



# REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

## REGULATORY GUIDE 8.40

(Draft was issued as DG-8039, dated August 2009)  
(New Regulatory Guide)

### METHODS FOR MEASURING EFFECTIVE DOSE EQUIVALENT FROM EXTERNAL EXPOSURE

#### A. INTRODUCTION

This regulatory guide describes dosimetry methods that the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for determining the effective dose equivalent (EDE) for external (EDEX) radiation exposures. These methods provide a conservative estimate of the EDEX and may be used to calculate the total effective dose equivalent (TEDE) in demonstrating compliance with TEDE-based NRC regulatory requirements.

Title 10, Section 20.1003, "Definitions," of the *Code of Federal Regulations* (10 CFR 20.1003) (Ref. 1), defines the TEDE as the sum of the effective dose equivalent (for external exposures), or the EDEX as used in this guide, and the committed effective dose equivalent (CEDE) (for internal exposures). The EDEX is the sum of the products of the tissue or organ weighting factors given in 10 CFR Part 20, "Standards for Protection against Radiation," and the dose to the corresponding body tissues and organs resulting from the exposure to radiation sources external to the body. In 10 CFR 20.1201(a), the NRC provides an annual dose limit of 0.05 sievert (5 rem) TEDE, and 10 CFR 20.1201(c) requires that when an external personal monitoring device is used to measure external exposure, the deep-dose equivalent (DDE) must be used as the EDEX unless the EDEX is determined more directly by an NRC-approved dosimetry method. In using the DDE as the EDEX, the assigned DDE must be for the part of the body receiving the highest radiation exposure.

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The NRC issues regulatory guides to describe and make available to the public methods that the NRC staff considers acceptable for use in implementing specific parts of the agency's regulations, techniques that the staff uses in evaluating specific problems or postulated accidents, and data that the staff needs in reviewing applications for permits and licenses. Regulatory guides are not substitutes for regulations, and compliance with them is not required. Methods and solutions that differ from those set forth in regulatory guides will be deemed acceptable if they provide a basis for the findings required for the issuance or continuance of a permit or license by the Commission.

This guide was issued after consideration of comments received from the public.

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This regulatory guide contains information collection requirements covered by 10 CFR Part 20 that the Office of Management and Budget (OMB) approved under OMB control number 3150-0014. The NRC may neither conduct nor sponsor, and a person is not required to respond to, an information collection request or requirement unless the requesting document displays a currently valid OMB control number.

## **B. DISCUSSION**

For the purpose of implementing workplace controls, and because of the difference in dosimetry methods, 10 CFR Part 20 breaks the TEDE into two components: (1) dose resulting from radioactive sources internal to the body and (2) dose resulting from radioactive sources external to the body. The doses from external and internal exposures are determined independently by measurement or by calculation and then summed to obtain the TEDE. Several requirements in 10 CFR Part 20 (such as the dose limits in 10 CFR 20.1201(a)(1)(i) and 10 CFR 20.1301(a)) are based on the TEDE.

In 10 CFR Part 20, the NRC defines the EDE as the sum of the products of the dose equivalent to each organ or tissue ( $H_T$ ) and the weighting factors ( $w_T$ ) applicable to each of the body organs or tissues that are irradiated ( $EDE = \sum w_T H_T$ ). Each organ or tissue weighting factor is the proportion of the risk of stochastic effects resulting from the dose to that organ or tissue to the total risk of stochastic effects when the whole body is irradiated uniformly. This formula is applicable whether the dose results from radiation sources internal or external to the body.

In most relatively uniform exposure situations, a single dosimeter calibrated to measure the DDE and worn on the body provides a reasonable measurement of the EDEX. If the body is not irradiated uniformly, a single-dose measurement cannot determine the dose to the various organs and tissues for an accurate determination of the EDEX. To ensure a conservative TEDE determination, 10 CFR 20.1201(c) requires that when an external monitoring device is used to measure external exposure, the DDE, measured for the part of the body receiving the highest exposure, must be used in place of the EDEX unless the EDEX is determined by an NRC-approved dosimetry method.

Using the DDE measured at the highest exposed part of the whole body as the EDEX can be overly conservative in extremely nonuniform irradiations (e.g., when only a small portion of the whole body is irradiated). Therefore, several methods acceptable to the NRC staff have been developed to determine the EDEX from dose measurements on the surface of the whole body. Each of these methods generally involves the measurement of the DDE at one or more locations on the whole body. The EDEX is then determined by applying a weighting factor to each dosimeter result. An algorithm that combines multiple measurements may be applied to provide a less conservative determination of the EDEX than that provided by the single dosimeter. Each of these methods has its own advantages and limitations. Care must be exercised to ensure that each method is used within the limitations noted below.

The use of the methods discussed in this regulatory guide for determining the EDEX component of the TEDE may not eliminate the need to determine the dose at the highest exposed part of the whole body. The regulations at 10 CFR 20.1201(a) and 10 CFR 20.1201(c) require doses to be measured at specific body locations for demonstrating compliance with the non-TEDE dose limits (i.e., dose to the

lens of the eye, dose to the skin of the whole body and extremities, or the total organ dose). Licensees will most likely need to provide additional dosimeters if 10 CFR 20.1502, “Conditions Requiring Individual Monitoring of External and Internal Occupational Dose,” requires monitoring to demonstrate compliance with any of these non-TEDE dose limits. Regulatory Guide 8.34, “Monitoring Criteria and Methods To Calculate Occupational Radiation Doses,” issued July 1992 (Ref. 2), provides guidance on meeting the monitoring requirements of 10 CFR 20.1502. Therefore, using the methods described below will not, in most cases, lead to any reduction in monitoring requirements. Instead, they may help provide a more accurate determination of the EDEX than may be possible using a single dosimeter when the radiation fields to which the monitored person is exposed are very nonuniform and particularly when significant parts of the body, especially the torso, are shielded.

### C. REGULATORY POSITION

Before the December 4, 2007, revision to 10 CFR Part 20, the TEDE was defined as the sum of the DDE (measured at the highest exposed portion of the whole body) and the CEDE. The current regulation, 10 CFR 20.1201(c), only requires the use of the DDE as the EDEX if the external exposure is measured with a personal monitoring device and if an NRC-approved method (such as those in this guide) for determining the EDEX from the measured dose is not used. The EDEX should be used in most cases in which the contribution to the TEDE from external radiation exposures is calculated (i.e., calculating doses from contaminated soils and buildings, assessing the effects of as low as reasonably achievable measures such as the installation of shielding or system decontamination, or assessing the environmental impacts of proposed licensing actions). However, in some dose assessment situations, a conservative bounding value may be all that is necessary to demonstrate compliance with NRC regulatory requirements. Calculating the DDE (for the highest exposed portion of the whole body) may be used as a conservative method for determining the EDEX.

#### 1. Using Multiple Dosimetry with Compartment Factors

Section 3.0 of American National Standards Institute (ANSI)/Health Physics Society (HPS) N13.41-1997, “Criteria for Performing Multiple Dosimetry,” issued December 1996 (Ref. 3), provides a method for estimating the EDEX from several dosimeter results. This method divides the whole body into seven separate compartments. Each compartment is monitored separately. The measured DDE for each compartment ( $DDE_C$ ) is then weighted with the associated “compartment factor” ( $W_C$ ) as listed in Table 1. The resulting weighted doses are then summed to determine the EDEX for the whole body as follows:

$$EDEX = \sum W_C DDE_C$$

**Table 1. Compartment Factors**

<b>AREA OF THE BODY/COMPARTMENT</b>	<b>COMPARTMENT FACTOR (<math>W_C</math>)</b>
Head and neck	0.10
Thorax, above the diaphragm	0.38
Abdomen, including the pelvis	0.50
Upper right arm	0.005
Upper left arm	0.005
Right thigh	0.005
Left thigh	0.005

- a. The weighting factor for each compartment was determined by summing the stochastic tissue weighting factors in International Commission on Radiological Protection (ICRP) Publication 26, "Recommendations of the International Commission on Radiation Protection," issued 1977 (specified in 10 CFR 20.1003, under the definition of the term "weighting factor  $W_T$ "), for all the organs located within that compartment (Ref. 4). For each tissue that resides in more than one compartment (e.g., red bone marrow), the weighting factor was apportioned between the compartments based on the fraction of the total mass of the tissue residing in each compartment, using the information in ICRP Publication 23, "Reference Man: Anatomical, Physiological and Metabolic Characteristics," issued 1975 (Ref. 5).
- b. Licensees who are authorized to use organ or tissue weighting factors other than those in 10 CFR 20.1003 should not use the compartment factors in Table 1 because doing so would lead to inconsistencies between their internal and external dosimetry. To use this method, such licensees should obtain NRC approval for use of an alternate set of compartment weighting factors based of their authorized set of organ or tissue weighting factors.
- c. ANSI/HPS N13.41-1997 allows the combination of adjacent compartments into a composite compartment. The composite compartment may be treated the same as one of the compartments defined in ANSI/HPS N13.41-1997. The weighting factor for the composite compartment is the sum of the weighting factors for the individual compartments included in the composite compartment.
- d. To ensure that the EDEX results are conservative, the dose to each compartment (or composite compartment) should be measured by locating the dosimeter (calibrated to the DDE) at the highest exposed portion of the respective compartment.

## 2. Using Two Dosimeters

This method uses two dosimeter readings and is based on research conducted by the Electric Power Research Institute (EPRI) (Ref. 6). The EDEX can be determined from a reading of a dosimeter worn on the front (DDE front) of the trunk (abdomen or thorax) of the body in combination with the reading of a dosimeter worn on the back (DDE back) of the trunk of the body (Ref. 7) consistent with the following items:

- a. EPRI gives two algorithms for combining the dosimeter results: (1) the mean method and (2) the weighted method. The mean method should not be used because it does not provide a conservative EDEX in all exposure geometries.
- b. The weighted method weights the higher of the two dosimeter readings such that

$$EDEX = \frac{1}{2} (Hi + MEAN).$$

The following is a mathematically simpler form of this weighted algorithm:

$$EDEX = \frac{3}{4} Hi + \frac{1}{4} Lo,$$

where  $Hi$  is the higher, and  $Lo$  is the lower, of the DDE front or the DDE back.

- c. Partial-body irradiations that shield the dosimeter(s) but not other portions of the whole body could bias the EPRI method results in the nonconservative direction. Any shielding of one of the dosimeters should also shield the whole corresponding side (front or back) of the trunk of the

body. If the trunk of the body is only partially shielded, then the dosimeter should be located to monitor the unshielded portion. At least one of the two dosimeters should “see” the major source or sources of radiation exposure.

- d. This method for determining the EDEX from dosimeter readings is not valid for exposure situations in which the individual is immersed in a shielding material (i.e., diving operations). Large dose-rate gradients resulting from such immersions over the space occupied by the body can bias the two-dosimeter results.
- e. As demonstrated in the technical paper entitled, “Effective Dose Equivalent for Point Gamma Sources Located 10 cm near the Body” (Ref. 8), this two-dosimeter method can significantly underreport the EDEX in exposure situations in which the source is lateral to the body, directly over head, or in the horizontal plane with the individual’s reproductive organs and is less than 30 centimeters (12 inches) from the surface of the body. For this reason, licensees should use other methods for determining the EDEX when a major source of radiation exposure is in one or more of these geometries relative to the individual’s body.
- f. The EDEX determined by this method can be affected by the angular dependency of the radiation monitoring devices used, as discussed in National Council on Radiation Protection and Measurements (NCRP) Report 122, “Use of Personal Monitors To Estimate Effective Dose Equivalent and Effective Dose to Workers for External Exposure to Low-LET Radiation,” issued 1995 (Ref. 9). If the dosimeter’s response decreases more rapidly than the EDEX, the resulting EDEX will be biased in the nonconservative direction as the angle of incident radiation increases. The EPRI principle investigators have addressed this issue of angular dependence in their published technical paper, “A Study of the Angular Dependence Problem in Effective Dose Equivalent Assessment” (Ref. 10). Therefore, to ensure this two-dosimeter method produces conservative results, licensees should use only dosimeters that meet the angular response characteristics described in Reference 10.

### 3. Using Dosimeter(s) While Wearing an Apron during Medical X-Ray Procedures

In 10 CFR 20.1001, “Purpose,” the NRC requires licensees to control radiation exposures in such a manner that the total dose to an individual (including doses resulting from licensed and unlicensed radioactive material and from radiation sources other than background) does not exceed the standards for protection in 10 CFR Part 20. Although the NRC does not regulate the use of x-ray equipment for medical procedures, the occupational radiation dose to an individual conducting these procedures must be considered for demonstrating compliance with 10 CFR Part 20 if the individual is also engaged in an NRC-licensed activity. During some medical x-ray procedures, occupational workers use protective aprons that provide radiation shielding to the trunk of the body. The use of these aprons results in nonuniform exposures to the whole body. Several methods have been developed for estimating the EDEX from this exposure geometry.

In those cases in which the State has regulatory jurisdiction in governing the use of its medical x-ray equipment and has approved a method for determining the EDEX when using dosimeters and protective aprons, the NRC will accept that method. In those situations in which a State regulatory entity does not have jurisdiction or for a State in which the State regulatory entity has not approved a specific method, NRC licensees may use one of the methods outlined below for determining compliance with 10 CFR Part 20. Nothing in this guide modifies the dosimetry methods that States authorize their respective licensees to use in complying with applicable State regulatory requirements or laws.

- a. When an occupational worker uses only one monitoring device, located at the neck outside the

protective apron ( $D_u$ ), and the reported dose exceeds 25 percent of the limit specified in Section D.201.a of Reference 11, then

$$EDEX = 0.3 (D_u).$$

Note that if the reported dose does not exceed 25 percent of the limit specified in Section D.201.a of Reference 11, then the EDEX is the unshielded DDE measured at the neck.

- b. NCRP Report 122 provides a method whereby individual monitoring devices are worn both under the protective apron at the waist ( $D_s$ ) and outside the protective apron at the neck ( $D_u$ ) such that

$$EDEX = 1.5 (D_s) + 0.04 (D_u).$$

Note that if this method is used with an apron that provides little shielding, the EDEX will be significantly overestimated.

- c. By applying the EDE method in ANSI/HPS N13.41-1997, as discussed in Regulatory Position 1(c), NRC licensees can add the weighted dose ( $D_s$ ) for the shielded composite compartment of the thorax, abdomen, and right and left thigh to the weighted dose ( $D_u$ ) for the unshielded composite compartment of the head, neck, and upper arms such that

$$EDEX = 0.89 (D_s) + 0.11 (D_u).$$

## **D. IMPLEMENTATION**

The purpose of this section is to provide information to applicants and licensees regarding the NRC's plans for using this regulatory guide. The NRC does not intend or approve any imposition or backfit in connection with its issuance.

In some cases, applicants or licensees may propose or use a previously established acceptable alternative method for complying with specified portions of the NRC's regulations. However, use of those alternative dosimetry methods would require NRC approval per 10 CFR 20.1201(c). Otherwise, the methods described in this guide will be used in evaluating compliance with the applicable regulations.

This regulatory guide consolidates guidance that was previously published in NRC Regulatory Information Summary (RIS) 2002-06, "Evaluating Occupational Dose for Individuals Exposed to NRC-Licensed Material and Medical X-Rays," dated April 16, 2002 (Ref. 12); RIS 2003-04, "Use of the Effective Dose Equivalent in Place of the Deep Dose Equivalent in Dose Assessments," dated February 13, 2003 (Ref. 13); RIS 2004-01, "Method for Estimating Effective Dose Equivalent from External Radiation Sources Using Two Dosimeters," dated February 17, 2004 (Ref. 14); and RIS 2009-09, "Use of Multiple Dosimetry and Compartment Factors in Determining Effective Dose Equivalent from External Radiation Exposures," dated July 13, 2009 (Ref. 15). The NRC has previously approved the methods described in each RIS for one or more licensees. Issuance of this regulatory guide is not intended to supersede any previous licensee specific NRC approval.

## REFERENCES<sup>1</sup>

1. 10 CFR Part 20, "Standards for Protection against Radiation," U.S. Nuclear Regulatory Commission, Washington, DC.
2. Regulatory Guide 8.34, "Monitoring Criteria and Methods To Calculate Occupational Radiation Doses," U.S. Nuclear Regulatory Commission, Washington, DC.<sup>2</sup>
3. ANSI/HPS N13.41-1997, "Criteria for Performing Multiple Dosimetry," American National Standards Institute, Washington, DC, and Health Physics Society, McLean, VA, December 1996.
4. ICRP Publication 26, "Recommendations of the International Commission on Radiological Protection," International Commission on Radiation Protection, Pergamon Press, Oxford, New York, Frankfurt, Seoul, Sydney, and Tokyo, 1977.
5. ICRP Publication 23, "Reference Man: Anatomical, Physiological and Metabolic Characteristics," International Commission on Radiation Protection, Pergamon Press, Oxford, New York, Frankfurt, Seoul, Sydney, and Tokyo, 1975.
6. EPRI Report No. 101909, "Assessment of the Effective Dose Equivalent for External Photon Radiation," Electric Power Research Institute, Palo Alto, CA, February 1993 (Volume 1) and June 1995 (Volume 2).
7. EPRI Report No. 109446, "Assessment of the Effective Dose Equivalent for External Photon Radiation—Implementation Guide," Electric Power Research Institute, Palo Alto, CA, September 1998.
8. Xu, X.G., S. Bushart, and R. Anderson, "Effective Dose Equivalent for Point Gamma Sources Located 10 cm near the Body," *Health Physics*, 91(2):108–118, August 2006.
9. NCRP Report 122, "Use of Personal Monitors To Estimate Effective Dose Equivalent and Effective Dose to Workers for External Exposure to Low-LET Radiation," National Council on Radiation Protection and Measurements, Bethesda, MD, 1995.
10. Xu, X.G., W.D. Reese, and J.W. Poston, "A Study of the Angular Dependence Problem in Effective Dose Equivalent Assessment," *Health Physics*, 68(2):214–224, February 1995.

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<sup>1</sup> All NRC regulations listed herein are available electronically through the Electronic Reading Room on the NRC's public Web site, at <http://www.nrc.gov/reading-rm/doc-collections/cfr/>. Copies are also available for inspection or copying for a fee from the NRC's Public Document Room (PDR) at 11555 Rockville Pike, Rockville, MD; the mailing address is USNRC PDR, Washington, DC 20555; telephone (301) 415-4737 or (800) 397-4209; fax (301) 415-3548; and e-mail [pdr.resource@nrc.gov](mailto:pdr.resource@nrc.gov).

<sup>2</sup> All regulatory guides listed herein were published by the U.S. Nuclear Regulatory Commission. Most are available electronically through the Electronic Reading Room on the NRC's public Web site, at <http://www.nrc.gov/reading-rm/doc-collections/reg-guides/>. Active guides may also be purchased from the National Technical Information Service (NTIS) on a standing order basis. Details on this service may be obtained by contacting NTIS at 5285 Port Royal Road, Springfield, VA 22161, online at <http://www.ntis.gov>, by telephone at (800) 553-NTIS (6847) or (703) 605-6000, or by fax at (703) 605-6900. Copies are also available for inspection or copying for a fee from the NRC's Public Document Room (PDR) at 11555 Rockville Pike, Rockville, MD; the mailing address is USNRC PDR, Washington, DC 20555-0001; telephone (301) 415-4737 or (800) 397-4209; fax (301) 415-3548, and e-mail [pdr.resource@nrc.gov](mailto:pdr.resource@nrc.gov). Copies of the non-NRC documents included in these references may be obtained directly from the publishing organizations.

11. "Suggested State Regulations for Control of Radiation, Volume 1 (Ionizing)," Conference of Radiation Control Program Directors, Inc., Frankfort, KY, 1995.
12. RIS 2002-06, "Evaluating Occupational Dose for Individuals Exposed to NRC-Licensed Material and Medical X-Rays," U.S. Nuclear Regulatory Commission, Washington, DC, April 16, 2002. (ADAMS Accession No. ML021080436)
13. RIS 2003-04, "Use of the Effective Dose Equivalent in Place of the Deep Dose Equivalent in Dose Assessments," U.S. Nuclear Regulatory Commission, Washington, DC, February 13, 2003. (ADAMS Accession No. ML030370122)
14. RIS 2004-01, "Method for Estimating Effective Dose Equivalent from External Radiation Sources Using Two Dosimeters," U.S. Nuclear Regulatory Commission, Washington, DC, February 17, 2004. (ADAMS Accession No. ML040420042)
15. RIS 2009-09, "Use of Multiple Dosimetry and Compartment Factors in Determining Effective Dose Equivalent from External Radiation Exposures," July 13, 2009. (ADAMS Accession No. ML082320040)