FRCR Lecture V

Nuclear Medicine



QA/QC, Measurement, Radiation Protection

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Quality Assurance in Nuclear Medicine

Quality Assurance

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What is **quality assurance** (Q/A) ?

"all those planned and systematic actions necessary to provide adequate confidence that a product or service under consideration will satisfy given requirements for quality"

Quality Assurance

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Regulation 33(3)-(4) of the Ionising Radiations Regulations 2017 states:

- *(3) Every employer ... must ... make arrangements for a suitable quality assurance programme to be provided in respect of the equipment or apparatus for the purpose of ensuring that it remains capable of restricting so far as is reasonably practicable exposure to the extent that this is compatible with the intended clinical purpose or research objective*
- *(4) … the quality assurance programme ... must require the carrying out of—*
  - *(a) … adequate testing of that equipment or apparatus before it is first used for clinical purposes;*
  - *(b) adequate testing of the performance of the equipment or apparatus at appropriate intervals and after any major maintenance procedure to that equipment or apparatus;*
  - *(c) … measurements at suitable intervals as are necessary to enable the assessment of representative doses from any radiation equipment to persons undergoing medical exposures.*

Quality Assurance vs Quality Control

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Quality Assurance (QA)– process orientated focuses on defect prevention

- Process of staff training
- Process of testing radiopharmaceuticals
- Process of assessment of equipment performance
- Process of reporting of clinical studies

Quality Control (QC) – product orientated focuses on defect identification

- Is there a defect on the imaging equipment (e.g. gamma camera)
- Is the radionuclide calibrator measuring the activity correctly ?

Radiopharmacy Quality Control

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- Radionuclide Purity
  - ^{99}Mo - use radionuclide calibrator to ensure <0.1% breakthrough
- Chemical Purity
  - Al - colorimetry test
- Radiochemical Purity

} first eluate from each generator

  - Free ^{99m}Tc ($Na^{99m}TcO_4$) - Thin Layer Chromatography (TLC)/test strip
    - Different bio-distribution
    - Unnecessary radiation of organs
    - Misdiagnosis

} First vial of new batch for commercial kits

- Sterility
  - Aseptic techniques
  - Monitoring for microbiological, particulate and radioactive contamination

Radionuclide Calibrator QC



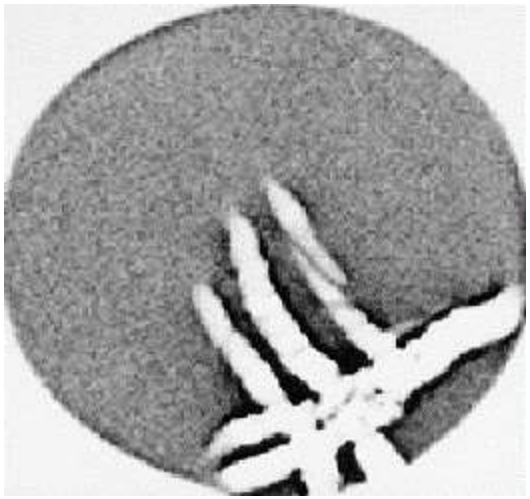
- Daily Quality Control
  - Voltage test
  - Background test
  - Accuracy test
    - Long lived source ^{137}Cs ($T_{1/2}$=30 years)
  - Relative response
    - Source assayed using several radionuclide settings
- Periodic quality control
  - Linearity
  - Accuracy testing against National Physical Laboratory (NPL)

Gamma Camera Quality Control

- Gamma camera – complex device
  - imaging characteristics may deteriorate gradually or fail acutely
- Acute deterioration of performance
  - may become apparent during normal use
- Gradual deterioration of performance
  - unlikely to be evident from normal clinical use
  - **errors** in the interpretation of clinical images

Non-Uniformity Artefacts

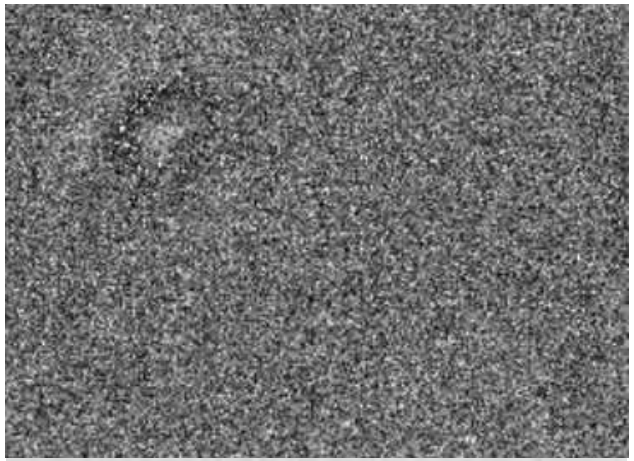
- Scintillation crystal cracked
  - due to mechanical shock perhaps during collimator exchange
  - due to thermal shock
- Collimator damaged
  - due to mechanical shock during collimator exchange
  - due to possible mishandling





Non-Uniformity Artefacts

- The image shows a non-uniformity artefact
- All values within acceptance limits



Parameter Name	Value	Acceptance Criteria
CFOV Integral Uniformity	1.502804373 %	<=3.0
CFOV X-Diff Uniformity	1.428145822 %	<=2.1
CFOV Y-Diff Uniformity	1.289800603 %	<=2.1
UFOV Integral Uniformity	1.502804373 %	<=3.6
UFOV X-Diff Uniformity	1.428145822 %	<=2.3
UFOV Y-Diff Uniformity	1.460370701 %	<=2.3

Gamma Camera Quality Control

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- National Electrical Manufacturers Association: "*NEMA Standards Publication NU1-2018 Performance Measurements of Gamma Cameras*"
  - contains instructions for how to perform and report gamma camera QC tests
  - contains guidelines for analysing the resulting data

NEMA
National Electrical Manufacturers Association

- Institute of Physics and Engineering in Medicine (IPEM) Report 86: "*Quality Control of Gamma Camera Systems*"
  - contains the type and frequency of testing gamma cameras in planar and SPECT imaging



Gamma Camera Quality Control

- Purpose of quality control in Nuclear Medicine Imaging
  - to detect decline in image quality which may influence the diagnostic quality of clinical images
  - to avoid image artefacts due to camera malfunction
- Factors contributing to final image quality
  - uniformity
  - resolution (spatial & energy)
  - centre of rotation (SPECT)
- The data is checked
  - visually
  - analysed to generate quantitative values characterising performance

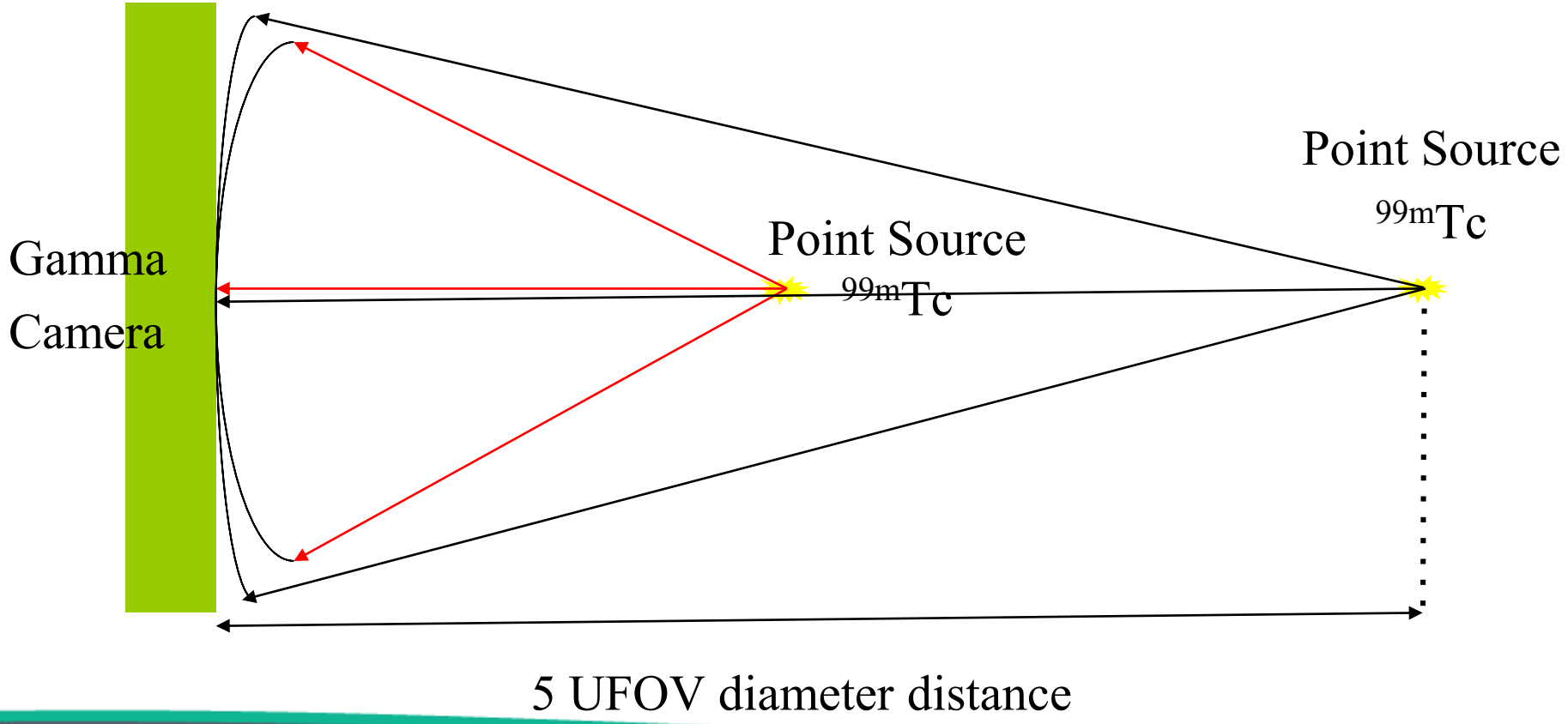
Uniformity

- Most sensitive parameter to changes due to variations in
  - photopeak location
  - photomultiplier tube performance
  - energy and linearity correction
- Most important quality control test
  - should be performed daily
- Performed to
  - ensure a uniform image is produced in response to a uniform flux of radiation
  - verify components are functioning properly

Intrinsic Uniformity

- Intrinsic uniformity measurement performed:
  - on a weekly basis
  - using a point source of ^{99m}Tc
  - activity of 40-50 MBq
  - acquiring 30,000,000 counts
  - positioned at five times the UFOV distance to ensure uniform irradiation of the detector

Intrinsic Uniformity



Intrinsic Uniformity

- *Advantages*
  - inexpensive technique
  - low radiation burden to users
  - system evaluated with the isotope that will be used for the majority of clinical studies
- *Disadvantages*
  - collimator not evaluated
  - time consuming to orientate the detector heads (on dual-headed systems)
  - increased risk of damage to the exposed crystal

Extrinsic Uniformity

- Measurement performed:
  - on a daily basis
  - generic assessment of uniformity
  - to check collimators for defects
- Extrinsic uniformity measurements performed:
  - using a ^{99m}Tc sheet source
  - using a ^{57}Co flood source
  - acquiring 4,000,000 counts





Extrinsic Uniformity

- *Advantages*
  - collimator does not need to be removed
  - simultaneous acquisition for both detectors
  - reduced time
- *Disadvantages*
  - expensive
  - needs to be replaced every 2-3 years
  - high-energy contaminants
    - (i.e. ^{56}Co and ^{58}Co)

Centre of Rotation (COR)

- Accurate COR:
  - important for high quality SPECT
- Alignment between mechanical and electronic COR essential
  - otherwise – ring artefacts & blurring
- Performed to maintain ability to resolve details in clinical SPECT studies
- Aims to quantify the lateral shift of the COR

Centre of Rotation (COR)

- Centre of Rotation measurements performed:
  - on a weekly basis
  - SPECT acquisition
  - using a ^{99m}Tc point source
  - approximately 100 MBq contained in a syringe
  - COR values compared against acceptance limits

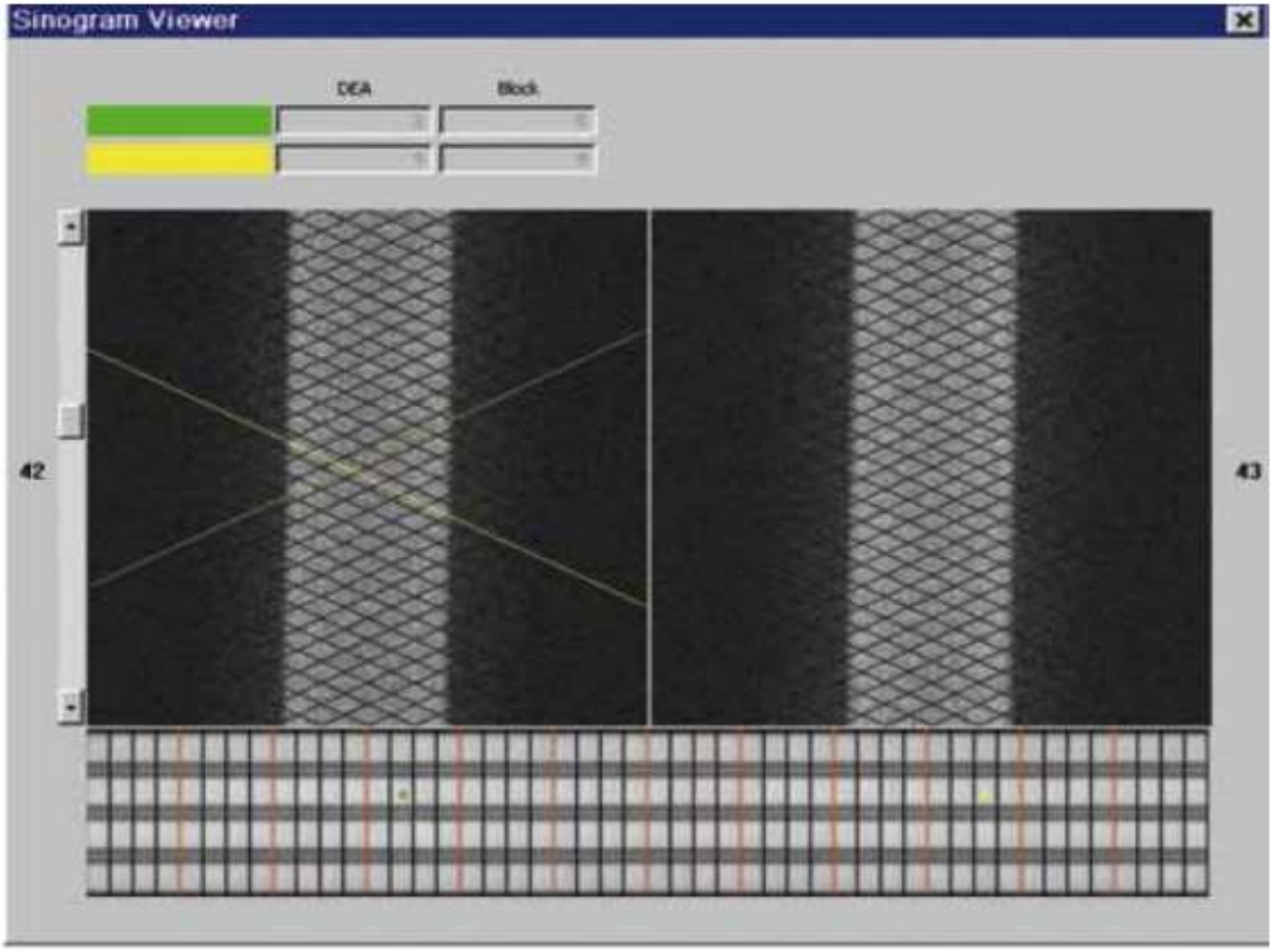


PET Quality Control

- Detector performance
  - daily QC (blank scan)
- Provides
  - overall assessment of PET detector response
  - identifies electronic drift or faulty detectors
- ^{68}Ge uniform cylinder ($\tau_{1/2}$=271 days)
  - positioned/scanned at the centre of scanner's FOV
  - review for defective detectors

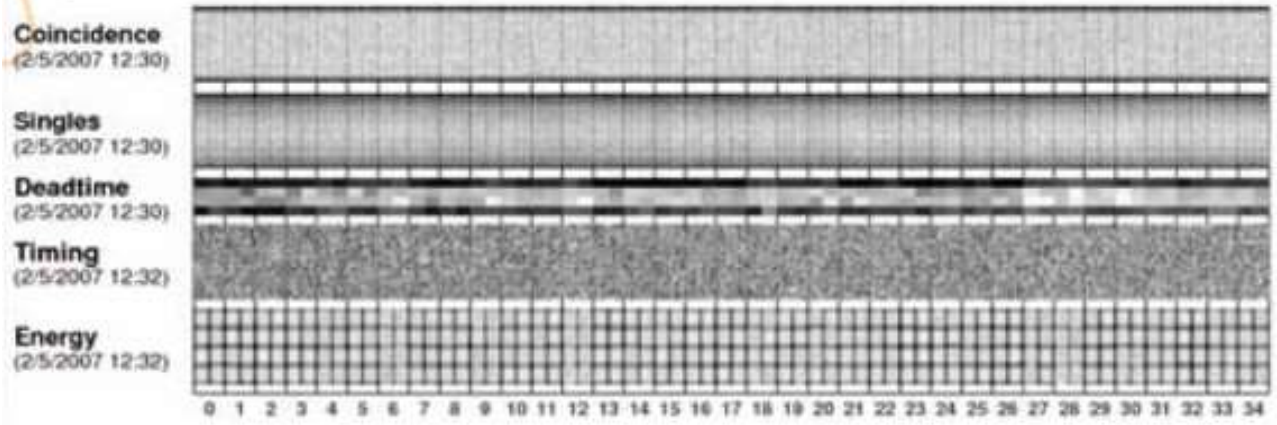


Detector Performance

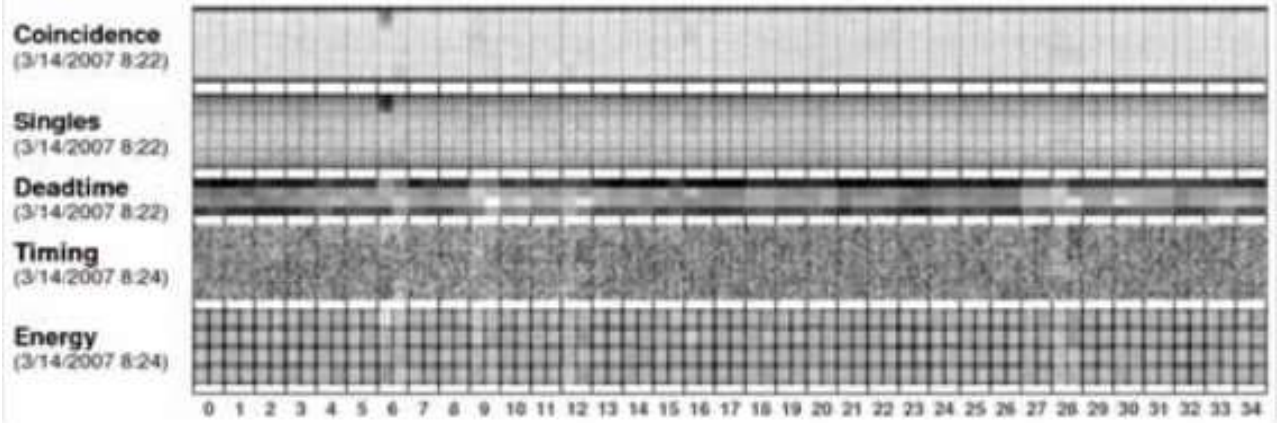


Detector Performance

Daily QC Good



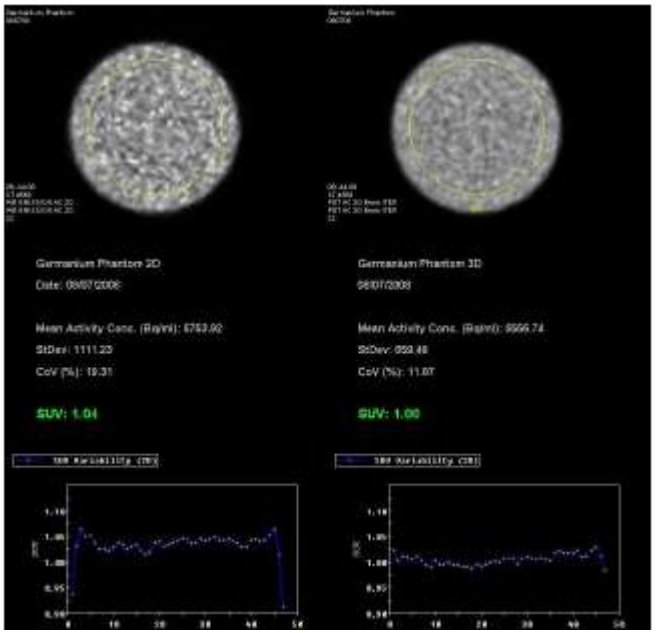
Daily QC – Block Error



SUV Stability

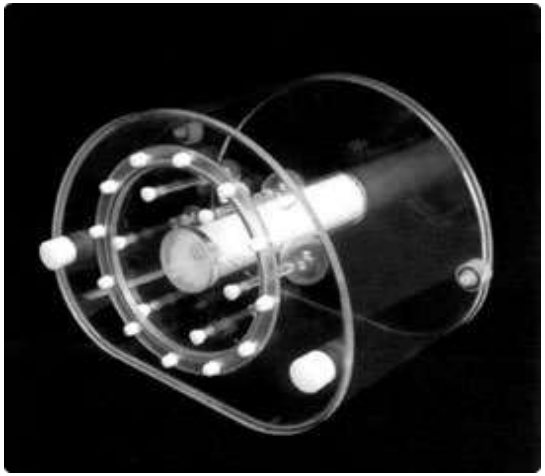
- SUV stability
  - ^{18}F of known activity
  - use uniform phantom
  - ensures correct quantitation

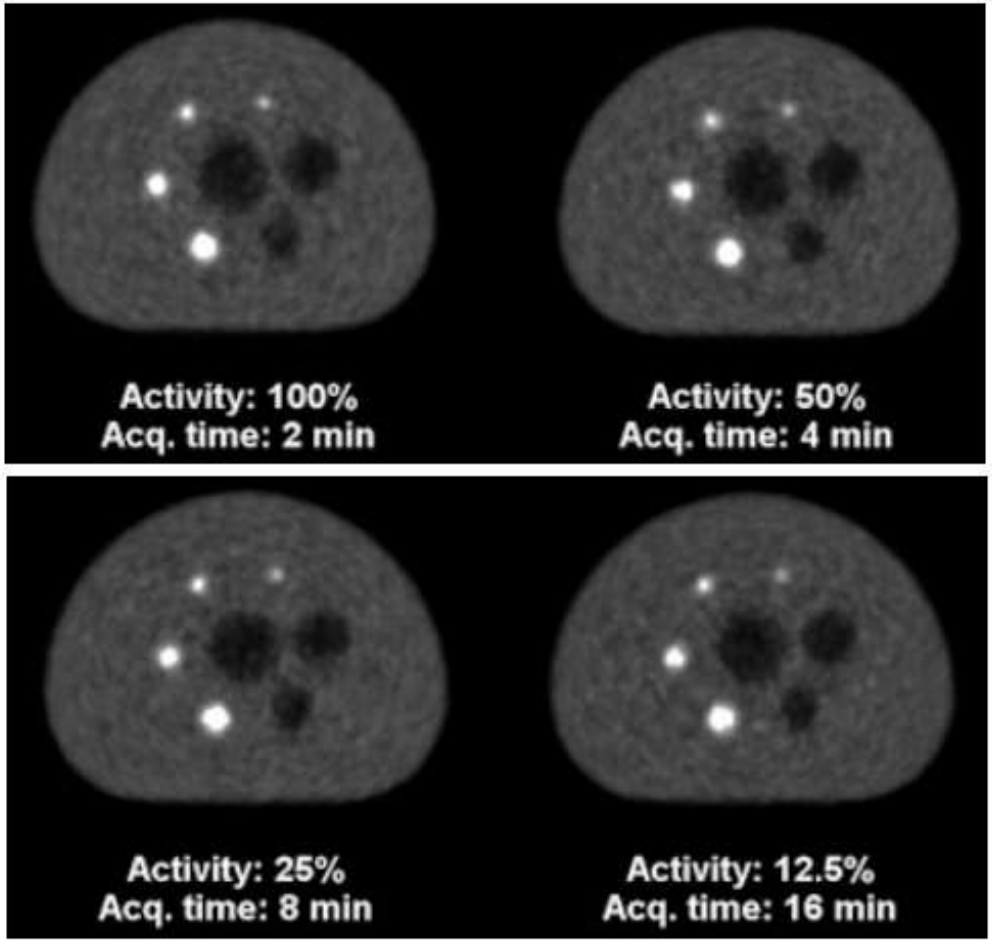




PET Image Quality

- Image quality
  - NEMA IQ phantom
  - assesses contrast and noise

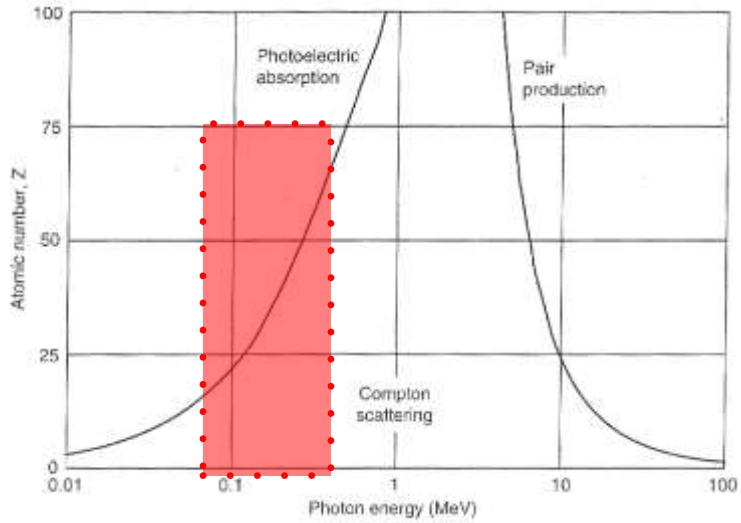




Radiation Detectors

Radiation Detectors

- Human senses unable to detect ionising radiation
  - reliance on devices to detect and quantify
- Detection of radiation is achieved via
  - ionisation in gases
  - Ionisation and excitation in certain solids/liquids
- Interaction mechanisms (Nuclear Medicine)
  - Photoelectric
  - Compton Scatter
- Typical isotopes
    - Tc^{99m} - 140keV
    - I^{123} - 159keV
    - In^{111} - 171 & 247keV
    - I^{131} - 363keV
    - F^{18} - 511keV



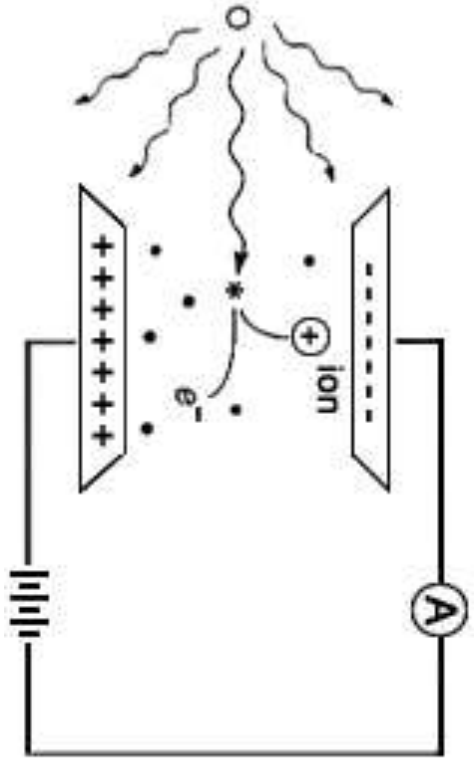
Detector Types

- Radiation detectors are classified by their material/detection method:
  - Gas detectors
    - Ionisation chamber
    - Proportional counter
    - Geiger-Muller (GM) counters
  - Scintillation detectors
    - Organic
    - Inorganic
  - Semiconductor detectors
  - … many others!



Gas-Filled Detectors

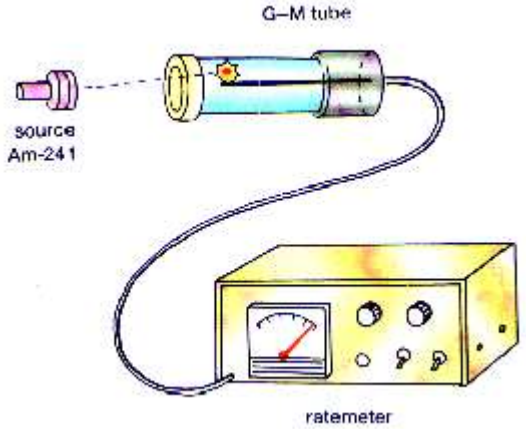
- Volume of gas between two electrodes
  - with voltage applied between electrodes
- Ion pairs produced
  - by incident radiation in the gas
- Positive ions (cations) are attracted
  - to the negative electrode (cathode)
- Electrons (anions) are attracted
  - to the positive electrode (anode)
- Electrical **current** is measured
  - with electrometer



Gas-Filled Detectors

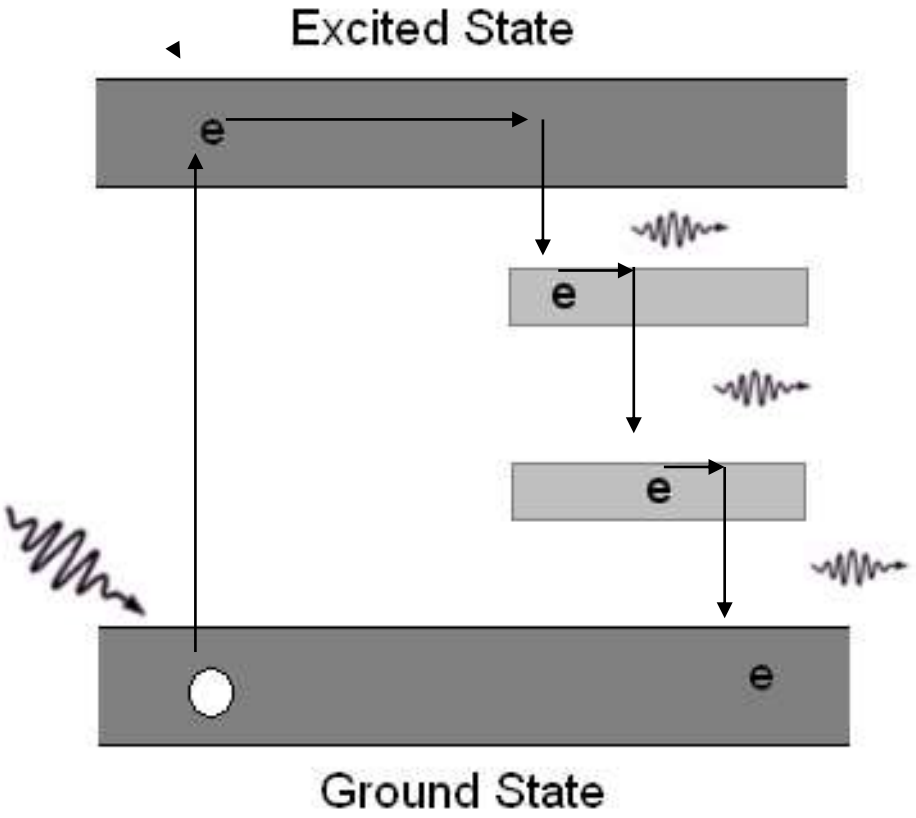
- Radionuclide calibrators
  - detects β and γ radiation
- Contamination monitors
  - large detection area
  - filled with a noble gas (eg Xe, Ar)
  - detects β and γ radiation
- Geiger-Muller Tube
  - small detection area
  - very sensitive
  - detects β and γ radiation



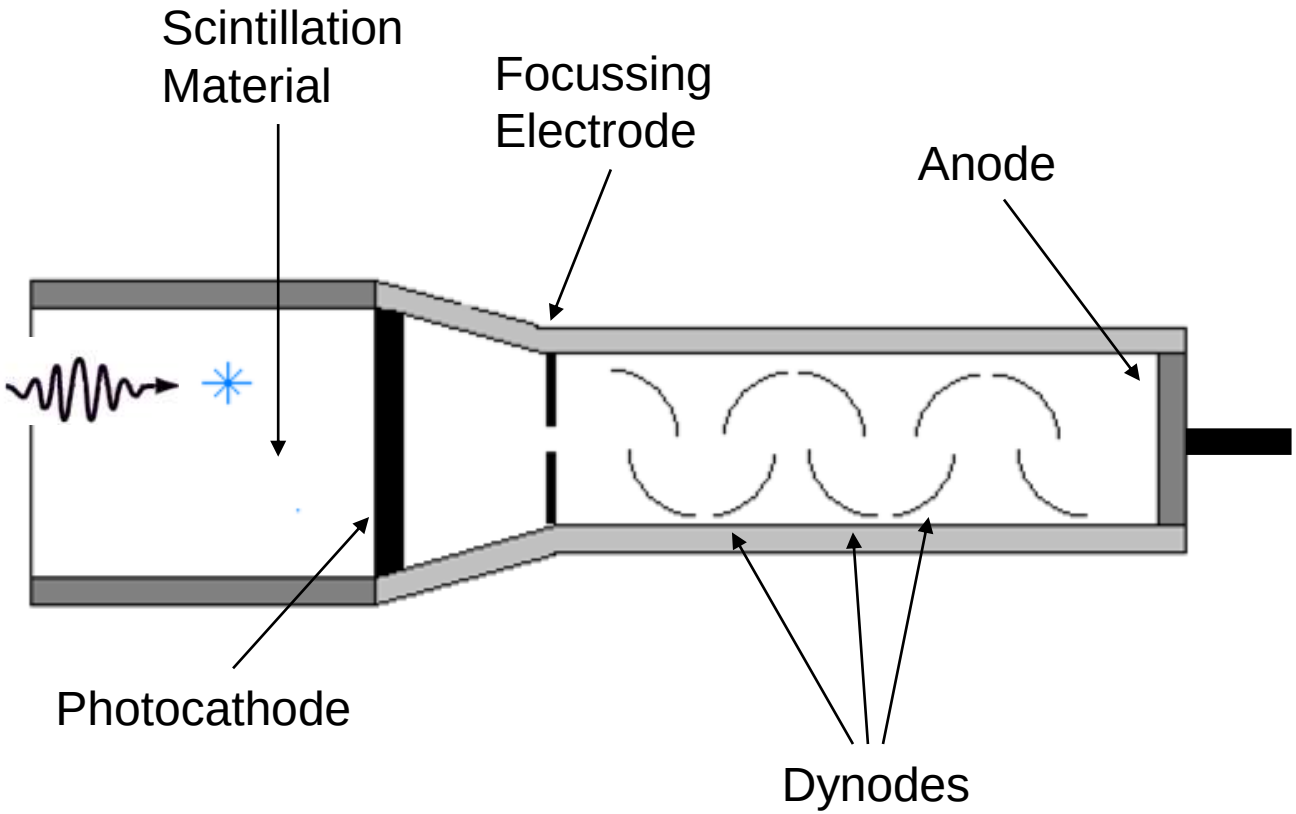


Scintillation Detectors

- Consist of
  - Scintillation crystal
  - Photomultiplier tube
  - Associated electronics
- Incoming radiation
  - Excites atoms of crystal
- Electrons
  - excited (excess energy)
  - release excess energy (photons)



Scintillation Detector



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Scintillation Detectors

- CoMo monitor
  - large area detector
  - plastic scintillator
  - can detect alphas



Scintillation Detectors

- Sample counter
  - very sensitive
  - energy discrimination
  - assays blood samples



Scintillation Detectors

- Sentinel node probes
  - localisation of nodes
  - mimises surgical trauma



Scintillation Detectors

- Gamma Camera
  - energy and positional discrimination



Radiation Dose

Radiation Dose

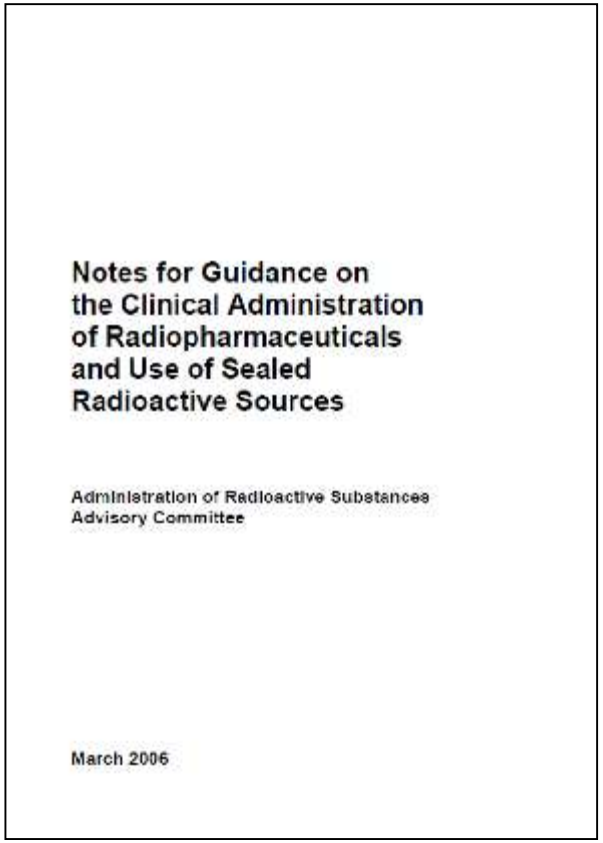
- Absorbed Dose (J/kg)
  - amount of energy deposited per unit mass (kg)
  - dose to an organ or tissue
  - unit is the Gray (Gy)
- Equivalent Dose
  - calculated for individual organs
  - unit is the Sievert (Sv)
  - depends on the radiation type



- Effective Dose
  - calculated for the whole body sum of all equivalent doses
  - Adjustments made for radiosensitivity of each organ
  - unit is the Sievert (Sv)
  - This gives us the risk of contracting cancer from the exposure
- THE EFFECTIVE DOSE IS THE OVERALL DOSE TO THE WHOLE BODY

Factors Affecting Patient Dose

- Administered activity
  - Diagnostic Reference Levels (ARSAC)
- Effective Half-Life
- Biodistribution
  - Radiochemical/nuclidic purity
  - pathology
  - drugs
- Type of radioactive decay
- Energy of emissions



Patient Dosimetry

- Need consider tissue radiosensitivity
- Use ICRP weighting factors to determine effective dose

Organ	ICRP
Gonads	0.08
Bone marrow (red)	0.12
Lung	0.12
Breast	0.12
Thyroid	0.04
Bone Surfaces	0.01
Remainder	0.12
Colon	0.12
Stomach	0.12
Bladder	0.04
Liver	0.04
Oesophagus	0.04
Skin	0.01
Salivary Glands	0.01
Brain	0.01

Radiopharmaceutical Doses

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Radiopharmaceutical	Route	Typical Activity	Effective Dose (mSv)	Clinical Use
^{99m}Tc-HDP	IV	600 MBq	3	Bone Imaging
^{9m9}Tc-MAG3	IV	100 MBq	0.7	Renal Imaging
^{201}Tl (thallous chloride)	IV	80 MBq	11	Myocardial Perfusion
^{123}I (sodium iodide)	Oral	400 MBq	5	Thyroid metastases
^{99m}Tc-labelled red cells	IV	800 MBq	6	Cardiac blood pool
^{99m}Tc-labelled white cells	IV	200 MBq	2	Localisation of infection

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Radiation Protection in Nuclear Medicine

Ionising Radiations (Medical Exposure) Regulations 2017 - IR(ME)R17

Protection of the Patient

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- Referral criteria
- Justification (ARSAC license holder)
- Patient identification procedures
- Labelling of syringes/vials
- Checking of activity prior to administration
- Thyroid blocking
- Conception, pregnancy, breast feeding

Protection of the Patient

- ARSAC certification of
  - medical practitioners
- Certificates
  - last for 5 years
  - specific to individual practitioner
  - named radiopharmaceuticals and uses
  - specific to individual site
- ARSAC Notes for Guidance

Pregnancy

- Departmental policy to check for pregnancy
  - in female patients of child bearing age
- Notices in departments
  - “Please inform a technologist if you may be pregnant”
- Does the risk to the patient from failure to diagnose and treat outweigh the radiation risk to the foetus?
  - Clinical benefit to the mother may be of indirect benefit to the unborn child

Conception: Advice to Males

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- Diagnostic administrations:
  - no evidence that pre-conceptual irradiation of males leads to any abnormality in their offspring (Doll R *et al.*1994)
  - no need to avoid conception for males undergoing routine diagnostic studies
- Therapeutic administrations:
  - possible appearance of larger quantities of such radionuclides in bodily fluids including semen and particularly in sperm.
  - avoid conception for 4 months

Conception: Advice to Females

- Diagnostic radiopharmaceuticals ($\tau_{1/2}$ < 7 days)
  - No need to avoid pregnancy (ARSAC Notes for Guidance)
- Diagnostic uses of longer lived radiopharmaceuticals
  - ^{131}I-MIBG (tumour imaging): 2 months
  - ^{131}I (thyroid metastases): 6 months
- Therapy
  - ^{131}I (≤800 MBq thyrotoxicosis therapy): 6 months
  - ^{32}P (≤200 MBq polycythemia therapy): 3 months
  - ^{89}Sr (≤150 MBq bone metastases therapy): 24 months

Breast Feeding

- Can the test be delayed?
- Mother to express breast milk prior to test
- Advise to stop breast feeding for a time depending upon the administered radiopharmaceutical
  - Any quantity of I131-iodide: STOP
  - 3 MBq of ^{32}P-phosphate: STOP
  - 80 MBq ^{99m}Tc-MAA: 12 hours
  - 800 MBq ^{99m}Tc-pertechnetate: 48 hours

Ionising Radiations Regulations 2017 - (IRR17)

Protection of Staff & Public

- **Time, Distance, Shielding**
  - handling techniques to reduce time
  - forceps
  - syringe shields
- **Contamination**
  - surfaces in rooms to be smooth and non-absorbent
  - isolators
  - protective clothing
  - no eating/drinking in rooms where unsealed sources used
  - wash hand basins close to exit of rooms
  - routine contamination monitoring

Statutory & Non-Statutory Guidance



- Health & Safety Executive
  - Working with ionising radiation. Ionising Radiations Regulations 2017. Approved code of Practice and Guidance 2018
- Institute of Physics in Engineering & Medicine (IPEM)
  - Medical & Dental Guidance Notes



Principles of Radiation Protection

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ALARP – ***A***s ***L***ow ***A***s ***R***easonably ***P***racticable

- Procedures optimised so staff doses ALARP
- Prior risk assessments
- Optimisation of protection in working areas
- Delineation of areas (controlled/supervised)
  - Avoidance of accidental entry

Radiation Protection

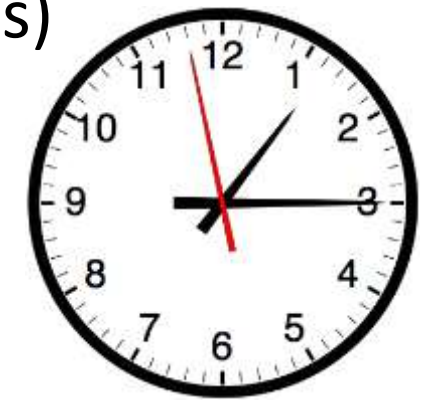


- Classification of radiation workers
- Information and training of staff
- Monitoring of exposures
- Monitoring of working environment



Radiation Protection of Staff

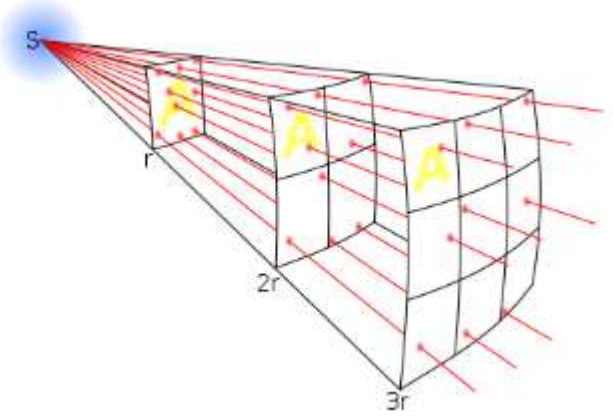
- ***Time***
  - Proximity of uptake rooms, toilets, scanner
  - Patient-free areas and access for staff
  - Working procedures (local rules)
  - Training
  - Automation



Radiation Protection of Staff

- ***Time***
  - Prepare every process carefully and perform tasks swiftly and carefully.
  - Examination and explanation *BEFORE* administration
  - Spend only as long as necessary with patients
  - Staff rotation to ‘share’ dose

Radiation Protection of Staff



- ***Distance***
  - make use of $1/r^2$ law
  - avoid staying beside patient unnecessarily
  - use intercom to communicate with patient
  - direct patients rather than escort them

Radiation Protection of Staff

- ***Distance***
  - use remote viewing
  - use long tongs (remote handling tools)
  - use trolley to carry doses



Radiation Protection of Staff

- ***Shielding***
  - Vial and syringe shields
  - Shielding waste etc.
  - Lead glass windows on cameras

    Lead mobile screens for positrons and γ-rays







Radiation Protection *from* Patients

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- No restrictions for diagnostic procedures
  - Exceptions:
    - > 10MBq ^{111}In-white blood cell studies
    - > 120MBq ^{111}In-octreotide
    - > 200MBq ^{67}Ga-citrate,
    - > 30MBq ^{131}I
    - > 150MBq ^{201}Tl-thallous chloride
    - > 800MBq ^{99}Tc^{m} myocardial perfusion agents
    - Assessment of exposure and contamination risk



- Routine restrictions for therapeutic administrations
  - Contamination – hygiene procedures
  - External irradiation - close-contact restrictions

Procedures in Wards

- Contamination
  - ward staff will be protected if they follow standard hygiene procedures (e.g. gloves/aprons)
  - handling & storage instructions should bedding/clothing become contaminated
- External irradiation
  - no special precautions usually required
  - risk assessment if patient requires intensive nursing

Keeping & Disposal of Radioactive Substances

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- EPR certificates for
  - use of radioactive materials
  - storage/disposal of radioactive materials
- Properly designed stores
- Stock records
- Reports annually sent to the Environment Agency
  - solid waste for incineration
  - solid waste to landfill
  - aqueous waste to drains

Transport of Radioactive Materials

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- Controlled under
  - Carriage of Dangerous Goods 2009 Regulations
- Staff involved
  - must be trained
- Vehicles
  - need to be marked
  - have emergency kits and instructions





Thank you for listening