# A Practical Guide to Radiation Safety Surveys

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## Conflicts/Disclosures

- Nothing to Disclose

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## Practical Guide Outline

- Motivation
- Definition
- Shielding Design Goals
- Shielding Process
- Instrumentation
- Shielding Integrity
- Radiation Scatter Survey

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## Motivation

Joint Commission Prepublication Requirements Effective July 1, 2015:

**Elements of Performance for EC.02.06.05**

**"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."

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## Motivation

Joint Commission Prepublication Requirements Effective July 1, 2015 (Cont.):

* 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

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## 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



## Definition – NCRP 147

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*)."

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## 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)

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## 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

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## Instrumentation

NaI

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

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## 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

451 P

451 B

450 B

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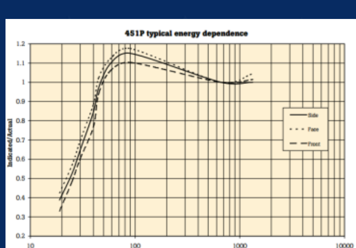
## Instrumentation – 451P




*From Fluke 451P Technical Data Sheet*

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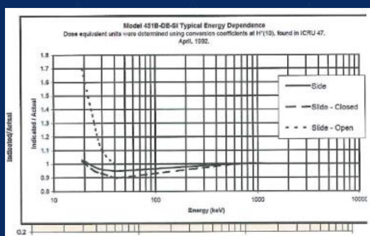
## Instrumentation – 451B




*From Fluke 451B-DE-SI Technical Data Sheet*

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## Instrumentation

Solid State

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

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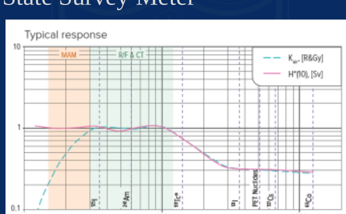
## Instrumentation

- Solid State Survey Meter




*RaySafe X2 specifications document*

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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

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# Shielding Integrity

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

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## 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

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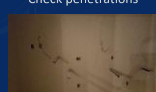
## Shielding Integrity - Visual Checks

Check to 7′

Check lead thickness

Check penetrations



Check Doors

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## Shielding Integrity - Visual Checks

Screws/Nails Covered

Check lead wrapping

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## 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

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## Shielding Integrity – Radioactive Source

- Typical radioactive sources used
  - Tc-99m (50 mCi) – 140 keV
  - F-18 (10-20 mCi) – 511 keV
    - ≥1/8” lead equivalent
  - Calibrate for use time
- 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

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## 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

$$t = -\frac{HVL}{0.693}\ln\left[\frac{I}{I_o}\right]$$

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

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## 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

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## 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

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## 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
- As built drawing

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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

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## 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.

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## Radiation Scatter Survey

- 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

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## Integrate Mode Surveys

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

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## Setups

Mammo/Stereo

6-8 cm BR-12

CT

32 cm CTDI Phantom

Radiography

8" Solid Water

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## Integrate Mode Surveys

$$K_{per\ week} = \frac{K_s}{mAs/exposure} * E_{CF} * mAs/week * T$$

$K_{per\ week}$ = Air kerma per week
$K_s$ = Air kerma scatter
$E_{CF}$ = Energy Correction Factor
T = occupancy factor

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

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## 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

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## Integrate Mode Surveys

Report

The survey was conducted with a RaySafe X2 utilizing the solid state survey sensor. Measurements were made around all significant barriers using a technique of 120 kVp and 350 mA for 2 sec (700 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 numbers are identified on the attached "as-built" drawing.

RADIATION SAFETY SURVEY RESULTS
CT UNIT IN CT SCAN ROOM

| Position | Area Protected | Limit Key | Measured Exp. Rate (mR/Scan) | mAs Correction (mAs/Scan) | Workload (mAs/week) | Calculated mGy/week | Occupancy Factor | Occupancy Corrected mGy/week |
|---|---|---|---|---|---|---|---|---|
| AB | Electrical Closet | U | 0.0006 | 700 | 300,000 | 0.0023 | 0.025 | 0.0001 |
| AB | Supply Closet | U | 0.0008 | 700 | 300,000 | 0.0030 | 0.025 | 0.0001 |
| AB | Corridor Wall | U | 0.0007 | 700 | 300,000 | 0.0026 | 0.200 | 0.0005 |
| BC | Corridor Door | U | 0.0006 | 700 | 300,000 | 0.0023 | 0.125 | 0.0003 |

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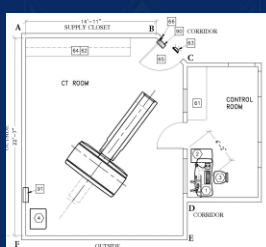
## Integrate Mode Surveys

Report

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## Rate Mode Surveys

- Fluoroscopy
  - Conventional Fluoroscopy
  - Interventional Radiology
  - Cath Labs
  - O-arms
  - C-arm (maybe)
- Bone Density
- Nuclear Medicine
  - PET
  - Hot Labs
  - Gamma Cameras

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## 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

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## 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

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## 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

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## Nuclear Medicine - Hot Labs

- Primarily concerned with shielding γ-rays
  - α stopped by paper
  - β should be stopped by container it is stored in
- Most common radionuclides of concern:
  - Tc-99m (140 keV)
  - F-18 (511 keV)
  - Should be assessed according to usage

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## 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
  - Vial

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## Nuclear Medicine (NM Hot Labs)

- Use unshielded source (20 – 30 mCi of 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

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## 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

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## Rate Mode Surveys

$$K_{per\ week} = K_{s\ per\ hour} * E_{CF} * W * T$$

$K_{per\ week}$ = 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

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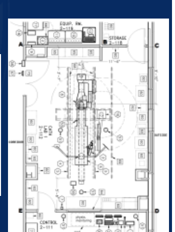
## Rate Mode Surveys

Survey Report

The survey was conducted with an Unfors X2 utilizing rate mode. Measurements were made around all significant barriers using a fluoroscopy technique of 101 kVp, 7.3 mA, and normal FOV using 8" solid water. A workload 30 hours of fluoroscopy on-time per week was assumed. The corresponding numbers are identified on the attached "as-built" drawing.

RADIATION SAFETY SURVEY RESULTS
FLUOROSCOPIC UNIT IN CATH LAB

| Position | Area Protected | Area Key | Measured Exposure (mR/hr) | Calculated (mGy/week) | Occupancy Factor | (Adjusted for Occupancy) |
|---|---|---|---|---|---|---|
| AB | Control | C | 0.049 | 0.013 | 1.00 | 0.013 |
| BC | Outside (Above Grade) | U | N/A | N/A | 0 | 0 |
| CD | Storage | U | 0.039 | 0.010 | 0.05 | 0.001 |



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## 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

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## 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

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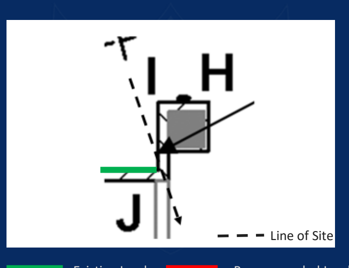
## Common Findings – Angular Void

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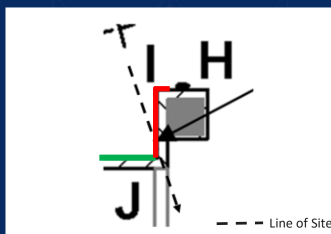
## Common Findings – Angular Void




Existing Lead Recommended Lead

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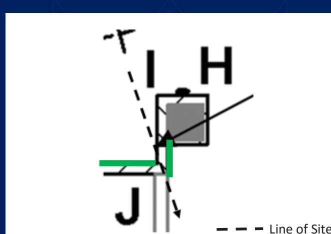
## Common Findings – Angular Void

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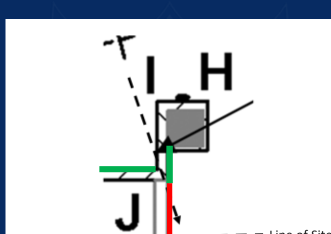


Existing Lead Recommended Lead

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## 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

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## 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

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## References


- National Council on Radiation Protection and Measurements Report No. 147, Structural Shielding Design for Medical X-Ray Imaging Facilities (2004)


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## Special Thanks

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

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## In Memoriam…


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

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