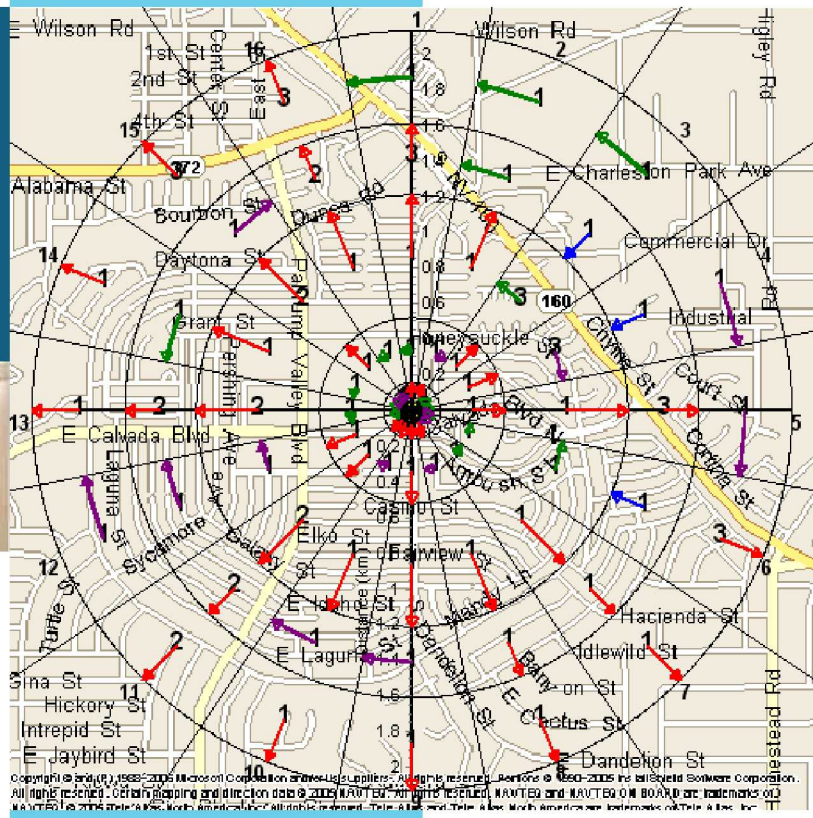
SAND2019-13354PE

New FGR 13 Dose Conversion Factor File for MACCS



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Presented at AMUG 2019, Nov. 4 – 6, 2019
Daejeon, Republic of Korea

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Contents

- Radiation doses
- Estimation of doses
- Historical view of DCF files used in MACCS
- FGR 13 DCFs
- Known issues with FGR 13 DCFs

Basic Radiological Quantities

- Activity
  - Measures disintegrations per unit time
  - Units are becquerel (Bq) or curie (Ci)
  - 1 Ci = activity of 1 g of Ra-226 = $3.7 \cdot 10^{10}$ Bq
  - 1 Bq = 1 decay/s
- Absorbed dose
  - Energy deposited per unit mass
  - Units are Gray (Gy) or rad
  - 1 Gy = 1 J/kg = 100 rad
- Equivalent dose
  - Measurement of biological effect
  - Absorbed dose times a radiation weighting factor
    - 1 for photons, electrons, and muons (low LET)
    - 20 for alpha particles
  - Units are Sievert (Sv) or rem
  - 1 Sv = 100 rem

Exposure Pathways

- Dose pathways include
  - External pathways
    - Cloudshine
    - Groundshine
    - Deposition onto skin
  - Internal pathways
    - Inhalation (direct and resuspension)
    - Ingestion
- External doses are concurrent with exposure period
- Internal doses continue after exposure period

Types of Doses

- Types of dose
  - Absorbed dose – energy deposited in a specific organ (Gy)
  - Equivalent dose – biological effect of dose to a specific organ (Sv)
  - Effective dose – weighted average of doses to a set of organs (represents entire body)
  - Committed dose – time integral (usually over 50-yr period) of internal dose
    - Referred to as lifetime dose in MACCS documents (L-organ)
- Acronyms
  - CEDE – Committed effective dose equivalent (internal)
  - TEDE – Total effective dose equivalent (internal + external)

Biological Effectiveness

- Quality factor
  - Only function of radiation type
- Radiation weighting factor
  - Function of radiation type and neutron energy
- Relative biological effectiveness (RBE)
  - Function of radiation type, energy(?), and organ or tissue

		Radiation Types		
Parameter Name	**Source**	**Beta, Gamma**	**Neutron**	**Alpha**
Quality Factor, Q	ICRP-26	1	20	20
Radiation Weighting Factor, W_R	ICRP-60	1	5 to 20	20
	ICRP-103	1	2.5 to 20	20
Relative Biological Effectiveness, RBE	ICRP-92	1		Tissue Dependent

Doses for Internal Pathways

- Direct inhalation

  Dose = χ x (Breathing Rate) x SF_{Inh} x DCF_{Inh}

- Resuspension inhalation

  Dose = D x (Resuspension Factor) x (Breathing Rate) x SF_{Inh} x DCF_{Inh}

- Ingestion

  Dose = D x (Area Occupied by Crops) x (Transfer Factor) x (Fraction Consumed) x DCF_{Ing}

Doses for External Pathways

- Cloudshine

$$\text{Dose} = \chi \times (\text{Finite Cloud Correction Factor}) \times SF_{CS} \times DCF_{Immersion}$$

- Groundshine

$$\text{Dose} = D \times SF_{GS} \times DCF_{GS}$$

Dose Conversion Factors

- MACCS DCF files are organized by
  - Radionuclide
  - Organ
  - Dose pathway
- Doses are summed over radionuclides and pathways to estimate an equivalent dose to an organ
- Effective doses are estimated as a weighted average over a set of organs using tissue weighting factors, W_T

DCF Files Used by NRC in MACCS

- DOSDATA (circa 1990)
  - Used in NUREG-1150
  - 19 organs and 60 radionuclides with acute and lifetime dose coefficients
- FGR13DCF (2007)
  - Distributed with all versions of WinMACCS
- FGR13GyEquiv (2008)
  - Used in 2012 SOARCA study and subsequent SOARCA UAs
- FGR13GyEquiv_RevA (2018)
  - Beginning to be distributed to MACCS users
  - Can be used to reproduce SOARCA results

Common Features of FGR 13 DCF Files

- Gonads contains the greater of the organ values for Testes and Ovaries
- Receptor is an adult (20 years of age; 25 years of age for bone seeking isotopes)
- Activity median aerodynamic diameter is (1 μm)
- Contain dose coefficients
  - 825 radionuclides for external doses
  - 500 radionuclides for internal doses
  - 27 tissues/organs
- Lifetime dose coefficients for internal pathways are based on a dose commitment period of 50 years
- Acute dose coefficients for internal pathways are based on multiple commitment periods of 1 to 365 d, depending on the organ, to account for dose protraction (NUREG/CR-4691)

Differences Between FGR 13 DCF Files

- FGR13DCF uses a standard radiation weighting factor for all organs
- FGR13GyEquiv uses RBE but reassigns coefficients for pancreas to bladder wall as a workaround
- FGR13GyEquiv_RevA uses RBE with no workarounds

		FGR13DCF		FGR13GyEquiv_RevA	
Organ Name	**Name in DCF File**	**Alpha**	**Beta & Gamma**	**Alpha**	**Beta & Gamma**
Breast	BREAST	20	1	10	1
Red Bone Marrow	RED MARR	20	1	1	1
Effective	ICRP60ED	20	1	20	1
All other organs		20	1	20	1

Issues with FGR 13 Dose Coefficients

- Inhalation and ingestion dose coefficients are known to be incorrect for the following isotopes
  - Samarium: Sm-146 and Sm-147
  - Gadolinium: Gd-148 and Gd-152
  - Curium: Cm-248 and Cm-250
  - Californium: Cf-252 and Cf-254

List of Acronyms

CEDE	Committed Effective Dose Equivalent
DCF	Dose Conversion Factor
ICRP	International Commission on Radiological Protection
LET	Linear Energy Transfer
MACCS	MELCOR Accident Consequence Code System
NRC	Nuclear Regulatory Commission
RBE	Relative Biological Effectiveness
SNL	Sandia National Laboratories
SOARCA	State-of-the-Art Reactor Consequence Analyses
TEDE	Total Effective Dose Equivalent