Derived Concentration Standard and Dose Coefficients used in Radiation Protection

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About this Presentation

- Provides an overview of use of derived concentrations and dose coefficients and how they are implemented and used in radiation protection of the public at the Department of Energy (DOE).
- Provides the dosimetry methodologies at DOE used in the development of dose coefficients and derived concentration values.
- The use of dose coefficients, concentration values and dose methodology methods used at other Federal agencies.
- Compare various dosimetry methods for radionuclide concentration values and risk assessment values for Tc-99 and I-129 based on the EPA Drinking Water Standards (DWS).

DOE-STD-1196-2021

- DOE-STD-1196-2021 *Derived Concentration Technical Standard*, July 2021 (hereafter the Standard) supports the implementation of radiation protection programs around the DOE Complex.
- The Standard is consistent with:
  - DOE Policy (P) 420.1, *Department of Energy Nuclear Safety Policy*, February 8, 2011, and
  - DOE P 450.4A, *Integrated Safety Management Policy*, Chg 1, Jan 18, 2018
- Standard also reflects recommendations and guidance from various national and international standards and scientific organizations:
  - International Commission on Radiological Protection (ICRP),
  - National Council on Radiation Protection and Measurements (NCRP),
  - and the American National Standards Institute (ANSI).

DOE-STD-1196-2021 (Cont.)

- DOE-STD-1196-2021 contains DOE-approved derived concentration values (also referred as DCS values) and DOE-approved effective dose coefficients [previously referred as Dose Conversion Factors (DCFs)] that may be used in:
  - estimating doses,
  - supporting pathway modeling,
  - and comparing measurements to criteria provided in DOE Order (O) 458.1, *Radiation Protection of the Public and the Environment*, Chg 4 (2020).
- The updated Standard provides DCS values and effective dose coefficients reflecting the current state of knowledge and practice in radiation protection, using the latest environmental and demographic data for the U.S.
- DOE O 458.1 uses the DCS to provide DOE-approved values for liquid effluents to establish criteria for determining if Best Available Technology (BAT) evaluation processes are required. If the DCS values are exceeded the BAT process should be implemented (DCS are not discharge limits).

Major changes incorporated in the New Standard

These updated values are based on:

- Dosimetric models and tissue weighting factors recommended in ICRP Publication 103 (2007), *The 2007 Recommendations of the International Commission on Radiological Protection*.
- Age-specific committed effective dose coefficients for inhalation and ingestion of radionuclides based on updated biokinetic models. ICRP 89(2002), *Basic Anatomical and Physiological Data for Use in Radiological Protection Reference Values*.
- Use of the latest updated biokinetic models –
  - the dosimetric models in Human Alimentary Tract Model [HATM] presented in ICRP Pub. 100 (2006), *Human Alimentary Tract Model for Radiological Protection*
  - The Human Respiratory Tract Model [HRTM] in ICRP Pub. 130 (2015), Occupational Intakes of Radionuclides: Part 1.
- New dosimetric term “per capita dose” coefficient (replacing the term “reference person” used in the previous DCS Standard).

Major changes incorporated in the New Standard (Cont.)

- Separate per capita dose coefficients for ingestion of radionuclides for water and milk.
- Age-specific effective dose coefficients for external exposure to airborne radionuclides from FGR 15, *External Exposure to Radionuclides in Air, Water and Soil* (EPA, 2019a).
- Per capita dose coefficients developed for external exposure to airborne radionuclides based on FGR 15 (EPA. 2019a).
- Distribution of the U.S. population by age and sex as indicated by U.S. Census 2010 (U.S. Census Bureau, 2011).
- Reference age- and sex-specific usage of environmental media by the U.S. population based on recent compilations.

Effective Dose Coefficients

- Like DCS, the dose coefficients are also based on current science and recommendations by national and international advisory organizations.
- They are based on ICRP 103 dose methodology and current EPA Federal guidance methods.
- They are the DOE approved dose coefficients for use in the calculation of doses to the maximally exposed individual (MEI) or representative person for purposes of demonstrating compliance with DOE radiation protection requirements in DOE O 458.1.
- The dose coefficients published in this Standard are the most up-to-date effective dose coefficients available and may be useful in providing the best estimate of potential doses for various exposure situations.

Effective Dose Coefficients (Cont.)

- Use of these dose coefficients is not required (and in some cases not permitted) where use of other coefficients and associated tissue WFs and methodology are approved or required at DOE. Examples are:
  - 10 CFR Part 835 *Occupational Radiation Protection*, requirements for radiation protection of DOE workers,
  - and, standards supporting DOE nuclear safety requirements in 10 CFR Part 830, *Nuclear Safety Management*.
- If dose coefficients in the updated DCS are based on more recent dosimetric methods, the changes do not require reassessments of any evaluations or modelling previously done. This includes:
  - Any related compliance with DOE O 458.1 dose limits, or
  - constraints or BAT process determinations based on the previous 2011 DCS version (or other DOE approved dose factors).

Effective Dose Coefficients (Cont.)

- DOE-STD-1196-2021 dose coefficients can be used in annual site environmental reports (ASER) reporting to demonstrate compliance with DOE dose limits in DOE 458.1.
  - The coefficients in the previous Standard may continue to be used where approved but the ASER should clearly reference which coefficients are being used.
- Dose coefficients (and the DCS values) in this updated Standard are provided as tools for future assessments supporting compliance with DOE public radiation protection requirements.

Per Capita Dose

(Previously known as Reference Person)

The per capita dose ($E_{per\ capita}$) is the population weighted sum of age-specific effective dose coefficients, where the weight takes into account the fraction of each subgroup in the age and sex distribution of U.S. population (Table 3) represented by an age-specific effective dose coefficient and the level of exposure to the radionuclide for that age group.

$$E_{per\ capita} = \frac{1}{\sum_i (f_i^M U_i^M + f_i^F U_i^F)} \sum_i (f_i^M U_i^M + f_i^F U_i^F) e_i$$

Table 3. Age and sex distribution of the 2010 U.S. population

Reference Age Group	Age x (years)	Population fraction		
		Male	Female	Total
Newborn	$0 \le x < 1$	0.00652	0.00625	0.01277
1-y	$1 \le x < 3$	0.01335	0.01280	0.02615
5-y	$3 \le x < 7$	0.02698	0.02583	0.05281
10-y	$7 \le x < 12$	0.03395	0.03249	0.06644
15-y	$12 \le x < 17$	0.03477	0.03309	0.06786
Adult	$x \ge 17$	0.37604	0.39793	0.77397

Per Capita Dose (Cont.)

Table A-1. Committed effective dose coefficients for ingested water and milk

	Dose Coefficient (Sv/Bq)							
							Per Capita	
Nuclide	Newborn	1-year	5-year	10-year	15-year	Adult	Water	Milk
Hydrogen								
H-3[a]	1.31e-10	7.21e-11	3.65e-11	2.73e-11	2.05e-11	1.95e-11	2.10e-11	3.08e-11
H-3[b]	2.29e-10	1.53e-10	7.87e-11	5.86e-11	5.09e-11	5.18e-11	5.40e-11	7.03e-11

(a) Tritiated Water
(b) Organic Bound Tritium

Table A-2. Committed effective dose coefficients for inhalation of particles *

		Dose Coefficient (Sv/Bq)						
Nuclide	Type	Newborn	1-year	5-year	10-year	15-year	Adult	Per Capita
Hydrogen								
H-3	F	6.73e-11	3.76e-11	1.66e-11	1.25e-11	8.36e-12	8.32e-12	9.16e-12
	M	2.95e-10	2.18e-10	1.14e-10	7.12e-11	4.98e-11	4.66e-11	5.19e-11
	S	1.45e-09	1.34e-09	8.82e-10	6.09e-10	5.45e-10	5.60e-10	5.79e-10

Table A-3. Committed effective dose coefficients for inhalation of gas or vapor *

	Dose Coefficient (Sv/Bq)						
Nuclide	Newborn	1-year	5-year	10-year	15-year	Adult	Per Capita
Tritiated water vapor							
H-3 (inhalation)	1.33e-10	7.28e-11	3.69e-11	2.75e-11	2.07e-11	1.97e-11	2.14e-11
H-3 (inhalation + skin absorption)[a]	2.00e-10	1.09e-10	5.54e-11	4.13e-11	3.11e-11	2.96e-11	3.21e-11

Table A-4. Effective dose rate coefficients for air submersion

	Dose Rate Coefficient (Sv/s per Bq/m3)						
Nuclide	Newborn	1-year	5-year	10-year	15-year	Adult	Per Capita
Hydrogen							
H-3	4.91e-20	4.73e-20	4.48e-20	4.27e-20	3.96e-20	3.80e-20	3.92e-20

Calculation of DCSs

- The calculation starts determining the effective dose coefficients for different age groups.
- In Table 4 of the Standard, members of the public are represented by these six age groups and refer to “Reference” usage data for the consumption of air, water and milk, and are based on intake at each of six ages addressed in ICRP documents supporting ICRP 103 (2007).
- Age groups are age 100 days (infant), 1 year, 5 years, 10 years, 15 years, and adults.

Daily Intake-Usage data

Reference Age Group	Age x (years)	Daily Intake					
		Air[a] (m^3)		Water[b] (L)		Milk[c] (L)	
		Male	Female	Male	Female	Male	Female
Newborn	$0 \le x < 1$	3.7	3.7	0.549	0.549	0.710	0.710
1-y	$1 \le x < 3$	6.0	6.0	0.348	0.348	0.577	0.577
5-y	$3 \le x < 7$	8.8	8.8	0.413	0.413	0.308	0.300
10-y	$7 \le x < 12$	15.2	15.2	0.555	0.555	0.289	0.279
15-y	$12 \le x < 17$	20.1	15.8	0.855	0.641	0.265	0.187
Adult	$x \ge 17$	22.2	18.2	1.817	1.363	0.158	0.128

[a]Age-specific air intake from ICRP Publication 89 (2002), p. 100.

[b]Intakes for ages 0-1 y were based on average values listed in Table 3-12 of EPA 2019b for birth to 1 y. Intakes for ages 1-3 y were based on the sample size and average values listed in EPA 2019b for ages 1-2 y and 2-3 y. Intakes for ages 3-7 y, 7-12 y, 12-17 y and adult were based on mean values listed in EPA 2019b for ages 3-6 y, 7-11 y, 11-16 y, and 21-50 y, respectively. For ages 11 y and greater it was assumed that intake by females is 75% of intake by males.

[c]Intake for ages 0-1 y were based on total milk intake listed in Table 3-43 of EPA 2019b, using average of intakes for ages 4-6 mo, 7-8 mo, and 9-11 mo. Intake for ages 1-3 y were based on total milk intake listed in Table 3-43 of EPA 2019b, using average of intakes for ages 12-14 mo, 15-18 mo, and 19-24 mo. Intake for ages 3-7 y, 7-12 y, 12-17 y, and >17 y were based on fluid milk intake listed in the U.S. Department of Agriculture (USDA 2019) *NHANES 2015-16, What We Eat in America*, for ages 2-5 y, 6-11 y, 12-19 y, and 20-49 y, respectively.

Equations to Derive a DCS value

Units

$$DCS_{ing-w} = \frac{Ec}{t * Eper\ capita_{ing-w} * \sum_{i=1,6}(f_i^M U_{ing-w,i}^M + f_i^F U_{ing-w,i}^F)}$$

Bq/L or uCi/mL

$$DCS_{ing-m} = \frac{Ec}{t * Eper\ capita_{ing-m} * \sum_{i=1,6}(f_i^M U_{ing-m,i}^M + f_i^F U_{ing-m,i}^F)}$$

Bq/L or uCi/mL

$$DCS_{inh} = \frac{Ec}{t * Eper\ capita_{inh} * \sum_{i=1,6}(f_i^M U_{inh,i}^M + f_i^F U_{in\ ,i}^F)}$$

Bq/m^3 or uCi/mL
(S, M, F)

$$DCS_{subm} = \frac{Ec}{t * E_{per\ capita-ext}*}$$

Bq/L or uCi/mL

* Sv/s per Bq/m^3

Federal regulators use various dosimetry Methods

- ICRP 2:
  - EPA Drinking Water Standard (DWS)
  - NRC 10 CFR Part 61, *Licensing Requirements for Land Disposal of Radioactive Waste*
- ICRP 26/30
  - NRC 10 CFR Part 20, *Standards for Protection Against Radiation*
  - Federal Guidance Report (FGR) No. 11. *Limiting Values Of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*
- ICRP 60
  - EPA 40 CFR 191, *Environmental Radiation Protection Standards For Management And Disposal Of Spent Nuclear Fuel, High-level And Transuranic Radioactive Wastes*
  - EPA 13. *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*
  - EPA FGR 15. *External Exposure to Radionuclides in Air, Water and Soil*

DOE Dosimetry Methodologies

- ICRP 103
  - DOE O 458.1 *Radiation Protection of the Public and the Environment*
  - Associated DCS standards to DOE O 458.1.
  - for specific reports, some DOE sites still use ICRP 60
- ICRP 60
  - DOE 10 CFR 835, *Occupational Radiation Protection*
  - DOE 10 CFR 830, *Nuclear Safety Management*
  - Associated standards to 10 CFR 830
- ICRP 26/30
  - DOE O 435.1 Radioactive Waste Management
    - many authorized facilities use ICRP 26/30
    - ICRP 60 at some DOE Facilities depending when they were authorized to use ICRP 60 dose methods.
    - Future update will reference DOE O 458.1 which is ICRP 103 dose methodology based.

Concentrations based on 4 mrem/yr using different dose methodologies and DOE Standards

Radionuclide	DWS-equivalent derived activity concentrations (pCi/L)(a)*	ICRP-26/30 (pCi/L)*	ICRP-72/FGR-13 (pCi/L)**	STD-1196-2011 ICRP-60 (pCi/L)	STD-1196-2021 ICRP-103 (pCi/L)
Tc-99	900	4800	1929	1780	15600
I-129	1	16	12	13	23

*0.08 x 10 CFR 20, Table 2, Liquid Effluents members of the public

**Downs et al, PNNL, Evaluation of Dose- and Risk-Based Groundwater Cleanup Levels for Low Energy Beta Radioisotopes, September 2020

Mortality Risk Using Different Dosimetry Methods for Drinking Water Standard of 4 mrem/yr

Radionuclide	ICRP 2 HEAST Adult	10 CFR 20, Table 2, Liquid Effluents members of the public-ICRP-26/30	ICRP-72/FGR-13	STD-1196-2011 ICRP-60	STD-1196-2021 ICRP-103
Tc-99	1.26E-09	1E-08	5E-09	5E-09	4E-08
I-129	1.84E-10	2E-09	2E-09	2E-09	3E-09

Resources

- DOE-STD-1196-2021
  - **Policies, Standards, Guidance, and Statutes** www.energy.gov/ehss/policies-standards-guidance-and-statutes
  - **REVCOM** www.standards.doe.gov/standards-documents/1100/1196-astd-2021
- DOE O 458.1: www.directives.doe.gov/directives-documents/400-series/0458.1-border-chg4-ltdchg/@@images/file
- Federal Guidance Report (FGR) No. 15: *External Exposure to Radionuclides in Air, Water and Soil,* 2019. www.epa.gov/sites/default/files/2019-08/documents/fgr_15_final_508_2019aug02.pdf
- ICRP: www.icrp.org
  - ICRP 89, *Basic Anatomical and Physiological Data for Use in Radiological Protection Reference Values*, 2002
  - ICRP 100, *The Human Alimentary Tract Model,* 2006
  - ICRP 103, *Recommendations of the International Commission on Radiological Protection*, 2007
  - ICRP 107, *Nuclear Decay Data for Dosimetric Calculations*, 2008
  - ICRP 130, *Occupational Intakes of Radionuclides: Part 1*
  - ICRP 133, *The ICRP Computational Framework for Internal Dose Assessment for Reference Adults: Specific Absorbed Fractions*, 2016

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Questions?

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