



# Standard Practice for Calculation of Dose Equivalent Xenon (DEX) for Radioactive Xenon Fission Products in Reactor Coolant<sup>1</sup>

This standard is issued under the fixed designation D7727; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This practice applies to the calculation of the dose equivalent to  $^{133}\text{Xe}$  in the reactor coolant of nuclear power reactors resulting from the radioactivity of all noble gas fission products.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*<sup>2</sup>

**D3648 Practices for the Measurement of Radioactivity**

**D7282 Practice for Set-up, Calibration, and Quality Control of Instruments Used for Radioactivity Measurements**

## 3. Terminology

3.1 *Definitions:*

3.1.1 **DOSE-EQUIVALENT XE-133 (DEX),  $n$** —shall be that  $^{133}\text{Xe}$  concentration (microcuries per gram) that alone would produce the same acute dose to the whole body as the combined activities of noble-gas nuclides  $^{85\text{m}}\text{Kr}$ ,  $^{85}\text{Kr}$ ,  $^{87}\text{Kr}$ ,  $^{88}\text{Kr}$ ,  $^{131\text{m}}\text{Xe}$ ,  $^{133\text{m}}\text{Xe}$ ,  $^{133}\text{Xe}$ ,  $^{135\text{m}}\text{Xe}$ ,  $^{135}\text{Xe}$ , and  $^{138}\text{Xe}$  actually present.

3.1.1.1 *Discussion*—This is the general definition of DEX. Each utility may have adopted modifications to this definition

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.04 on Methods of Radiochemical Analysis.

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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

through agreement with the U.S. Nuclear Regulatory Commission (U.S. NRC). The definition as approved for each utility by the U.S. NRC is the one that should be applied to the calculations in this practice.

## 4. Summary of Practice

4.1 A sample of fresh reactor coolant is analyzed for noble gas activities using gamma ray spectrometry. The individual activity of each detectable radioactive fission gas is divided by a factor that normalizes its dose to that of  $^{133}\text{Xe}$ . This practice is to replace the previous practice of calculating the reactor coolant  $\bar{E}$  calculation when allowed by the plant's revised technical specifications. The quantity DEX is acceptable from a radiological dose perspective since it will result in a limiting condition of operation (LCO) that more closely relates the non-iodine RCS activity limits to the dose consequence analyses which form their bases.

NOTE 1—It is incumbent on the licensee to ensure that the dose conversion factors (DCFs) used in the determination of DEX are consistent with the DCFs used in the applicable dose consequence analysis used by the plant in their dose calculation manual for radioactive releases.

## 5. Significance and Use

5.1 Each power reactor has a specific DEX value that is their technical requirement limit. These values may vary from about 200 to about 900  $\mu\text{Ci/g}$  based upon the height of their plant vent, the location of the site boundary, the calculated reactor coolant activity for a condition of 1 % fuel defects, and general atmospheric modeling that is ascribed to that particular plant site. Should the DEX measured activity exceed the technical requirement limit, the plant enters an LCO requiring action on plant operation by the operators.

5.2 The determination of DEX is performed in a similar manner to that used in determining DEI, except that the calculation of DEX is based on the acute dose to the whole body and considers the noble gases  $^{85\text{m}}\text{Kr}$ ,  $^{85}\text{Kr}$ ,  $^{87}\text{Kr}$ ,  $^{88}\text{Kr}$ ,  $^{131\text{m}}\text{Xe}$ ,  $^{133\text{m}}\text{Xe}$ ,  $^{133}\text{Xe}$ ,  $^{135\text{m}}\text{Xe}$ ,  $^{135}\text{Xe}$ , and  $^{138}\text{Xe}$  which are significant in terms of contribution to whole body dose.

5.3 It is important to note that only fission gases are included in this calculation, and only the ones noted in Table 1. For example  $^{83\text{m}}\text{Kr}$  is not included even though its half-life is 1.86 hours. The reason for this is that this radionuclide cannot

**TABLE 1 Table of Equivalence Factors for Noble Gas Fission Products**

Number	Radionuclide	Factor
1	Kr-85m	4.796
2	Kr-85	0.076
3	Kr-87	26.403
4	Kr-88	65.385
5	Xe-131m	0.249
6	Xe-133m	0.878
7	Xe-133	1.000
8	Xe-135m	13.077
9	Xe-135	7.628
10	Xe-138	36.989

be easily determined by gamma spectrometry (low energy X-rays at 32 and 9 keV) and its dose consequence is vanishingly small compared to the other, more prevalent krypton radionuclides.

5.4 Activity from  $^{41}\text{Ar}$ ,  $^{19}\text{F}$ ,  $^{16}\text{N}$ , and  $^{11}\text{C}$ , all of which predominantly will be in gaseous forms in the RCS, are not included in this calculation.

5.5 If a specific noble-gas radionuclide is not detected, it should be assumed to be present at the minimum-detectable activity. The determination of DOSE-EQUIVALENT XE-133 shall be performed using effective dose-conversion factors for air submersion listed in Table III.1 of EPA Federal Guidance Report No. 12,<sup>3</sup> or the average gamma-disintegration energies as provided in ICRP Publication 38 (“Radionuclide Transformations”) or similar source.

## 6. Interferences

6.1 The analytical determination of the radionuclides used for this calculation is made by gamma ray spectrometry. Commercially available software is generally used to perform the spectrum analysis and data reduction. However, there can be significant number of interferences from gamma ray emitters with multiple gamma ray emissions. The user must carefully select the appropriate interference-free gamma ray energy for each radionuclide in order to determine accurately the activity of each radionuclide.

6.2 The short half-lives of several of the noble gas radionuclides, the low abundance of their gamma rays, and high background activity at their principal gamma ray energies, may require that separation of the gases from the reactor coolant liquid be performed in order to reliably determine their individual activities.

## 7. Sampling

7.1 Separation of gases should be done at the sample point from the reactor coolant system and there should be no chemical treatment process preceding this sample point (that is, prior to letdown demineralization).

7.2 Containers used for containing the noble gases must “gas-tight” to ensure insignificant losses of radionuclides during sample counting.

<sup>3</sup> “External Exposure to Radionuclides in Air, Water and Soil,” Federal Guidance Report No. 12, EPA-402-R-93-081.

7.3 Separation may be achieved by any form of reactor coolant degassing process (for example, gas expansion into an evacuated container) as long as the sample line remains pressurized until degasification can occur.

## 8. Calibration and Standardization

8.1 Any calibrations and standardizations required in support of this practice should be in accordance with the applicable sections of Practices **D3648** and **D7282** and in accordance with the manufacturers’ specifications for the gamma ray spectrometry system used for analysis.

8.2 Sample geometry and container size and physical composition must be the same for sample and standards.

## 9. Procedure

9.1 A sample of reactor coolant is analyzed by gamma ray spectrometry within a short period of time after the sample being taken from the reactor coolant system.

9.2 An appropriate aliquant of the sample is counted as a pressurized liquid or degasified and the removed gas counted on a gamma ray spectrometer immediately after degasification occurs.

9.3 If a separated gas sample is counted, the method used should ensure that noble gas radionuclides are not retained by the liquid phase. If they are, then the concentration from the liquid phase should be included in the calculation in **10.1**.

9.4 A second count of the same aliquant of gas may be required several hours later for accurate determination of longer lived noble gas radionuclides.

9.5 Tabulate the concentrations, uniformly measured in  $\mu\text{Ci/cc}$  (37 kBq/cc) or  $\mu\text{Ci/g}$  (37 kBq/g), of all applicable noble gas radionuclides identified in the sample.

9.6 The times between taking the reactor coolant sample and performing DEX gamma ray spectrometry analyses should be consistent from sample to sample so that the ingrowth from progenitors and decay to progeny will be consistently accounted using the calculation in **10.1**.

## 10. Calculation

10.1 The DEX value is calculated as follows:

$$DEX_1 \frac{\mu\text{Ci}}{\text{g}} = \sum_{i=1}^{i=10} A_i \times DF_i \quad (1)$$

where:

$DEX$  = an activity concentration equivalent to  $^{133}\text{Xe}$  by all noble gas fission products from **Table 1**,  $\mu\text{Ci/g}$ ,

$A_i$  = the activity of the individual radionuclide identified in **Table 1**,  $\mu\text{Ci/g}$ , and

$DF_i$  = the ratio of the dose conversion factor each radionuclide to the dose conversion factor for  $^{133}\text{Xe}$  (listed in **Table 1**), dimensionless.

10.2 If a radionuclide listed in **Table 1** is not detected, the minimum detectable concentration for the gamma ray spectrometry count time and sample volume (gas and liquid) used for analysis shall be the activity of that radionuclide.

10.3 If the methodology to provide a degasified liquid contains gas activity, the activity for each individual radionuclide shall be added to the gas phase activity of that radionuclide, respectively, in [Eq 1](#).

## 11. Keywords

11.1 DEX; dose correction; dose equivalent xenon; noble gases

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- (2) "Calculation of Annual Doses to Man from Routine releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10CFR Part 50, Appendix I," U.S. NRC Regulatory Guide 1.109, Rev. 1, Table E-7, 1977.
- (3) "Committed Dose Equivalent in Target Organs or Tissues per Intake of Unit Activity," ICRP 30, Supplement to Part 1, pp. 192–212.
- (4) "Standard Radiological Effluent Technical Specifications For Pressurized Water Reactors," U.S. NRC NUREG-0472, Rev 3, 1983.
- (5) 10CFR50 Domestic Licensing of Production and Utilization Facilities, Appendix I.
- (6) 10CFR100 Reactor Site Criteria.
- (7) "Deletion of E Bar Definition and Revision to RCS Specific Activity Technical Specification," TSTF-490, Rev 0 ADAMS Number ML052630462, 2007.

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