Chapter 9: Physics in the Radiopharmacy

Slide set of 107 slides based on the chapter authored by R. C. Smart
of the IAEA publication (ISBN 978–92–0–143810–2):
Review of Nuclear Medicine Physics:
A Handbook for Teachers and Students

Objective:

To familiarize the student with the basic physics of the radiopharmacy laboratory.

IAEA
International Atomic Energy Agency

Slide set prepared in 2015 by R. Fraxedas (INEF, Havana, Cuba)

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9.1.1 Construction of dose calibrators

9.1 THE MODERN RADIONUCLIDE CALIBRATOR

9.1.1 Construction of dose calibrators

A typical dose calibrator (e.g. CRC 25R).

- Commercial systems comprise a cylindrical well ionization chamber connected to a microprocessor-controlled electrometer, providing calibrated measurements for a range of common radionuclides.
- The chamber is usually constructed of aluminium filled with argon under pressure (typically 1–2 MPa or 10–20 atm).

9.1 THE MODERN RADIONUCLIDE CALIBRATOR

9.1.1 Construction of dose calibrators

- The chamber is typically shielded by the manufacturer with 6 mm of lead to ensure low background readings.
- If additional shielding is used, the dose calibrator should be recalibrated or correction factors determined to ensure that the activity readings remain correct.

9.1 THE MODERN RADIONUCLIDE CALIBRATOR

9.1.1 Construction of dose calibrators

SPECIFICATIONS OF TWO COMMERCIAL DOSE CALIBRATORS

Specification	Capintec CRC-25R	Atomlab 200
Ionization chamber dimensions	26 cm deep × 6 cm diameter	26.7 cm deep × 7 cm diameter
Measurement range	Autoranging from 0.001 MBq to 250 GBq	Autoranging from 0.001 MBq to 399.9 GBq
Nuclide selection	8 pre-set, 5 user-defined (80 radionuclide calibrations in memory)	10 pre-set, 3 user-defined (94 radionuclide calibrations in manual)
Display units	Bq or Ci	Bq or Ci
Electrometer accuracy	<±2%	±1%
Response time	Within 2 s	1 s for activities >75 MBq
Repeatability	±1%	±0.3%

9.1 THE MODERN RADIONUCLIDE CALIBRATOR

9.1.2 Calibration of dose calibrators

9.1 THE MODERN RADIONUCLIDE CALIBRATOR

9.1.2 Calibration of dose calibrators

- A dose calibrator can be calibrated in terms of activity by comparison with an appropriate activity standard that is directly traceable to a national primary standard.
- The nuclide efficiency ε_N can be expressed as the sum of two components:

$$\varepsilon_N = \sum_i p_i(E_i) \cdot \varepsilon_i(E_i)$$

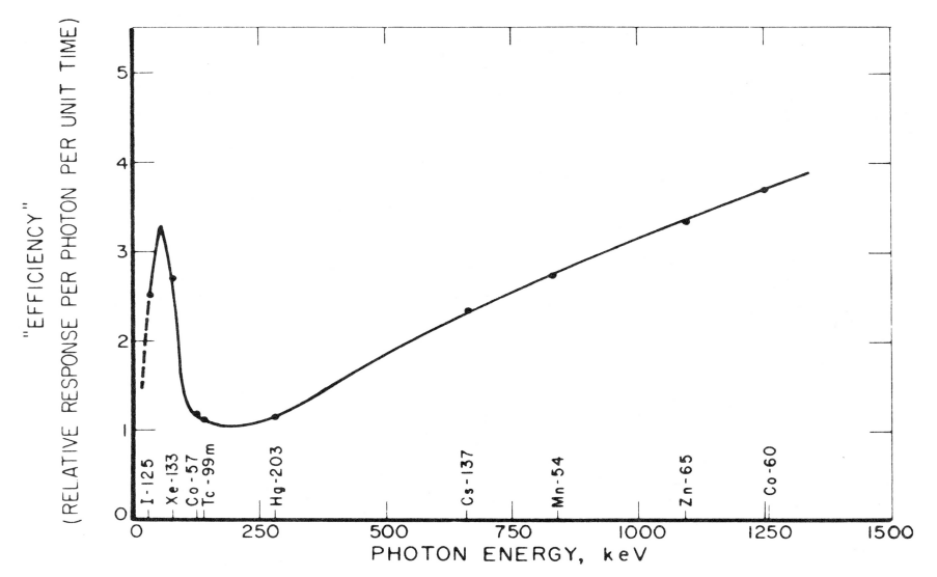
where

$p_i(E_i)$ is the emission probability per decay of photons of energy E_i;

$\varepsilon_i(E_i)$ is the energy dependent photon efficiency of the ionization chamber.

9.1 THE MODERN RADIONUCLIDE CALIBRATOR

9.1.2 Calibration of dose calibrators



Efficiency curve as a function of photon energy.

- Thin-walled aluminium chambers show a strong peak in efficiency at photon energies around 50 keV.
- Knowing the energy dependent photon efficiency curve for a specific ionization chamber will enable the nuclide efficiency for any radionuclide to be determined from the photon emission probability for each photon in its decay.

9.1 THE MODERN RADIONUCLIDE CALIBRATOR

9.1.3 Uncertainty of activity measurements

Major sources of uncertainty in dose calibrator measurements

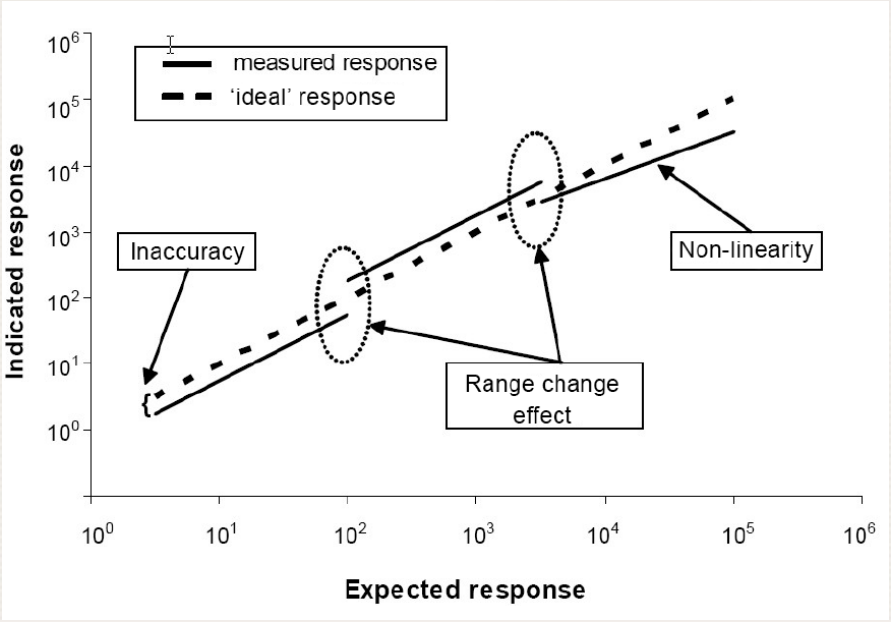
- Calibration factor
- Electronics
- Statistical considerations
- Ion recombination
- Background radiation
- Source container and volume effects
- Source position
- Source adsorption

9.1.3.1 Calibration factor

- For ^{99m}Tc and ^{131}I, the uncertainty of national standards is typically in the range of 1–3%.
- The calibration factor for different containers and/or a different volume may vary from the established calibration by a significant amount.

9.1 THE MODERN RADIONUCLIDE CALIBRATOR

9.1.3 Uncertainty of activity measurements



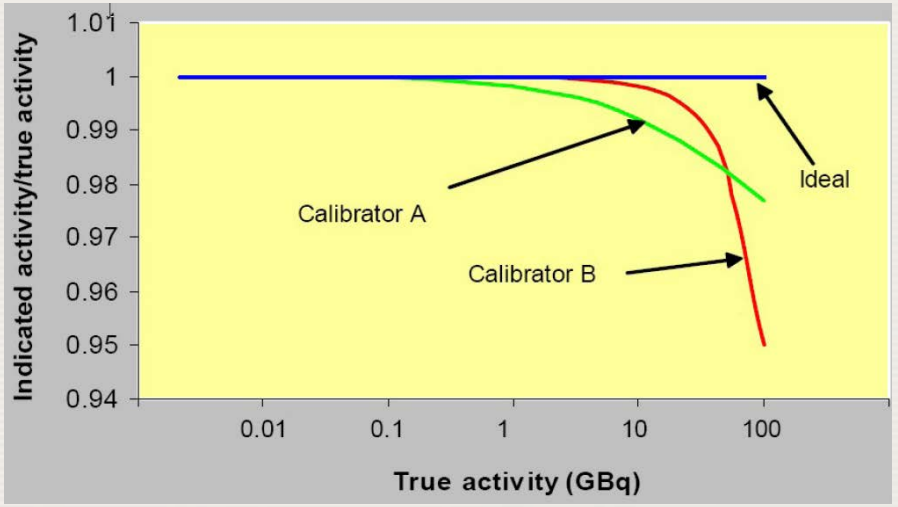
Electrometer inaccuracies (National Physical Laboratory Guide 2.1).

9.1.3.2 Electronics

- Electrometers measure the current output from the ionization chamber ranging from tens of femtoamperes up to microamperes — a dynamic range of 10^8.
- The potential for different linearity characteristics for each range may result in discontinuities when the range is changed.

9.1.3.4 Ion recombination

- As the activity of the source increases, the probability of recombination of the positive ions with electrons increases.
- At high source activities, this can become significant and lead to a reduction in the measured current.
- For most modern calibrators, the effects of recombination should be less than 1% when measuring 100 GBq of ^{99m}Tc.



Effects of recombination (National Physical Laboratory Guide 2.2).

9.1.3.6 Source container and volume effects

- Variations in the composition and thickness of the source container will give rise to corresponding variations in the measured activity.
- These effects will be most noticeable for low energy photon emitters and pure beta emitters.

9.1.3.6 Source container and volume effects

REDUCTION IN DOSE CALIBRATOR RESPONSE DUE TO INCREASES IN GLASS WALL THICKNESS OF 0.08 AND 0.2 mm

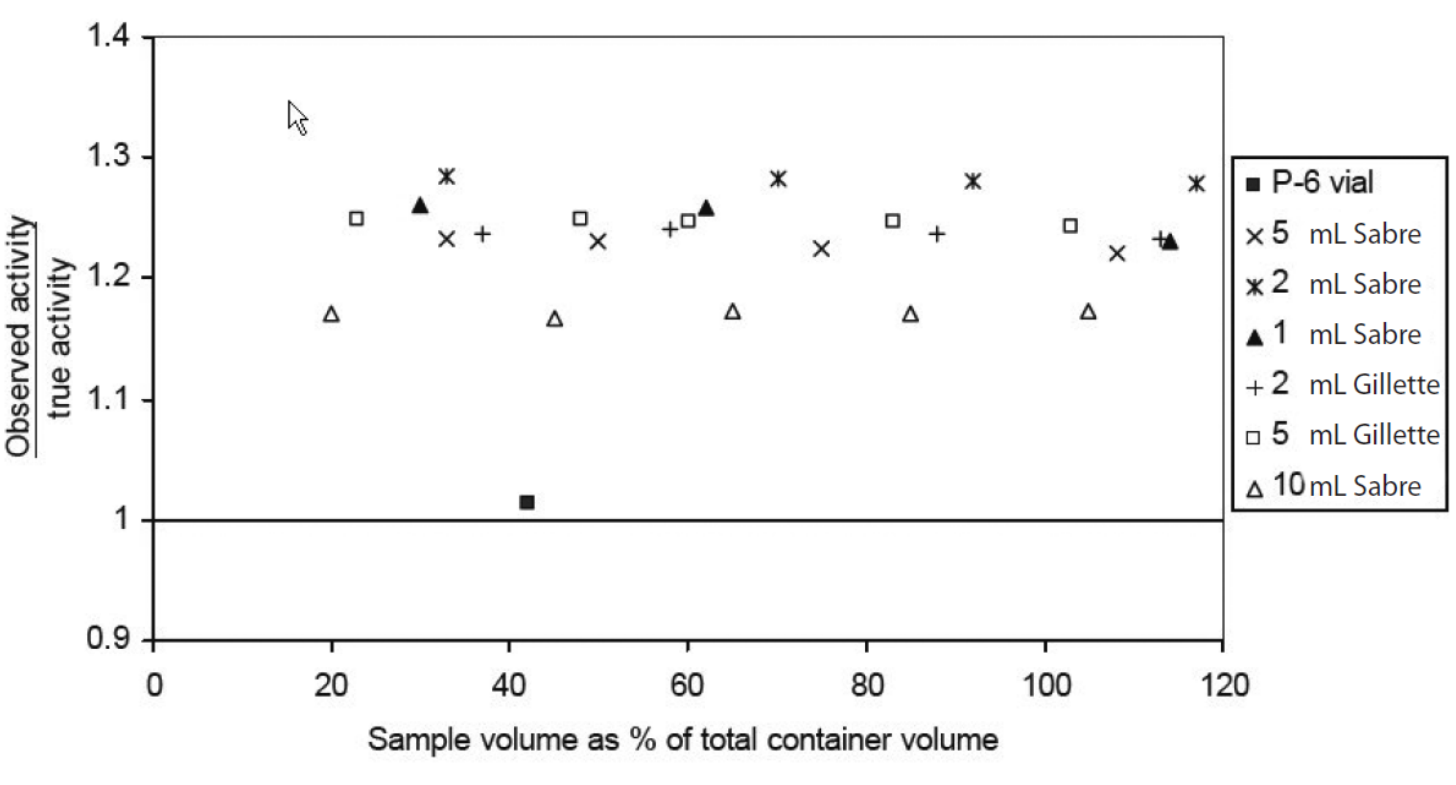
Radionuclide	Reduction in response with increase in vial wall thickness of	
	0.08 mm	0.2 mm
^{125}I	3%	7%
^{123}I	0.6%	1.5%
^{111}In	0.2%	0.4%
^{131}I	0.1%	0.25%

Variations in source geometry

- When the activity is drawn into a syringe, the source geometry will be different from that in a vial.
- Composition of the container, thickness and distribution will affect the measurement.
- Self-absorption of the emitted radiation will change as the source volume changes.

9.1 THE MODERN RADIONUCLIDE CALIBRATOR

9.1.3 Uncertainty of activity measurements



Activity measurements variation due to container type and size.

9.1.3.7 Source position

- The manufacturer's source holder is designed to keep the source at the area of maximum response on the vertical axis of the well.
- Variations in response due to changes in vertical height or horizontal position of a few millimetres are usually insignificant.

9.1.3.8 Source adsorption

- Certain radiopharmaceuticals have been observed to adsorb to the surface of the container.
- Adsorbed activity can be a significant percentage of the total.
- The possibility of activity adsorption should be considered whenever the facility uses syringes from a different manufacturer.

9.1 THE MODERN RADIONUCLIDE CALIBRATOR

9.1.4 Measuring pure beta emitters

Characteristics of beta emitters measurement

- The detection efficiency of ionization chambers for beta radiation is low.
- The dose calibrator response from beta particles will be almost entirely from bremsstrahlung radiation.

Measured activities of beta emitters

- In argon-filled ionization chambers, significant activities are required in order to obtain a precise estimate of the activity.

- However, as substantial activities of radionuclides are required to be used therapeutically, reliable measurements are possible using pure beta emitters used clinically such as ^{90}Y, ^{89}Sr and ^{32}P.

Dose calibrators efficiency

- The intrinsic efficiencies of dose calibrators can vary widely.
- Data from five different manufacturers showed that all systems had:
  - a good calibration for ^{32}P.
  - a reduction in efficiency of approximately 10–20% for ^{89}Sr.
  - a wide divergence in efficiency for ^{90}Y.

^{90}Y measurements

- The results obtained using the calibration factors supplied by the manufacturers ranged from 64 to 144% of the true value.
- This re-emphasizes the need for the calibration to be confirmed within the nuclear medicine department.

^{153}Sm and ^{186}Re measurements

- ^{153}Sm (103 keV, 28% abundance) and ^{186}Re (137 keV, 9.5% abundance) are gamma-beta emitting radionuclides.
- For these radionuclides the ionization chamber efficiency is primarily determined by the gamma contribution and the manufacturer's supplied calibrations will usually be accurate to within ±10%.

9.1 THE MODERN RADIONUCLIDE CALIBRATOR

9.1.5 Problems arising from radionuclide contaminants

Radionuclide purity

- The proportion of the total radioactivity that is present as a specific radionuclide is defined as the radionuclide purity.
- National and international pharmacopoeia specify the radionuclidic purity of a radiopharmaceutical.

9.1 THE MODERN RADIONUCLIDE CALIBRATOR

9.1.5 Problems arising from radionuclide contaminants

Effects of contaminants

- The presence of contaminants, even when less than 1% of the total activity, can have a marked effect on the ionization chamber current and, thus, on the measured activity.

- The presence of high energy contaminants will have an adverse effect on image quality due to increased septal penetration and will also lead to an increased radiation dose to the patient.

9.2 DOSE CALIBRATOR ACCEPTANCE TESTING AND QC

9.2.1 Acceptance tests

Acceptance tests for dose calibrators

- Accuracy and reproducibility
- Linearity
- Geometry response

9.2.1.1 Accuracy and reproducibility

- The accuracy is determined by comparing activity measurements using a traceable calibrated standard with the supplier's stated activity, corrected for radioactive decay.
- The reproducibility, or constancy, can be assessed by taking repeated measurements of the same source.

9.2.1.2 Linearity

Methods for assessment of linearity of dose response:

- Decaying source method
- Multiple dilutions method
- Graded attenuators method

9.2.1.3 Geometry response

- The measured activity may vary with:
  - the position of the source within the ionization chamber
  - the composition of the vial or syringe
  - the volume of liquid within the vial or syringe

- Correction factors can be determined for the different volumes or containers used.

9.2 DOSE CALIBRATOR ACCEPTANCE TESTING AND QC

9.2.2 Quality control

9.2.2.1 Background check

- Even if the source holder is empty, the dose calibrator will still record an 'activity' due to background radiation.
- At a minimum, the background should be determined each morning before the dose calibrator is used, and recorded.
- The technologist should also confirm the absence of any additional background before all activity measurements during the day.

9.2.2.2 Check source reproducibility

- A long lived check source should be used on a daily basis to confirm the constancy of the response of the dose calibrator.
- Sealed radioactive sources of ^{57}Co and ^{137}Cs, shaped to mimic a vial, are available commercially for this purpose.
- The check source should be measured on all radionuclide settings that are used clinically.
- A reading outside of that expected from previous results may indicate a faulty dose calibrator or a change in calibration factor.

9.3 STANDARDS APPLYING TO DOSE CALIBRATORS

9.3 STANDARDS APPLYING TO DOSE CALIBRATORS

International and national standards

- The International Electrotechnical Commission (IEC) has published two standards and a technical report relating to dose calibrators.
- IEC standards are often adopted by national standards organizations.
- There should also be national standards covering dose calibrators. The American National Standards Institute publication ANSI N42.13-2004 is often referenced by US manufacturers.

9.4 NATIONAL ACTIVITY INTERCOMPARISONS

9.4 NATIONAL ACTIVITY INTERCOMPARISONS

- National metrology institutes are responsible for the development and maintenance of standards, including activity standards and have undertaken national comparisons of the accuracy of the dose calibrators used in clinical practice.

- Such comparisons have used, where possible, the clinical radionuclides ^{67}Ga, ^{123}I, ^{131}I, ^{99m}Tc and ^{201}Tl.

- In some countries they are voluntary, while in others it is mandatory.

9.4 NATIONAL ACTIVITY INTERCOMPARISONS

SUMMARY OF THE RESULTS OF THE DOSE CALIBRATOR SURVEY UNDERTAKEN IN AUSTRALIA IN 2007

Radionuclide	^{99m}Tc	^{131}I	^{67}Ga	^{201}Tl
No. of calibrators	167	164	116	162
Within ±5% error	86%	80%	84%	73%
Within ±10% error	98%	95%	97%	94%
Within ±10% reproducibility	100%	100%	100%	100%

9.5 DISPENSING RADIOPHARMACEUTICALS FOR INDIVIDUAL PATIENTS

9.5.1 Adjusting the activity for differences in patient size and weight

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9.5.1 Adjusting the activity for differences in patient size and weight

Protocols

- Protocols used in nuclear medicine practices should specify the usual activity of the radiopharmaceutical to be administered to a standard patient.
- If a fixed activity is used for all patients, this will lead to an unnecessarily high radiation exposure to an underweight patient and may lead to images of unacceptable quality or very long imaging times in obese patients.

Scaling factors

- Scaling factors for the activity, to give a constant effective dose, can be derived from the expression

$$(W/70)^a$$

where W represents the weight of the person and the power factor a is specific for the radiopharmaceutical (ICRP 53,80,106).

9.5 DISPENSING RADIOPHARMACEUTICALS FOR INDIVIDUAL PATIENTS

9.5.1 Adjusting the activity for differences in patient size and weight

THE POWER FACTOR *a* RELATING BODY WEIGHT TO A CONSTANT EFFECTIVE DOSE ACCORDING TO THE EXPRESSION $(W/70)^a$ FOR 14 COMMON RADIOPHARMACEUTICALS

Radiopharmaceutical	*a* value	Radiopharmaceutical	*a* value
^{99m}Tc-DMSA	–0.706	^{99m}Tc-IDA	–0.840
^{99m}Tc-DTPA	–0.801	^{99m}Tc-tetrafosmin	–0.834
^{99m}Tc-MAG3	–0.520	^{99m}Tc-red cells	–0.859
^{99m}Tc-HMPAO	–0.849	^{99m}Tc-white cells	–0.869
^{99m}Tc-MAA	–0.842	^{18}F-FDG	–0.782
^{99m}Tc-sestamibi	–0.871	^{67}Ga-citrate	–0.931
^{99m}Tc-phosphonates	–0.763	^{123}I or ^{131}I iodide	–1.11

9.5 DISPENSING RADIOPHARMACEUTICALS FOR INDIVIDUAL PATIENTS

9.5.2 Paediatric dosage charts

Paediatric dose considerations

- Children are approximately three times more radiosensitive than adults, so determining the appropriate activity to be administered for paediatric procedures is essential.
- In addition to the scaling factor to be applied to the adult activity, a minimum activity must be specified in order to ensure adequate image quality.

9.5 DISPENSING RADIOPHARMACEUTICALS FOR INDIVIDUAL PATIENTS

9.5.2 Paediatric dosage charts

Dose scaling factors

- In the past, the scaling factors were assessed using weight alone or body surface area obtained from both height and weight.
- Recently, the European Association of Nuclear Medicine (EANM) Dosimetry and Paediatric Committees have prepared a dosage card which recognizes that a single scaling factor is not optimal for all radiopharmaceuticals.
- Radiopharmaceuticals could be grouped into three classes (renal, thyroid and others), with different scaling factors for each class.

9.5 DISPENSING RADIOPHARMACEUTICALS FOR INDIVIDUAL PATIENTS

9.5.2 Paediatric dosage charts

Dosage Card *(Version 1.2.2014)*

Multiple of Baseline Activity

Weight kg	Class A	Class B	Class C	Weight kg	Class A	Class B	Class C
3	1	1	1	32	3.77	7.29	14.00
4	1.12	1.14	1.33	34	3.88	7.72	15.00
6	1.47	1.71	2.00	36	4.00	8.00	16.00
8	1.71	2.14	3.00	38	4.18	8.43	17.00
10	1.94	2.71	3.67	40	4.29	8.86	18.00
12	2.18	3.14	4.67	42	4.41	9.14	19.00
14	2.35	3.57	5.67	44	4.53	9.57	20.00
16	2.53	4.00	6.33	46	4.65	10.00	21.00
18	2.71	4.43	7.33	48	4.77	10.29	22.00
20	2.88	4.86	8.33	50	4.88	10.71	23.00
22	3.06	5.29	9.33	52-54	5.00	11.29	24.67
24	3.18	5.71	10.00	56-58	5.24	12.00	26.67
26	3.35	6.14	11.00	60-62	5.47	12.71	28.67
28	3.47	6.43	12.00	64-66	5.65	13.43	31.00
30	3.65	6.86	13.00	68	5.77	14.00	32.33

$$A[MBq]_{\text{Administered}} = BaselineActivity \times Multiple$$

a) For a calculation of the administered activity, the baseline activity value has to be multiplied by the multiples given above for the recommended radiopharmaceutical class (see reverse).

b) If the resulting activity is smaller than the minimum recommended activity, the minimum activity should be administered.

c) The national diagnostic reference levels should not be exceeded!

- A dosage card is available on the EANM web site that gives the minimum recommended activity and a weight dependent scaling factor for each radiopharmaceutical.
- It was determined to give weight independent effective doses.
- An app for iOs and Android devices featuring the chart is now available.

Dosage card can be accessed online:
http://www.eanm.org/docs/EANM_Dosage_Card_040214.pdf?PHPSESSID=sf56mg9ehjv5r9t4v50mre3375

9.5 DISPENSING RADIOPHARMACEUTICALS FOR INDIVIDUAL PATIENTS

9.5.3 Diagnostic reference levels in nuclear medicine

Diagnostic reference levels

- The ICRP introduced in 1996 the term 'diagnostic reference level' (DRL) for patients.
- DRLs are investigation levels and are based on an easily measured quantity, usually the entrance surface dose in the case of diagnostic radiology, or the administered activity in the case of nuclear medicine.
- DRLs are referred to by the IAEA as guidance levels in Safety Report Series No. 40.

9.6 RADIATION SAFETY IN THE RADIOPHARMACY

9.6.1 Surface contamination limits

9.6 RADIATION SAFETY IN THE RADIOPHARMACY

9.6.1 Surface contamination limits

External and internal contamination

- Surface contamination with radioactivity could lead to:
  - contamination of a radiation worker
  - external irradiation of the skin of the worker

- Internal contamination could arise from
  - inhalation of the radionuclide
  - ingestion of the radionuclide

9.6 RADIATION SAFETY IN THE RADIOPHARMACY

9.6.1 Surface contamination limits

DERIVED LIMITS FOR SURFACE CONTAMINATION

Nuclide	Surfaces in designated areas, including protective clothing (Bq/cm^2)	Interiors of glove boxes and fume cupboards (Bq/cm^2)	Non-designated areas including personal clothing (Bq/cm^2)
^{18}F	100	1 000	5
^{32}P	100	1 000	5
^{51}Cr	1 000	10 000	50
^{67}Ga	1 000	10 000	50
^{89}Sr	100	1 000	5
^{90}Y	100	1 000	5
^{99m}Tc	1 000	10 000	50
^{111}In	1 000	10 000	50
^{123}I	1 000	10 000	50
^{125}I	100	1 000	5
^{131}I	100	1 000	5
^{177}Lu	1 000	10 000	50
^{201}Tl	1 000	10 000	50

The surface contamination limits given in this table were derived based on a committed effective dose limit of 20 mSv/a and the models for inhalation and ingestion given in ICRP publications

9.6 RADIATION SAFETY IN THE RADIOPHARMACY

9.6.2 Wipe tests and daily surveys

Surveys of the radiopharmacy areas

- To ensure that contamination limits are not exceeded, surveys of radiopharmacy areas should be routinely done.
- Logical sequence of surveys
  - Use survey meter to find unexpected exposed sources.
  - Check surfaces with contamination meter with appropriate probe, according to the radionuclides used.
  - Use wipe tests for areas of high background or for low energy beta emitters.

9.6 RADIATION SAFETY IN THE RADIOPHARMACY

9.6.2 Wipe tests and daily surveys

Wipe tests

- A minimum area of 100 cm^2 should be wiped.
- Activity can be assessed using a pancake probe, or more accurately in a well counter.
- For low energy beta emitters such as ^{3}H or ^{14}C, liquid scintillation counting must be used.
- When quantifying the surface contamination, it is generally assumed that a wipe test using a dry wipe will remove one tenth of the contamination.
- It is assumed that a wet wipe will remove one fifth of the contamination.

9.6 RADIATION SAFETY IN THE RADIOPHARMACY

9.6.3 Monitoring of staff finger doses during dispensing

9.6 RADIATION SAFETY IN THE RADIOPHARMACY

9.6.3 Monitoring of staff finger doses during dispensing

Hand and finger doses

- The most exposed parts of the hands are likely to be the tips of the index and middle fingers, and the thumb of the dominant hand.
- Finger doses may approach or exceed the annual dose limit of 500 mSv to the extremities.
- A practical way to monitor hands is to wear a ring monitor at the base of the finger.
- The ICRP recommends that the ring monitor be worn on the middle finger with the element positioned on the palm side, and that a factor of three should be applied to derive an estimate of the dose to the tip.
- The dose to the fingers is critically dependent on the dispensing technique used and the skill of the operator.

9.7 PRODUCT CONTAINMENT ENCLOSURES

9.7.1 Fume cupboards

9.7 PRODUCT CONTAINMENT ENCLOSURES

9.7.1 Fume cupboards

Fume cupboard suitable for use with radioactive materials

- A fume cupboard is an enclosed workplace designed to prevent the spread of fumes to the operator and other persons.
- The fume cupboard is designed to provide operator protection rather than protection for the product within the cabinet.
- The most common type of fume cupboard is known as a variable exhaust air volume fume cupboard which maintains a constant velocity of air into the cabinet (the face velocity).

Cupboard air discharge

- Air discharge type
  - Direct (or through filter) to the atmosphere.
  - Recirculating, after filtration or absorption (normally not applicable in radiopharmacies).
- Air discharged must meet local regulatory requirements.
- Smoke tests should be performed as part of QC schedule.

9.7 PRODUCT CONTAINMENT ENCLOSURES

9.7.2 LAMINAR FLOW CABINETS

Laminar flow cabinets characteristics

- Laminar flow cabinets provide a non-turbulent airstream of near constant velocity, which has a substantially uniform flow cross-section and with a variation in velocity of not more than 20%.
- Laminar flow cabinets provide product protection while a fume cupboard is designed to provide operator protection.
- The air supplied to the cabinet is usually passed through a high efficiency particulate air filter (99.999%).
- Operator protection cannot be ensured if airflow is disturbed during radiopharmaceutical manipulation.

9.7 PRODUCT CONTAINMENT ENCLOSURES

9.7.3 Isolator cabinets

9.7 PRODUCT CONTAINMENT ENCLOSURES

9.7.3 Isolator cabinets

Isolator cabinets characteristics

- Isolator cabinets provide both operator and product protection, used frequently for cell labelling.
- The product is manipulated through glove ports so that the interior of the cabinet is maintained totally sterile and full operator protection is provided.
- The isolator incorporates timed interlocks on the vacuum door seals to ensure that the product remains sterile.

9.8 SHIELDING FOR RADIONUCLIDES

9.8.1 Shielding for gamma, beta and positron emitters

Shielding requirements and materials

- Shielding is required
  - in the walls of the radiopharmacy.
  - in any containment enclosures.
  - in a body shield to protect the operator at the dispensing station
  - around individual vials and syringes containing radionuclides.
- Shielding materials for different purposes
  - Lead and concrete in walls.
  - Lead or tungsten in local shielding for gamma emitting radionuclides.
  - Aluminium or Perspex for pure beta emitters (to minimize bremsstrahlung radiation).

Shielding for beta emitters

- For beta emitters, the thickness of the shielding must be greater than its range to ensure that all betas are absorbed.
- Polymethyl methacrylate (Perspex or lucite) has a density of 1.19 g/cm^3, similar to the density of tissue and water, and is highly suitable for absorbing betas.

9.8 SHIELDING FOR RADIONUCLIDES

9.8.1 Shielding for gamma, beta and positron emitters

MAXIMUM BETA ENERGY AND THE RANGE IN WATER FOR FOUR BETA EMITTERS USED CLINICALLY IN NUCLEAR MEDICINE

Radionuclide	E_{max} (MeV)	Range in water (mm)
^{14}C	0.156	0.30
^{32}P	1.709	8.2
^{89}Sr	1.463	6.8
^{90}Y	2.274	11

9.8 SHIELDING FOR RADIONUCLIDES

9.8.1 Shielding for gamma, beta and positron emitters

Doses due to generators

- The highest surface dose rates encountered in the radiopharmacy are likely to be from $^{99}Mo/^{99m}Tc$ generators.
- It requires several centimetres of lead shielding to reduce the dose rates to an acceptable level.
- The generator as supplied will already contain substantial shielding but additional shielding will usually be required.

9.8 SHIELDING FOR RADIONUCLIDES

9.8.1 Shielding for gamma, beta and positron emitters

Manipulation of vials

- Vials of radiopharmaceuticals must be kept shielded.
- The shields are usually constructed so that only the rubber septum of the vial is accessible, thereby protecting the hands of the operator during dispensing.

9.8 SHIELDING FOR RADIONUCLIDES

9.8.1 Shielding for gamma, beta and positron emitters

Manipulation of vials

- Measurements in calibrators are done with the unshielded vials, increasing the exposure to the operator.
- Long forceps should always be used to manipulate radioactive vials.

9.8 SHIELDING FOR RADIONUCLIDES

9.8.1 Shielding for gamma, beta and positron emitters

Manipulation of syringes

- Syringe shields must be used whenever possible.
- These must be made of Perspex for the pure beta emitters and of lead or tungsten for the gamma emitters.
- A lead–glass window is necessary to permit observation of the contents of the syringe.

9.8 SHIELDING FOR RADIONUCLIDES

9.8.2 Transmission factors for lead and concrete

Transmission factors characteristics

- The attenuation of monoenergetic photons through materials such as lead or concrete will be exponential, characterized by the linear attenuation coefficient or the half-value layer (HVL).
- This is only true for narrow beam geometries.
- Moreover, non-monoenergetic radionuclides emit more than one gamma photon and their attenuation cannot be expressed as a simple HVL.
- Measured broad-beam transmission factors are available for lead and concrete, two of the most common shielding materials.

9.8 SHIELDING FOR RADIONUCLIDES

9.8.2 Transmission factors for lead and concrete

MEASURED TRANSMISION FACTORS FOR LEAD

Thickness of lead (mm)	^{99}Mo	^{99m}Tc	^{67}Ga	^{131}I	^{201}Tl[a]	511 keV
0	1.00	1.00	1.00	1.00	1.00	1.00
1	0.876	0.105	0.455	0.769	0.136	0.891
2	0.776	0.00835	0.280	0.601	0.0709	0.787
3	0.694	6.52×10^{-4}	0.191	0.475	0.0557	0.690
4	0.623	5.09×10^{-5}	0.135	0.379	0.0485	0.602
5	0.561	3.97×10^{-6}	0.0983	0.306	0.0438	0.523
6	0.507	3.10×10^{-7}	0.0730	0.248	0.0430	0.452
7	0.458		0.0551	0.203	0.0422	0.390
8	0.414		0.0420	0.168	0.0415	0.336
9	0.375		0.0324	0.139	0.0408	0.289
10	0.340		0.0253	0.116	0.0291	0.249
12	0.279		0.0157	0.0829	0.0282	0.183
14	0.229		0.0102	0.0605	0.0273	0.135
16	0.188		0.00682	0.0451	0.0193	0.0990
18	0.154		0.00476	0.0342	0.0187	0.0728
20	0.127		0.00345	0.0263	0.0132	0.0535
25	0.0774		0.00177	0.0143	0.00893	0.0247
30	0.0473		0.00104	0.00805	0.00602	0.0114
40	0.0176		4.11×10^{-4}	0.00267	0.00274	0.00240
50	0.00659		1.71×10^{-4}	9.04×10^{-4}	0.00124	5.00×10^{-4}

9.8 SHIELDING FOR RADIONUCLIDES

9.8.2 Transmission factors for lead and concrete

MEASURED TRANSMISSION FACTORS FOR CONCRETE (DENSITY: 2.35 g/cm^3)

Thickness of concrete (mm)	^{99}Mo	^{99m}Tc	^{67}Ga	^{131}I	^{201}Tl[a]	511 keV
0	1.00	1.00	1.00	1.00	1.00	1.00
10	0.845	0.779	0.884	0.916	0.759	0.958
20	0.718	0.607	0.769	0.825	0.581	0.909
30	0.614	0.473	0.661	0.735	0.449	0.852
40	0.527	0.368	0.564	0.649	0.349	0.789
50	0.454	0.287	0.477	0.570	0.274	0.722
60	0.393	0.224	0.402	0.498	0.217	0.653
70	0.341	0.174	0.338	0.434	0.173	0.584
80	0.296	0.136	0.282	0.377	0.139	0.518
90	0.258	0.106	0.236	0.327	0.112	0.456
100	0.225	0.0824	0.196	0.284	0.0912	0.399
120	0.172	0.0500	0.135	0.212	0.0612	0.301
140	0.132	0.0304	0.0928	0.158	0.0418	0.224
160	0.101	0.0184	0.0635	0.118	0.0290	0.166
180	0.0777	0.0112	0.0434	0.0879	0.0203	0.123
200	0.0598	0.00679	0.0296	0.0654	0.0143	0.0904
250	0.0312	0.00195	0.0113	0.0312	0.00607	0.0419
300	0.0163	5.60×10^{-4}	0.00433	0.0149	0.00262	0.0194
400	0.00443	4.61×10^{-5}	6.30×10^{-4}	0.00339	4.95×10^{-4}	0.00417
500	0.00121	3.80×10^{-6}	9.16×10^{-5}	7.70×10^{-4}	9.39×10^{-5}	8.95×10^{-4}

9.9 DESIGNING A RADIOPHARMACY

9.9 DESIGNING A RADIOPHARMACY

Location of a radiopharmacy

- The radiopharmacy should be located in an area that is not accessible to members of the public.
- There should be easy access from the radiopharmacy to the injection rooms and imaging rooms to minimize the distance that radioactive materials need to be transported.
- The radiopharmacy should not be adjacent to areas that require a low and constant radiation background such as a counting room.

9.9 DESIGNING A RADIOPHARMACY

Storage needs for the radiopharmacy

- A refrigerator will be required for the storage of lyophilized radiopharmaceutical kits.
- A storage area will be required for reconstituted radiopharmaceuticals, in shielded containers, together with radiopharmaceuticals purchased ready for dispensing such as ^{67}Ga-citrate and ^{201}Tl-chloride.
- The radiopharmacy must contain facilities for radioactive waste disposal.
- In addition, there must be shielded containers for ‘sharps’, such as syringes with needles.
- A separate shielded storage bin may be required if a large number of bulky items, such as aerosol or Technegas kits, need to be stored.

9.9 DESIGNING A RADIOPHARMACY

Areas of the radiopharmacy

- There should be an area within the radiopharmacy designated as a non-active area that is used for record keeping and/or computer entry.
- A dedicated dispensing area with a body shield and lead–glass viewing window will be required.
- If a Mo/Tc generator is used, this should be positioned away from the dispensing area to minimize the dose received by the person dispensing the radiopharmaceuticals.
- Labelling areas are dependent of the type of radiopharmaceutical that will be prepared, generally requiring specialized equipment.

9.9 DESIGNING A RADIOPHARMACY

Dedicated equipment for specific labelling techniques

- If cell labelling procedures are to be performed, a dedicated area with a laminar flow cabinet or isolator will be required to ensure that the product remains sterile during the labelling procedure.
- A fume cupboard, together with an activated charcoal filter on the exhaust, will be required if radio-iodination procedures are to be performed.
- Some radiopharmaceuticals require a heating step in their preparation. This is often performed using a temperature controlled heating block. This must be in a dedicated separately shielded area,. Similarly, the radiolabelling of blood samples may require local shielding of mixers and centrifuges.

9.9 DESIGNING A RADIOPHARMACY

Characteristics of surfaces

- Wall, floor and ceiling surfaces should be smooth, impervious and durable, and free of externally mounted features such as pipes or ducts to facilitate any radioactive decontamination.
- Bench surfaces should be constructed of plastic laminate or resin composites or stainless steel, and benches must be able to safely withstand the weight of any required lead shielding.

9.9 DESIGNING A RADIOPHARMACY

Contamination monitoring

- A contamination monitor must be available in a readily accessible location.
- A wall-mounted monitor to check for any hand contamination should be mounted near the exit from the radiopharmacy.
- A model which can be removed and used as a general contamination monitor is useful.

9.9 DESIGNING A RADIOPHARMACY

Decontamination facilities

- Hand washing facilities must be available which can be operated without the use of the operator's hands to prevent the spread of any contamination.
- An eye-wash should also be available.

9.10 SECURITY OF THE RADIOPHARMACY

9.10 SECURITY OF THE RADIOPHARMACY

Category of radioactive sources

- The IAEA has categorized radioactive sources on a scale of 1 to 5, based on activity and nuclide, where category 1 is potentially the most hazardous.
- Sources categorized as 1, 2 or 3 are known as security-enhanced sources.
- The security measures in place for safety purposes are considered adequate to ensure the physical security of category 4 and 5 sources.
- A Mo/Tc generator with an activity of greater than 300 GBq is a category 3 source.

9.10 SECURITY OF THE RADIOPHARMACY

Physical security of radioactive sources

- Radioactive materials are at most risk of being stolen or lost when they are being transported to and from the facility.
- It is essential that all consignments of radioactive materials to the nuclear medicine facility are left in a secure area and not left, for example, on a loading dock.

9.10 SECURITY OF THE RADIOPHARMACY

Radiopharmacy access

- Whether secure access (such as electronic card access) to the radiopharmacy during working hours is required will depend on local requirements and the layout of the nuclear medicine department.
- It is essential that only trained nuclear medicine staff have access to the radiopharmacy.

9.11 RECORD KEEPING

9.11 RECORD KEEPING

Record generation and keeping

- Records can be generated as
  - part of the quality assurance (QA) programme.
  - for the receipt and subsequent administration of a radiopharmaceutical to a patient.
  - for waste disposal.
- The local regulations may specify
  - the form in which these must be kept (paper and/or electronic).
  - the minimum records that must be kept at the facility.
  - the time for which the records must be kept.

9.11 RECORD KEEPING

9.11.1 Quality control records

9.11 RECORD KEEPING

9.11.1 Quality control records

Records should at the very least include details of:

- Acceptance testing of the dose calibrator
- All constancy tests
- Radiopharmaceutical testing

Record of failures and malfunctions

- Failures identified at acceptance testing.
- Failures of constancy testing.
- Failures of radiopharmaceutical testing.
- The actions taken to remedy those failures.

All these should be documented and these records kept for the lifetime of the equipment.

Generator elutions records

The following records should be kept for all generator elutions:

- Time of elution
- Volume of eluate
- ^{99m}Tc activity
- ^{99}Mo activity
- Radionuclidic purity

9.11 RECORD KEEPING

9.11.2 Records of receipt of radioactive materials

Radioactive materials records

- Complete records should be kept of:
  - The radionuclide
  - Activity
  - Chemical form
  - Supplier
  - Supplier's batch number
  - Purchase date
- On arrival, if a package containing radioactive material is suspected of being damaged, the package should be:
  - Monitored for leakage with a wipe test;
  - Checked with a survey meter for unexpectedly high external radiation levels.

  If a package is damaged or suspected of being damaged, the supplier should be contacted immediately, and the details recorded

9.11 RECORD KEEPING

9.11.3 Records of radiopharmaceutical preparation and dispensing

Radiopharmaceutical preparations records

Records of each preparation should include the:

- Name of the radiopharmaceutical
- Cold kit batch number
- Date of manufacture
- Batch number of final product
- Radiochemical purity results
- Expiry date

Patient dose dispensed records

A record for each patient dose dispensed must be kept with the:

- Name of the patient
- Name of the radiopharmaceutical
- Measured radioactivity
- Time and date of measurement

9.11 RECORD KEEPING

9.11.4 Radioactive waste records

Characteristics of Nuclear Medicine radioactive wastes

- Radioactive waste generated within a nuclear medicine facility usually consists of radionuclides with half-lives of less than one month.
- This waste will normally be stored on-site, be allowed to decay to background radiation levels.
- After decay, it can then be disposed of as normal waste or biologically contaminated waste.

Radioactive waste packages labelling

Each package of waste (bag, sharps container, wheeled bin) must be marked with the:

- Radionuclide, if known.
- Maximum dose rate at the surface of the container or at a fixed distance (e.g. 1 m).
- Date of storage.

Records information and update

- The wastes information should be recorded, together with information identifying the location of the container within the store, and the likely release date (e.g. ten half-lives of the longest lived radionuclide in the container).

- When the package is finally released for disposal, the record should be updated to record the dose rate at that time, which should be at background levels, the date of disposal, and the identification of the person authorizing its disposal.

Disposal of old sealed sources

Old sealed sources, previously used for quality control or transmission scans, such as

- ^{137}Cs
- ^{57}Co
- ^{153}Gd
- ^{68}Ge

should be kept in a secure store until the activity has decayed to a level permitted for disposal, or the source can be disposed of by a method approved by the regulatory authority.