Millstone OpenEMS Dose Factors Bases

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What is OpenEMS ?

Glad you asked -
with apologies to the vendor
(they would appreciate the plug)

It's a Next Generation System from Canberra for Computation of Off-Site Dose From Effluent Releases

OpenEMS dose formula for fish and shellfish ingestion

Dose [mRem] =
Activity X Duration/60 X Dilution X Mixing ÷ Additional Dilution X Decay X DCF

Activity = radioactivity concentration in uCi/ml of sample from permit data

Duration = Time of discharge in minutes from permit data

Dilution = Avg Rel Flow Rate/(Avg Rel Flow Rate + Dilution Flow Rate)

Mixing = 1.06 to account for reconcentration of released activity back to intake

Additional Dilution = 3 for near field dilution

Decay = Radioactive decay correction

DCF = Dose conversion factor in units of mRem-mL/uCi-hr

Reg Guide 1.109 dose formula for fish and shellfish ingestion

Dose [mRem/yr] = 1100 X U X M X Q ÷ F X B X Decay X DCF

1100 = Units conversion = 1E12 [pCi/Ci] X 3.17E-8 [yr/sec] X 3.53E-2 [ft^3/L]

U = Usage factor in units of kg/year

M = mixing ratio (reciprocal of dilution factor)

Q = activity released in Ci/year

F = effluent dilution flow rate in units of ft^3/sec

B = bioaccumulation factor in units of liters/kg

Decay = radioactive decay = exp(-λt)

DCF = Dose Conversion Factor in units of mRem/pCi

How is OpenEMS equivalent to RG 1.109?

OpenEMS

Dose = Activity X Duration/60 X {(Dilution X Mixing)/Add Dilution} X Decay X Dose Conversation Factor in mRem-mL/uCi-hr

Reg Guide 1.109

Dose = Usage X Mixing ÷ Flow X Activity per year X Bioaccumulation X Decay X Dose Conversion Factor in mRem/pCi

To equate OpenEMS dose to Reg Guide 1.109 dose:

- ❑ Recognize equivalent parameters
- ❑ Incorporate some parameters into the OpenEMS dose conversion factor
- ❑ Make unit conversions

Equivalent Parameters

In OpenEMS the multiplied parameters of
Activity Concentration X Duration X Dilution
Are equivalent to Q/F in RG 1.109

Dilution = (Avg Rel Flow Rate)/(Avg Rel Flow Rate + Dilution Flow Rate) = (Avg Rel Flow Rate)/(Dilution Flow Rate) when Dilution Flow Rate >> Ave Rel Flow

Avg Rel Flow = Release volume / release duration

Dilution = Release volume/release duration/dilution flow rate

Thus: Activity Concentration X Duration X Dilution = Activity Concentration X Duration X Release volume + Release Duration + Dilution flow rate = Activity released in year/Dilution flow rate = Q/F

Equivalent Parameters

The ratio of ‘Mixing’ to ‘Add Dilution’ in OpenEMS dose formula is equivalent to M in the RG 1.109 formula.

Thus the OpenEMS formula of:

Activity X Duration X Dilution X Mixing
÷ Additional Dilution X Decay X DCF

equates to the equivalent formula of:

Q ÷ F X M X Decay X DCF

The equivalent OpenEMS formula of:

Q ÷ F X M X Decay X DCF

Still does not look like the RG 1.109 formula of:

1100 X U X M X Q ÷ F X B X Decay X DCF

Incorporate Parameters

The parameters of usage and bioaccumulation must be incorporated into the OpenEMS formula

Question: Where?
Answer: Within the OpenEMS dose conversion factor

Incorporate Parameters

Usage and bioaccumulation were factors to be incorporated for fish and shellfish ingestion

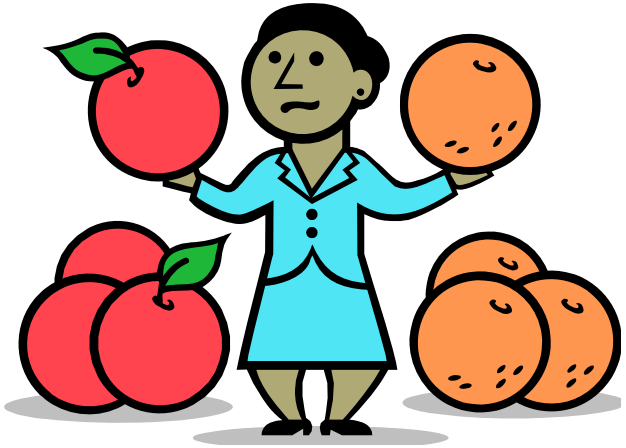
Usage is an incorporated factor for all pathways except inhalation and ground deposition

Other incorporated parameters included:

- ❑ Transit time for shoreline
- ❑ Geometry factor for boating and swimming
- ❑ Annual air intake for inhalation
- ❑ Shielding factor for ground deposition
- ❑ Fraction of plant matter that is water, ratio of H-3 in plant matter to H-3 in air and absolute atmospheric humidity for tritium ingestion from vegetation
- ❑ Fraction of plant mass as natural carbon and concentration of natural carbon in atmosphere for C-14 ingestion from vegetation
- ❑ Feed consumed, fractional intake to milk or meat, and time from feed to receptor for tritium and C-14 ingestion from milk and meat
- ❑ Fraction retained on crops, concentration factor, time soil is exposed, soil density, agricultural productivity for iodine and particulates ingestion from milk, meat and vegetation.

Unit Conversions

But there are conflicting units!



Need apples to apples

Incorporating Parameters and Equating Units

For fish and shellfish ingestion:

OpenEMS DCF = RG 1.109 DCF X U X B X 114155

unit conversions:

OpenEMS DCF [**mRem**-**mL**/**uCi**-**hr**]

RG 1.109 DCF [**mRem**/~~pCi~~]

X U [~~kg~~/~~yr~~]

X B [~~L~~/~~kg~~]

X 114155 [1E3 **ml**/~~L~~ X 1E6 ~~pCi~~/**uCi** X 1/8760 ~~yr~~/**hr**]

Incorporating Parameters and Equating Units

For shoreline exposure:

OpenEMS DCF = RG 1.109 DCF X U X T X [1-exp(-λt)] X 1.142E7

unit conversions:

OpenEMS DCF [**mRem**-**mL**/**uCi**-**hr**]

RG 1.109 DCF [**mRem**-~~M²~~/~~pCi~~-~~hr~~]

X U [~~hr~~/~~yr~~]

X T = transit time [~~days~~]

X 1142E7

[1E3 **ml**/~~L~~ X 1E6 ~~pCi~~/**uCi** X 1/8760 ~~yr~~/**hr** X 100 ~~L~~/~~M²~~-~~days~~]

Incorporating Parameters and Equating Units

For swimming and boating exposure:

OpenEMS DCF = WASH-1258 DCF X U ÷ K X 1.14E5

Note: Not RG 1.109, but from WASH-1258, USAEC, July 1973

unit conversions:

OpenEMS DCF [**mRem**-**mL**/**uCi**-**hr**]

WASH-1258 DCF [**mRem**-~~L~~/~~pCi~~-~~hr~~]
X U [~~hr~~/~~yr~~]
X K = geometry factor = 1 for swimming and 2 for boating
X 114E5 [1E3 **ml**/~~L~~ X 1E6 ~~pCi~~/**uCi** X 1.14E-4 ~~yr~~/**hr**]

Incorporating Parameters and Equating Units

For noble gas exposure:

OpenEMS DCF = RG 1.109 DCF X 0.7 X 1E6

unit conversions:

OpenEMS DCF [**mRem-M^3/uCi-yr**]

RG 1.109 DCF [**mRem**-**M^3**/~~pCi~~-**yr**]

X 0.7 = shielding factor

X 1E6 [~~pCi~~/**uCi**]

Incorporating Parameters and Equating Units

For inhalation:

OpenEMS DCF = RG 1.109 DCF X R X 1E6

unit conversions:

OpenEMS DCF [**mRem-M^3/uCi-yr**]

RG 1.109 DCF [**mRem**/~~pCi~~]

X R = annual air intake [**M^3/yr**]

X 1E6 [~~pCi~~/**uCi**]

Incorporating Parameters and Equating Units

For ground deposition exposure:

OpenEMS DCF = RG 1.109 DCF X S X 0.5* ÷ λ X [1-exp(-λt)] X 8.76E9

* only for iodine

unit conversions:

OpenEMS DCF [**<u>mRem</u>-<u>M²</u>/<u>uCi</u>**]

RG 1.109 DCF [**<u>mRem</u>**-**<u>M²</u>**/~~pCi~~-~~hr~~]

X S = shielding factor = 0.7

÷ λ [~~hr~~]

X 1E6 [~~pCi~~/**<u>uCi</u>**]

Incorporating Parameters and Equating Units

For H-3 in produce and leafy vegetable ingestion:

OpenEMS DCF = RG 1.109 DCF X U X 0.76* ÷ H X 1.2E7 X 1E-6

* produce only

unit conversions:

OpenEMS DCF [**mRem**-**M^3**/**uCi**-**sec**]

RG 1.109 DCF [**mRem**/~~pCi~~]

X U [~~kg~~/~~yr~~]

÷ H [**M^3**/~~g~~]

X 1.2E7 = 1E12 [~~pCi~~/~~Ci~~] X 1E3 [~~g~~/~~kg~~] X 1/3.15E7 [~~yr~~/**sec**] X 0.75 X 0.5

0.75 = fraction of total plant mass that is water (produce only)

0.5 = ratio of tritium concentration in plant water to tritium concentration in atmosphere

X 1E-6 [~~Ci~~/**uCi**]

Incorporating Parameters and Equating Units

For C-14 in produce and leafy vegetable ingestion:

OpenEMS DCF = RG 1.109 DCF X U X 0.3 X 0.76* X 2.2E7 X 31.5

0.3 = carbon dioxide fraction *produce only

unit conversions:

OpenEMS DCF [**mRem**-**M^3**/**uCi**-**yr**]

RG 1.109 DCF [**mRem**/~~pCi~~]

X U [~~kg~~/~~yr~~]

X 2.2E7 = 1E12 [~~pCi~~/~~Ci~~] X 1E3 [~~g~~/~~kg~~] X 1/3.15E7 [~~yr~~/**sec**] X

0.11 X 1/0.16 [**M^3**/~~g~~]

0.11 = fraction of total plant mass that is natural carbon

0.16 = concentration of natural carbon in atmosphere

X 31.5 = 1E-6 [~~Ci~~/**uCi**] X 3.15E7 [~~sec~~/**yr**]

Incorporating Parameters and Equating Units

For H-3 in milk and meat ingestion:

OpenEMS DCF = RG 1.109 DCF X U X Q X F ÷ H X 1.2E7 X 1E-6

unit conversions:

OpenEMS DCF [**mRem**-**M^3**/**uCi**-**sec**]

RG 1.109 DCF [**mRem**/~~pCi~~]

X U [~~L~~/~~yr~~]

X Q [~~kg~~/~~days~~] = feed consumed

X F [~~days~~/~~L~~] = fraction of intake to milk or meat

÷ H [**M^3**/~~g~~]

X 1.2E7 = 1E12 [~~pCi~~/~~Ci~~] X 1E3 [~~g~~/~~kg~~] X 1/3.15E7 [~~yr~~/**sec**] X 0.75 X 0.5

0.75 = fraction of total plant mass that is water (produce only)

0.5 = ratio of tritium concentration in plant water to tritium concentration in atmosphere

X 1E-6 [~~Ci~~/**uCi**]

Incorporating Parameters and Equating Units

For C-14 in milk and meat ingestion:

OpenEMS DCF = RG 1.109 DCF X U X 0.3 X Q X F X 2.2E7 X 31.5

0.3 = carbon dioxide fraction

unit conversions:

OpenEMS DCF [**mRem**-**M^3**/**uCi**-**yr**]

RG 1.109 DCF [**mRem**/~~pCi~~]

X U [~~kg~~/~~yr~~]

X Q [~~kg~~/~~days~~]

X F [~~days~~/~~kg~~]

X 2.2E7 = 1E12 [~~pCi~~/~~Ci~~] X 1E3 [~~g~~/~~kg~~] X 1/3.15E7 [~~yr~~/**sec**] X

0.11 X 1/0.16 [**M^3**/~~g~~]

0.11 = fraction of total plant mass that is natural carbon

0.16 = concentration of natural carbon in atmosphere

X 31.5 = 1E-6 [~~Ci~~/**uCi**] X 3.15E7 [~~sec~~/**yr**]

Millstone OpenEMS Dose Factors Bases

Revision 1

4/25/2013

Millstone OpenEMS Dose Factors Bases

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Inhalation
Ground deposition
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Ingestion of H-3 and C-14 in milk and meat
Ingestion of iodines and particulates in produce & vegetation
Ingestion of iodines and particulates in milk & meat

Millstone OpenEMS Dose Factors Bases

From fish and shellfish bases section:

Millstone Specific Changes to Reg Guide 1.109

Bioaccumulation factors not found in Reg Guide 1.109 were taken from Reference 2.
Shellfish bioaccumulation factors have been modified for Ag and Zn. For Ag, the factor is changed from 3,300 to 66,000 and, for Zn, from 50,000 to 1,000,000. These changes are based on measurements of these radionuclides in oysters from the Millstone quarry compared to curies released (Refs 3,4).

Adult Fish

	Bone	Liver	Total Body	Thyroid	Kidney	Lung	GI
AC-225	2.64E+02	3.63E+02	1.77E+01		4.14E+01		2.44E+04
AC-227	1.12E+05	1.49E+04	6.65E+03		4.79E+03		4.91E+03
AG-110M	1.27E+03	1.17E+03	6.95E+02		2.30E+03		4.78E+05
AG-111	4.60E+02	1.92E+02	9.57E+01		6.20E+02		3.53E+05
AM-241	4.52E+04	4.23E+04	3.24E+03		2.44E+04		4.45E+03
AM-242M	4.56E+04	3.97E+04	3.25E+03		2.43E+04		5.60E+03
AM-243	4.52E+04	4.14E+04	3.18E+03		2.39E+04		5.21E+03
BA-139	2.33E+00	1.66E-03	6.81E-02		1.55E-03	9.40E-04	4.12E+00
BA-140	4.87E+02	6.11E-01	3.19E+01		2.08E-01	3.50E-01	1.00E+03
BA-141	1.13E+00	8.53E-04	3.81E-02		7.93E-04	4.84E-04	5.32E-10
BA-142	5.11E-01	5.25E-04	3.21E-02		4.43E-04	2.97E-04	7.19E-19
BE-10	1.52E+03	2.35E+02	3.81E+01		1.78E+02		1.28E+04
BI-210M	1.66E+01	1.14E+02	9.49E+00		1.38E+03		1.71E+03
BR-82			8.13E-02				9.31E-02
BR-83			1.45E-03				2.08E-03
BR-84			1.87E-03				1.47E-08
BR-85			7.70E-05				
C-14	1.23E+04	2.45E+03	2.45E+03	2.45E+03	2.45E+03	2.45E+03	2.45E+03
CA-41	2.19E+01		2.40E+01				2.21E-01
CD-113M		2.29E+04	7.34E+02		2.52E+04		1.84E+05
CD-115M		1.32E+04	4.22E+02		1.05E+04		5.57E+05
CE-141	2.24E-01	1.52E-01	1.72E-02		7.05E-02		5.80E+02
CE-143	3.96E-02	2.92E+01	3.24E-03		1.29E-02		1.09E+03
CE-144	1.17E+01	4.89E+00	6.28E-01		2.90E+00		3.96E+03
CF-252	1.56E+04		3.77E+02				1.73E+04
CM-242	1.23E+03	1.31E+03	8.21E+01		3.73E+02		4.75E+03
CM-243	3.59E+04	3.29E+04	2.25E+03		1.05E+04		4.68E+03
CM-244	2.73E+04	2.56E+04	1.72E+03		8.03E+03		4.52E+03
CM-245	5.62E+04	4.90E+04	3.45E+03		1.61E+04		4.22E+03
CM-246	5.57E+04	4.89E+04	3.45E+03		1.61E+04		4.14E+03
CM-247	5.44E+04	4.82E+04	3.40E+03		1.58E+04		5.45E+03
CM-248	4.52E+05	3.97E+05	2.80E+04		1.31E+05		8.81E+04
CO-57		4.20E+01	6.98E+01				1.06E+03
CO-58		1.79E+02	4.00E+02				3.62E+03
CO-60		5.13E+02	1.13E+03				9.64E+03
CR-51			2.55E+00	1.52E+00	5.62E-01	3.38E+00	6.42E+02
CS-134	5.96E+03	1.42E+04	1.16E+04		4.59E+03	1.52E+03	2.48E+02
CS-134M	2.04E+00	4.30E+00	2.20E+00		2.33E+00	3.67E-01	1.52E+00
CS-135	1.87E+03	1.73E+03	7.66E+02		6.53E+02	1.96E+02	4.04E+01
CS-136	6.24E+02	2.46E+03	1.77E+03		1.37E+03	1.88E+02	2.80E+02
CS-137	7.64E+03	1.05E+04	6.85E+03		3.55E+03	1.18E+03	2.02E+02
CS-138	5.29E+00	1.05E+01	5.18E+00		7.68E+00	7.58E-01	4.46E-05
CS-139	3.27E+00	4.87E+00	1.77E+00		3.90E+00	3.55E-01	1.05E-22
CU-64		1.34E+02	6.28E+01		3.37E+02		1.14E+04
EU-152	1.17E+01	2.66E+00	2.34E+00		1.65E+01		1.53E+03
EU-154	3.69E+01	4.53E+00	3.22E+00		2.17E+01		3.28E+03
EU-155	5.15E+00	7.31E-01	4.72E-01		3.37E+00		5.75E+02
EU-156	8.21E-01	6.35E-01	1.02E-01		4.24E-01		4.35E+03
F-18	5.39E+00		5.97E-01				1.60E-01
FE-55	1.98E+04	1.37E+04	3.19E+03			7.62E+03	7.84E+03
FE-59	3.12E+04	7.34E+04	2.81E+04			2.05E+04	2.45E+05
H-3		2.27E-01	2.27E-01	2.27E-01	2.27E-01	2.27E-01	2.27E-01
HO-166M	1.62E+01	5.05E+00	3.84E+00		7.55E+00		
I-129	7.84E+01	6.74E+01	2.21E+02	1.73E+05	1.45E+02		1.06E+01
I-130	1.81E+01	5.35E+01	2.11E+01	4.53E+03	8.34E+01		4.60E+01
I-131	9.97E+01	1.43E+02	8.17E+01	4.67E+04	2.45E+02		3.76E+01
I-132	4.87E+00	1.30E+01	4.55E+00	4.55E+02	2.07E+01		2.45E+00
I-133	3.40E+01	5.92E+01	1.81E+01	8.70E+03	1.03E+02		5.32E+01
I-134	2.54E+00	6.90E+00	2.47E+00	1.20E+02	1.10E+01		6.02E-03
I-135	1.06E+01	2.78E+01	1.03E+01	1.83E+03	4.46E+01		3.14E+01

Questions ?