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Public Exposure Due to Natural Radioactivity in Madagascar Uranium Zone Using Direct and Indirect Method, Case of Vatovory Abandoned Site and Its Surroundings

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Abstract: The rural Municipality of Vinaninkarena (19°57'21.9"S; 47°02'22.1"E) has abandoned uranium site, located in the Vatovory village. The uranium mining has been exploited by CEA (Commissariat à l'Energie Atomique) French Company between 1946 and 1952. After closing of exploitation, the hazards of internal and external exposures persist, because most of the populations are not aware of the harmfulness effects of the ionizing radiations. In fact, this present work enable to compare the results of the mean annual effective dose received by the population in the outdoor and the indoor of the studied areas using direct method TLD dosimeters and IdentiFinder; and the indirect method from the soil radioactivity measurement for the external exposure. The obtained results of annual effective dose have been compared with the three international (UNSCEAR 2000, BSS 115, and GS Part 3 Interim), and the national (Radiation Protection Regulation in Madagascar) references values. It has been established that the direct method using Thermoluminescent Dosimeters (TLDs) and IdentiFinder are shown more efficient of the received dose assessment compared to the indirect method. In addition, the dose rate values provided by the IdentiFinder spectrometer are relatively similar to the value indicated by the individual TLDs using the correlation plot.

Keywords: Uranium, External Exposure, Effective Dose, Correlation, Indoor and Outdoor

1. Introduction

The public lives in a radioactive area and undergoes an external exposure coming on the one hand from the radioactivity contained in the terrestrial crust and on the other hand from cosmic radiations. The Human himself is radioactive, because it is permanently incorporates substances containing natural radioactivity such as radon, radium, potassium, uranium, etc. The major sources of these radionuclides come from air, drinking water and food. The average global human exposure due to external and internal natural exposures is about 2.4 $mSv.y^{-1}$. Although in some parts of the globe, the populations are living in higher experiencing exposure areas, up to 6-15 $mSv.y^{-1}$ [1].

Madagascar is a country endowed of several mining zones, containing radioactive minerals. The rural Municipality of Vinaninkarena is among these regions in which the radioactivity level is relatively high. An abandoned uranium mining site, exploited by the CEA between from 1946 and 1952 [2] is located at that Municipality.

The biological effects due to natural radioactivity can occur such as cancers or other diseases, even at low dose rates. Some protective measures should be established to mitigate such a fact. Some past studies has been carried-out by Malagasy researchers, from the INSTN for internal and external exposure assessment in Vinaninkarena, the aim of such studies were to estimate the doses around the legacy uranium site [3] [4], studies of water radioactivity [5], environmental dosimetry and radon studies [6] [7].

The present study consists of improving what has been done before to focus particularly on the study of external exposure to the public (population). Throughout this work, a comparative study has been established between the average result of annual effective dose received by the population in the indoor and outdoor study areas, using direct and indirect method. Such studies has been carried-out to the City of Vinaninkarena, Village de Jeunesses, Ambanimaso, Ambohitrinimasina, Fitatahana, Ambohitraivo Anjanamanjaka, Mangamasoandro, Vatovory, Amparihimborona, Tsaratanana, Anivosaha Mandrosoa. The present study treats the case of the legacy uranium mining site of Vatovory.

2. Description of Studies Areas

The Municipality of Vinaninkarena is located in the district of Antsirabe II, Region of Vakinakaratra, 179 km from Antananarivo, Capital city of Madagascar, in the direction of the south, National Road 7 (RN7). The centre of the village is located at latitude 19°58'21.4"S and longitude 47°02'55.8"E, covering an area of 48 km^2. The ambient temperature in this commune varies from a minimum of 4°C in July to a maximum of 28°C in November-December.

This study has been carried-out in the uranium zone of Vinaninkarena, represented by the following studies areas: City of Vinaninkarena (19°57'25.1"S; 47°02'36.6"E), Village des Jeunesses (19°57'28.0"S; 47°03'22.5"E), Ambanimaso (19°57'10.7"S; 47°03'31.0"E), Fitatahana (19°57'26,2"S; 47°03'33,5"E), Ambohitrinimasina (19°57'42.2"S; 47°03'29.8"E), Ambohitraivo Anjanamanjaka (19° 57' 35.7"S; 47° 04' 10, 2"E), Mangamasoandro (19° 58' 00.2"S, 47° 04' 05.4"E), Vatovory (19° 57' 47.4"S; 47° 03' 43.2"E), Amparihimborona (19° 57' 07.3"S, 47° 03' 01.4"E), Tsaratanana (19° 56' 51.3"S; 47° 03' 14.1"E), Anivosaha Mandrosoa (19° 56' 40.9"S; 47° 03' 25.9"E) and the old uranium mining site of Vatovory (19°57'51.6"S 47°03'45.2"E).

3. Materials and Methods

3.1. Materials

Two detection equipments (TLDs [8] and IdentiFinder [9]) have been used for the direct method. These two equipments have been calibrated at the INSTN Secondary Standard Dosimetry Laboratory before being used in situ [10]. The soil analyses have been carried out at the Nuclear Technique and Analysis Laboratory (ATN) of the INSTN. Each measurement point has been located using GPS (Global Positioning System) [11].

3.2. Methods

3.2.1. Direct Methods Using Doses Measurements Calculated from TLDs and Identifinder

The direct method consists of measuring the annual indoor and outdoor effective dose, by using both an Identifinder spectrometer and TLDs.

1. For absorbed dose measurements, TLDs were placed indoor at 1 m above the ground. At outdoor, it has been placed at 2 m above the ground on the tree foot for safety reasons. Their shifts were done four times for a quarterly period. All the location points, where the TLDs have been placed, were identified by the GPS. They were brought to the INSTN Radiation Protection Department (DRP) for reading with HARSHAW 6600 reader [12]. The equivalent dose for whole body was obtained after reading. The ambient dose rate has been measured at 1 m above the soil, using the IdentiFinder spectrometer, endow with internal GPS system for the geographical location.

2. For annual effective dose calculation, we have used the indoor and outdoor occupancy factor that is respectively 0.58 and 0.42. According to the interviews with the local peoples, based in the studied areas, they spent on average 14 hours (58%) outdoor for work and 10 hours (42%) indoors for the night.

The indoor and outdoor annual effective doses are given by relations (1):

$$E_{in}(mSv.h^{-1}) = \overset{\circ}{D} \times T \times F_{in} \times Q \times 10^{-3} \quad (1)$$

$$E_{ou}(mSv.h^{-1}) = \overset{\circ}{D} \times T \times F_{ou} \times Q \times 10^{-3}$$

With,

D	Absorbed dose at 1 m above the ground surface (nGy.h^{-1}),
T	Annual period (8760 days),
$F_{éxt}$	Outdoor occupancy factor (42 %)
F_{int}	Indoor occupancy factor (58 %)
Q	Dose conversion factor (0.7 Sv.Gy^{-1})

3.2.2. Indirect Method

For the indirect method, two types of approaches have been used.

1. The first one consists on the determination of activity concentration of ^{232}Th, ^{226}Ra and ^{40}K in Bq.kg^{-1} from the soil samples analysis by gamma spectrometry. Activity measurements have been determined by gamma spectrometry equipment, with NaI(Tl) detector. In laboratory, all samples were physically prepared according to the environmental sample preparation procedures [13]. After oven-drying, each sample was put in 100 cm^3 polyethylene cylindrical container, hermetically closed and stocked during 3 weeks to have secular equilibrium between parents and short-lived

progenies (for uranium-238 series) prior to analyses. Depending on the sample activity, counting time varied from 8 to 15 hours in order to have a good statistical counting precision. Obtained gamma spectra were treated by ScintiVision software.

The measurement system was calibrated by using three certified reference materials (RGK-1, RGU-1 and RGTh-1) of the International Atomic Energy Agency.

The mass activities (Bq.kg^{-1}) of radionuclide are determined by the following formula (2):

$$A = \frac{N_N}{\varepsilon \cdot P_\gamma \cdot t_c \cdot m} \tag{2}$$

Where,

N_N	Total net count peak at energy E (keV);
A	Mass activity (Bq.kg^{-1});
t_c	Counting time (s);
P_γ	Emission probability;
ε	Efficiency of detection at energy E
m	Sample dry masse (kg)

2. The second one consists on absorbed dose estimation at 1 m above the ground has been calculated using UNSCEAR 2000 [14] by equation (3) and annual effective dose.

$$\overset{\circ}{D} = 0.0417\, C_K + 0.462\, C_U + 0.604\, C_{Th} \tag{3}$$

Where,

$\overset{\circ}{D}$	Absorbed dose rate at 1 m above the ground (nGy. h^{-1})
C_U, C_{Th}, and C_K	Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the soil (Bq.kg^{-1}), respectively.
0.0417; 0,462; and 0,604	Dose conversion factors for ^{226}Ra, ^{232}Th and ^{40}K, respectively.

The annual effective dose E has been calculated using the equation (1) [15] [16]. The indoor and outdoor occupancy factors are respectively 0.8, and 0.2. The conversion factor that converts the absorbed dose into effective dose is 0.7 Sv.Gy^{-1}.

4. Results and Discussion

4.1. Absorbed Dose and Activity Concentration of Radionuclide

The absorbed dose rates measurements have been performed with the IdentiFinder (197 outdoor and 55 indoor measurements); 55 TLDs for outdoor and 45 TLDs indoor at the measuring points (Tables 1 and 2). The average absorbed dose rate values measured using TLDs and IdentiFinder in all studied areas and the abandoned mine site of Vatovory were higher than the value published by UNSCEAR 2000 (0.057 µGy.h^{-1} at outdoor and 0.075 µGy.h^{-1} indoors).

Table 1. *Indoor and outdoor absorbed dose rate by TLDs.*

Studied areas	Indoor absorbed dose rate [µGy.h^{-1}]			Outdoor absorbed dose rate [µGy.h^{-1}]		
	Number of points	Range	Mean	Number of points	Range	Mean
Ambohitrinimasina	-	-	-	5	0.220- 0.324	0.265± 0.034
Vatovory	5	0.190- 0.252	0.217± 0.030	4	0.252- 0.355	0.98± 0.044
Village des Jeunesses	5	0.201– 0.219	0.211± 0.007	5	0.228- 0.288	0.266± 0.022
Fitatahana	-	-	-	5	0.190- 0.205	0.196± 0.005
Anivosaha Mandrosoa	5	0.199- 0.221	0.213± 0.010	5	0.136- 0.144	0.139± 0.003
Tsaratanana	5	0.225- 0.257	0.241± 0.012	5	0.136- 0.148	0.142± 0.004
Amparihimborona	5	0.191- 0.208	0.198± 0.008	5	0.128- 0.136	0.131± 0.003
Ambanimaso	5	0.201- 0.215	0.210± 0.006	5	0.124- 0.156	0.135 ± 0.011
Ambohitraivo	5	0.175- 0.214	0.202± 0.015	5	0.148- 0.164	0.158± 0.006
City of Vinaninkarena	5	0.191- 0.233	0.210± 0.018	5	0.116- 0.124	0.121 ± 0.003
Mangamasoandro	5	0.214- 0.238	0.226± 0.010	5	0.116- 0.128	0.123± 0.005
Near the old uranium site of Vatovory	-	-	-	1	-	6.196± 0.324
UNSCEAR 2000		0.020- 0.020	0.075		0.018- 0.093	0.057

Table 2. *Indoor and outdoor absorbed dose rate by IdentiFinder.*

Studied area	Indoor absorbed dose rate [µGy.h^{-1}]			Outdoor absorbed dose rate [µGy.h^{-1}]		
	Number of points	Range	Mean	Number of points	Range	Mean
Ambohitrinimasina	-	-	-	31	0.132- 0.994	0.249± 0.177
Vatovory	7	0.049- 0.355	0.220± 0.104	29	0.130- 1.530	0.291± 0.245
Village des Jeunesses	9	0.117- 0.242	0.197± 0,037	15	0.125- 0.800	0.248± 0.168
Fitatahana	-	-	-	8	0.153- 0.269	0.193± 0.042
Anivosaha Mandrosoa	5	0.182- 0.207	0.190± 0,010	16	0.076- 0.190	0.134 ± 0.028
Tsaratanana	5	0.202- 0.264	0.234± 0,024	11	0.121- 0.163	0.143± 0.013
Amparihimborona	5	0.174- 0.201	0.190± 0,010	27	0.086- 0.160	0.124± 0.016
Ambanimaso	5	0.190- 0.202	0.195± 0,005	12	0.118- 0.154	0.131± 0.013
Ambohitraivo	9	0.118- 0.298	0.204± 0,052	15	0.108- 0.214	0.158± 0.033
City of Vinaninkarena	5	0.196- 0.206	0.200± 0,003	22	0.072- 0.211	0.121± 0.036
Mangamasoandro	5	0.192- 0.221	0.212± 0,011	10	0.096- 0.191	0.123± 0.025
Old uranium site of Vatovory	-	-	-	1	-	12.017
UNSCEAR 2000		0.020- 0.020	0.075		0.018- 0.093	0.057

In total, 56 soil samples were collected in the studied areas and the Vatovory abandoned or old uranium mining site. The activity concentrations of radionuclide were calculated using equation (2). The activity concentrations, measured at the abandoned uranium mining site represents the highest values of all the studied areas, with the mean values of 25 700 ± 305 Bq.kg^{-1}, 491 ± 44 Bq.kg^{-1} and 14 365 ± 8 Bq.kg^{-1}, respectively for ^{226}Ra, ^{232}Th and ^{40}K (Table 3).

These values are higher than the value published by UNSCEAR 2000. The increase of these values is due to the effect of uranium mining during the colonial period by the CEA. So the old uranium mining site of Vatovory is more radioactive, the ground is no longer in the natural state because no on-site recovery has been done.

Similarly, in all studied areas, the activity concentrations of ^{226}Ra and ^{232}Th were higher than the UNSCEAR 2000 values.

For the cases of the others studied zones, the measured activities are less than 400 Bq.kg^{-1}, published values by the UNSCEAR 2000. The measured activities concentration of ^{40}K in the studies areas at Ambohitraivo, Ambanimaso, Tsaratanana, and Anivosaha Mandrosoa are respectively 335 ± 22 Bq.kg^{-1}, 340 ± 17 Bq.kg^{-1}, 263 ± 20 Bq.kg^{-1} and 237 ± 16 Bq.kg^{-1}. That could be justified by the distances from the uranium site of Vatovory to these others areas.

After calculation of activity concentration of soil samples, the relation (3) was used to estimate the absorbed dose rates in air at 1 m above the ground level in the studied areas as shown in Table 3. Results showed that the absorbed dose rates obtained from the soil samples in the studied areas and at the abandoned uranium mining site of Vatovory are higher than the UNSCEAR2000 value (0.057 µGy.h^{-1}).

Table 3. *Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K, and absorbed dose rate from the soil samples.*

Studied areas	Number of samples	Activity Concentrations [Bq.kg^{-1}]			Absorbed dose rate [µGy.h^{-1}]
		^{226}Ra	^{232}Th	^{40}K	
Ambohitrinimasina	5	120 ± 6	112 ± 4	555 ± 28	0.158 ± 0.012
Vatovory	5	451 ± 28	107 ± 12	605 ± 40	0.298 ± 0.015
Village des Jeunesses	5	356 ± 24	119 ± 7	637 ± 22	0.263 ± 0.012
Fitatahana	5	265 ± 11	110 ± 6	667 ± 20	0.217 ± 0.006
Anivosaha Mandrosoa	5	116 ± 7	141 ± 7	237 ± 16	0.148 ± 0.005
Tsaratanana	5	92 ± 7	158 ± 6	263 ± 20	0.149 ± 0.005
Amparihimborona	5	96 ± 3	127 ± 7	496 ± 30	0.141 ± 0.005
Ambanimaso	5	103 ± 5	127 ± 6	340 ± 17	0.139 ± 0.004
Ambohitraivo	5	118 ± 8	142 ± 5	335 ± 22	0.155 ± 0.005
City of Vinaninkarena	5	107 ± 5	124 ± 8	549 ± 25	0.147 ± 0.005
Mangamasoandro	5	117 ± 7	122 ± 7	448 ± 32	0.143 ± 0.015
Old Uranium site of Vatovory	1	25 700 ± 305	491 ± 44	14 365 ± 8	12.769 ± 0.144
UNSCEAR 2000		35	30	400	0.057

4.2. Annual Effective dose

The relation (1) was used to calculate the annual indoor and outdoor effective dose. Figure 1 and 2 show respectively the obtained results from TLDs and IdentiFInder.

The indoor and outdoor annual effective doses using TLDs in the Vatovory abandoned uranium mining site had a mean value of 15.957 mSv.y^{-1} (Figure 1). This value was significantly higher than the annual acceptable dose-limit value for the public published by UNSCEAR 2000 (0.48 mSv.y^{-1}) [15], BSS 115 (1 mSv.y^{-1}) [17] and Regulation of Radiation Protection in Madagascar (1 mSv.an^{-1}) [18], it was included in the interval of GS part 3 Interim (1 to 20 mSv.y^{-1}) [19] for the existing exposure to the public. This effective dose value was also 15 times higher than the annual effective dose rates received by the population in all the studies areas. This was due to the presence of the abandoned uranium mining site of Vatovory carried out by the CEA during the colonization.

The studies areas at Ambohitrinimasina and Fitatahana had the average annual effective dose values of 0.682 mSv.y^{-1} and 0.505 mSv.y^{-1} (Figure 1), respectively, compared to the effective dose limit published by BSS and the Radiation Protection Regulation in Madagascar, which were lower because no construction was made in these two areas, the outdoor annual effective dose was taken for the dose assessment of the population.

In any study area other than Fitatahana and Ambohitrinimasina (Figure 1), the annual effective doses are slightly higher than the public dose limit in BSS 115 and the Radiation Protection Regulations in Madagascar.

The annual indoor and outdoor effective dose calculated using an IdentiFinder at the Vatovory abandoned uranium mining site had an average value of 30.949 mSv.y^{-1} (Figure 2). This value was higher than the annual effective dose limit for the public established by UNSCEAR 2000 (0.48 mSv.y^{-1}), BSS 115 (1 mSv.y^{-1}), Regulation of Radiation Protection in Madagascar (1 mSv.y^{-1}) and GS Part 3 Interim (1 to 20 mSv.y^{-1}). So, this abandoned uranium mining presents a real risk for the surrounding populations even after decommissioning.

For the case of Ambohitrinimasina, Fitatahana and Amparihimborona; they represent respectively annual outdoor and indoor effective doses of 0.641 mSv.y^{-1}; 0.497 mSv.y^{-1}, and 0.995 mSv.y^{-1} (Figure 2). These three values are low than the annual effective dose limit for the public, provided by the BSS 115 and the Radiation Protection Regulations in Madagascar.

As there are no dwelling in Ambohitrinimasina and

Fitatahana, the annual outdoor effective dose was taken into account to estimate the population received dose. The study area at Amparihimborona was also far away from the old or abandoned uranium mining site of Vatovory, so no protection measurement doesn't take in consideration.

The annual indoor and outdoor effective dose from the soil samples (figure 3) has been calculated using the equation (1).

The abandoned uranium mining site of Vatovory represented a very high annual effective dose value of 15.660 $mSv.y^{-1}$ (Figure 3). This value is significantly higher than the value provided by UNSCEAR 2000 (0.48 $mSv.y^{-1}$), BSS115 (1 $mSv.y^{-1}$) and the Radiation Protection Regulation in Madagascar (1 $mSv.y^{-1}$) for the annual effective dose limit to the public.

This value does not exceed also the dose limit to the public, given by GS Part 3 Interim (1 to 20 $mSv.y^{-1}$). As stated before, this significant high annual effective dose value is due to the presence of the Vatovory abandoned uranium mining site operated by the CEA in 1945.

For Ambohitrinimasina and Fitatahana zones, the mean values of annual effective dose are respectively 0.195 $mSv.y^{-1}$ and 0.266 $mSv.y^{-1}$ (Figure 3). These two values are less than the annual public effective dose limit published by UNSCEAR 2000 and the Radiation Protection Regulations in Madagascar. This is due to the non-existence of dwelling. For that zone, it has been taken as assumption that the annual outdoor effective dose represents only considered for received dose by the population.

In term of distance, the Vatovory and Village des Jeunesses, zones are the nearest studied zones, from the Vatovory abandoned uranium mining site, the annual effective dose for those zones were respectively 1.827 $mSv.y^{-1}$ and 1.613 $mSv.y^{-1}$ (Figure 3). These two values are slightly higher than the annual effective dose limit for public in BSS 115 and the Radiation Protection Regulations in Madagascar.

For all the studied areas, the annual effective dose values are included in the range of 1 to 20 $mSv.y^{-1}$ for the existing exposure situation for the annual effective dose limit to the public published by GS Part 3 Interim (figure 1), (figure 2) and (figure 3).

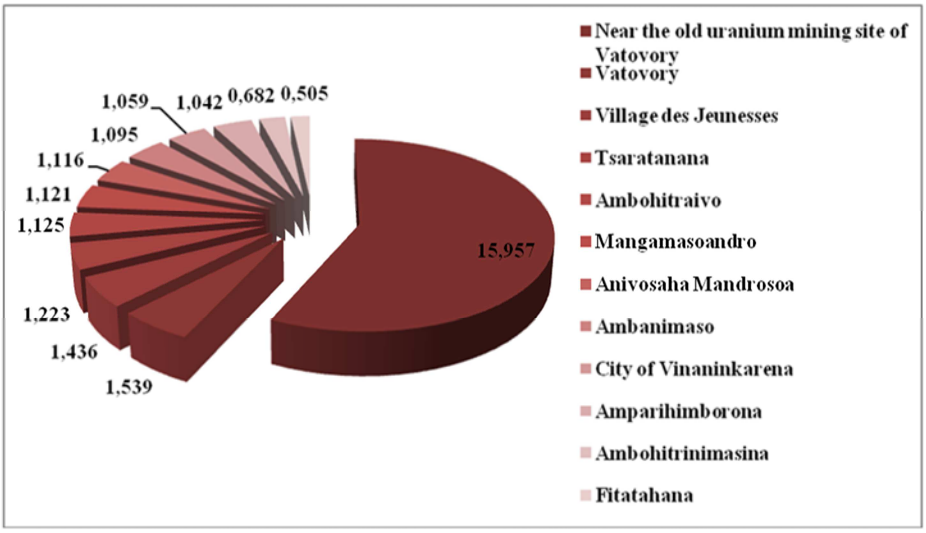

Figure 1. *Annual indoor and outdoor effective dose by TLD dosimeter [$mSv.y^{-1}$].*

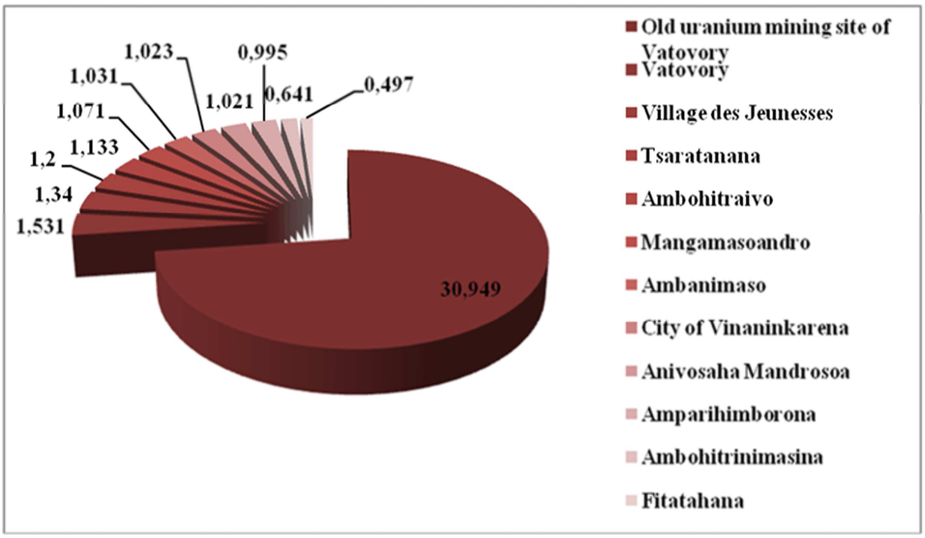

Figure 2. *Annual indoor and outdoor effective dose by IdentiFinder [$mSv.y^{-1}$].*

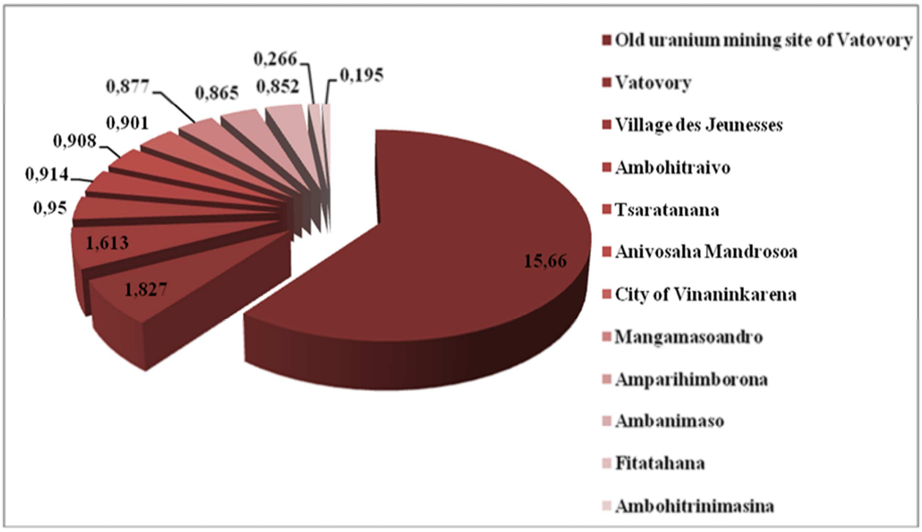

Figure 3. *Annual indoor and outdoor effective dose by soil samples [mSv.y^{-1}].*

4.3. Correlation Between Direct and Indirect Method

The correlation between the mean value of annual effective dose using TLDs and IdentiFinder is given in figure 4, indicating a significant positive correlation with R = 0.993 (N = 11) between the results of the two methods. The mean values of annual effective dose indicated by the IdentiFinder are very close, compared with the value indicated by TLDs. However, as indicated by the correlation plot, the agreement between the two techniques is good for low annual effective dose values and the deviation increases at higher annual effective dose values. Therefore, the direct method using the TLDs and the IdentiFinder is more efficient to assess the annual effective dose received by the population in the study area, compared with the indirect method.

For the assessment of annual effective dose received by the member of public in the study area, the correlation method was made to compare the estimated and measured annual effective dose. The correlation plots are given in figures 5 and 6

Figure 5 shows the correlation plot between the annual effective doses measured by IdentiFinder and estimated from soil radioactivity. A significant positive correlation was observed with R = 0.953 (N = 11). The correlation plot between the estimated dose and the TLDs measurements is shown in Figure 6. It should be noted that in both these two plots, the estimated dose of the axis (X) is due to soil radioactivity obtained from of terrestrial radiation, and the measured axis (Y) from terrestrial and cosmic radiation. The correlation plot clearly indicate that the estimated dose is better correlated with the dose measured from TLDs (R = 0.954), when compared to those obtained from IdentiFinder (R = 0.953). The Intercept in the correlation plot between the estimated dose and the TLD dosimeter is 0.763 mSv.y^{-1} (Figure 6).

The annual effective dose in the studied areas for cosmic radiation is 0.763 mSv.y^{-1} (Figure 6) which is higher by a factor of 2, compared to the value of 0.36 mSv.y^{-1}, which is the worldwide annual effective dose for cosmic radiation published by UNSCEAR 2000.

We can conclude that the direct method using TLDs is better to estimate the dose received by the population.

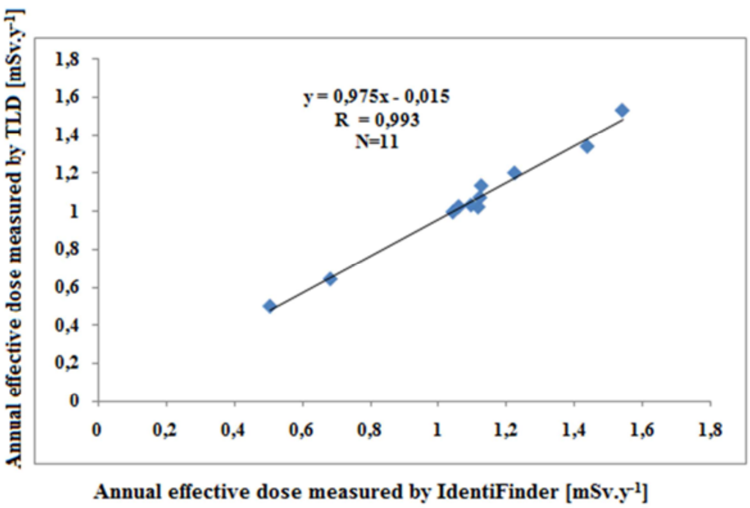

Figure 4. *Correlation between the mean value of annual effective dose by TLD dosimeters and IdentiFinder.*

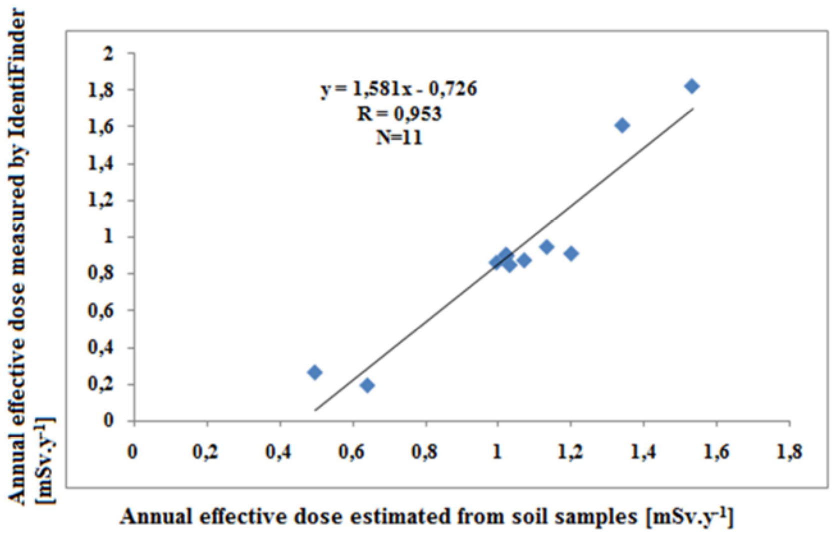

Figure 5. *Correlation between the mean value of annual effective dose by IdentiFinder and the soil samples.*

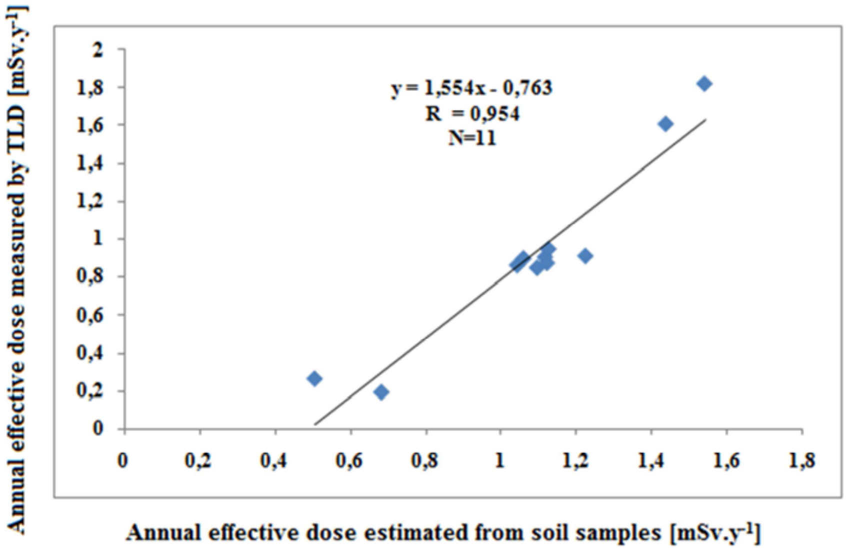

Figure 6. *Correlation between the mean value of annual effective dose by TLDs and the soil samples.*

5. Conclusions

In general, this work has been conducted jointly by the DRP Department for TLDs reading and ATN Department (INSTN- Madagascar) for the soil samples analysis in order to determine the activity concentrations of the radionuclide.

Two methods were used to estimate the average annual effective dose received by the population in each studied area and the Vatovory abandoned uranium mining site.

The direct method consisted of using IdentiFinder and the TLDs. 252 points of measurement, including 197 outdoor and 55 indoor points area were performed from the IdentiFinder. 100 TLD, including 45 TLDs placed indoor and 55 TLDs placed outdoor have been used for an annual period.

The indirect method was based on analysis of the soil samples at ATN department using the NaI (T1) gamma spectrometry. 56 soils samples were collected on site and measured in the laboratory to determine the activity concentrations of ^{232}Th, ^{226}Ra and ^{40}K. The concentration values of these three radionuclides were converted to an annual effective dose at 1 m above the ground surface by the UNSCEAR method.

Three International (UNSCEAR 2000, BSS115, and GSR Part 3 Interim) and one national (Radiation Protection Regulation in Madagascar) reference values were used during the work to compare the mean values of the annual effective doses obtained by the public in the studied areas and the abandoned uranium mining site of Vatovory. Results have shown that:

For the Vatovory abandoned uranium mining site, the average value of indoor and outdoor effective dose using IdentiFinder is 30.949 mSv.y^{-1}, this value is higher than the international and national reference values. But, TLDs and soils samples results represented respectively the annual effective dose of 15.957 mSv.y^{-1} and 15.957 mSv.y^{-1}, these two values are included in the GSR Part 3 Interim value and higher than the national and UNSCEAR 2000 and BSS 115 reference values for the annual effective dose limit to the public. In relation to the high increase of the annual effective dose values, the following recommendation must be carried out:

1. Zoning with the warning panel (radioactive trefoil)
2. It is also forbidden to make the construction near of the site,
3. It is also necessary to make the rehabilitation of the site from the cover which has for the objective to reduce the direct emission of gamma radiation, to protect against the erosion, to avoid the emanation of the radon.

For all studied areas at City of Vinaninkarena, Village des Jeunesses, Ambanimaso, Fitatahana, Ambohitrinimasina, Ambohitraivo Anjanamanjaka, Mangamasoandro, Vatovory, Amparihimborona, Tsaratanana, and Anivosaha Mandrosoa, the average values of indoor and outdoor effective dose using TLDs, IdentiFinder and gamma spectrometry for soil samples are included in GS Part 3 Interim value for public dose limit. For the case of study area at Fitatahana and Ambohitrinimasina, there is no dwelling so, the annual outdoor effective dose has been taken in consideration for dose assessment to the public, the annual effective doses are lower than the national and BSS 115 reference values.

According to the correlation result, the direct method using the TLDs and the IdentiFinder is more efficient to assess the annual effective dose received by the population in the study area, compared with the indirect method. The correlation plot clearly indicate that the estimated dose for soil samples is better correlated with the dose measured from TLDs (R = 0.954), when compared to those obtained from IdentiFinder (R = 0.953). The mean values of annual effective dose indicated by the IdentiFinder are closer than the value indicated by TLDs (R=0.993).

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