Quality Control and Non-Imaging Instrumentation
What can go wrong?

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SNM Annual Meeting - Toronto
Objectives

- Explain the purpose of quality control procedures on non-imaging instrumentation in nuclear medicine including:
  - Dose calibrators
  - Well counters
  - Thyroid/surgical probes
- Describe the pitfalls and bloopers associated with non-imaging equipment
Dose Calibrator: Chambers

- Sealed, pressurized container that has a voltage potential applied to it.
- Sensitivity is inversely related to the pressure of the inert gas in the chamber.
Dose Calibrator: Chambers

- Interaction of the radiation with the pressurized gas causes current to flow from the anode to the cathode.
- The current flow is detected and measured by the electronic circuitry which converts the ionizations into a displayed activity.

Let's take a look inside the chamber:

[Diagram of a cylindrical chamber with anode and cathode marked, and voltage potential applied from anode to cathode.]

The voltage potential is applied from anode to cathode.
Dose Calibrator: Chambers

Pressing the corresponding nuclide button or entering a calibration number displays activity for a specific isotope.

Let's take a look inside the chamber:

- Pressurized Gas (inert)
- Anode
- Cathode

The voltage potential is applied from anode to cathode.
Dose Calibrators

- Calibration tests
  - Daily test
  - Constancy
  - Accuracy
- Quality Control
  - Linearity
  - Geometry

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Acceptance/QC Testing

- **Daily or Self Test - Chamber:**
  - Performed daily prior to measuring any patient dose
    - **Auto Zero/electrometer sensitivity** – measures voltage drift since the last measurement.
    - **Background** – measures, stores and automatically subtracts from all measurements
    - **Chamber voltage/bias** – measurement compared with the factory value.
    - **Data (software) check** – internal assessment of the built-in nuclide data
    - **Accuracy/Constancy** – performed with pre-defined reference sources

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Acceptance/ QC Testing

- **Constancy**¹,²:
  - Also known as precision testing, determines the reproducibility of measurements from day to day
    - Uses a long-lived reference source of known activity (e.g. Cs-137, Co-57) traceable to the National Bureau of Standards (NIST or ANSI)
    - Measured at each of the commonly used radionuclide settings and compared to expected values, corrected for decay.
    - Measurements should be within ± 5-10% of the expected value
  - *Important:* Geometry plays a key role in measurements

Consistent Geometry

- Vial placement must be consistent:
  - Centered
  - Upright
  - Not touching sides
Consistent Geometry

- Inconsistent placement affects:
  - activity reading
  - percent deviation
  - comparison to previous data
Constancy Testing

![Constancy Chart]

Days: 0 to 25
Activity: 188.00 to 195.00

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Acceptance/QC Testing

- Accuracy\textsuperscript{1,2}:
  - Assesses the ability of the dose calibrator to provide a true measure of the activity of different gamma energies.
    - At least two different long-lived NIST or ANSI traceable sources of known activity should be used
    - One source should have a photon energy between 100-500 keV
    - Measurements should be within $\pm$ 5-10\% of the expected value
  - \textit{Important:} Consistent geometry required

## Acceptance/QC Testing

**Accuracy Test**

**Performed 11-22-2008**

<table>
<thead>
<tr>
<th>Source</th>
<th>Cal Date</th>
<th>S/N</th>
<th>Activity mB</th>
<th>Activity mCi</th>
<th>Corrected for current date</th>
<th>Actual</th>
<th>%Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co57</td>
<td>01-Jul-08</td>
<td>A9538</td>
<td>213.4 mB</td>
<td>5.76 mCi</td>
<td>1.24 mCi</td>
<td>1.22 mCi</td>
<td>1.9%</td>
</tr>
<tr>
<td>Ba133</td>
<td>01-Dec-02</td>
<td>A9549</td>
<td>8.639 mB</td>
<td>233.48 uCi</td>
<td>211 uCi</td>
<td>214 uCi</td>
<td>1.4%</td>
</tr>
<tr>
<td>Cs137</td>
<td>01-Dec-02</td>
<td>A4519</td>
<td>8.253 mB</td>
<td>223.05 uCi</td>
<td>215 uCi</td>
<td>218 uCi</td>
<td>1.4%</td>
</tr>
</tbody>
</table>

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Acceptance/QC Testing

- **Linearity**: Assesses the linear response of the dose calibrator over a wide range of activity from curies or millicuries to microcuries.

- Linearity may be performed using the:
  - **Manual decay method**: a single radioactive source is periodically measured over several days
  - **Calicheck or Lineator System**: a single radioactive source is measured multiple times in a short period of time using various leaded tubes simulating decay from mCi to uCi

- Measurements should be within ± 5% of the expected value

- **Important**: Consistent geometry required for each measurement

Acceptance/ QC Testing - Linearity

Calicheck/Lineator Test -
- determine correction factors:

<table>
<thead>
<tr>
<th>Tube Insert</th>
<th>mCi</th>
<th>Calibration Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black only</td>
<td>209.00</td>
<td>1</td>
</tr>
<tr>
<td>Black and red</td>
<td>120.30</td>
<td>1.737</td>
</tr>
<tr>
<td>Black and orange</td>
<td>66.50</td>
<td>3.142</td>
</tr>
<tr>
<td>Black and yellow</td>
<td>19.40</td>
<td>10.773</td>
</tr>
<tr>
<td>Black and green</td>
<td>5.59</td>
<td>37.388</td>
</tr>
<tr>
<td>Black and blue</td>
<td>1.89</td>
<td>110.582</td>
</tr>
<tr>
<td>Black and purple</td>
<td>0.45</td>
<td>466.517</td>
</tr>
</tbody>
</table>

All measurements completed and recorded within 6 minutes.

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Acceptance/ QC Testing - Linearity

- Calicheck/Lineator Test:
  - applying correction factors

<table>
<thead>
<tr>
<th>Tube Insert</th>
<th>Measured Activity mCi</th>
<th>Calibration Factor</th>
<th>Result mCi</th>
<th>% Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>124.50</td>
<td>1</td>
<td>124.5</td>
<td></td>
</tr>
<tr>
<td>Black and red</td>
<td>71.40</td>
<td>1.737</td>
<td>124.0</td>
<td>0.24%</td>
</tr>
<tr>
<td>Black and orange</td>
<td>40.10</td>
<td>3.142</td>
<td>126.0</td>
<td>1.19%</td>
</tr>
<tr>
<td>Black and yellow</td>
<td>11.50</td>
<td>10.773</td>
<td>123.9</td>
<td>0.49%</td>
</tr>
<tr>
<td>Black and green</td>
<td>3.31</td>
<td>37.388</td>
<td>123.8</td>
<td>0.60%</td>
</tr>
<tr>
<td>Black and blue</td>
<td>1.11</td>
<td>110.582</td>
<td>122.7</td>
<td>1.40%</td>
</tr>
<tr>
<td>Black and purple</td>
<td>0.26</td>
<td>466.517</td>
<td>122.7</td>
<td>1.45%</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>123.9</td>
<td></td>
</tr>
</tbody>
</table>

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Acceptance/ QC Testing

- Geometric Variation/Calibration\textsuperscript{1,2}:
  - Assesses the effect of sample volume and/or configuration in a vial or syringe on the measurement of a sample’s activity

  - Type of container and syringe (glass or plastic)
  - Depth

Acceptance/ QC Testing

- **Geometric Calibration:** Container
  - Use a glass or plastic vial or syringe
  - Measure/add 1 ml of activity to the container
  - Measure/record the activity
  - Add one additional ml of saline or water
  - Measure/record the activity
  - Repeat process until the container is full
  - Plot the results and note possible deviations not attributed to decay
  - **Important:** maintain consistent geometry for each measurement

**Notes:**
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Acceptance/ QC Testing

- **Geometric Variation:** Depth\(^{1,2}\):
  - Use a glass or plastic vial
  - Measure/add 5-10 ml of activity to the vial
  - Measure the vial in 1 cm intervals from the bottom to the top of the chamber
  - Plot the results and note where the change occurs


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Acceptance/ QC Testing

- **Diagnostics:**
  - Tests the integrity of the system
  - If attached to a printer, a report is printed containing the system configuration
    - List of nuclides including half life, calibration number (for chamber) and efficiency (for well)
    - Defines user added nuclide information
    - Describes user key assignments
    - Lists test source data
    - Lists chamber and well counter system parameters

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Acceptance/ QC Testing

- **Daily – Chamber:**
  - Daily self test – initialized from the display unit
  - Constancy – measured from the display unit or nuclear medicine manager computer-type system

- **Quarterly - Chamber:**
  - System Test or Diagnostics
  - Accuracy
  - Linearity
Potential Errors in QC Testing

- Selecting the incorrect reference source
- Incorrectly positioning the reference source in the chamber:
  - Correct vial source placement: Centered in dipper cup
- Interfering radioactive sources
  - Patients
    - Recently injected patients
    - Patients with residual activity from a recent study
  - Room/Lab Background
    - Patient doses
    - Laboratory waste
- Battery test/test button – not routinely tested can lead to measurement failures
Potential Errors in QC Testing

- Constancy error:
  - Incorrect calibration source information
    - Time/date entered incorrectly
    - Activity entered incorrectly
  - Time/date error on dose calibrator
    - Many years behind
    - Many years in the future
Dose Calibrator

**Linearity Pitfalls:**
- Incorrect correction factors for each sleeve device
- Bent/damaged sleeve devices
- Geometry errors
  - Volume in syringe or vials
  - Placement of vial/syringe in chamber
Dose Calibrator

- Measurement pitfalls:
  - Inadequate measurement time:
    - \( \geq 6 \) seconds for high activity measurements
    - \( \geq 20 \) seconds for low activity measurements
  - Placement of vial or syringe in chamber:
    - Syringes too large/small for the syringe holder
    - Vials placed incorrectly in dipper cup
Dose Calibrator

- Measurement pitfalls continued:
  - Inappropriate components and/or accessories:
    - Dippers
    - Liners
    - Moly Canister

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Probe and Well Technology
Probe and Well Technology

- New Terminology
  - CPM
  - DPM
  - MDA
  - MCA
  - Dead time
  - Real time
  - Live time

- New Terminology
  - Efficiency
  - Conversion factors
  - Sensitivity
  - Chi-Square
  - Energy spectrum

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Probe and Well Technology

- **Realtime**: Actual clock time
- **Livetime**: Active counting time - always lower than the Realtime
- **Deadtime**: Time that the instrument is not counting
  - The higher the deadtime the more saturated the crystal
  - Deadtimes greater than 80% can compromise results.

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Probe and Well Technology

- **CPM:** Counts per minute – energy from a radioactive source that is detected by the sodium iodide crystal. *Note:* Background is always in CPM.

- **DPM:** Radioactive decay or disintegrations per minute, calculated at a constant rate of $2.22 \times 10^{10}$ disintegrations per minute or $3.7 \times 10^7$ per second per 1 mCi.

- **EFF:** Efficiency – the ratio of detected counts measured by the system to the actual rate of decay, or disintegrations per minute for a specific nuclide or region of interest.

- **CF:** Conversion factors – constants used to convert measurements in cpm to dpm.
Probe and Well Technology

- **MDA:** minimum detected activity – the smallest activity that can be detected by an instrument for a specific nuclide or region of interest.
- **MCA:** multichannel analyzer
- **Chi-square:** performed to assess the reproducibility of measurements
- **Nanocurie:** 1/1000th of a microcurie and most often used to record results from wipe testing of sealed sources or bioassay results.

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# Probe and Well Technology

## Sensitivity
- the ability to detect low levels of activity

<table>
<thead>
<tr>
<th>Capabilities and Features</th>
<th>Nal Drilled-Well Crystal</th>
<th>GM-Tube Detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counting time required to achieve sensitivity of 1 nCi (2220 dpm), required by regulations</td>
<td>6 to 180 sec (0.1 to 3.0 min)</td>
<td>300 to 6,000 sec (5 min to 10 min)</td>
</tr>
<tr>
<td>Counting time recommended for low background levels</td>
<td>1 to 3 min</td>
<td>at least 20 min</td>
</tr>
<tr>
<td>Offers energy discrimination, which helps users identify radionuclide contaminants with gamma spectroscopy</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Achieves sensitivity of 200 dpm, required for iodine therapy</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Handles high count rates (60,000 cps) before exceeding 30% dead time</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Evaluates identity of radiopharmaceuticals and brachytherapy sources, helps identify contaminants</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
Daily
- Daily test and/or Auto Calibration
  - Self calibration - probe and well
  - FWHM - detector resolution - probe and well
- Constancy - measured activity versus decay-corrected activity
- Linearity - performed on some probes/wells
  - Assesses activity over a broad range of energy peaks and corrects for any non-linearity in the NaI detector
  - Provides accurate identification of energy peaks
  - ROI’s in the thyroid uptake and lab tests are based on the energy ranges defined by the Eu-152 energy calibration

Quarterly
- Chi-Square (reproducibility)
Potential Errors in QC Testing

- Selecting the incorrect reference source
- Incorrectly positioning the reference source:
  - Well source: Activity Side Down
  - Probe source: Activity Side Down
- Inconsistent distance
- Interfering radiation
Probe and Well Technology

- **Common Pitfalls:**
  - Reference source information entered incorrectly
  - Reference source activity too high/low
  - Wrong isotope selected for wipe or probe measurement
  - Distance
  - Background errors:
    - Not measured
    - Not subtracted

- **Common Pitfalls:**
  - Contamination
    - Well/probe
  - Interfering radioactive sources
    - Patients
    - Trash
    - External sources
      - X-ray or CT machines

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Probe: Surgical

- Calibration
- Nuclide Selection
- Directional Measurements
- Sensitivity
- Volume and Visuals
- Cleaning
- Storage

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Probe: Surgical

- **Calibration**
  - Performed just prior to use on the day of surgery:
    - Select the probe for the correct nuclide
    - Perform the constancy test on the nuclide setting required for the surgical procedure
      - Record the results of the constancy test
Probe: Surgical

- Procedure in the surgical suite:
  - Select the proper nuclide for the surgical procedure
  - Understand that the detectors for surgical probes are highly directional.
  - Set the sensitivity settings for the surgical procedure.
  - Correctly adjust the volume and visual controls for the selected surgical procedure.
Probe Surgical

- Following the surgical procedure:
  - Follow the manufacturer’s recommendation for disconnecting the probes (power off/on)
  - Cleaning (per manufacturer’s recommendations)
    - Performed with wipes
  - Sterilization (per manufacturer’s recommendations)
    - Most often performed with a gas.
    - NO HEAT!
  - Storage
    - Clean and/or sterilized, as necessary
    - Fully charged. If equipped, batteries should be fully charged following surgery and just prior to surgery.
Surgical Probe

- **Pitfalls**
  - Constancy or calibration not performed before each use – potential problems not identified
  - Selecting the wrong probe
  - Low battery (on battery operated systems)
  - Incorrect energy selection
Summary

- Quality control procedures for non-imaging equipment is defined/required by:
  - The manufacturer
    - Unless otherwise specified, always follow the manufacturer’s recommendation as outlined in the instrument’s user manual
  - Radioactive Material License
  - State and regulatory agencies
Summary continued – what, more?

- Performed to:
  - Assess the integrity of the system
  - Confirm precision or reproducibility of measurements
    - Avoid repeat procedures
  - Identify potential malfunctions
  - Avoid costly and/or unnecessary maintenance and repair

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Conclusions - finally!

- Performed to avoid:
  - the ‘look’ we get from the RSO, medical health physicist or department administrator when cited by regulatory inspectors for non-compliance with required QC testing