A Practical Guide to Radiation Safety Surveys
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Conflicts/Disclosures
• Nothing to Disclose

Practical Guide Outline
• Motivation
• Definition
• Shielding Design Goals
• Shielding Process
• Instrumentation
• Shielding Integrity
• Radiation Scatter Survey
Joint Commission Prepublication Requirements Effective July 1, 2015:

6. For computed tomography (CT), positron emission tomography (PET), or nuclear medicine (NM) services: After installation of imaging equipment or construction in rooms where ionizing radiation will be emitted or radioactive materials will be stored, a medical physicist or health physicist conducts a radiation protection survey to verify the adequacy of installed shielding. This survey is conducted prior to clinical use of the room.

For additional guidance on shielding designs and radiation protection surveys, see National Council on Radiation Protection and Measurements Report No. 147 (NCRP-147).

TJC allows for flexibility, i.e. could do either a Shielding Integrity or Radiation Scatter Survey or both.
Outline

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• Radiation Scatter Survey

Definition – NCRP 147

“The radiation protection survey is an on-site evaluation of the x-ray facility performed by or under the direction of a qualified expert. It is typically performed after the facility is completed, although some components may be conducted prior to the completion of construction. The purpose of the survey is to ensure the protection of employees and members of the public. The survey consists of two basic elements:

1. an inspection to verify that barriers are properly placed, contiguous and free of voids or defects; and
2. an evaluation of shielding adequacy to verify that barriers adequately attenuate exposures in nearby occupied areas to the relevant shielding design goal divided by the appropriate occupancy factor ($P/T$).”
Outline

• Motivation
• Definition
• **Shielding Design Goals**
• Shielding Process
• Instrumentation
• Shielding Integrity
• Radiation Scatter Survey

Shielding Design Goals

• Uncontrolled Area
  – 1 mGy/year (100 mrad/year)
  – 0.02 mGy/week (2 mrad/week)
  – 0.02 mGy in any 1 hour (Nuclear Medicine)

• Controlled Area
  – 5 mGy/year (500 mrad/year)
  – 0.1 mGy/week (10 mrad/week)
Shielding Process

1. Shielding Plan
   • Prior to construction/renovation
2. Shielding Integrity
   • Prior to unit/equipment installation
   • Following completion of construction or renovation
3. Radiation Scatter Survey
   • Following unit installation
   • Following room completion for NM and PET
4. Monitoring Exposure and Future Use
   • Continuous

Note: Shielding processes/requirements/regulations vary by state

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Instrumentation

GM Counter
• Detects interactions of photons
• Appropriate for shielding integrity surveys
Instrumentation

NaI
- Scintillation probe
- High sensitivity
- Appropriate for measuring very low exposure rates
  - Can be used for some shielding integrity surveys

Instrumentation

Pressurized/Non Pressurized Ion Chambers
- Modes
  - Rate
  - Integrate
  - Freeze
- Measures exposure in air
- Appropriate for radiation scatter surveys
- Consider energy response
- Consider response time of survey instruments when setting exposure techniques
- Meter must be calibrated and capable of measuring the range

Instrumentation – 451P

From Fluke 451P Technical Data Sheet
Instrumentation – 451B

From Fluke 451B DE-SI Technical Data Sheet

Instrumentation

Solid State
- Energy compensated silicon diode array
- Best used for radiation scatter surveys
- Consider energy response
- Meter must be calibrated

RaySafe X2 specifications document
Outline

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  - Shielding Integrity
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Shielding Integrity

- Shielding Integrity Survey
  - Verify that the installed lead and facility layout meets the shielding plan requirements
  - Check for voids and consistency
  - Best done prior to equipment installation
  - Determine lead equivalence

- Shielding Integrity Methods
  - Core samples
  - Visual check during construction
  - Portable X-Ray unit
  - Radioactive source, i.e. Tc-99m, F-18
Shielding Integrity – Core Samples

- Validates lead thickness
- Need to shield over holes created
- Does not account for lead flow
- Does not validate for voids
- Does not validate lead wrapping
- Does not easily validate installed lead height

Shielding Integrity - Visual Checks

- Check to 7'
- Check lead thickness
- Check penetrations
- Check Doors

- Screws/Nails Covered
- Check lead wrapping
Shielding Integrity – X-Ray Source

- Requires unit to be installed
- Could use portable unit
- Easy to validate HVL or TVL of beam
  - Use to determine the lead equivalence of barrier
- Takes longer to validate voids

Shielding Integrity – X-Ray Source

Process
- Use ion chamber or solid state integrate mode to measure attenuation of the beam.
- Measure exposure in front of and behind barrier
- Ensure measurement distances are equivalent
- Meter should be set in a stable position and not held
- Area behind barrier should be controlled during exposure

- Use a cassette or CR to validate voids

Shielding Integrity – Radioactive Source

- Typical radioactive sources used
  - Tc-99m (50 mCi) – 140 keV
  - F-18 (10-20 mCi) – 511 keV
  - ≥0.5” lead equivalent
- If possible, use a vial with low volume to approximate point source
- Place in glove to prevent contamination
- Ideally use a leaded container with a shutter
- Keep source in lead pig when not in use
- Post temporary radiation warning signage
  - Room access should be controlled
Shielding Integrity – Radioactive Source

- To determine lead equivalence
  - Make sure in front and behind barrier measurements are made at a consistent distance
  - Use calculate using attenuation equation
    \[ t = \frac{HVL}{\ln \left( \frac{I}{I_0} \right)} \]
    - Tc-99m HVL ~ 0.293 mm Lead
    - F-18 HVL ~ 4 mm Lead
  - Could also look at known lead (top of a door) to calibrate to a thickness
  - Put Tc-99m source 6’ from the detector
    - Allows for attenuation measurement and continuity check
    - F-18 distance dependent on activity and meter

Conduct a post use survey for potential contamination

Shielding Integrity – Radioactive Source

- Instruments
  - GM works for both Tc-99 and F-18
  - NaI may be necessary for low activities or very thick barriers
- Focus on areas behind
  - Electrical boxes
  - Door/Window Frames
  - Door Handles
  - Penetrations

Shielding Integrity

Common Findings
- Improper/incomplete lead wrapping of window and door frames
- Unsealed punctures, electrical boxes
- Wrong lead thickness or no shielding installed
- Gaps between double doors
  - Heavy lead doors can sag if not reinforced properly
Shielding Integrity Report

• Date, purpose of survey, and surveyor
• Identify composition (and/or lead equivalence) of all barriers
• Indicate equipment (cal date) and methods used
• Reference shielding plan requirements
• Indicate presence of voids
• Indicate any addition shielding needed

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Radiation Scatter Survey

• The purpose is to determine that the existing barriers provide sufficient protection to meet regulatory exposure limits
• Also verify that the equipment and facility layout agrees with the shielding design
Radiation Scatter Survey

- Use a tissue simulation material
  - 8” Solid Water
  - Water Bucket
  - Anthropomorphic Phantom
  - CTDI Phantoms
  - Other appropriate phantom for specialized units
- Use ion chamber or solid state to measure exposure and/or exposure rates in surrounding areas
- Calculate estimated mGy per 40 hour week
- Be mindful of the position of attenuating devices in the room, i.e. lead drapes, shields, generators, cabinets, etc.

There are many ways this can be accomplished.

- Assumptions can vary and should be validated with the facility.
  - Consult the facility to determine type of exams being done and volume (if no shielding plan available)
  - Can then determine conservative technique for scatter survey
- Can follow up with area monitors.
- May have to update the survey in the future:
  - Change in surrounding occupancy
  - New penetrations
  - Lead flow
  - Room modifications
  - Equipment modifications, changes, or layouts

Integrate Mode Surveys

- Radiographic units
- Dental intraorals
- Computed Tomography
- Cone beam CT
- Mammography/Tomosynthesis
- Stereotactic Breast Biopsy Units
Setups

- Mammography/Stereo 6-8 cm BK-12
- 32 cm CTDI Phantom
- 8" Solid Water

Radiography

Integrate Mode Surveys

\[ K_{\text{per week}} = \frac{K_s}{\text{mAs/exposure}} \times E_{\text{CF}} \times \text{mAs/week} \times T \]

- \( K_{\text{per week}} \) = Air kerma per week
- \( K_s \) = Air kerma scatter
- \( E_{\text{CF}} \) = Energy Correction Factor
- \( T \) = occupancy factor

- If \( K_s \) is in R, divide by 114 to get Gy
- Compare \( K_{\text{per week}} \) to \( P \) (design goal)

Survey Documentation

- Date, purpose of survey, and surveyor
- Method of testing
- Instrument used
  - Calibration date/certificate
- Scatter material used
- Technique factors used
- Table of barriers and adjacent occupied areas with calculations
- Include diagram of room
  - Equipment layout
  - Locations of doors, windows, points of access, etc.
Integrate Mode Surveys

The survey was conducted with a RadSafe X2 utilizing the solid state survey sensor. Measurements were made around all significant barriers using a technique of 120 kvp and 350 mAs for 2 sec (100 mAs) with a thickness of 20 mm. A CT Body Phantom was used as a scatter medium. A patient workload of 60 patients per week was assumed. The corresponding number is identified on the attached "as-built" drawing.

<table>
<thead>
<tr>
<th>Position</th>
<th>Area Potential</th>
<th>Light Ker</th>
<th>Standard Exposure rate (mrad/sec)</th>
<th>Area Corrected [mrad/sec]</th>
<th>Workload mrad/week</th>
<th>Calculated mrad/week</th>
<th>Occupancy Factor</th>
<th>Occupancy Corrected mrad/week</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB Electrical Chute</td>
<td>U = 0.0006</td>
<td>700</td>
<td>300 000</td>
<td>0.0323</td>
<td>0.0325</td>
<td>0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AB Supply Closet</td>
<td>U = 0.0008</td>
<td>700</td>
<td>300 000</td>
<td>0.0370</td>
<td>0.025</td>
<td>0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AB Corridor Wall</td>
<td>U = 0.0007</td>
<td>700</td>
<td>300 000</td>
<td>0.0260</td>
<td>0.200</td>
<td>0.0005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BC Corridor Door</td>
<td>U = 0.0006</td>
<td>700</td>
<td>300 000</td>
<td>0.0283</td>
<td>0.125</td>
<td>0.0003</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Rate Mode Surveys

• Fluoroscopy
  – Conventional Fluoroscopy
  – Interventional Radiology
  – Cath Labs
  – O-arms
  – C-arm (maybe)
• Bone Density
• Nuclear Medicine
  – PET
  – Hot Labs
  – Gamma Cameras
Rate Mode Surveys (non-NM)

- 8” Solid Water
  - May need to add a copper attenuator to increase the technique factors (i.e. kVp)
- Be mindful of the position of attenuating devices in the room, i.e. lead drapes
- Use ion chamber or solid state detector in the rate mode
- Identify peak dose rate along each barrier
- Record peak dose rate for each barrier

Rate Mode Surveys - Nuclear Medicine (Gamma Camera/SPECT)

- Use Jaszczak Phantom with typical patient dose of Tc-99m (30-40 mCi). Could also use a more clinically relevant dose depending on exam profile.
- Calculate approximate time per patient and patients per week using rate mode.
- Scatter
  - Gamma Camera/SPECT Component
  - Possible CT Component

Be mindful of camera head position

Rate Mode Surveys - PET

- Using Jaszczak phantom with typical PET dose (10-15 mCi F-18).
- Calculate approximate time per patient and patients per week using rate mode.
- Scatter
  - PET Component
  - CT Component

Can also be used for quiet room survey
Nuclear Medicine - Hot Labs

• Primarily concerned with shielding $\gamma$-rays
  – $\alpha$ stopped by paper
  – $\beta$ should be stopped by container it is stored in

• Most common radionuclides of concern:
  – $\text{Tc-99m}$ (140 keV)
  – $\text{F-18}$ (511 keV)
  – Should be assessed according to usage

Nuclear Medicine - Hot Labs

• Primarily handled by shielded containers
  – Syringe Shields
  – Vial Shields
  – Rad Waste Containers
  – Shielded Sharps Container
  – Lead lined storage cabinets

• An unshielded source can be used for a dose rate measurement
  – PET or Gamma Camera Phantom
  – Syringe

Nuclear Medicine (NM Hot Labs)

• Use unshielded source (20 – 30 mCi of $\text{Tc-99m}$) and take rate measurements outside of room.
• Unshielded source use:
  5 min/1 hour period * 40 hr/week
  200 min/week = 3.33 hr/week
• Typical measurement outside hotlab: 0.1 mR/hr
  0.1 mR/hr * 3.33 hr/week = 0.33 mR/week
  =0.002 mGy/week
• May have to adjust assumptions
• If difficult to determine, make a conservative educated guess and follow up using area monitors.
• Correct for occupancy
• Compare to controlled or uncontrolled design limit
Nuclear Medicine (PET Hot Labs)

- Use unshielded source (15 mCi F-18 (~5 mR/hr @ 1 m)) and take rate measurements outside of room.
- Typical unshielded measurement may be ~ 1.25 mR/hr at 2 m (outside hotlab)
- Unshielded source use:
  2.5 min/1 hour period * 40 hr/week
  100 min/week = 1.67 hr/week
- Typical measurement outside hotlab: 1.25 mR/hr
  1.25 mR/hr * 1.67 hr/week = 2.08 mR/week = 0.018 mGy/week
- Correct for occupancy
- Compare to controlled or uncontrolled design limit

Rate Mode Surveys

\[ K_{per\ week} = K_s\ per\ hour \times E_{CF} \times W \times T \]

- \( K_{per\ week} \) = Air kerma per week
- \( K_s \) = Air kerma scatter per hour
- \( E_{CF} \) = Energy Correction Factor
- \( T \) = Occupancy factor
- \( W \) = Workload (hr/week)

- Beam on time for fluoro
  - \# of patients per week * time per patient for NM
- If \( K_s \) is in R/hr, divide by 114 to get Gy/hr
- Compare \( K_{per\ week} \) to P
- Also consider dose rate to public areas does not exceed 2 mR in any one hour for NM and PET areas

Rate Mode Surveys

Survey Report

<table>
<thead>
<tr>
<th>Section</th>
<th>Time (hr)</th>
<th>Task</th>
<th>Measurement (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>2</td>
<td>Images</td>
<td>0.004</td>
</tr>
<tr>
<td>PET</td>
<td>8</td>
<td>PET Images</td>
<td>0.004</td>
</tr>
<tr>
<td>Nuclear</td>
<td>19</td>
<td>Images</td>
<td>0.004</td>
</tr>
</tbody>
</table>

Radiation Safety Survey Results

FUSIONCORE UNIT & CAT & DSC
Common Findings

- Inadequate shielding
  - Adjacent offices
  - Open control rooms
  - Wood doors not attenuating enough (Hollow)
- Most issues occur
  - Behind CT scanners
  - Primary X-ray barriers

Follow Up Surveys

- If supplemental shielding is required
  - Voids or Inadequate shielding
- Change in surrounding occupancy
  - Reassess calculations
- Change of equipment or orientation
- Any modifications to surrounding walls
  - As an example, we have found several existing facilities where lead is not sufficient when coming in the first time

Common Findings – Angular Void
Caveats

• Radioactive Sources
  – Follow NRC/Agreement state regulations
  – Radioactive materials license and/or reciprocity if working in multiple states
• Check your local regulations
  – Specific states/municipalities have varying requirements about what must be in a Radiation Protection Survey

Summary

For a Radiation Safety Survey:
• Understand your instrumentation
• Validate shielding assumptions
• Perform either or both:
  – Shielding Integrity
    • Verify room layout, shielding continuity, shielding equivalence
  – Radiation Scatter Survey
    • Verify shielding meets regulatory requirements based on radiation scatter measurements

References

Special Thanks

Thomas Ruckdeschel, MS, DABR
Michael Tressler, MS, DABR

In Memoriam…

Patrick L. Booton, MMSc., DABR
February 10, 1951 - July 16, 2016