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Effective dose evaluation for external exposure from surface soil by using resrad-onsite code

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Abstract: An external effective dose evaluation from Dong Nai surface soil (45 samples) to the humans was presented in this work. ResRad-Onsite software (Version 7.2) has been applied to estimate the maximum exposure effective dose by considering different exposure levels across an area of 5905.7 km^2 with a topsoil thickness of 20 cm. The calculation grid used in ResRad Onsite software is divided in the form of a circle of radius 3, 5, 10, 20, and 30 km, respectively, calculated from the circle center in terms of 16 wind directions. The HPGe detector was used to determine ^{238}U, ^{232}Th, ^{226}Ra, ^{137}Cs, and ^{40}K isotopes. The range of their activity concentration was found to be 6.46 ÷ 48.11, 13.95 ÷ 58.75, 5.71 ÷ 35.27, 0.15 ÷ 1.23 and 6.7 ÷ 222 Bq/kg, respectively. The isotope $^{239+240}$Pu was determined by the radiochemical separation method, measured on the alpha spectrometer system, and the calculated value range is 0.009 ÷ 0.073 Bq/kg. The activity of ^{90}Sr was determined by the separation technique, measured on the low-background alpha/beta total counting system (MPC 9300) with a calculated value range of 0.10 ÷ 0.83 Bq/kg. By ResRad-Onsite code, the external effective dose derived from the ground (excluding Radon's contribution) is calculated to be 170 ÷ 658 µSv/year with an average value of 368.6 ± 30.3 µSv/year. The external effective dose from the soil is 136.5 µSv/year (accounting for 37%). The results showed that the external effective dose distribution derived from the ground equivalent to the average of some different regions in the territory of Vietnam and the world. In addition, the external effective dose from the ResRad-Onsite code tended to be about 1.36 times smaller than the practical measuring one due to the library's different dose conversion coefficients.

Keywords: *External effective dose, ResRad-Onsite, surface soil.*

I. INTRODUCTION

Humans have always been exposed to radiation every day from natural and artificial radioactive sources (including external and internal exposure) at an average annual effective dose of about 2.96 mSv/year; up to 2.42 mSv/year (approximately 82%) of which is caused by natural occurring radioactive isotopes [1]. The biological impact of radiation exposure on the population is the main concern in nuclear power plant accidents. The number of people exposed to radiation and dose distributions in residential areas are assessment criteria for the impact of accidents. The radiation dose at a certain position is an indicator of the radioactive substances released into the environment. The dose value depends on the amount of radioactive contamination, the radiation characteristics (gamma, neutron, ions, etc.) and radiant energy intensity, the duration of exposure, weather conditions, and terrain conditions between the emission source and the measurement position. Therefore, it is necessary to develop a procedure for the population dose assessment and apply it for a

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specific location to gradually meet the national requirements and international standards on environmental protection, for the sustainable development of nuclear energy. Moreover, to ensure and control the impact of natural as well as man-made radionuclides, it is necessary to determine the existent level of pollutants content in the environment from which to evaluate the dose due to radioactive substances that the public receives. This is also quite important work in controlling emission limits.

This study focuses on determining the external effective dose caused by radiation in Dong Nai's surface soil using the ResRad-Onsite model. The input data of the model include the concentration of radioisotopes ^{238}U, ^{232}Th, ^{226}Ra, ^{137}Cs, ^{40}K, ^{239,240}Pu, and ^{90}Sr, deposition velocity in the survey area, dose coefficients, transport factors, …[2-7].

II. CONTENTS

A. Material and method

1. Sample collection and preparation

Collection of surface soil was carried out at 45 locations (with a depth of 0-30 cm) distributed across the entire area of 5905.7 km^2 in Dong Nai province (Fig. 1).

The collected sampling volume was about 2 – 4 kg/sample, packed in a 2-layer polyethylene bag, marked, and transferred back to the laboratory of Dalat Nuclear Research Institute. Here, the sample was left in air for 5 days to dry completely, and in an oven at 110 ^{0}C for 10 hrs to attain unchanged mass. The soil was crushed, and screened to obtain a homogeneous sample to prevent soft-degradation and put in a cylindrical polyethylene box.

Fig. 1. The diagram of soil sampling locations in Dong Nai

2. Research method

ResRad is a computer code designed for assessing radiation doses and risks from residual radioactive contaminants in soil. The software is developed based on the RESidual RADioactivity model of the US Department of Energy to support the development of cleanup standards and the assessment of the radiation dose. ResRad-Onsite (Version 7.2) is mainly used for purposes such as:

- Calculating radionuclide concentrations in soil based on regulatory standards that allow cleaning of contaminated areas; calculating annual doses or risks to an on-site individual (worker or resident) from radioactive contamination of the soil; calculating radiochemical concentrations in water, air, food, and other environmental components resulting from the transportation and conversion of radioactive particles in the soil.

- Supporting the application of the ALARA principle in the analysis and treatment of environmental radiation incidents to achieve maximum effectiveness and cost-effectiveness.

ResRad-Onsite uses a dose and risk assessment method, specifically, the software relies on the user-collected datasets in the radiation-affected areas, combined with conversion factors (from recommended libraries or customized as required) to assess the effective dose of individuals in the area and the radiation pollution level of environmental components. Accordingly, it helps users to evaluate the level of radiation contamination and the associated risks over time [8-11].

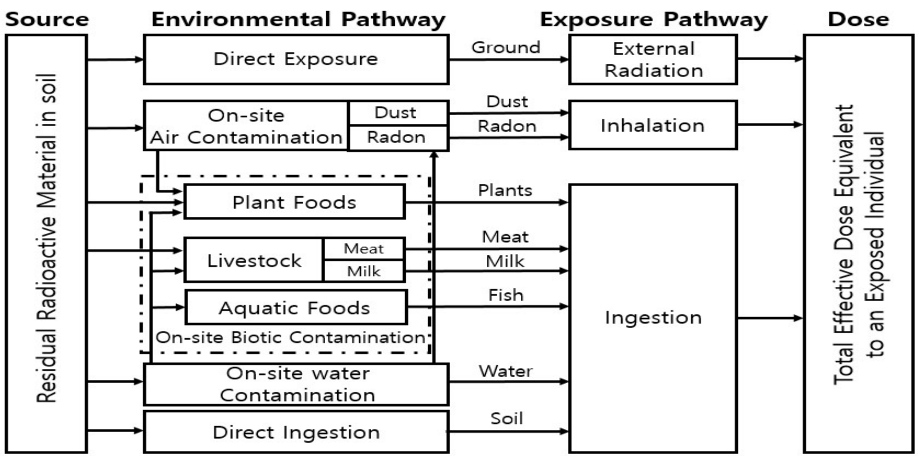

Fig. 2. Exposure pathways in ResRad-Onsite software

The location of nuclear facility project is in Hang Gon commune, Long Khanh city, Dong Nai province. The project (reactor with a capacity of 15 MWt) will be a modern scientific and technological research facility serving the fields of nuclear power such as calculating, designing, and implementation of nuclear power, fuel, fuel improvement, and radioactive waste management. Therefore, report on external effective dose assessment due to the radioactive background effects of the soils surrounding the project's location is tested at coordinates X=1201375 and Y=444333.

The computational grid used in the ResRad-Onsite software is divided in the form of a circle of radius 3, 5, 10, 20, and 30 km, respectively, calculated from the circle center in terms of 16 wind directions. The grid cells are numbered as shown in Fig. 3.

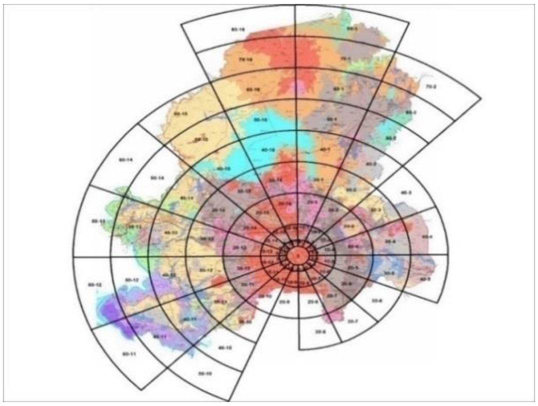

Fig. 3. Grids and cell names used for ResRad-Onsite calculations

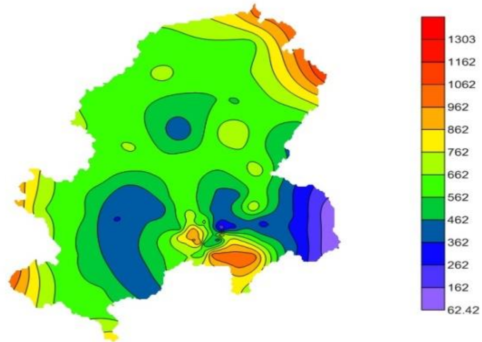

Fig. 4. Distribution of effective dose after one year (170 ÷ 658 µSv/year)

The main input data for ResRad-Onsite include (Table I):

- Data related to the radioisotopes which existed in the environmental study area: Concentration of radioactive isotopes present in the contaminated area.The transport coefficients of each type of isotope, the distribution coefficients for radioactive isotopes; The rate of water infiltration into the soil; The solubility of isotopes in water; The transport coefficient from soil to plants, to animal products, from water to seafood; The deposition rate in the atmosphere and infiltration rate into groundwater.

- Data related to the basic geometry of the radioactively contaminated area: Contaminated area, thickness of the contaminated soil layer, and the characteristics of the terrain.

- Data related to the pathway of ingestion through food and diet.

- Data related to the inhalation pathway of the public.

- Data related to the source terms.

- Data related to the surface cover and hydrodynamics of the contaminated area.

Table I. Input values used in ResRad Onsite code

Input parameter	Value	Source
Concentration	Table II	This study
Exposure duration	30 years	RESRAD default
Area of the contamination zone	Table II	This study
Distribution coefficients of contaminated zone		This study
^{137}Cs	4600 cm^3/g	RESRAD default
^{40}K	5.5 cm^3/g	RESRAD default
^{226}Ra	70 cm^3/g	RESRAD default
^{232}Th	30 cm^3/g	RESRAD default
^{238}U	50 cm^3/g	RESRAD default
Cover depth	0 m	RESRAD default
Thickness of the contaminated zone	0.3 m	This study
Average annual wind speed	1.3 m/s	This study
Density of the contaminated zone	1.5 g/cm^3	RESRAD default
Density of saturated zone	1.5 g/cm^4	This study

Inhalation rate for onsite resident	8364 m^3/year	This study
Ingestion pathway, Dietary data		
Fruit, vegetable, and grain consumption	200 kg/year	This study
Leafy vegetable consumption	14 kg/year	RESRAD default
Milk consumption	92 L/year	RESRAD default
Outdoor fraction	0.25	RESRAD default
Indoor fraction	0.5	RESRAD default

B. Results

The results of ResRad-Onsite for the external effective dose rates for each grid cell are shown in Table III, and the distribution of effective dose rates over the whole Dong Nai province after one year of assessment is presented in Fig. 4.

Table II. The average and activity range of radioactive isotopes in each soil grid cell used for ResRad-Onsite calculations

No.	Sample Name	Area/cell (m^2)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	^{226}Ra (Bq/kg)
1	3	28,000,000	26.51	40.61	17.48	18.16
2	5 (1-16)	3,100,000	24.34 ± 14.42 6.46 ÷ 48.11	36.66 ± 15.11 15.57 ÷ 58.75	24.80 ± 18.54 6.70 ÷ 61.65	19.43 ± 8.31 5.71 ÷ 31.73
3	10 (1-16)	14,600,000	24.08 ± 8.80 11.09 ÷ 41.52	34.35 ± 11.76 16.78 ÷ 54.39	41.20 ± 46.81 8.41 ÷ 190.17	19.26 ± 5.72 10.51 ÷ 30.52
4	20 (1-16)	59,000,000	20.47 ± 7.38 9.01 ÷ 33.77	30.53 ± 9.04 17.13 ÷ 46.69	52.46 ± 67.59 18.38 ÷ 300.83	18.81 ± 6.85 9.15 ÷ 35.27
5	30 (1-16)	97,500,000	16.23 ± 5.19 8.92 ÷ 24.89	23.97 ± 7.83 13.93 ÷ 40.89	68.18 ± 65.29 11.46 ÷ 222.4	14.78 ± 4.46 9.22 ÷ 25.54

No.	Sample Name	Area/cell (m^2)	^{137}Cs (Bq/kg)	$^{239+240}$Pu (Bq/kg)	^{90}Sr (Bq/kg)
1	3	28,000,000	0.66	0.039	0.44
2	5 (1-16)	3,100,000	0.48 ± 0.24 0.08 ÷ 1.10	0.029 ± 0.014 0.007 ÷ 0.065	0.33 ± 0.16 0.10 ÷ 0.74
3	10 (1-16)	14,600,000	0.68 ± 0.21 0.42 ÷ 1.02	0.040 ± 0.012 0.025 ÷ 0.061	0.46 ± 0.14 0.28 ÷ 0.69
4	20 (1-16)	59,000,000	0.59 ± 0.27 0.15 ÷ 1.23	0.035 ± 0.016 0.009 ÷ 0.073	0.40 ± 0.18 0.10 ÷ 0.83
5	30 (1-16)	97,500,000	0.43 ± 0.24 0.15 ÷ 1.23	0.025 ± 0.014 0.009 ÷ 0.059	0.29 ± 0.16 0.10 ÷ 0.68

Table III. The external effective dose range from 0 to 100 years calculated by ResRad-Onsite software

ID	Set pathways	The external effective dose, D (µSv/year), calculated at times T (year)							
		0	1	5	10	30	50	70	100
3	Full	709	694	648	603	495	428	369	332

	No Radon	439	429	400	375	322	289	258	238
5-1	Full	549	535	510	493	414	343	280	250
	No Radon	283	277	273	275	254	225	195	186
5-2	Full	438	427	394	364	297	256	218	204
	No Radon	286	277	254	236	203	182	162	158
5-3	Full	249	243	224	209	173	151	132	123
	No Radon	170	165	152	142	123	112	100	97
5-4	Full	236	230	213	198	165	145	127	119
	No Radon	164	159	146	136	118	108	97	94
5-5	Full	946	925	859	798	650	553	467	423
	No Radon	586	570	529	496	429	386	342	325
5-6	Full	403	392	361	334	272	232	196	183
	No Radon	255	247	227	211	181	163	144	142
5-7	Full	487	477	446	415	338	288	243	214
	No Radon	301	294	276	260	224	201	178	163
5-8	Full	479	469	439	408	333	285	243	215
	No Radon	311	304	284	266	227	203	180	164
5-9	Full	528	517	483	449	366	314	269	238
	No Radon	348	340	318	297	252	225	200	182
5-10	Full	1012	991	927	863	701	600	511	451
	No Radon	658	643	602	564	479	427	379	343
5-11	Full	856	838	784	731	598	512	437	387
	No Radon	550	538	504	474	407	365	325	296
5-12	Full	987	967	904	842	686	588	503	444
	No Radon	646	632	591	554	471	421	374	339
5-13	Full	935	916	856	797	650	558	477	422
	No Radon	614	600	561	526	447	400	356	323
5-14	Full	844	827	773	719	586	502	429	379
	No Radon	551	538	503	471	401	359	319	290
5-15	Full	557	542	498	459	370	313	264	248
	No Radon	353	342	311	287	244	218	193	192
5-16	Full	730	713	661	611	487	409	342	305
	No Radon	455	442	409	380	318	281	247	230
10-1	Full	457	446	412	381	307	261	221	202
	No Radon	274	266	244	227	192	171	151	145
10-2	Full	431	420	386	355	282	237	198	184
	No Radon	254	246	223	205	172	152	134	132
10-3	Full	428	417	382	352	279	235	196	183
	No Radon	253	244	221	204	170	150	132	131
10-4	Full	347	338	311	287	230	194	163	150
	No Radon	205	199	181	168	141	125	110	108
10-5	Full	742	726	676	627	507	430	364	326
	No Radon	438	427	396	370	315	281	249	232
10-6	Full	875	857	799	742	598	506	425	378
	No Radon	505	493	459	430	367	327	289	267
10-7	Full	954	934	872	812	666	575	495	445
	No Radon	593	578	539	505	433	389	347	320
10-8	Full	1034	1013	947	880	712	605	513	453
	No Radon	613	599	560	525	446	398	352	320
10-9	Full	621	608	567	528	431	369	316	283
	No Radon	375	366	341	320	274	246	219	203

10-10	Full	696	683	640	597	489	420	359	318
	No Radon	415	406	382	359	311	280	249	227
10-11	Full	727	712	666	620	505	432	369	328
	No Radon	440	430	402	377	322	288	256	234
10-12	Full	839	822	768	714	579	494	420	374
	No Radon	503	491	458	429	366	327	290	265
10-13	Full	547	522	455	408	325	276	234	264
	No Radon	351	329	275	243	202	181	161	204
10-14	Full	648	627	567	517	412	348	293	291
	No Radon	393	376	332	302	253	225	199	215
10-15	Full	754	737	685	635	511	433	367	329
	No Radon	450	439	406	379	320	284	251	234
10-16	Full	545	533	494	457	366	310	262	237
	No Radon	328	319	294	273	229	203	179	168
20-1	Full	472	461	428	396	319	271	229	207
	No Radon	279	271	250	233	198	177	156	147
20-2	Full	432	420	384	352	277	230	190	179
	No Radon	248	239	215	197	164	144	126	127
20-3	Full	798	759	656	585	460	388	326	378
	No Radon	509	476	392	342	280	250	221	293
20-4	Full	334	325	297	274	221	189	160	153
	No Radon	202	195	176	162	138	124	110	112
20-5	Full	573	557	509	467	369	307	255	240
	No Radon	328	317	285	262	219	193	169	171
20-6	Full	1042	1020	948	877	695	577	476	419
	No Radon	568	554	514	480	406	358	313	291
20-7	Full	974	953	886	821	656	550	458	407
	No Radon	546	532	494	462	392	349	307	285
20-8	Full	739	723	671	623	502	425	357	323
	No Radon	418	406	376	352	304	273	241	230
20-9	Full	809	793	739	685	550	465	391	346
	No Radon	472	460	429	401	339	301	265	243
20-10	Full	657	643	600	558	454	387	329	294
	No Radon	385	375	350	328	283	254	226	209
20-11	Full	557	545	508	473	384	328	279	250
	No Radon	327	319	297	279	240	216	192	178
20-12	Full	549	538	501	465	372	311	259	228
	No Radon	301	294	275	258	220	196	172	159
20-13	Full	507	495	456	420	336	283	238	220
	No Radon	296	287	262	242	205	182	161	157
20-14	Full	412	402	372	344	277	236	200	183
	No Radon	245	238	219	203	173	154	137	131
20-15	Full	624	608	561	518	418	357	305	283
	No Radon	384	372	340	315	265	237	210	204
20-16	Full	587	573	530	491	395	336	284	260
	No Radon	350	340	313	291	246	219	194	186
30-1	Full	616	587	510	456	361	306	259	296
	No Radon	394	369	306	269	222	199	176	228
30-2	Full	741	714	637	578	456	382	318	328
	No Radon	442	420	364	327	272	241	212	243
30-3	Full	435	416	366	328	253	208	170	184

	No Radon	254	239	201	177	144	126	110	138
30-4	Full	358	346	313	286	226	190	158	156
	No Radon	210	201	178	162	135	120	106	114
30-5	Full	366	355	321	293	226	185	150	145
	No Radon	202	193	171	155	127	111	96	103
30-6	Full	388	377	347	321	264	230	199	190
	No Radon	244	235	214	198	172	156	140	140
30-7	Full	628	615	575	534	431	365	307	271
	No Radon	358	350	327	307	263	235	208	190
30-8	Full	875	849	772	708	564	475	398	386
	No Radon	514	494	441	404	340	303	268	281
30-10	Full	410	402	373	347	277	232	194	172
	No Radon	230	224	208	195	166	147	130	120
30-11	Full	416	407	378	350	279	234	194	173
	No Radon	232	226	209	195	166	147	129	121
30-12	Full	422	414	386	358	286	240	200	176
	No Radon	235	230	214	201	171	152	134	123
30-13	Full	363	355	330	305	242	202	168	150
	No Radon	204	198	184	171	144	128	112	104
30-14	Full	401	392	362	335	272	233	199	183
	No Radon	243	236	217	202	172	154	137	131
30-15	Full	590	574	526	483	388	330	280	265
	No Radon	361	348	315	289	243	216	192	192
30-16	Full	632	617	570	527	423	359	303	279
	No Radon	374	363,1	333	309	262	233	207	199

Table IV. Contributing dose levels of each radiation exposure pathway during the evaluation period of one year (µSv/year)

Exposure pathways	**Contributing dose levels (µSv/year)**	**Contribution rate (%)**
External radiation from soils	136.5	37.0
Inhalation (On-site air concentration)	1.5	0.4
Plant-based foods	196.8	53.4
Meat	17.5	4.7
Milk	10.5	2.8
On-site Soil (eat)	5.8	1.6
Total	***368.6***	***100***
Southern Vietnam [13]	***441***	
South Korea [14]	***880***	
Nigeria [15]	***1570***	
Dose limited - ICRP [16]	***1000***	

C. Discussion

The results of the external effective dose distribution according to soil origin (excluding Radon contribution) throughout Dong Nai province, which were obtained by using ResRad-Onsite for simulation, ranged from 170 to 658 µSv/year, with an average value of 368.6 µSv/year. This value was equivalent to the average level in some different regions in Vietnam and is less than several other countries and the ICRP recommended limit of 1 mSv/year for members of the public (ICRP, 2007) in the world (Table IV). The external dose from the soil was 136.5 μSv/year (37%), close to semi-empirical measurements data. The dose due to inhalation, ingestion of plant-based food, ingestion of meat, drinking milk and ingestion of soil are 1.5 μSv/year (0.4%), 196.8 μSv/year (53.4%), 17.5 μSv/year (4.7%), 10.5 μSv/year (2.8%), and 5.8 μSv/year (1.6%), respectively.

III. CONCLUSIONS

In this study, the external effective dose rate due to the influence of the soil background in the planned construction area of the Dong Nai nuclear reactorwas calculated by using the ResRad-Onsite code. The results showed that the semi-empirical method gave higher results than ResRad-Onsite by about 1.36 times [12]. This indicates good agreement between the experimental values and the simulation method. The results obtained from this study can also be used to supplement the surface soil radioactivity database, risk management, and make effective decisions to protect public health from high levels of radiation exposure.

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