Estimating Effective and Equivalent dose rates for submersion in a semi-infinite radioactive cloud based on ICRP 107 and 110

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INTRODUCTION

- The effective dose rate and equivalent dose rates of radioactive noble gas have been calculated with nuclear decay data(ICRP 107) and adult reference phantoms(ICRP 110)
- Each maximum exposed distances(MED) of 24 photon energies ranging from 0.01 to 10 MeV were estimated using 1 meter diameter tissue equivalent sphere target above 1 m ground level with MCNPX 2.7.0.
- Effective dose rate and equivalent dose rates of each photon energy were computed at MED.
- Computed equivalent dose rates over 0.1 MeV at each MED are corrected with EDRM(Equivalent Dose Ratio Method)
- The errors of corrected equivalent dose rates by EDR are estimated by formula (1)and(2)
- Effective and equivalent dose rates of radioactive noble gases are compared with IAEA BSS 115, FGR12 and FGR13.

OBJECTIVES

- In ICRP 2007 Recommendations, ICRP adopted Reference Male and Female computational phantoms(ICRP 110) for forthcoming updates of organ dose coefficients for both internal and external radiation sources.
- ICRP 38(Radionuclide Transformations-Energy and Intensity of Emissions) is updated with ICRP 107(Nuclear decay data for Dosimetric Calculations)
- So, we need to present new Dose Conversion Factor(DCF) in air submersion, water immersion, ground surface contamination and soil contamination.
- We present the method to calculate DCF in air immersion with radioactive noble gases and the DCF of them.
- When IAEA newly revised BSS concerned with ICRP 103 will be published and that time we must change DCF following New Standards.
- So, we present NEW DCFs following ICRP 103 recommendation.

METHODS

- MED estimation[Table-1]
  1. In order to calculate MED of each photon energies, we did MCNP simulations with increasing distance.
  2. The result of simulation, absorbed dose rate is saturated certain distance far from the target.
  3. So, we defined MEDs of each photon energies.
- Equivalent Dose Ratio Method(EDRM)[Table-2]
  1. In order to decrease errors in MCNP, we can use variance reduction techniques but they have many uncertainties. Therefore, In case of analysis of huge radioactive volume, we can get various results.
  2. To verify EDRM, we did compared dose ratios of 50 m with MED using directional disk source and dose ratios of 50m with MED using submersion source.
  3. Corrected equivalent doses was calculated with EDR of 50m submersion source.
  4. In order to decrease errors, we just use a history number increasing up to 3E10.
  5. So, we get dose ratios of other organs for MUSCLE(organ of reference, lowest error).
  6. Our conclusion is equivalent dose at MED will be replaced with EDR multiplied by equivalent dose of Organ of Reference(MUSCLE) at MED.
- DCF error verification[Table-3]

$$F(x,y) = \frac{x}{y} \pm \frac{x}{y}\sqrt{\left(\frac{\sigma_x}{x}\right)^2+\left(\frac{\sigma_y}{y}\right)^2} \quad (1)$$

$$F(x,y) = x \cdot y \pm x \cdot y\sqrt{\left(\frac{\sigma_x}{x}\right)^2+\left(\frac{\sigma_y}{y}\right)^2} \quad (2)$$

RESULTS

- Table-1. MED of each photon energies

Energy[MeV]	MFP[m]	MED[m]	MED/MPF	Energy[MeV]	MFP[m]	MED[m]	MED/MFP
0.010	1.51	6	3.97	0.400	80.99	330	4.07
0.015	4.79	23	4.80	0.500	88.77	350	3.94
0.020	9.94	37	3.72	0.600	96.01	375	3.91
0.030	21.86	85	3.89	0.800	109.33	410	3.75
0.040	31.12	105	3.37	1.000	121.64	450	3.70
0.050	37.18	140	3.77	1.250	135.99	510	3.75
0.060	41.25	155	3.76	1.500	149.45	550	3.68
0.080	46.53	225	4.84	2.000	173.91	600	3.45
0.100	50.19	265	5.28	3.000	215.97	650	3.01
0.150	57.04	275	4.82	4.000	251.18	725	2.89
0.200	62.72	295	4.70	5.000	281.13	775	2.76
0.300	72.48	320	4.42	10.000	378.19	1000	2.64

- Table-2. Dose Ratio of MUSCLE(Organ of Reference) with Disk Source, REX

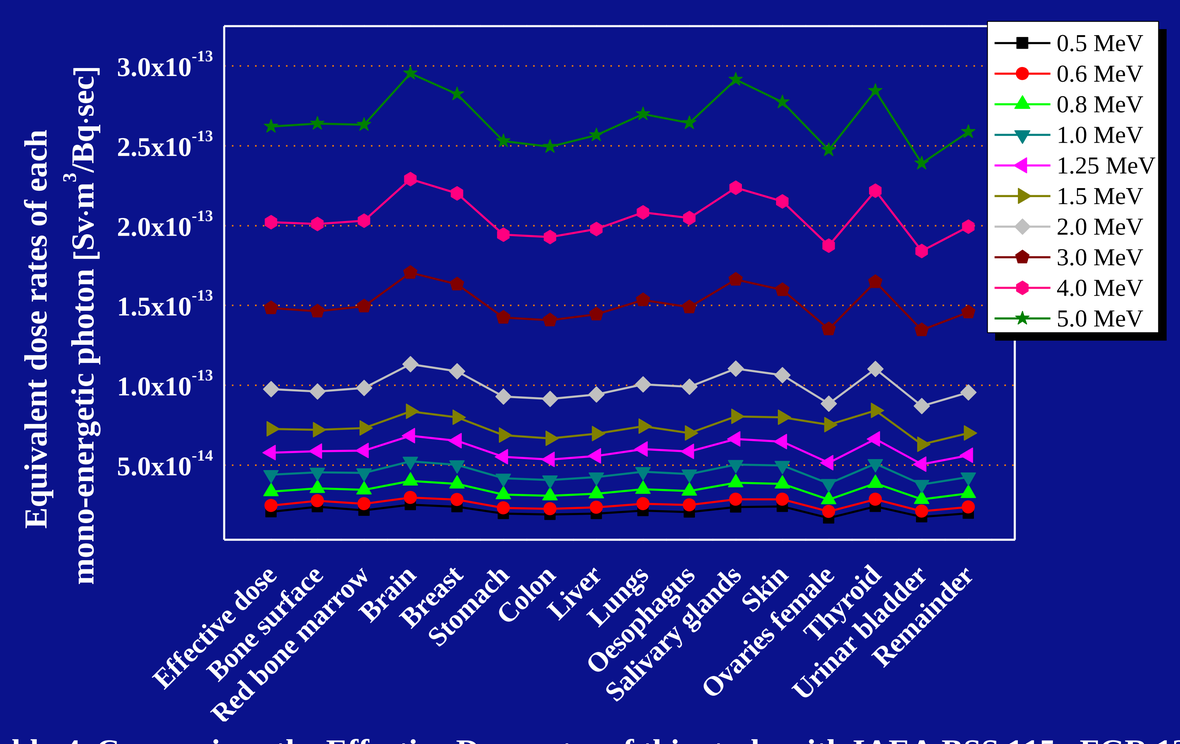
Order	Major organ	Low Energy(0.1 MeV)		Intermediate Energy(1.25 MeV)		High Energy(4.0 MeV)	
		50m	MED	50m	MED	50m	MED
1	Bone surface	239.60%	240.23%	93.81%	93.67%	96.38%	96.41%
2	Red bone marrow	111.18%	111.12%	96.79%	96.71%	97.79%	97.92%
3	Brain	71.94%	71.84%	89.11%	88.83%	94.46%	94.46%
4	Breast	28.57%	27.61%	75.93%	75.29%	86.44%	86.82%
5	Stomach	63.55%	62.91%	79.56%	79.92%	87.19%	87.32%
6	Colon	73.68%	73.49%	86.11%	86.41%	91.51%	91.26%
7	Liver	77.77%	77.48%	86.18%	86.27%	90.72%	91.07%
8	Lungs	89.41%	89.81%	96.28%	96.35%	97.49%	97.79%
9	Oesophagus	82.53%	83.00%	91.11%	92.10%	95.24%	94.27%
10	Salivary glands	83.70%	83.86%	103.77%	104.17%	102.73%	103.36%
11	Skin	91.55%	91.46%	99.55%	99.59%	99.13%	99.21%
12	Gonads male	65.25%	65.73%	85.32%	85.13%	91.89%	91.55%
13	Thyroid	64.29%	66.99%	82.59%	84.05%	88.75%	90.12%
14	Urinar bladder	78.06%	76.36%	86.78%	86.11%	90.94%	91.43%

- Table-3. DCF error Verification of Major organ for 5000keV photon at 775 m(MED)

Organ	Bone surface	Red bone marrow	Brain	Breast	Stomach	Colon	Liver
W_T	0.01	0.12	0.01	0.12	0.12	0.12	0.04
Relative error	3.81%	3.81%	3.87%	6.05%	4.31%	4.02%	3.86%

Organ	Lungs	Oesophagus	Salivary glands	Skin	Ovaries female	Thyroid	Urinar bladder
W_T	0.12	0.04	0.01	0.01	0.08	0.04	0.04
Relative error	3.88%	5.39%	4.61%	3.81%	5.82%	6.60%	4.20%

- Graph-1. Equivalent dose rates of each mono-energetic photon



- Table-4. Comparison the Effective Dose rates of this study with IAEA BSS 115, FGR 12 and FGR 13 unit : $[\frac{Sv \cdot m^3}{Bq \cdot sec}]$

Order	Noble Gas	This Study(TS)	FGR-12	FGR-12/TS	FGR-13	FGR-13/TS	BSS-115	BSS-115/TS
1	Ne-19	4.22E-14	4.92E-14	116.59%	-	-	-	-
2	Ne-24	2.24E-14	-	-	-	-	-	-
3	Ar-37	7.48E-20	1.27E-19	169.79%	-	-	4.75E-20	63.50%
4	Ar-39	Pure β emitter	9.10E-18	-	1.15E-16	-	1.27E-16	
5	Ar-41	5.93E-14	6.50E-14	109.61%	6.15E-14	103.71%	6.13E-14	103.37%
6	Ar-42	Pure β emitter	-	-	-	-	-	-
7	Ar-43	7.03E-14	-	-	-	-	-	-
8	Ar-44	9.03E-14	-	-	-	-	-	-
9	Kr-74	4.29E-14	5.59E-14	130.30%	5.21E-14	121.45%	5.21E-14	121.45%
10	Kr-75	5.27E-14	-	-	-	-	-	-
11	Kr-76	1.67E-14	2.03E-14	121.56%	1.87E-14	111.98%	1.85E-14	110.78%
12	Kr-77	4.21E-14	4.86E-14	115.44%	4.52E-14	107.36%	4.51E-14	107.13%
13	Kr-79	1.02E-14	1.21E-14	118.63%	1.12E-14	109.80%	1.12E-14	109.80%
14	Kr-81	3.81E-17	2.67E-16	700.79%	2.45E-16	643.04%	2.43E-16	637.80%
15	Kr-81m	4.90E-15	6.14E-15	125.31%	5.57E-15	113.67%	-	
16	Kr-83m	2.56E-18	1.50E-18	58.59%	1.20E-18	46.88%	2.43E-18	94.92%
17	Kr-85	9.21E-17	1.19E-16	129.21%	2.40E-16	260.59%	2.55E-16	276.87%
18	Kr-85m	5.91E-15	7.48E-15	126.57%	6.88E-15	116.41%	6.83E-15	115.57%
19	Kr-87	3.61E-14	4.12E-14	114.13%	3.98E-14	110.25%	3.94E-14	109.14%
20	Kr-88	9.19E-14	1.02E-13	110.99%	9.72E-14	105.77%	9.72E-14	105.77%
21	Kr-89	8.88E-14	-	-	-	-	-	-
22	Xe-120	1.52E-14	1.94E-14	127.63%	1.79E-14	117.76%	1.74E-14	114.47%
23	Xe-121	6.46E-14	9.14E-14	141.49%	8.63E-14	133.59%	8.68E-14	134.37%
24	Xe-122	2.02E-15	2.46E-15	121.78%	2.20E-15	108.91%	2.20E-15	108.91%
25	Xe-123	2.65E-14	3.03E-14	114.34%	2.82E-14	106.42%	2.78E-14	104.91%
26	Xe-125	9.77E-15	1.19E-14	121.80%	1.08E-14	110.54%	1.08E-14	110.54%
27	Xe-127	1.01E-14	1.25E-14	123.76%	1.13E-14	111.88%	1.12E-14	110.89%
28	Xe-127m	5.80E-15	-	-	-	-	-	-
29	Xe-129m	8.17E-16	1.06E-15	129.74%	9.18E-16	112.36%	9.38E-16	114.81%
30	Xe-131m	3.04E-16	3.89E-16	127.96%	3.50E-16	115.13%	3.70E-16	121.71%
31	Xe-133	1.21E-15	1.56E-15	128.93%	1.34E-15	110.74%	1.39E-15	114.88%
32	Xe-133m	1.09E-15	1.37E-15	125.69%	1.29E-15	118.35%	1.27E-15	116.51%
33	Xe-135	9.70E-15	1.19E-14	122.68%	1.11E-14	114.43%	1.11E-14	114.43%
34	Xe-135m	1.74E-14	2.04E-14	117.24%	1.90E-14	109.20%	1.85E-14	106.32%
35	Xe-137	8.09E-15	-	-	-	-	-	-
36	Xe-138	5.14E-14	5.77E-14	112.26%	5.48E-14	106.61%	5.44E-14	105.84%

DISCUSSION and CONCLUSIONS

- Each MED is ranging from 2 to 5 MFP dependent on photon energy.
- Effective Dose rates in this study are between 94.92 % to 116.51 % difference for IAEA BSS 115 except a few nuclides.
- Following the analysis, that differences came from MED, Nuclide Decay Data and Phantoms.
- So, DCFs are appropriate to calculate new effective dose and equivalent dose for submersion of radioactive noble gases.
- In case of Co-60, Cs-137(ɤ-ray), the former is 1.15E-14(FGR13 : 1.21E-14), the latter is 2.64E-14(FGR-13 : 2.69E-14)

FUTURE WORKS

- To calculate All DCFs of Gamma-ray and Pure Beta emitting nuclides in air submersion, ground surface contamination, water immersion and soil contamination.