ELSEVIER

Techniques in Vascular and Interventional Radiology

# Make Radiation Protection a Habit

Donald L. Miller, MD, FSIR, FACR

This review describes the basic concepts and methods for optimization of occupational dose in the interventional suite. In fluoroscopy, the source of virtually all radiation exposure to the operator is scattered radiation from the patient. All other things being equal, reducing patient radiation dose will reduce operator and staff dose. Most tools and methods of occupational radiation protection are entirely operator dependent. These methods must be used routinely and properly to be effective. Your occupational dose depends on how well you follow good radiation protection practices and on the kinds of procedures you do. The only way to know your own occupational dose is to wear your dosimeters for every case. If proper protection practices are followed and appropriate protection tools are used, annual effective dose for an interventionalist should be well below 10 mSv/y, and will more likely be in the range of 2-4 mSv/y. However, if proper protection practices and tools are not used, annual effective doses may be much higher. You should review your own doses periodically.
Tech Vasc Interventional Rad ■:■■■-■■■ Published by Elsevier Inc.

**KEYWORDS** Occupational exposure, radiation, radiation risk, cataract, cancer, safety

## Introduction

The objectives of radiation protection are to eliminate the occurrence of tissue reactions (eg, skin injuries) and to reduce the likelihood of a stochastic effect (eg, cancer induction) to a level that is reasonably achievable.[1] The aim is "to provide an appropriate level of protection without unduly limiting the desirable human actions that may be associated with such exposure."[1]

There are 3 basic principles of radiation protection used to achieve these objectives—justification, optimization of protection ("optimization"), and application of dose limits ("dose limits").[1] The principle of justification applies broadly to all occupational exposure in medicine—this exposure is considered justified because the benefit to our patients and to society exceeds the risk to us. The other 2 principles of radiation protection have immediate application to occupational exposure in the interventional suite. Radiation protection is optimized when exposure is "as low as reasonably achievable, economic, and societal factors being taken into account"[1]—the ALARA principle. Dose limits are maximums that should not be reached. When protection is optimized, your occupational dose should be well below the dose limit.

This review describes the basic concepts and methods for optimization of occupational dose in the interventional suite. Some methods of radiation protection, such as the architectural shielding built into the interventional suite, are not modifiable by the interventionalist. However, most tools and methods of occupational radiation protection are entirely operator dependent. They must be used routinely and properly to be effective. They must be learned and practiced until their use becomes automatic.

## Dose Limits

The International Commission on Radiological Protection (ICRP) provides guidance and recommendations for radiation protection internationally, including recommended occupational dose limits.[1] The U.S National Council on Radiation Protection and Measurements (NCRP) provides recommendations for radiation protection for the United States.[2,3] Both organizations provide 2 types of occupational dose limits—those that establish an acceptable level of risk for stochastic effects (principally cancer induction), and those that are intended to protect specific organs or tissues (lens of the eye, skin, extremities). Limits for

Center for Devices and Radiological Health, US Food and Drug Administration, Silver Spring, MD.

Address reprint requests to Donald Miller, MD, FSIR, FACR, Building 66, Room 4318, 10903 New Hampshire Avenue, Silver Spring, MD 20993-0002. E-mail: donald.miller@fda.hhs.gov

1089-2516/14/$ - see front matter Published by Elsevier Inc.
https://doi.org/10.1053/j.tvir.2017.12.008

**Table** NCRP Recommended Dose Limits (Maximum Permissible Doses) for Occupational Exposure

| Dose Quantity | NCRP Maximum Permissible Dose |
|---|---|
| *Effective dose* | |
| Annual | 50 mSv/y |
| Cumulative | 10 mSv × age (y) |
| *Equivalent dose* | |
| Lens of the eye* | 150 mSv/y |
| Skin† | 500 mSv/y |
| Extremities (hands and feet) | 500 mSv/y |

Adapted from NCRP Publication 116.[2]

* Likely to be changed to 50 mGy/y.[5]

† Averaged over 1 $cm^2$ of the most highly irradiated area of the skin.

stochastic effects are provided in terms of effective dose, a calculated radiation protection quantity that is intended to be proportional to the risk for radiation-induced stochastic effects. Limits for organs and tissues are expressed in terms of equivalent dose. Both ICRP and NCRP provide dose limits in SI units. Inconveniently, the SI unit for both equivalent dose and effective dose is the Sievert (Sv).

Properly, dose limits for organs and tissues should be expressed as absorbed dose rather than equivalent dose, since the intent is to protect against the development of a tissue reaction.[4,5] The SI unit for absorbed dose is gray (Gy). However, for the x-ray energies used in fluoroscopy, 1 mSv = 1 mGy, so for practical purposes this difference can be ignored in interventional radiology.

Current NCRP recommended dose limits (maximum permissible doses) are presented in the Table. These differ somewhat from the ICRP recommendations. These differences are discussed more fully elsewhere.[6] In 2011, the ICRP recommended annual dose limit for the lens of the eye was reduced from 150-20 mSv/y averaged over 5 y, with no single y exceeding 50 mSv.[7] As of 2017, the NCRP recommendations are under revision. The NCRP dose limit for the lens of the eye is also likely to be reduced, but to 50 mGy/y.[5,8]

ICRP and NCRP dose limits are only recommendations. In the United States, regulatory requirements (also known as maximum permissible doses) for radiation protection from x-rays are set by the Occupational Safety and Health Administration (OSHA) in 29 CFR 1096, and by the individual states. Maximum permissible doses for radiation protection from radioactive materials (10 CFR 20.1101) and for all sources of ionizing radiation (10 CFR 20.1001(b)) are set by the Nuclear Regulatory Commission (NRC).[9] When an individual receives occupational exposure from both types of sources, the NRC standards take precedence.[9] As a result, and in order to simplify the administrative burden, most hospital radiation safety officers apply the NRC regulations to all radiation workers at the facility. OSHA and NRC regulations generally follow NCRP recommendations, but typically lag behind updates to NCRP recommendations by years. Note that dose limits in the United States are specified currently using traditional radiation units—rad and rem—not the SI units of Gy and Sv.

Additional dose limits are specified for pregnant workers.[10] Protection of pregnant workers is discussed in detail elsewhere in this issue of the journal.

## Occupational Doses for Interventionalists

Workers involved in interventional procedures can receive high effective doses.[11] Actual occupational radiation dose should be well below any regulatory limit. What annual dose is achievable for an interventionalist? If proper protection practices are followed and appropriate protection tools are used, annual effective dose should be well below 10 mSv/y, and will more likely be in the range of 2-4 mSv/y.[12-15] At 1 large hospital in the United States, the mean annual effective dose was 1.6 mSv for physicians who performed interventional procedures, and 1.1 mSv for technologists and nurses involved in these procedures.[16] These doses were lower than those for radiopharmacists (4.6 mSv) and nuclear medicine technologists and nurses (2.3 mSv) at the same hospital.

However, if proper protection practices and tools are not used, annual doses may be much higher. In 1 review of operator doses from interventional cardiology procedures, Kim et al[17] observed a range of per procedure occupational dose of as much as 3 orders of magnitude. In another review, Kim et al observed a range of per procedure operator doses greater than an order of magnitude for biliary procedures and transjugular intrahepatic portosystemic shunt creation, and a range of per procedure operator dose of 3 orders of magnitude for vertebroplasty.[18]

Most data on eye exposure are from phantom studies or from extrapolations based on data from collar dosimeters. There are relatively few data on eye exposures based on dosimeters placed near the eye during clinical cases. In a study of cardiologists, with dosimeters placed near the left eye and between the eyes, the median dose to the eye was 23 μSv/procedure.[19] Estimated annual doses to the unprotected eye ranged from 9-210 mSv. Using data from dosimeters worn over the apron, Vañó et al[20] compared the dose to the lens of the eye for urologists performing nephrolithotomy using a mobile C-arm fluoroscope and interventional radiologists and interventional cardiologists in interventional suites. The urologists did not use ceiling-suspended shields; the other physicians did. The urologists had eye doses 18.7 times higher than did the interventional radiologists and interventional cardiologists, despite urology patients receiving doses (kerma-area product) that were about half of those received by interventional radiology and interventional cardiology patients. Dauer[16] reported lens of the eye dose for interventional physicians ranging from 0.1-36.5 mSv/y when no leaded eyewear was used. As part of the European ORAMED project (Optimization of RAdiation protection for MEDical staff; http://www.oramed-fp7.eu), eye doses were measured for a number of interventional procedures.[21,22]