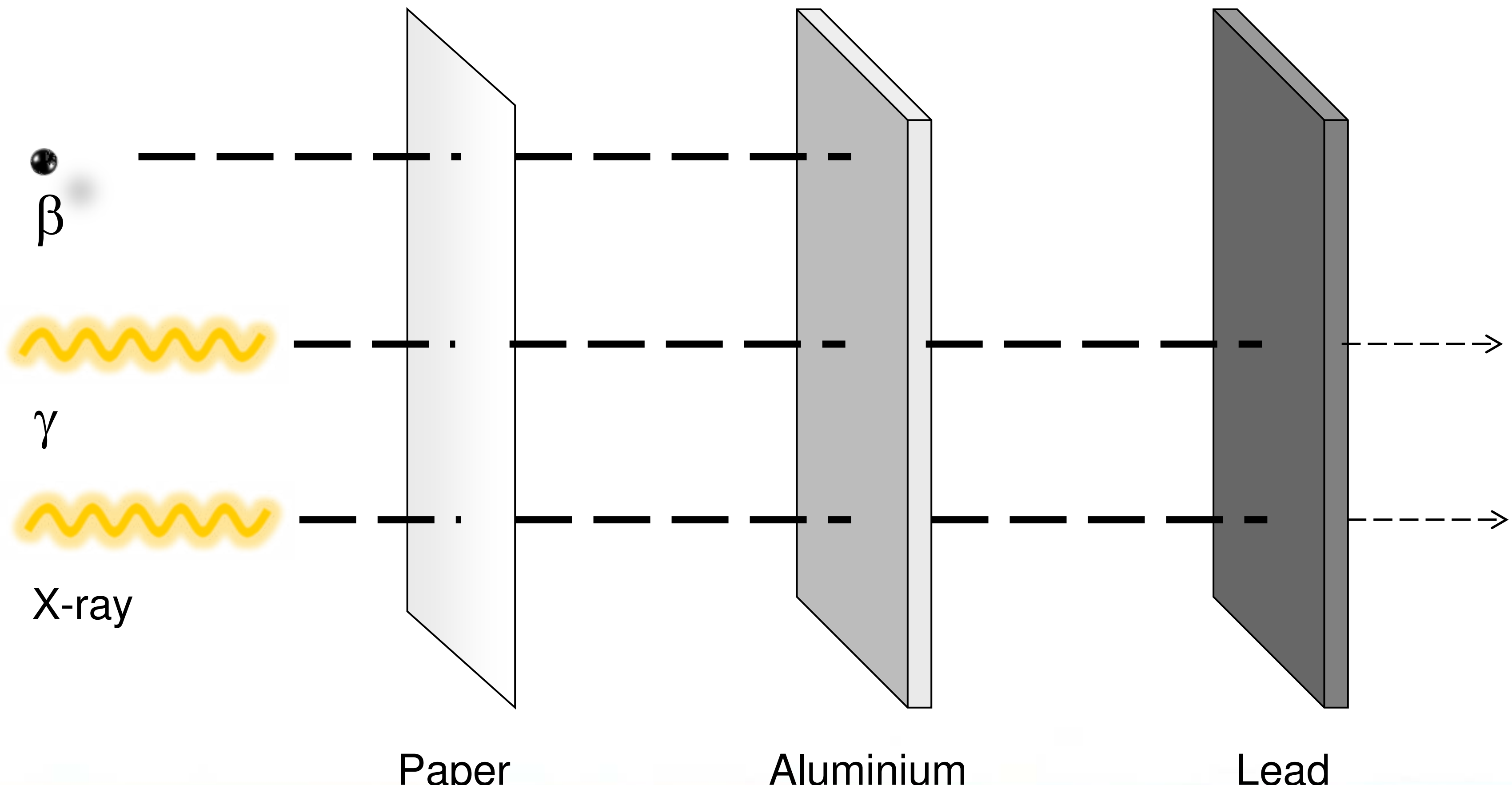


Image based on one from Uranium Information Centre.

Radiation Safety Institute of Canada
Institut de radioprotection du Canada

Provincial Responsibilities

- Low energy X-ray equipment
- Low energy particle accelerators
- Non-ionizing radiation
  - Laser
  - UV
  - Ultrasound
  - Noise
- Naturally occurring radioactive material (NORM)
  - Except transport, import, export

Federal Legislation

- All aspects of nuclear energy
  - Nuclear Safety and Control Act
  - Nuclear Energy Act
  - Nuclear Fuel Waste Act
  - Nuclear Liability and Compensation Act
- Environmental Protection Act
- Transportation of Dangerous Goods Act
- Radiation Emitting Devices Act

CNSC

CNSC Mandate

Regulate use of	To Protect	To Implement	To Disseminate
• Nuclear energy • Nuclear materials • Prescribed equipment • Prescribed information	• Health • Safety • Security • Environment	• International commitments • Peaceful use • Nuclear energy	• Scientific, technical, and regulatory information • To public

- Independent tribunal
- Reports through Minister of Natural Resources
  - Reviewable by Federal Court
- 7 appointed members
  - 800 employees
- Transparency

Radiation Safety Institute of Canada
Institut de radioprotection du Canada

CNSC Licensed PET Facilities

City	Site
Edmonton, AB	Capital Health Authority Walter C. McKenzie Centre
Halifax, NS	Capital District Health Authority
Hamilton, ON	Hamilton Health Sciences Corporation Juravinski Cancer Centre
London, ON	St. Joseph's Health Care
Montreal, QC	McGill University Health Centre Montreal Neurological Hospital
Ottawa, ON	The Ottawa Hospital Civic Campus University of Ottawa Heart Institute
Sherbrooke, QC	Centre hospitalier universitaire de Sherbrooke Hôtel-Dieu
Toronto, ON	University of Toronto Centre for Addiction and Mental Health
Vancouver, BC	British Columbia Cancer Agency Vancouver Cancer Centre
Winnipeg, MB	Winnipeg Regional Health Authority Winnipeg General Hospital

From https://www.nuclearsafety.gc.ca/eng/resources/maps-of-nuclear-facilities/results.cfm?category=medical-facilities

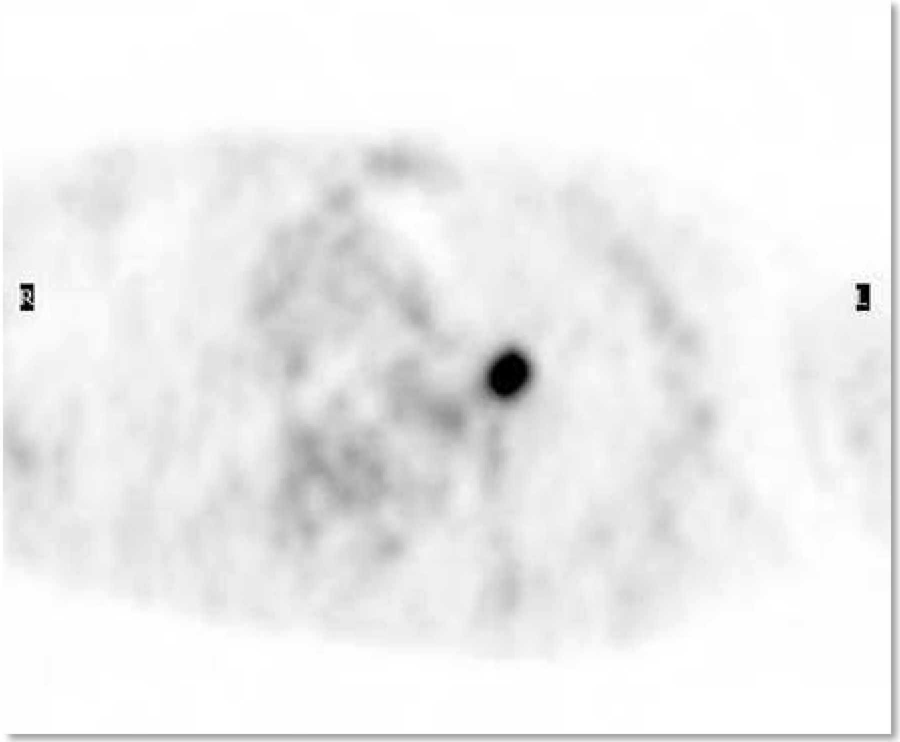
CNSC Certified Radiation Devices - PET

Certificate Number	Radiation Device Description	Radiation Device Type	Issue Date	Expiry Date
R-484-0001-0-2023	Scanwell Systems PET Central Timing Alignment Probe, Model No. 2	Calibrator	2008-07-02	2023-06-30
R-216-0002-0-2026	Philips Medical Systems Mosaic PET Animal Imaging System and Mosaic H	Source holder	2011-07-28	2026-07-31
R-194-0011-1-2024	GE Medical Systems Discovery PET/CT 600, PET/CT 610, PET/CT 690 and PET/CT 710	Calibrator	2012-08-30	2024-10-31
R-194-0008-4-2021	GE Medical Systems Discovery ST PET/STE PET; VCT PET/CT; VCT RX PET/CT & RX PET/CT	Calibrator	2007-06-18	2021-03-31
R-194-0005-2-2022	GE Medical Systems Discovery LS & PET Advance NXi	Calibrator	2019-04-02	2022-09-30
R-057-0009-0-2023	Siemens Inveon Dedicated PET	Source holder	2008-04-02	2023-03-31

From https://www.nuclearsafety.gc.ca/eng/nuclear-substances/certification-radiation-devices.cfm

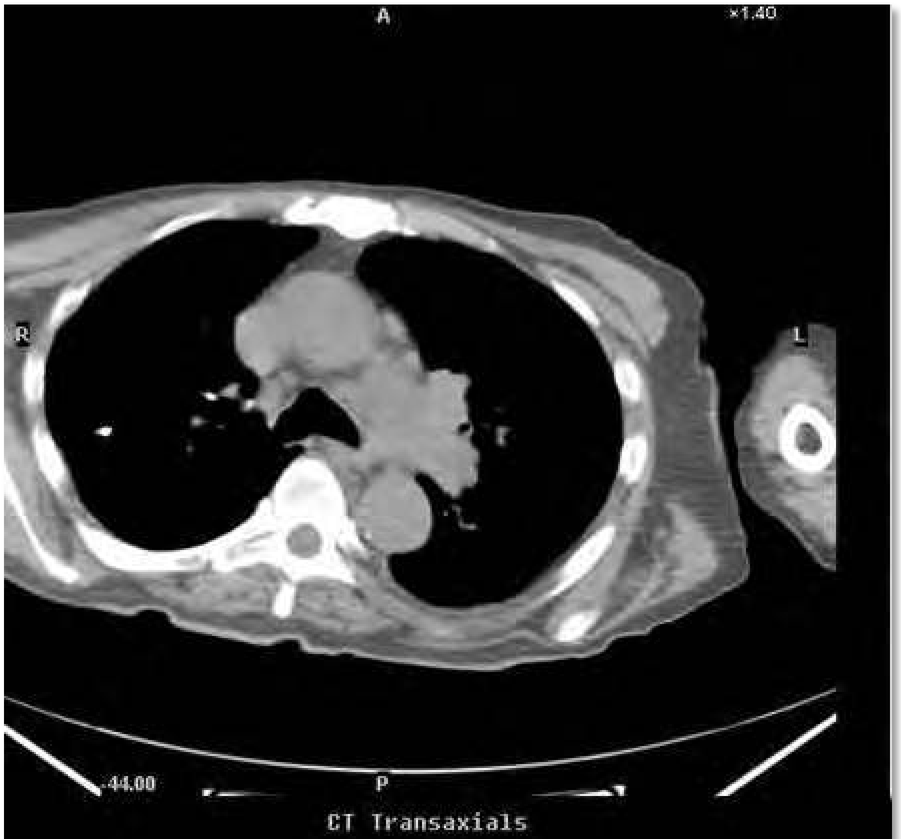
PET

- Positron Emission Tomography
- Functional information
- Tracers produced in cyclotron
- Biological tracers
- ‘Hot spot’ on image
- Few anatomical landmarks



IAEA

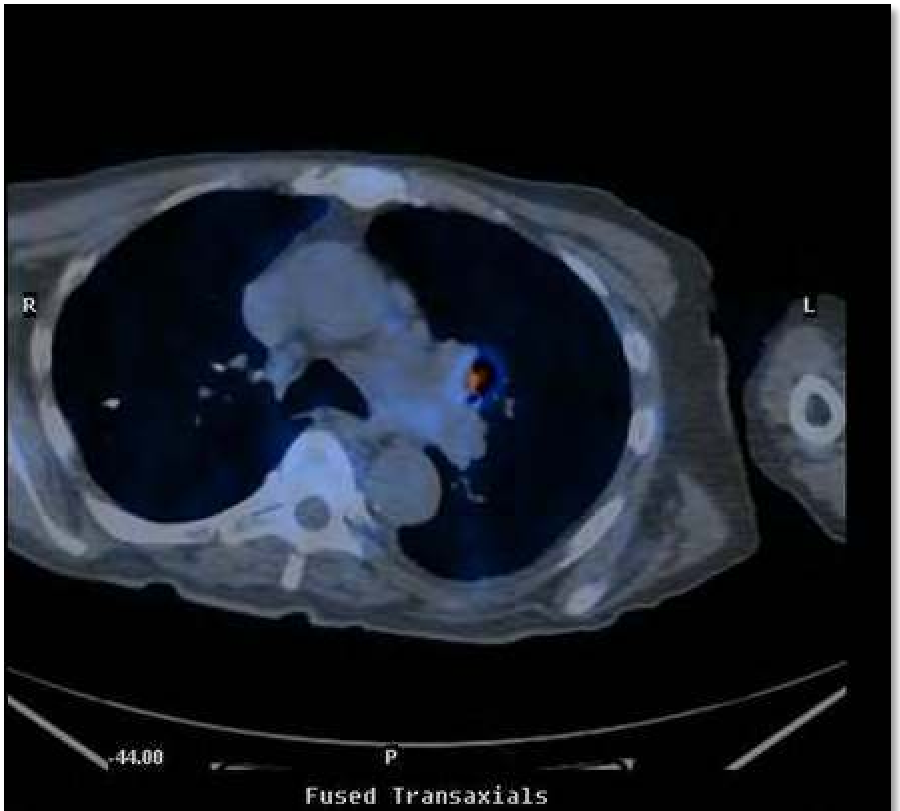
CT



- Anatomical detail
- Better resolution than PET
- Good dynamic range bone to lung
- Cannot differentiate between active and benign disease

[IAEA]

PET/CT



- Combines the functional information with the anatomical detail
- Accurate anatomical registration
- Higher diagnostic accuracy than PET or CT alone

IAEA

Components of a PET/CT System

- Cyclotron
- Radiopharmaceuticals
- CT Scanner

Cyclotron

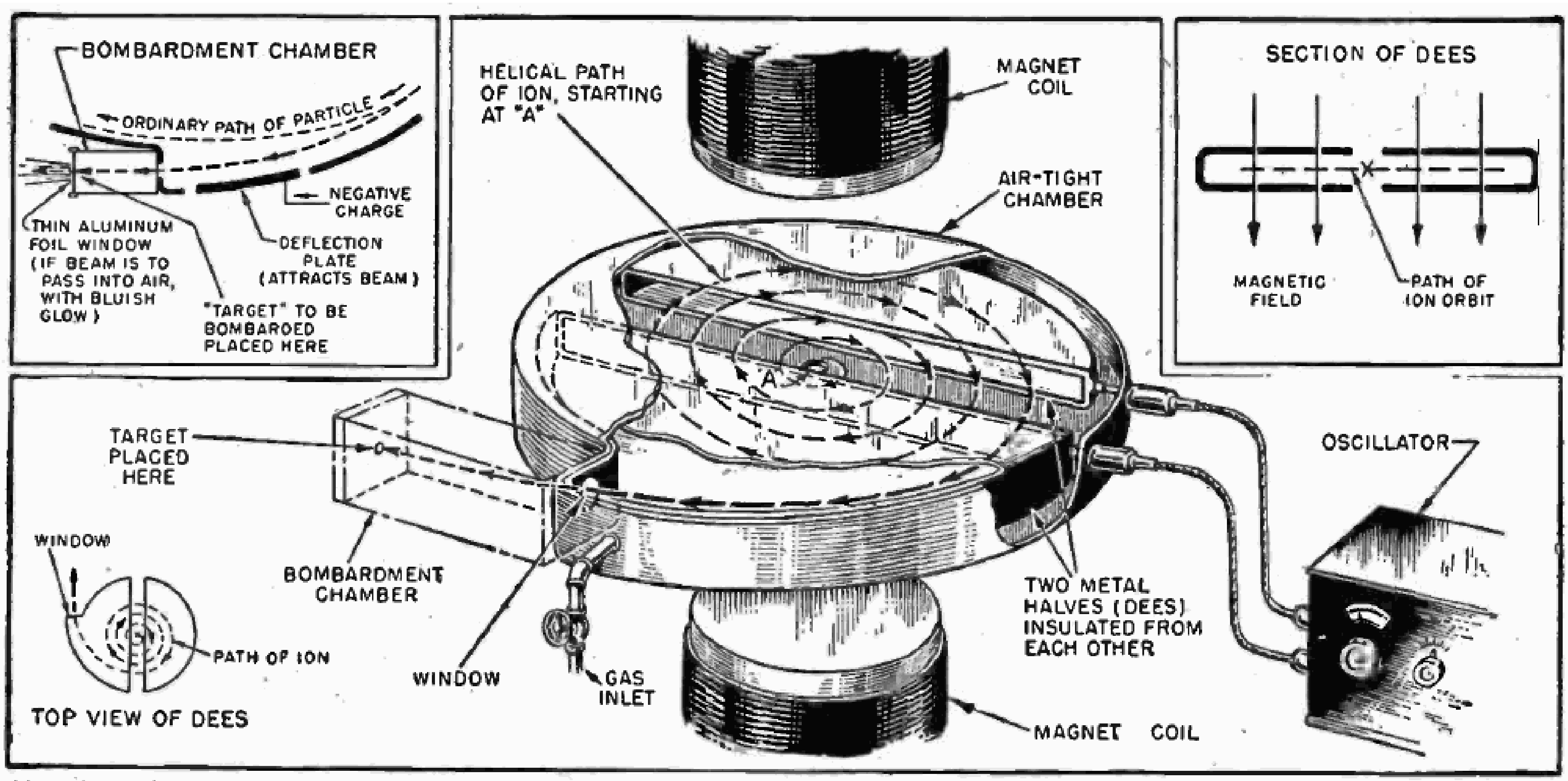


Image and information from Radio-Craft, Radcraft Publications, Springfield, Massachusetts, Vol. 18, No. 9, June 1947 p. 23

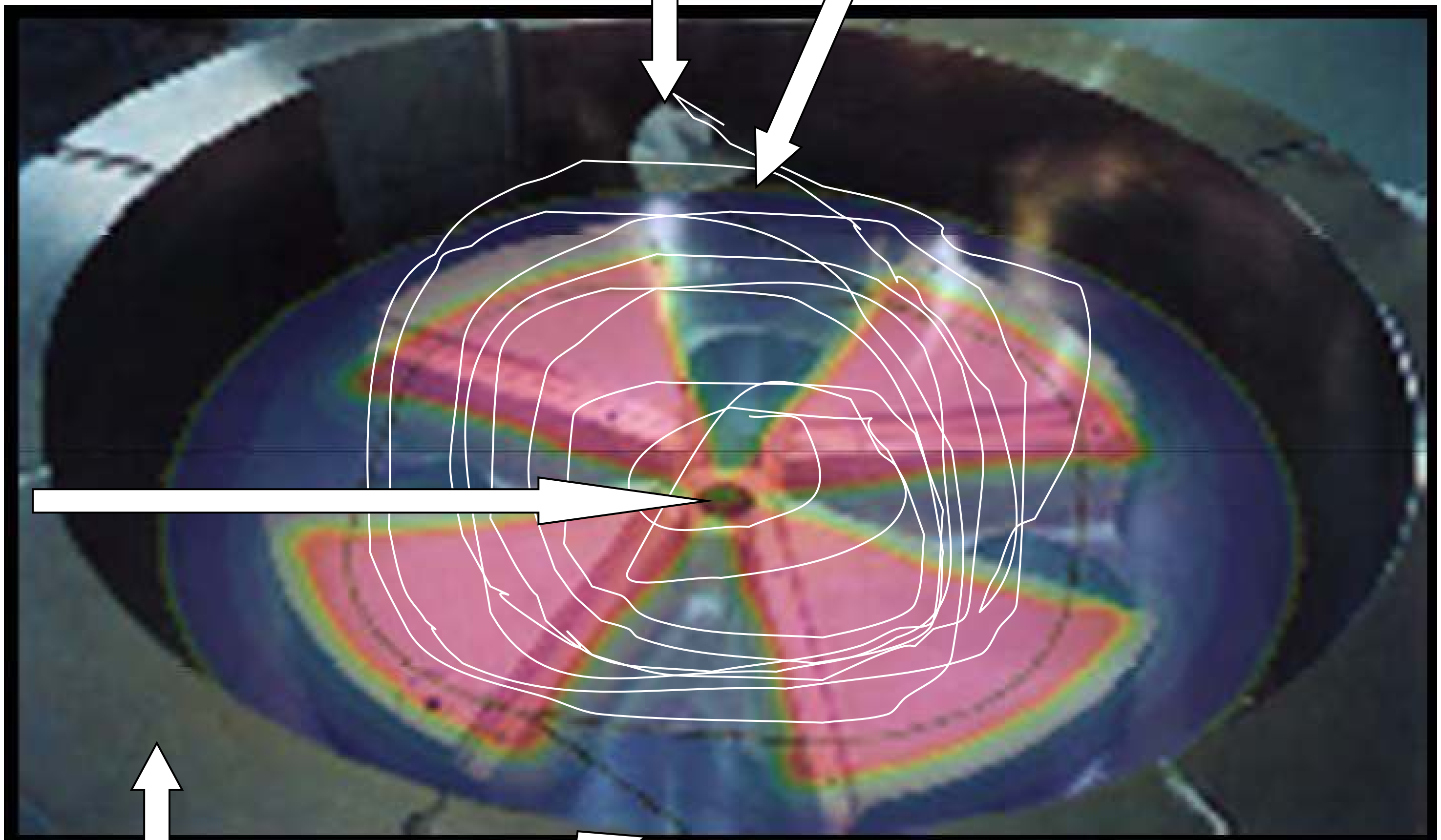
Cyclotron

Target

Beam extractor

Ion

Source



Magnetic coil

Dees

IAEA

25

Cyclotrons for Radionuclide Production

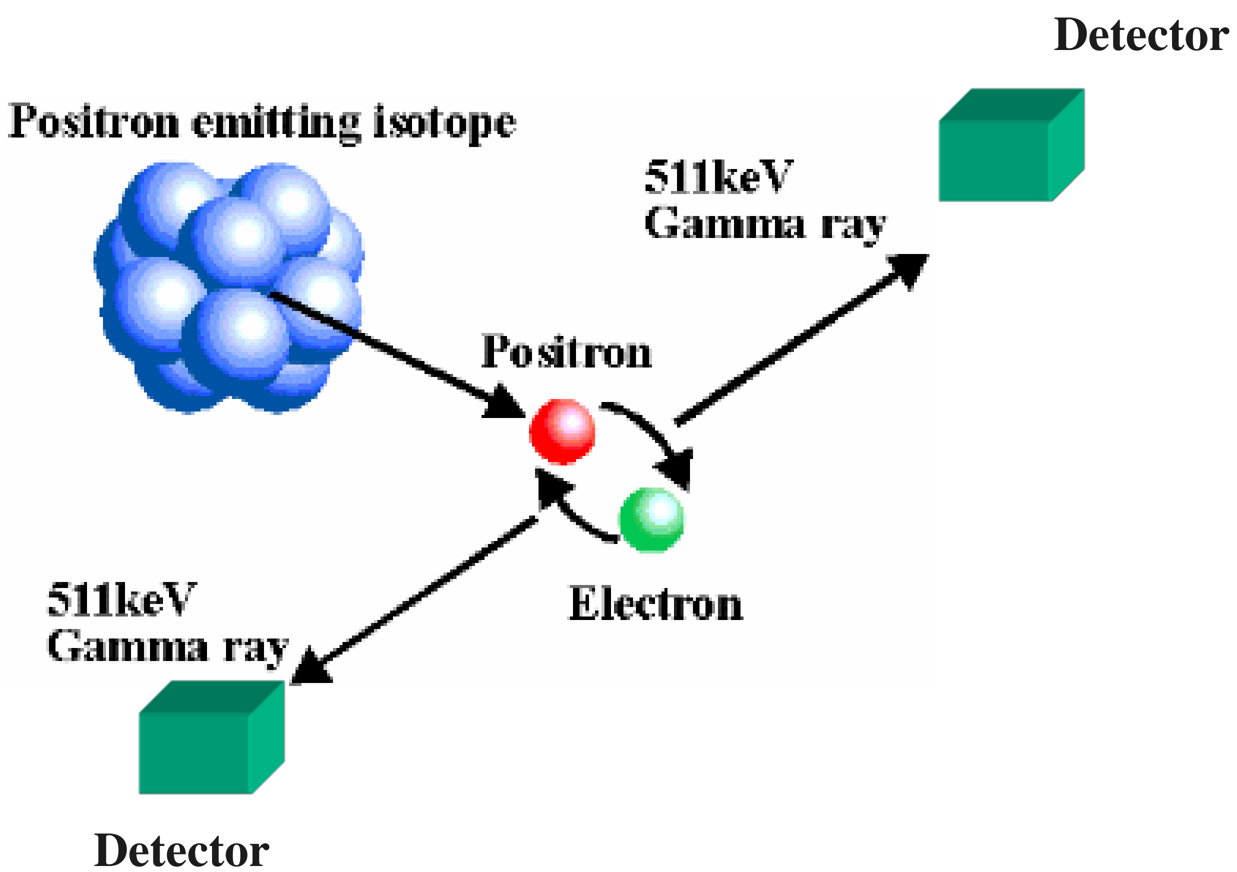
Radiation Safety Institute of Canada
Institut de radioprotection du Canada

Good Science in Plain Language®

City	Facility	Proton energy (MeV)	City	Facility	Proton energy (MeV)
Alberta	Cross Cancer Institute / Alberta Health Services	19	Sherbrooke	Centre Hospitalier Universitaire de Sherbrooke	19
Edmonton	University of Alberta	24	St John's	Eastern Health Nuclear And Molecular Medicine Facility	18
Halifax	Victoria General Hospital	16	Thunder Bay	Thunder Bay Regional Health Sciences Centre	24
Hamilton	McMaster University	16	Toronto	No Title	18
Hamilton	No Title	11	Toronto	Toronto General Hospital UHN	16
London	Lawson Health Research Institute	16	Toronto	No Title	18
Missisauga	No Title	11	Vancouver	TRIUMF	13
Montreal	Montreal Neurological Institute and Hospital – The Neuro	18	Vancouver	BC Cancer Agency	19
Montreal	Pharmalogic 5	16	Vancouver	TRIUMF	24
Montréal	Centre Hospitalier de l'Université de Montréal	18	Vancouver	Nordion (TRIUMF)	30
Mount Pearl	No Title	18	Vancouver	Nordion (TRIUMF)	30
Ottawa	No Title	11	Vancouver	Nordion Inc.	42
Saskatoon	University of Saskatchewan	24	Vancouver	No Title	700
Sherbrooke	Centre Hospitalier Universitaire de Sherbrooke	24	Winnipeg	Health Sciences Centre Winnipeg	11

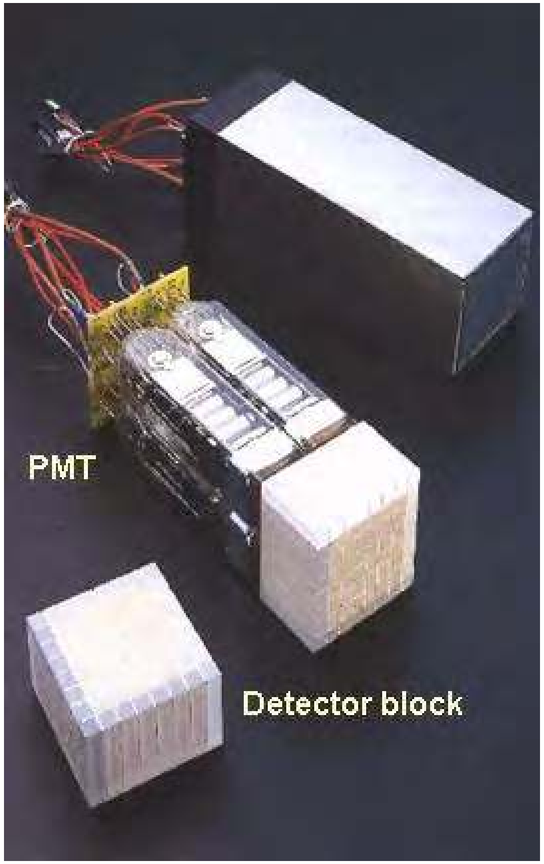
Image and data from https://nucleus.iaea.org/sites/accelerators/Pages/Cyclotron.aspx

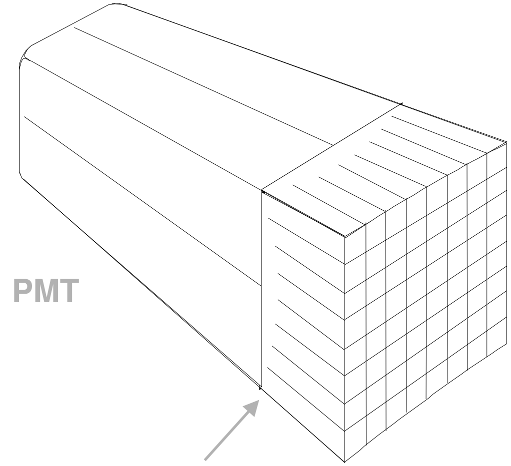
Coincidence Detection



IAEA

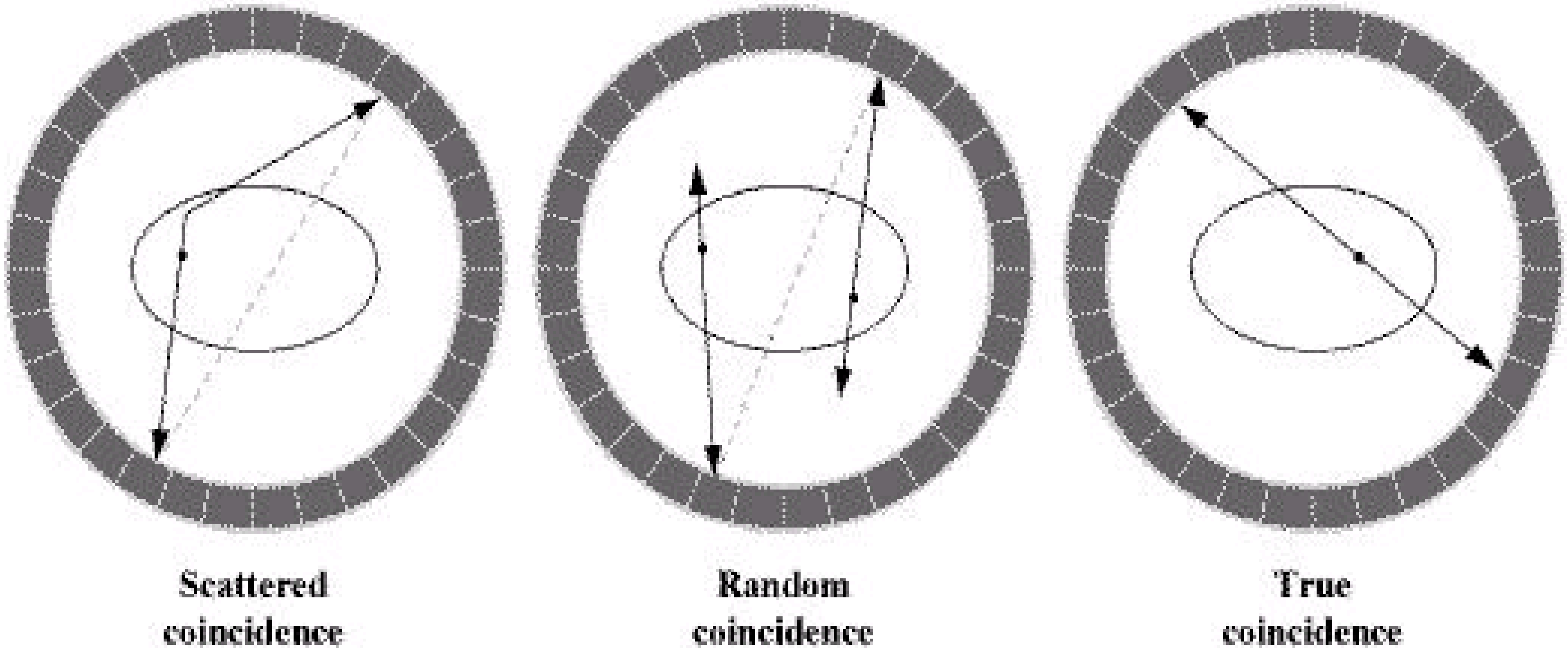
Scanner Detectors





IAEA

Scatter and Randoms



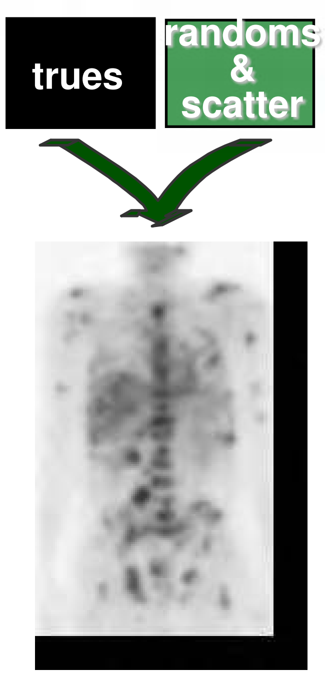
· Annihilation event

→ Gamma ray

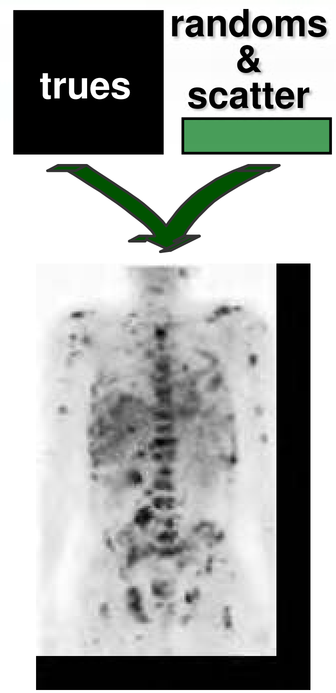
----- Line of response

IAEA

Scatter and Randoms



Typical coincidence image* containing a high percentage of randoms and scatter



Same image with same number of counts but a positive change in the ratio of trues to randoms & scatter

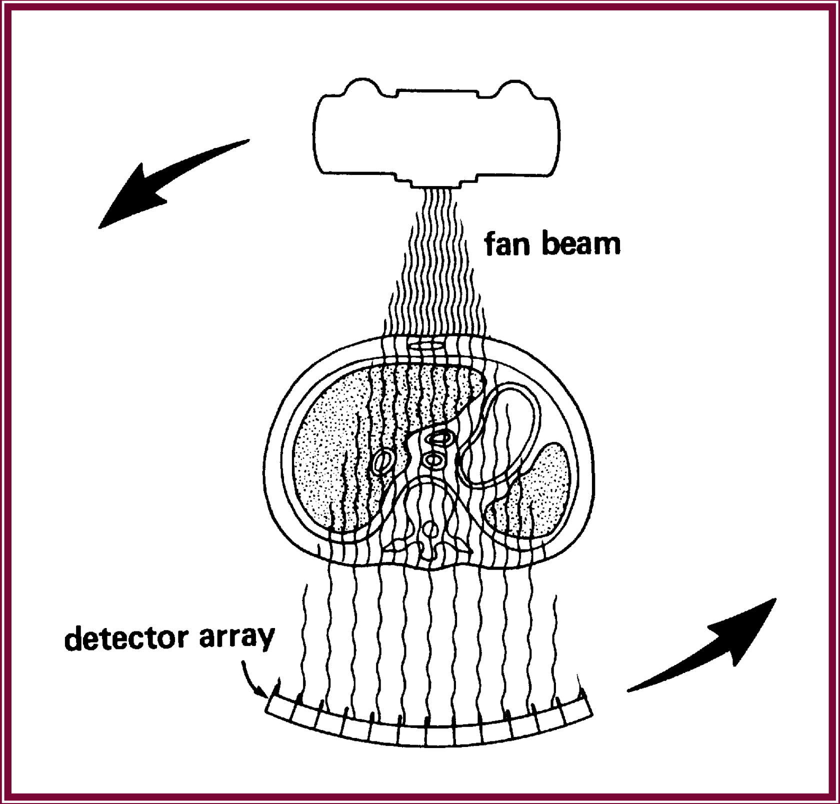
Randoms and scatter degrade image both qualitatively and quantitatively

Siemens

IAEA

Computed Tomography

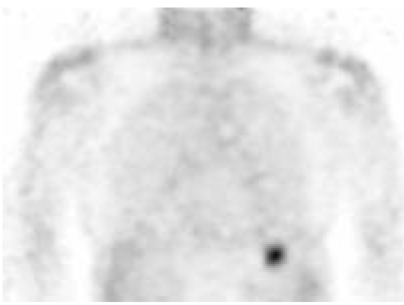
- CT uses a rotating X Ray tube, with the beam in the form of a thin slice (about 1 - 10 mm)
- The “image” is a simple array of X Ray intensity, and many hundreds of these are used to make the CT image, which is a “slice” through the patient



IAEA

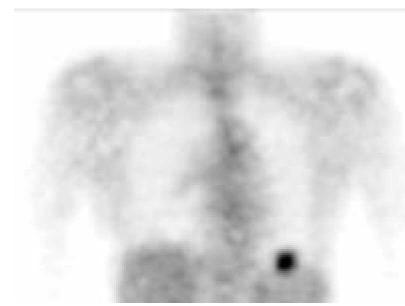
Attenuation Correction

- Attenuation map applied to the emission images during iterative reconstruction



Emission

Transmission



Corrected

IAEA

PET/CT Scanner

CT unit

PET scanner

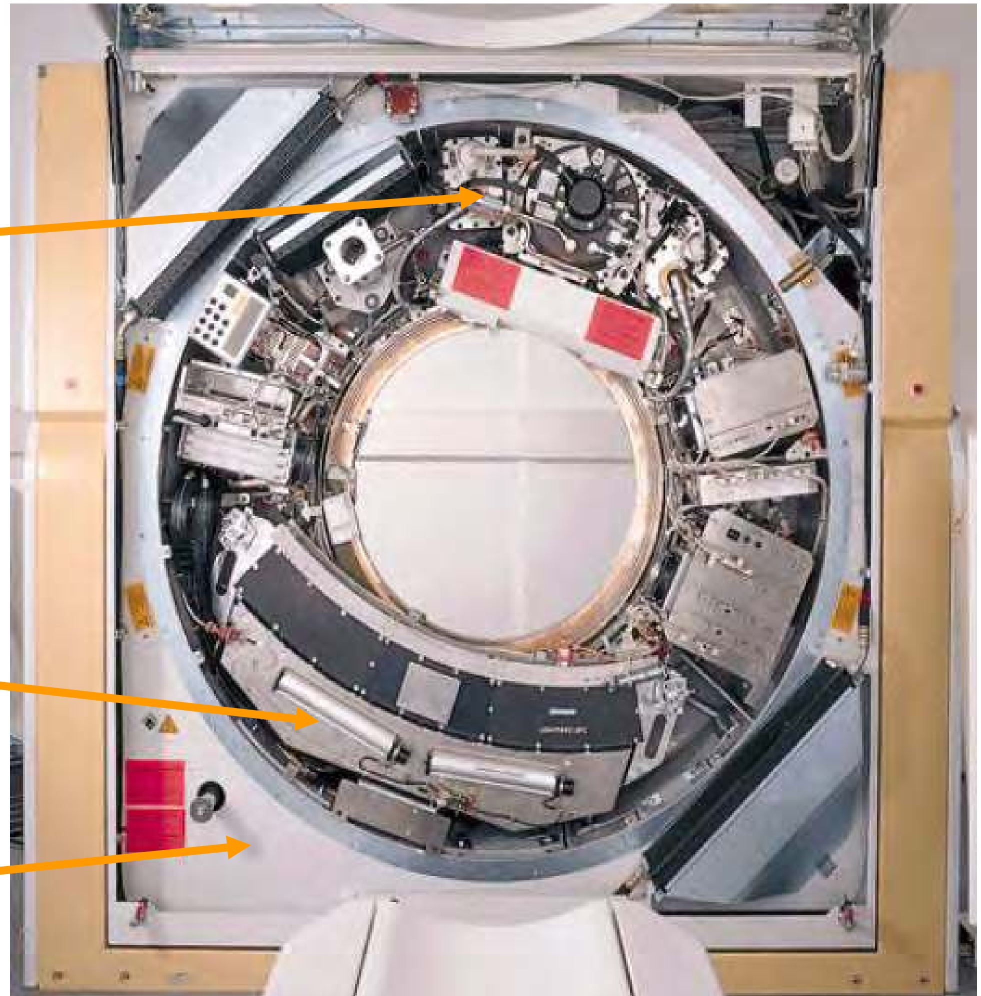
IAEA

A Look Inside a Slip Ring CT

X Ray Tube

Detector Array

Slip Ring



IAEA

Helical (spiral) Scan Principle

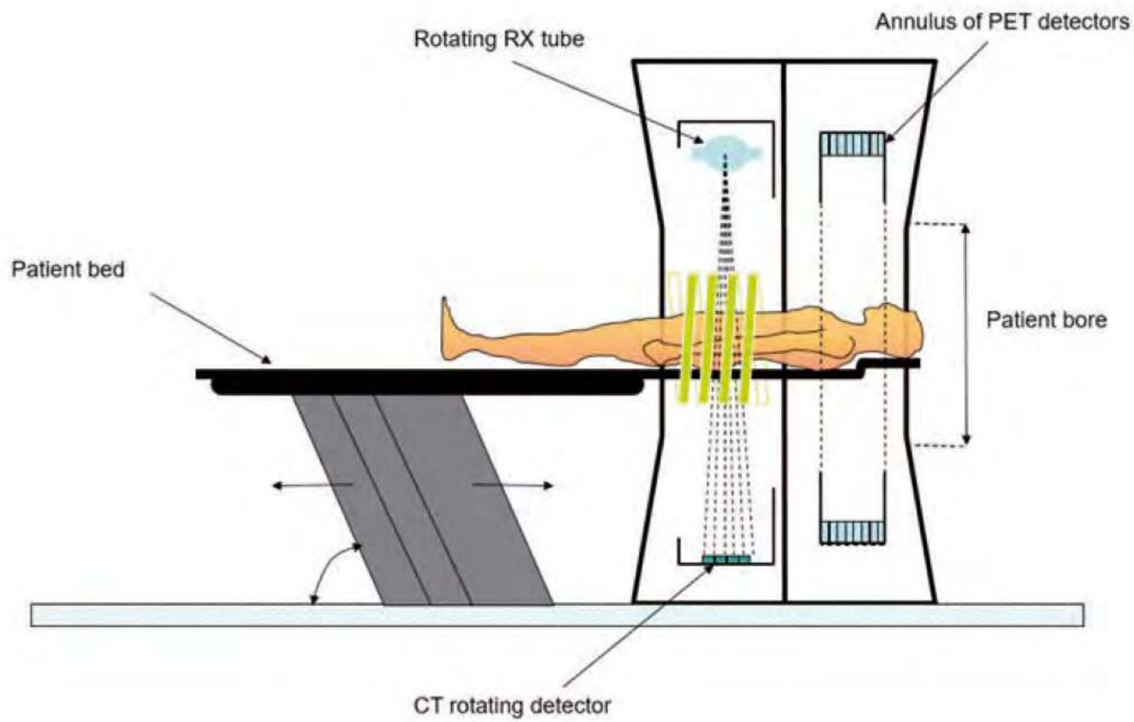
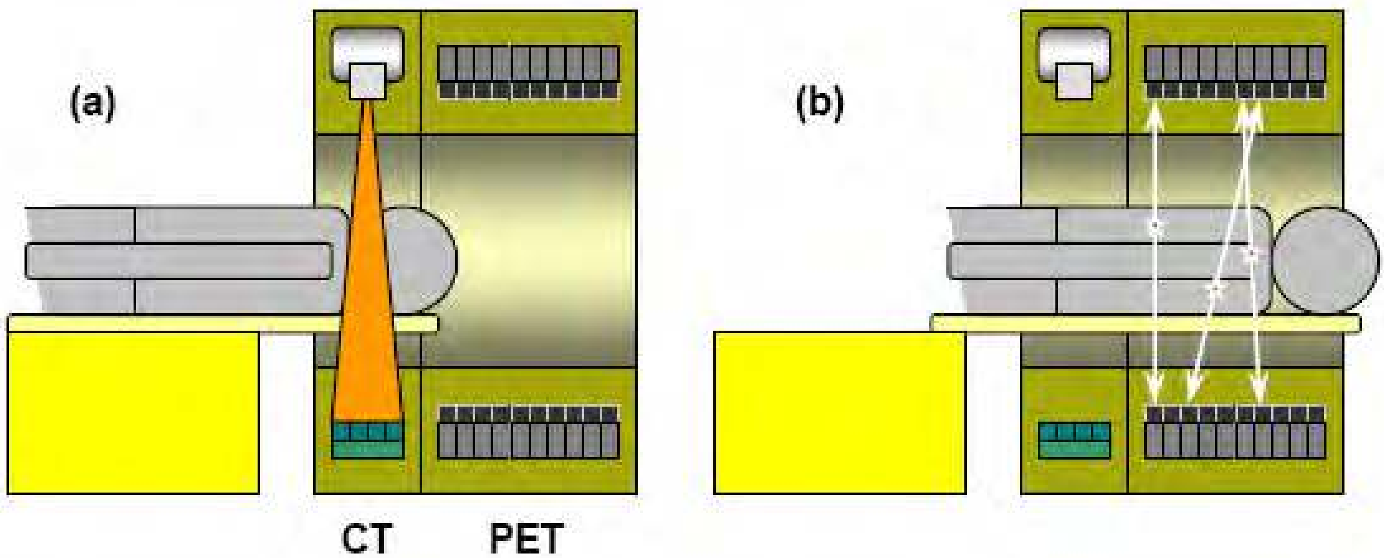


FIG. 12. PET–CT scanner (courtesy of M. Marengo).

IAEA

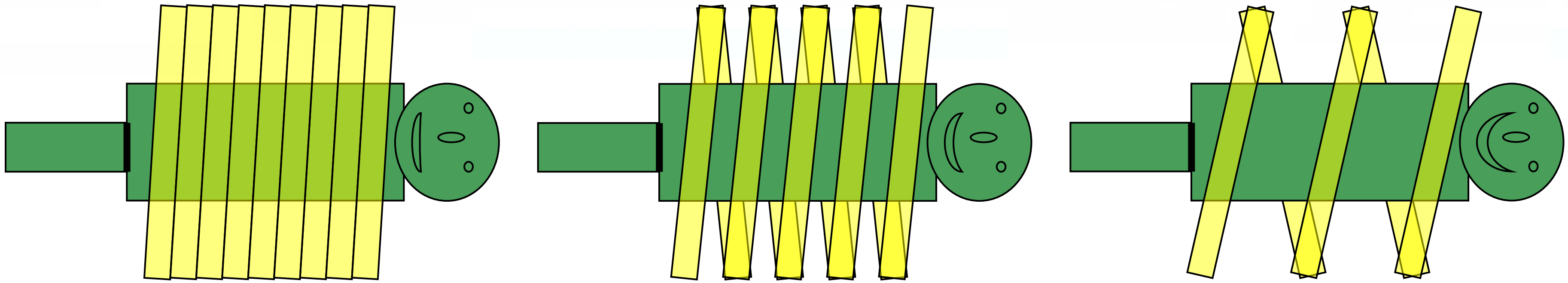
Scan Process



1) CT scanogram performed first
2) Full CT performed second
3) Patient moved further into scanner and PET scan acquired third

IAEA

Pitch



Number rotations	10		5		2.5
Slice thickness	10	10	10	10	10
Table movement per rotation	10	15	20	30	40
Pitch	1	1.5	2	3	4
Dose	10	7.5	5	3.33	2.5

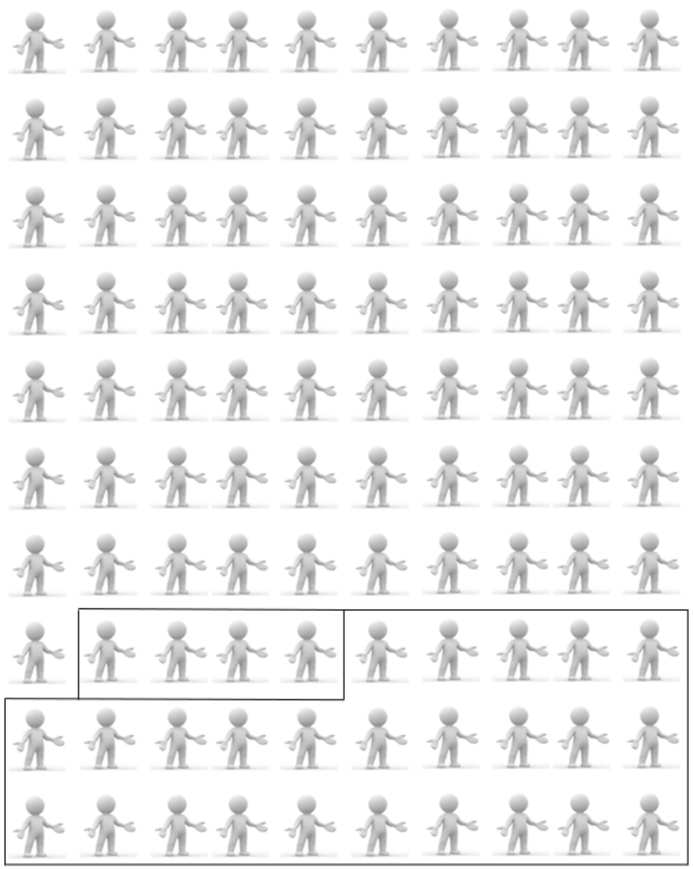
IAEA

Stochastic Effect: Cancer

- Radiation exposure increases the ***likelihood*** of developing cancer.
- The greater the exposure, the greater is the chance.
- Effect is similar to the fact that smoking increases the risk of lung cancer

Radiation Safety Institute of Canada
Institut de radioprotection du Canada

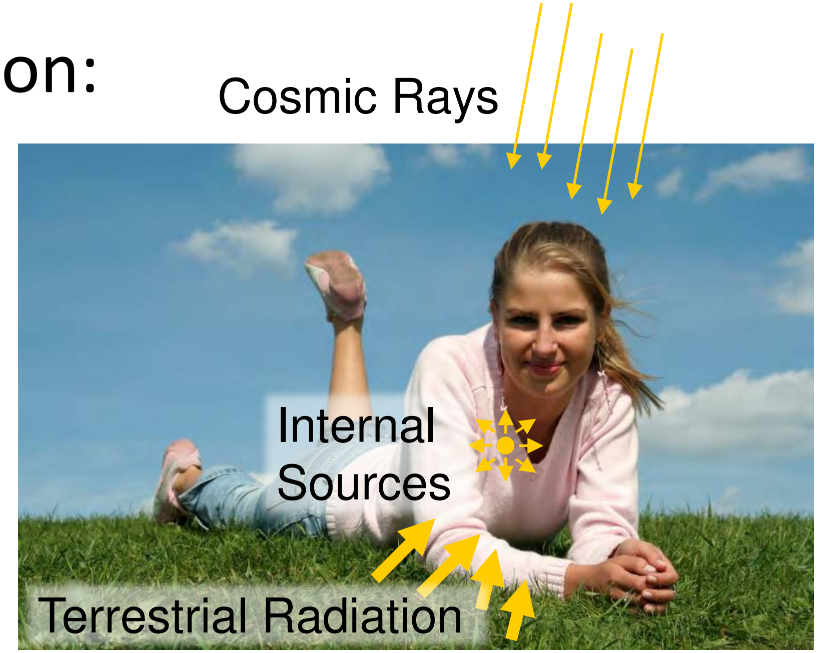
Cancer Risk from Radiation



- The risk of developing a fatal cancer as a result of exposure to radiation is approximately **4% per 1000 mSv.**
  - Consider a person who worked for 50 years and received 20 mSv per year.
  - This person's total lifetime radiation dose is 1000 mSv.
  - This person will have an extra 4% chance of developing a fatal cancer.

Radiation Exposure

- We are all exposed to radiation:
  - Cosmic radiation
    - sun, space
  - Terrestrial radiation
    - soil, rocks
  - Internally
    - Food, air (radon gas)



- On average, we receive about 2 – 4 mSv per year from background radiation

Radiation Safety Institute of Canada
Institut de radioprotection du Canada

Summary of Exposures

Public exposures and threshold effects:

Source or Effect	Effective Dose
Average Dose limit	20 mSv (NEW) 1 mSv (public)
Background Radiation	~1.8 mSv/year 0.005 mSv/day
Acute dose which affects the blood	> 250 mSv
4% increased risk of fatal cancer	1000 mSv
Cross country plane ride	0.03 mSv

Medical Exposures:

Source	Effective Dose
Chest X-ray	0.1 mSv
Chest CT	7 mSv
PET/CT scan	25 mSv
SPECT w/ Tc-99m	10 mSv
Mammography (x4)	0.42 mSv
Dental X-rays (x4)	0.005 mSv
Radiation Therapy	Up to 60 Gy (equivalent dose)

Deterministic Effects: Acute Exposure

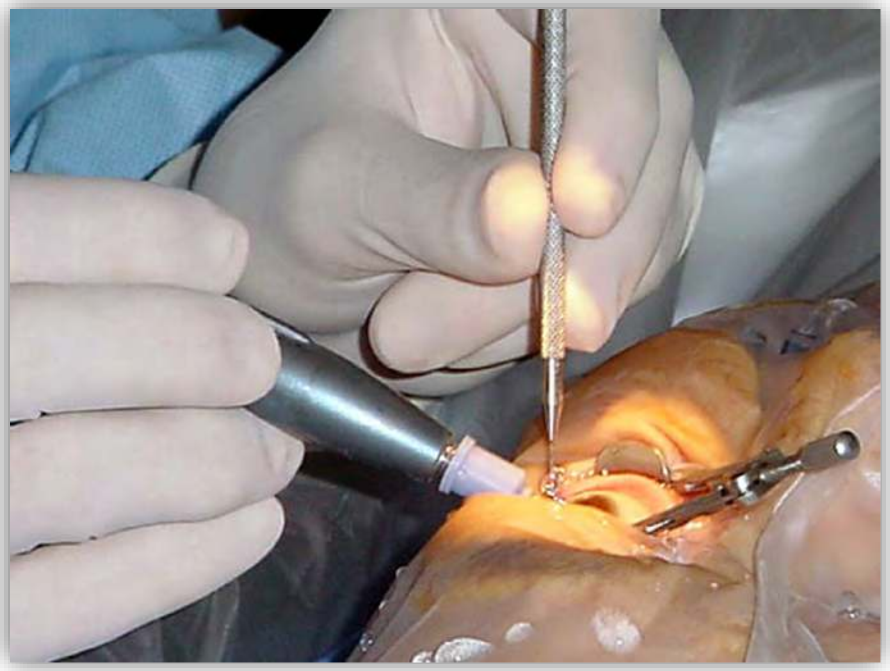
- Exposure to a high dose delivered within seconds, minutes or days
- Possible deterministic effects
  - Cataracts
  - Blood changes
  - Nausea
  - Diarrhea
  - Hair-loss
  - Skin damage
  - Death

Acute Exposure

Acute Dose (mGy)	Effect
< 250	No detectable effects
> 3,500	Chance of death 50% and above
> 6,000	Death an almost certainty, time between exposure and death depends on amount of dose

Cataracts

- Threshold: 0.5 Gy (500 mGy)
- New ICRP recommendation:
  - 20 mSv per year on average
- CNSC annual dose limit for the lens of the eye for designated workers:
  - 50 mSv per year
- Provinces each have dose limits for x-rays
  - Ontario: 150 mSv/hear; 50 mSv/year



PET/CT Radiation Protection

- Both nuclear medicine and radiology
- Nuclear sources, nuclear devices, and x-ray equipment
- Both internal and external exposures
- Tracers give more dose than traditional nuclear medicine
- CT gives more dose than traditional x-ray
- No dose limits for patients

Radiation Protection

- Radiation Safety Officer
- Radiation Protection Manual
- ALARA
- Internal Radiation
  - Keep contamination out
- External Radiation
  - Time/Distance/Shielding
- Engineering/Administrative Controls
- SOP
- Emergency Procedures
- Dosimetry
- Training
- Inspections/investigations/records
- Female workers
- Children

Radiation Safety Institute of Canada
Institut de radioprotection du Canada

CNSC Resources

Canadian Nuclear Safety Commission | Commission canadienne de sûreté nucléaire

Classes of Nuclear Substances

The following table organizes a number of common nuclear substances, including those for which surface contamination and waste disposal limits are typically incorporated into CNSC licences, into three classes – Class A, Class B, or Class C – on the basis of common radiological characteristics.

To find out the classification, for regulatory purposes, of any nuclear substance that is not listed below, contact the CNSC.

CLASS	RADIONUCLIDE				
CLASS A	Any listed alpha emitters and their daughter products				
	Ag-110m	Bi-210	Co-56	Co-60	Cs-134
	Cs-137	I-124	Lu-177m	Mn-52	Na-22
	Po-210	Pu-238	Pu-239	Pu-240	Sb-124
	Sc-46	Sr-82	U-234	U-235	U-238
	V-48	Zn-65			
CLASS B	Au-198	Ba-133	Br-82	Ce-143	Co-58
	Cu-67	Fe-59	Hg-194	Hg-203	I-131
	Ir-192	La-140	Mo-99	Nb-95	Pa-233
	Ra-223	Re-186	Re-188	Ru-103	Sb-122
	Sm-153	Sr-90	Xe-127	Y-86	Y-90
	Yb-169	Zr-89	Zr-95		
CLASS C	C-11	C-14	Ca-45	Cd-109	Ce-141
	Cl-36	Co-57	Cr-51	Cu-60	Cu-61
	Cu-64	F-18	Fe-55	Ga-67	Ga-68
	Ge-68	H-3	I-123	I-125	In-111
	In-113m	In-114	K-42	Kr-85	Lu-177
	Mn-52m	Mn-56	N-13	Na-24	Nb-98
	Ni-63	O-15	P-32	P-33	Pd-103
	Pr-144	Pu-241	Rh-106	S-35	Sc-44
	Sn-113	Sr-89	Tc-94m	Tc-99	Tc-99m
	Te-127	Tl-201	V-49	W-181	W-188
	Xe-133	Zn-63			

280 Slater Street, Post Office Box 1046, Station B
Ottawa, Ontario K1P 5S9 Canada
Fax 613-995-5086 nuclearsafety.gc.ca

Canada

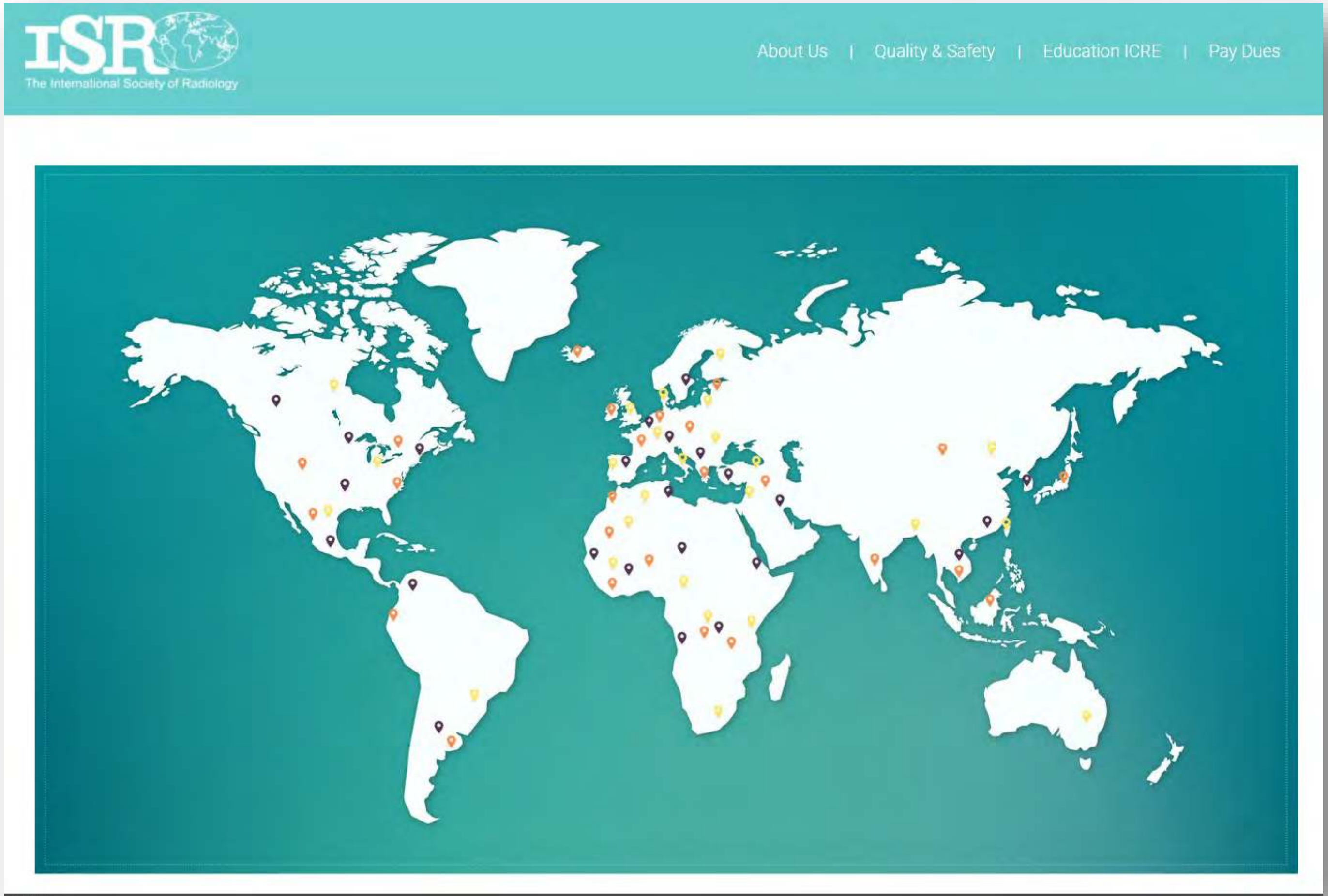
280 rue Slater, Case postale 1046, Succursale B
Ottawa (Ontario) K1P 5S9 Canada
Télécopieur : 613-995-5086 suretenucleaire.gc.ca

http://www.nuclearsafety.gc.ca/eng/pdfs/class-II/Classes-of-Nuclear-Substances-acc-eng.pdf

- Support the safe use of nuclear substances and radiation devices
- Technical Information & Infographics
- Guidance documents
  - Radionuclide information booklet
  - Design guides
- Regulatory Documents
  - Developing and implementing RPP
  - Application Guides
    - Certification of equipment
    - Facilities Licenses
    - Nuclear Substances and Radiation Devices

Radiation Safety Institute of Canada
Institut de radioprotection du Canada

ISR/ISRQSA



Radiation Safety Institute of Canada
Institut de radioprotection du Canada

BONN Call to Action

IAEA

World Health Organization

PAHO Pan American Health Organization World Health Organization REGIONAL OFFICE FOR THE Americas

Radiation Safety Institute of Canada
Institut de radioprotection du Canada

Safe Imaging Organizations

AFROSAFE RAD
Championing Radiation Safety

Arab Safe
Promoting Radiation Safety

ASIASAFE

Canada Safe Imaging | Imagerie Sécuritaire Canada

ESR EUROSAFE IMAGING

image gently®

IMAGE WISELY®
Radiation Safety in Adult Medical Imaging

JRS
JAPAN RADIOLOGICAL SOCIETY

LATIN SAFE

TABLE 1 - METHODS TO DECREASE RADIATION EXPOSURE IN FDG-PET-CT	
Optimize utilization of FDG-PET-CT	**Optimize protocols to reduce dose while maintaining sufficient image quality**
Perform FDG-PET-CT only when clinically indicated • Use evidence-based guidelines for guidance, including American College of Radiology (ACR) Appropriateness Criteria®, Society of Nuclear Medicine and Molecular Imaging (SNMMI) Procedure Guidelines, European Association of Nuclear Medicine (EANM) Procedure Guidelines, National Comprehensive Cancer Network (NCCN) Clinical Practice Guidelines in Oncology, among others) • Implement use of decision support systems	PET-related methods to reduce dose • Optimize/minimize injected dose of FDG • Encourage hydration and frequent voiding to reduce urinary bladder and adjacent pelvic organ radiation dose from FDG excretion • Use 3D PET emission acquisition mode • Use time-of-flight (TOF) information in image reconstruction • Increase duration of acquisition time per bed position
Use alternative non-ionizing radiation imaging technologies (US, MRI) whenever possible	CT-related methods to reduce dose • Minimize z-axis coverage whenever possible • Decrease tube voltage (kVp) • Decrease tube current and exposure time (mAs) • Increase pitch • Use automatic tube current modulation
Consider use of PET-MRI in place of PET-CT for certain clinical applications to reduce dose, although more research data is needed	
Perform routine quality assurance and quality control of imaging instrumentation and optimization of imaging protocols	
Monitor patient dose exposure from individual imaging examinations and on a cumulative basis	
Monitor patient dose exposure from individual imaging examinations and on a cumulative basis	

Optimizing CT protocols (Optimizing CT protocols portion was used with permission from Adam M. Alessio, PhD and Paul E. Kinahan, PhD, "CT Protocol Selection in PET-CT Imaging" Image Wisely, 2012.")

https://www.imagewisely.org/Imaging-Modalities/Nuclear-Medicine/Optimizing-Oncologic-FDG-PETCT-Scans

Canada Safe Imaging

canadasafeimaging.ca

Canada Safe Imaging | Imagerie Sécuritaire Canada

EN FR

ABOUT CSI | INITIATIVES | INFORMATION FOR HEALTH PROFESSIONALS | INFORMATION FOR PATIENTS | RESOURCES | INFORMATION FOR MEMBERS | NEWS

HOW TO BECOME A MEMBER

To become a member of Canada Safe Imaging, please register through the Stakeholders Registration Portal at:

Stakeholders Registration Portal

Search ...

QUESTIONS ABOUT RADIATION

- WHO Scholar Level 1 course on radiation risk communication to improve benefit-risk dialogue in paediatric imaging
- IOMP webinar jointly with WHO, IRPA and IAEA on Radiation Safety Culture
- Please see the latest news from IAEA:
- Click here to find out how we can help you answer questions about radiation!

Powered by WordPress and Dynamic News.

IAEA

IAEA - International Atomic Energy Agency

IAEA

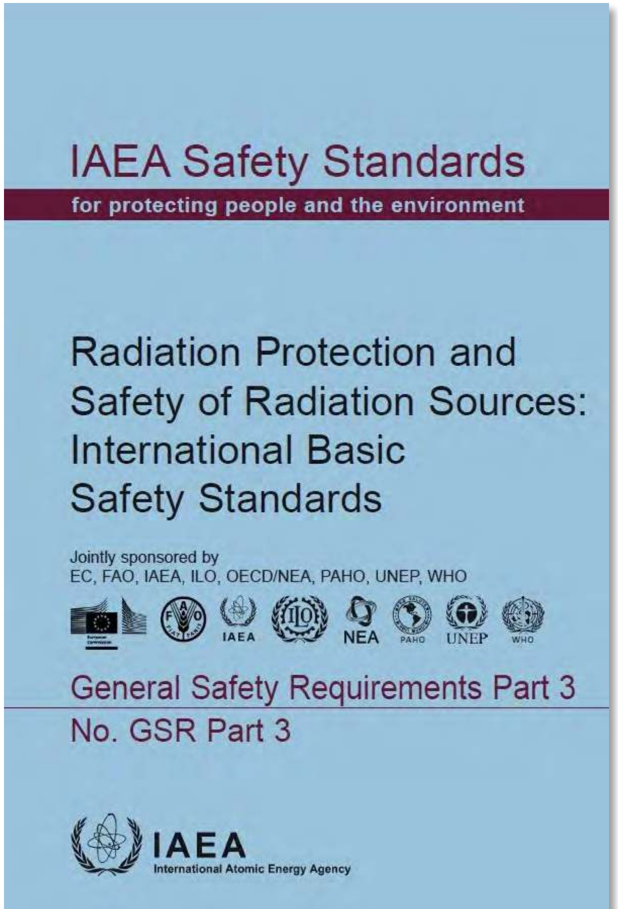
IAEA - International Atomic Energy Agency

@iaeaorg

IAEA is the 🌍's centre for cooperation in the #nuclear field, promoting the safe, secure & peaceful use of nuclear technology.

Vienna, Austria   iaea.org

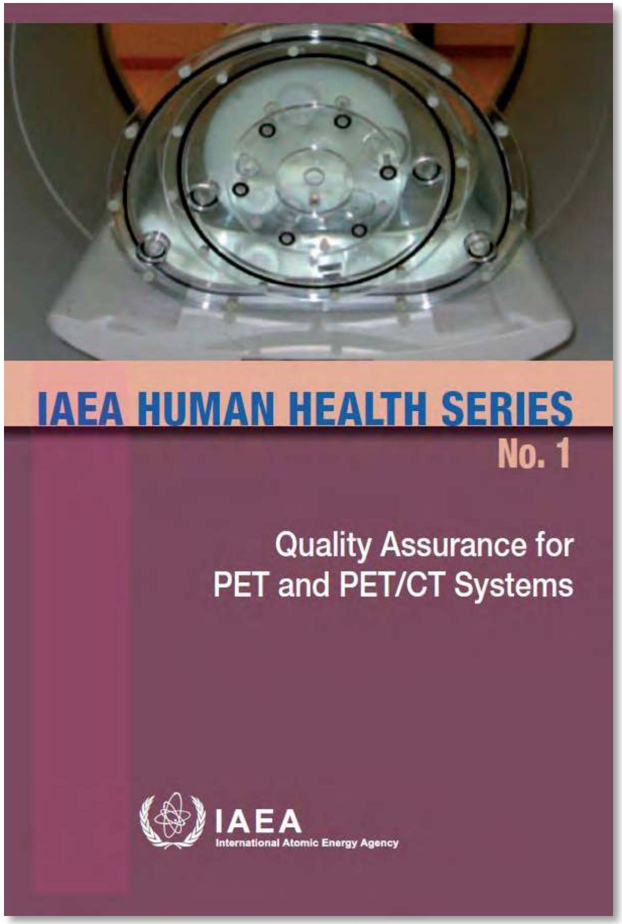
IAEA Resources



- International Basic Safety Standards
- Strategies for Clinical Implementation and Quality Management of PET Tracers
- SRS No. 58
  - Radiation Protection in Newer Medical Imaging Techniques: PET/CT
- Publish update papers

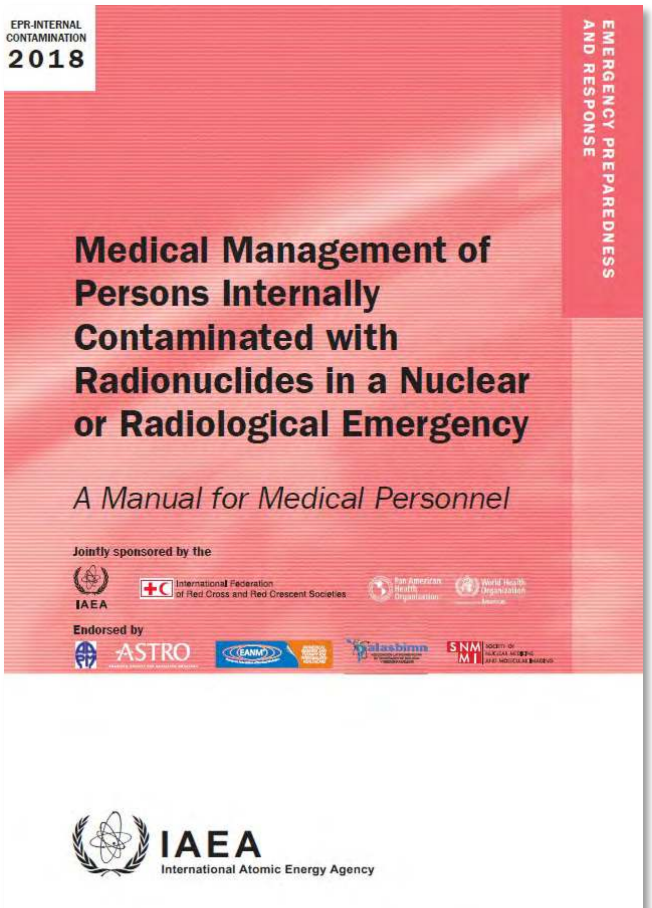
IAEA Resources

- Human Health Series
  - QA
  - Appropriate Use of FDG-PET
  - Planning a Clinical PET Centre
  - Standard Operating Procedures
  - PET/CT Atlas on QC
  - Clinical Atlas
  - Nuclear Medicine Resource Manual



Radiation Safety Institute of Canada
Institut de radioprotection du Canada

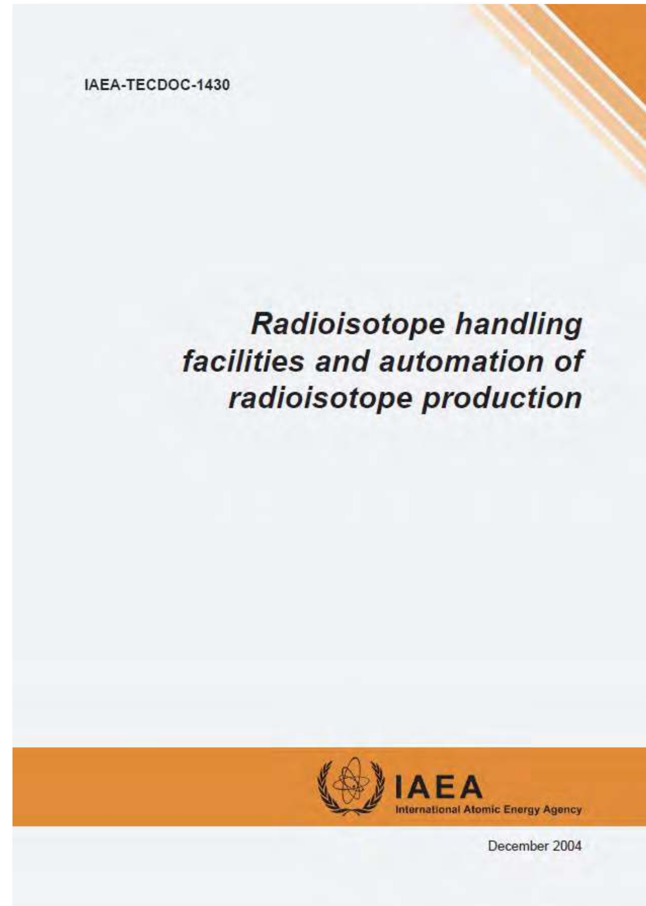
IAEA Resources



- Pocket Guides
  - Medical Management of Persons Internally Contaminated with Radionuclides in a Nuclear or Radiological Emergency
  - Medical Physicists Supporting Response to a Nuclear or Radiological Emergency
- RRR Cyclotron Radionuclides
  - Emerging Positron Emitters for Medical Applications
  - Guidance on Facility Design and Production of FDG

IAEA Resources

- TECDOC
  - Radioisotope Handling Facilities
  - Guide to Clinical PET in Oncology
- TRS Cyclotron Radionuclides
  - Physics Characteristics and Production Methods
  - Guidelines for Setting Up a Facility


IAEA-TECDOC-1430

Radioisotope handling facilities and automation of radioisotope production

IAEA
International Atomic Energy Agency

December 2004

"Good science in plain language"®

Thank you for listening!

www.radiationsafety.ca

1-800-263-5803

info@radiationsafety.ca