Updates on Shielding Design for Diagnostic Medical Physicists

NCRP-147: Overview and New Challenges

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Conflict of Interest Statement

- I am a member of AAPM TG 313 - Nuclear Medicine Shielding Requirements.
- President of Therapy Physics, Inc., a diagnostic medical physics consultant company that performs more than 100 diagnostic shielding designs and 40 linear accelerator vault designs per year

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Objectives

1. Review Fundamental Principles of NCRP-147.
2. Discuss New Shielding Problems since the publication of NCRP-147.
3. Make recommendations for Additional Resources Useful in Shielding Calculations.

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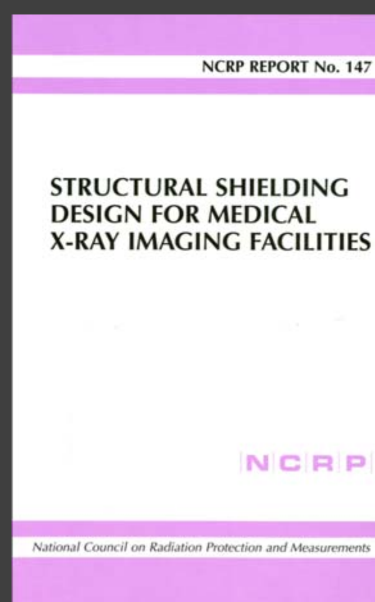
NCRP Report No. 147

- Published in 2004.



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Purpose and Scope of NCRP-147

- NCRP 147 supersedes NCRP 49 (1976) and discusses the various factors to be considered in the selection of appropriate shielding materials and the calculation of barrier thicknesses.
- Uses Effective Dose (E) as the limiting radiation protection quantity, but sets shielding design goals in terms of Air Kerma (K) in milligray.
  - Controlled Area Limit of 0.1 mGy air kerma per week.
    - This allows a pregnant worker to continue to access their work areas.
  - Uncontrolled Area Limit of 0.02 mGy air kerma per week.

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Conservative Assumptions in NCRP-147

- Attenuation of the primary beam by the patient is neglected.
- Always assumed to be a perpendicular incidence on barriers.
- Ignores the presence of shielding materials in the room (lead curtains, ceiling mounted shields, equipment cabinets).
- Leakage is assumed to be the maximum allowed value by the FDA.
- Scattered radiation was measured with large field sizes and phantoms that produce conservatively high scatter levels.
- Recommended occupancy factors are conservatively high.
- Lead sheets are installed in standard sizes that are greater than the minimum thickness required.
- Protected distance of 0.3 m away from walls is unrealistic for most situations.

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Fundamental Equation

$$B(x_{\text{barrier}}) = \left(\frac{P}{T}\right)\frac{d^2}{K^1 N}$$

- P is the Shielding Design Goal
- T is the Occupancy at the Protected Area
- d is the Distance from the source to the Protected Area
- K is the average unshielded air kerma per patient at 1 m from the source.
- N is the average number of patients examined per week.

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Barrier Thickness Calculation

$$x_{\text{barrier}} = \frac{1}{\alpha\gamma} \ln\left[\frac{\left(\frac{N T K^1}{P d^2}\right)^{\gamma} + \frac{\beta}{\alpha}}{1 + \frac{\beta}{\alpha}}\right].$$

- Parameters are provided for α, β, and γ to solve for the barrier thickness.
- Appendix A

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Challenges in NCRP-147 with Modern Imaging Departments and Equipment

- Out-Dated Workload Estimates
- No mention of Nuclear Medicine
- No mention of frequently used Operating Rooms with Mobile Equipment
- New Equipment with unique capabilities.
- Shielding from multiple sources
- Radiation Protection Surveys

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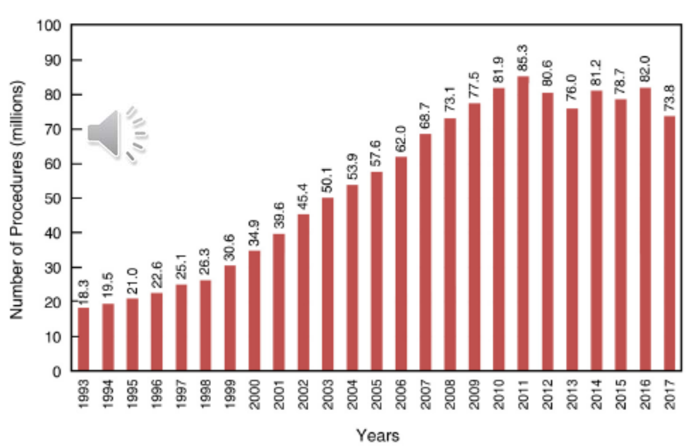
Workload Estimates

- NCRP 147 provides estimates for Workload based on AAPM-TG9 (1996)
- NCRP 184 (2019) shows trends of CT exams by year.
- Can vary significantly by scanner.
  - Range of # of Exams: 1000-9500 per year. (Kumar. Radiation Shielding Design for Diagnostic Radiology)

Total CT Exams in the US by Year. (NCRP 184, pg 61)



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Workload Estimates

- From 2006 to 2016, the number of radiographic and fluoroscopic examinations has decreased slightly.
- It is estimated that the collective effective dose has decreased 39% from Cardiac Interventional procedures between 2006 and 2016.

TABLE 7.2—*Estimated number of radiographic and diagnostic fluoroscopic examinations for 2006 and 2016 for the U.S. population (based on Medicare extrapolation).*[a]

	2006	2016
	Number in thousands	
Chest	128,994	110,388
Mammography	34,500	39,252
Skull	329	229
Cervical spine	5,800	4,884
Thoracic spine	2,590	2,509
Lumbar spine	11,197	11,255
Esophagus		2,105
Upper GI	4,044	938
Abdomen	14,964	12,228
Barium enema	656	192
Urography	1,180	647
Pelvis	8,185	5,411
Hip	11,778	14,995
Hands and feet	26,677	31,694
Knees	19,364	25,757
Shoulder	9,213	11,951
Other head and neck	1,975	1,121
Total	281,446	275,556
Dual-energy x-ray absorptiometry	8,734	9,332

[a]A multiplier of 3.75 was used to extrapolate from Medicare data to the U.S. population except for mammography which used FDA data without a multiplier.

Table 7.2, NCRP 184 & Executive Summary

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Nuclear Medicine

- NCRP 147 does not address Nuclear Medicine in any substantive way.
- Table A.1 (Archer fit data) does not apply to mono-energetic gamma rays.
- AAPM TG108 Provides a method to shield PET facilities.
- AAPM TG313 is in process to determine a method to shield diagnostic nuclear medicine departments.

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Recommended Resources to Use Until TG313 is Published

- "Considerations for Release of Patients Administered Radiopharmaceuticals" – Available at https://www.doseinfo-radar.com/ExposureCalculator.html
- This page includes a discussion of the effective dose calculation, dose rate constants for various isotopes, and physical half-life data.
- Package Inserts generally provide HVL data for lead.

$$D(0 \rightarrow t) = \frac{34.6 \times OF \times A \times T_{1/2} \times \Gamma \left(1 - e^{\frac{-0.693\, t}{T_{1/2}}}\right)}{r^2}$$

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What to do with Mobile C-Arms in Heavily Used Operating Rooms?

- NCRP 147 states: "**If** the mobile x-ray equipment is used in a fixed location, or frequently in the same location, a qualified expert *shall* evaluate the need for structural shielding."
- No workload estimates are provided for C-Arm use.
  - Some facilities use C-Arms for Interventional Procedures with Fluoro times > 60 minutes.
- No unshielded leakage, scatter or total air kermas are given for C-Arms.

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New Equipment Since 2004

- FFDM and Tomosynthesis
  - Archer equations assume Mo/Mo Target/Filter
  - No data provided for new Targets/Filters
  - No data provided at Increased kVp used in Tomosynthesis
- O-Arm
  - Cone-Beam CT acquisition and Fluoroscopy
- Interventional 3D Spins
- 320-Slice CT Scanners
- Multi-Modality Systems (SPECT-CT, PET-CT, PET-MR)

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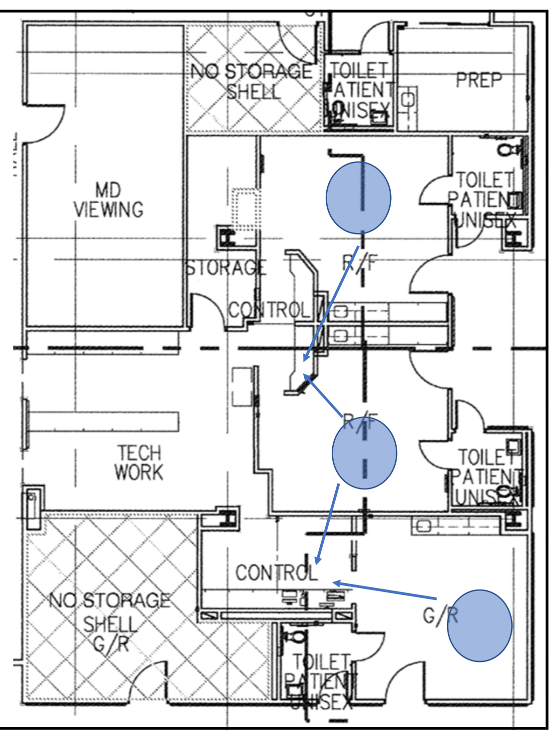
Shielding From Multiple Sources

- NCRP 147 briefly mentions a shared control room and recommends a decrease in the shielding design goal to account for contributions from two sources.
- This could be further complicated by more than two sources and requires an iterative optimization process by the shielding expert.



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Radiation Protection Surveys

- NCRP-147 discusses two types of Radiation Protection Surveys:
  - Shielding Integrity (voids & defects)
  - Shielding Adequacy
- Joint Commission requires "a radiation protection survey to verify the adequacy of installed shielding."

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Shielding Integrity Surveys

- Can be performed visually *IF* the physicist is present on site during the time between lead installation and the other side of the wall being closed. (unlikely)
- After construction, requires either a radioactive source or a fluoroscopic system to maintain constant scattered x-rays.
- Also requires a sensitive GM or Scintillator to locate voids or other defects in construction.

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Shielding Adequacy Surveys

- Must be performed after equipment installation.
- Requires similar assumptions of workload, kVp distribution, occupancy, etc.
- Alternative method would be to measure the Transmission, estimate the thickness of installed lead, and then calculate the maximum workload for the room.

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Thank You for Your Attention!

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