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Article

Natural radiation exposure to the public in the oil-bearing Bakassi Peninsula, Cameroon

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Abstract – The objective of the present study was to carry out natural radioactivity measurements and corresponding dose assessment in the Bakassi Peninsula, an oil-bearing area located in the Gulf of Guinea. This pilot study required E-perm Electret Ionization Chamber (EIC) exposure in homes and the sampling of soils and foodstuffs representative of the food consumption patterns of the population of Bakassi. The results show high exposure of members of the public to natural radiation. Elevated indoor radon concentrations due to building construction were observed, and high exposure to ^{210}Po attributable to the dietary habits of the local population, mainly consisting of seafood. Finally, a total dose of 34.6 mSv.y^{-1} was found, much higher than the world average value. In the case of confirmation of the results of this study, countermeasures must be taken into consideration to avoid such a high level of exposure, to reduce the radiation dose to the population. Taking into account the limited number of samples, the present work should be considered as a preliminary study.

Keywords: oil-bearing region / indoor radon / polonium-210 / lead-210 / seafood

1 Introduction

Human exposure occurs by irradiation from sources (cosmic and terrestrial rays) outside the body and upon the decay of radionuclides taken into the body through internal exposure. In terms of dose, the principal primordial radionuclides are ^{40}K, ^{232}Th and ^{238}U series (UNSCEAR, 1993, 2000). Several studies on natural radioactivity and corresponding dose assessment have been carried out in Cameroon. Saïdou *et al.* (2011) reported radioactivity measurements and total dose assessment in the uranium region of Poli. Most of the dose assessed is attributable to the intake of radon and high levels of ^{210}Po and ^{210}Pb contained in vegetables, food items which constitute an important part of the diet in Northern Cameroon. Consequently, bringing uranium ore from underground to the surface might lead to an increased dose for the population of Poli through a higher deposition of ^{222}Rn decay products on leafy vegetables. Indoor radon measurements were extended in the uranium regions of Poli and Lolodorf (Saïdou *et al.*, 2014). Results show that 20% of houses in Poli and 50% in Lolodorf have indoor radon above the reference level at 300 Bq/m^3 (WHO, 2009), requiring radon mitigation. Ele Abiama *et al.* (2010) and Beyala Ateba *et al.* (2011) studied the high background radiation and internal/external radiation exposure to the public of the uranium region of Lolodorf. These studies evidenced high radioactivity occurring in this region. Ngachin *et al.* (2007) reported a study on external radiation exposure from building materials used in Cameroon. This study concluded that all the materials examined are acceptable for use as building materials as defined by the Organization for Economic Cooperation and Development criterion (OECD, 1979).

The Bakassi Peninsula, located in the hollow of the Gulf of Guinea, is rich in oil and fish stocks and has several offshore production platforms, which could lead to the environmental pollution of the area by Naturally Occurring Radioactive Materials (NORM) (ICJ, 2002). Reported studies concluded that materials found in the downhole and surface structures of oil and gas production facilities do not include ^{238}U and ^{232}Th (Jonkers *et al.*, 1997; IAEA, 2003). These elements are not mobilized from the reservoir rock that contains the oil, gas and formation water. The formation water contains Group II (Periodic Table) cations of calcium, strontium, barium and radium dissolved from the reservoir rock. As a consequence, formation water contains the radium isotopes ^{226}Ra, ^{228}Ra and ^{224}Ra.

The aim of the present study is to carry out radioactivity monitoring and to assess the corresponding dose for the inhabitants of the Bakassi Peninsula. An E-perm Electret Ionization Chamber (EIC) was used for the measurement of radon exposure in homes. Sampling of soils and foodstuffs representative of the food consumption patterns was performed to assess the

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Fig. 1. Location of the Bakassi Peninsula in the Gulf of Guinea.

corresponding radiation dose of the local population. Because of the limited number of samples analyzed, this work should be considered as a pilot study.

2 Material and methods

2.1 Area of study and sampling

The Bakassi peninsula is situated in the hollow of the Gulf of Guinea and is bounded by the River Akwayafe to the West and by the Rio del Rey to the East (Fig. 1). It is an amphibious environment, characterized by an abundance of water, fish stocks and mangrove vegetation (ICJ, 2002). The localities of Jabane, I, II and Idabato I, II were considered for sampling. Respectively, about 5000 and 6000 people live in Jabane and Idabato. The landscapes are the same for the total area of the peninsula. The inhabitable areas where sampling was carried out are surrounded by the sea (Fig. 1). A random method was chosen for soil sampling. Each sample was collected from the top 5 cm of a 1-m^2 area, and provided a dry mass of about 500 g. In total, 15 soil samples were collected. In addition, 10 foodstuff samples (leafy vegetables, dried fish and shrimps, etc.) were collected in Jabane and Idabato. Most of the foodstuffs except seafood come from Nigeria because the salty and sandy soil of Bakassi is not adapted to agriculture. Fishing is the main activity of the local population of this part of Bakassi. Most of the fishers come from Nigeria and other West African countries.

All the soil and foodstuff samples gathered were dried, sieved and homogenized. Conditioned soil samples were kept in Marinelli beakers, hermetically sealed to avoid radon escape. This ensures secular equilibrium between ^{226}Ra and its progeny (Saïdou *et al.*, 2008).

2.2 Radioactivity measurements

2.2.1 Alpha spectrometry (^{210}Po) for foodstuff samples

The procedure used for measuring ^{210}Po is based on microwave digestion under pressure for sample mineralization. After spontaneous deposition on a silver disk, polonium sources were measured using Passivated Implanted Planar Silicon (PIPS) detectors with an active area of 450 mm^2 in a Canberra Alpha Analyst Spectrometer. The procedure is fully described in (Saïdou *et al.*, 2007).

2.2.2 Gamma spectrometry using a HPGe detector for foodstuff samples

Gamma spectrometry measurements in foodstuff samples were performed with a Canberra p-type HPGe well detector (GCW4523) with a total active volume of 206 cm^3, a relative photopeak efficiency of 45%, and a resolution at 122 and 1332 keV of 1.24 and 1.93 keV, respectively, as described in (Saïdou *et al.*, 2007). Semadeni D5 geometry (40 ml) was used for the counting time, ranging between 170 000–450 000 seconds. ^{214}Bi and ^{214}Pb were used to determine activity concentrations of ^{226}Ra after reaching secular equilibrium between ^{222}Rn and its daughter products.

2.2.3 Gamma spectrometry using a NaI detector for soil samples

Gamma spectrometry measurements of soil samples were performed with a Canberra NaI(Tl) detector (Model 802) with a crystal size of 7.6 cm × 7.6 cm and a resolution of 7.5% at 662 keV. This Model 802 plugs directly into the Model 2007 Tube Base which provides power for the photomultiplier tube. Treatment of the data was carried out using GENIE 2000 software. The spectrometer was calibrated using a customer-supplied 500-ml Marinelli Beaker containing ^{155}Eu, ^{57}Co, ^{113}Sn, ^{137}Cs, ^{54}Mn and ^{65}Zn traceable to international standards and emitting gamma-rays in the energy range of 60–1115.5 keV. The same geometry was used for the counting time of 172 800 seconds to measure radioactivity in soil samples. Gamma-lines of ^{214}Bi were used to determine ^{226}Ra activity concentrations after reaching secular equilibrium between ^{222}Rn and its daughter products ^{214}Bi and ^{214}Pb. Gamma-lines of ^{228}Ac were considered to determine activity concentrations of ^{232}Th.

2.2.4 Indoor radon measurements

The EICs were manufactured by Rad Elec Inc., 5714-C Industry Lane, Frederick, MD 21704, USA. Detailed descriptions of their design and operation are given in the Rad Elec Manual (Kotrappa *et al.*, 1996). An EIC for monitoring radon consists of a stable electret (electrically charged Teflon®disc) mounted inside an electrically conducting chamber. The electret serves both as a source of the electric field and as a sensor. The ions produced inside the chamber are collected by the electret. The reduction in charge of the electret is related to total ionization during the period of exposure. This charge reduction is measured using a battery-operated Electret Voltage Reader. Using appropriate calibration factors and the exposure time, the desired parameters such as the airborne radon concentration in air is calculated. Normally, the temperatures, humidity and mechanical shocks encountered do not affect the performance of the EICs, making them robust for field use. More details are given in (Saïdou *et al.*, 2014).

Fifteen EICs were exposed in dwellings of Jabane and Idabato for three months, relatively far from the open access (windows, door) of dwellings at 1 m above the ground to avoid biased measurements due to the influence of outdoor air.

2.3 Dose assessment

2.3.1 External radiation dose

The radiation exposure from external sources results from natural and artificial ground radiation as well as from cosmic background. The conversion coefficients used to determine the radiation dose from natural series of ^{238}U, ^{232}Th and for ^{40}K, are listed in Table 1 (UNSCEAR, 2000).

Table 1. Air kerma conversion coefficients [(nGy/h)/(Bq/kg)] of radioactivity in soil.

Radionuclides	Air kerma conversion coefficient of radioactivity in soil (nGy.h^{-1})/(Bq.kg^{-1})
^{238}U series	0.46
^{232}Th series	0.60
^{40}K	0.042

A conversion coefficient of 0.7 mSv.mGy^{-1} was used to determine the corresponding effective annual dose (UNSCEAR, 1993). In order to combine indoor and outdoor dose rates to calculate the total external dose, we used an indoor occupancy factor of 0.6, which implies that people spend 40% of the time outdoors. However, since the materials used in the construction of most of these buildings also contain radionuclides, the average factor of 1.4 was applied to take into account their contribution and estimate the indoor dose rate (UNSCEAR, 2000).

Exposure to cosmic rays is strongly dependent on altitude and weakly dependent on latitude. Analytical expressions have been developed for the general relationship between the annual dose and altitude for both the directly and indirectly ionizing components. In order to combine indoor and outdoor dose rates to compute the cosmic ray dose, an indoor occupancy factor of 0.6 was assumed. Cosmic rays are also attenuated by 20% indoors (UNSCEAR, 1993, 2000).

$$E_I(z) = E_{I_0}\left[A_I e^{-\alpha_I z} + B_I e^{\beta_I z}\right]$$
$$E_N(z) = E_{N_0} e^{\alpha_N z}$$

where E_I is the effective dose rate in μSv.yr^{-1} for the directly ionizing component; E_{I_0} is the reference value at sea level, 240 μSv.y^{-1}; z is the altitude in km; $A_I = 0.21$; $\alpha_I = 1.6$ km^{-1}; $B_I = 0.80$; $\beta_I = 0.45$ km^{-1}; E_N is the effective dose rate in μSv.y^{-1} for the indirectly ionizing component from neutrons and $E_{N_0} = 30\,\mu$Sv.y^{-1}; $\alpha_N = 1.0$ km^{-1}.

2.3.2 Ingestion and inhalation dose

The ingestion conversion coefficients used in the present work are taken from ICRP Publication 67 (1994) and ICRP Publication 69 (1995). The ingestion dose for each radionuclide is given by the product of the annual ingested activity and corresponding ingestion conversion coefficient. The total ingestion dose is calculated by summing all the contributions of radionuclides.

The inhalation dose is given by the product of the average indoor radon concentration of the studied area and the updated inhalation conversion coefficient of radon given in ICRP Publication 115 (2010).

3 Results and discussion

3.1 Radioactivity in soil and corresponding external radiation dose

As displayed in Figure 2, activity concentrations in soil samples range between 15.6–23.2 Bq.kg^{-1} for ^{226}Ra,

Table 2. Activity concentrations of ^{226}Ra, ^{210}Pb, ^{210}Po and ^{40}K in the main items of food consumed in Jabane and Idabato. ^{226}Ra and ^{210}Pb activity concentrations are lower than the minimum detectable concentrations (MDC) using γ-spectrometry.

Sample identifier	Sample	^{226}Ra (Bq.kg^{-1})	^{210}Pb (Bq.kg^{-1})	^{210}Po (Bq.kg^{-1})	^{40}K (Bq.kg^{-1})
GRE-11-136	Cowpea	<1.5	<23	0.72 ± 0.04	359 ± 8
GRE-11-137	White tapioca	<3.3	<14	0.63 ± 0.04	111 ± 10
GRE-11-143	Yellow tapioca	<4.5	<20	0.33 ± 0.05	147 ± 15
GRE-11-138	Fish	<3	<21	27.5 ± 0.8	258 ± 14
GRE-11-140	Fish	<6	<64	21.6 ± 0.8	226 ± 15
GRE-11-141	Fish	<5	<20	14.3 ± 0.7	271 ± 13
GRE-11-139	Shrimps	<5	<45	122 ± 4	237 ± 13
GRE-11-142	Waterleaf	<6	<70	2.7 ± 0.2	1880 ± 32
GRE-11-144	Eru leaf	<25	1.6 ± 0.3	14.5 ± 0.5	1063 ± 77

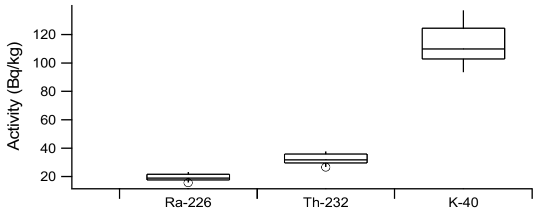

Fig. 2. Radionuclide concentrations in soil samples.

26.5–37.8 Bq.kg^{-1} for ^{232}Th, and 93–138.2 Bq.kg^{-1} for ^{40}K. The corresponding average activity is 19 Bq.kg^{-1} for ^{226}Ra, 32 Bq.kg^{-1} for ^{232}Th and 110 Bq.kg^{-1} for ^{40}K, respectively. As reported by Agbalagba and Onoja (2011), the mean activity level of ^{226}Ra, ^{232}Th and ^{40}K in soil, sediment and water samples in four flood-plain lakes of the Niger Delta quite close to the Bakassi Peninsula is, respectively, 20 Bq.kg^{-1}, 20 Bq.kg^{-1} and 180 Bq.kg^{-1}

These values are lower than the average activity concentrations observed in the world: 38 Bq.kg^{-1} for ^{238}U, 45 Bq.kg^{-1} for ^{232}Th and 420 Bq.kg^{-1} for ^{40}K (UNSCEAR, 2000). The level of natural radioactivity is in agreement with what can be expected when there is no contamination. Finally, no radioactive contamination is evidenced due to the presence of offshore production platforms in the Bakassi Peninsula. The corresponding annual external radiation is 0.27 mSv.y^{-1} for terrestrial radiation and 0.27 mSv.y^{-1} for cosmic radiation.

3.2 Radioactivity in foodstuffs and corresponding ingestion dose

Table 2 shows activity concentrations of ^{226}Ra, ^{210}Pb, ^{210}Po and ^{40}K in the main items of food consumed in Bakassi. The results show high variability of these radionuclides in foodstuffs. Activity concentrations of ^{210}Po range, respectively, between 0.33–122 Bq.kg^{-1}. The derived product of cassava (tapioca) and cowpea have the lowest activity concentrations, while meat, fish, shrimps and leafy vegetable samples such as Eru leaves have the highest activity concentrations of ^{210}Po.

^{226}Ra and ^{210}Pb activity concentrations are lower than the Minimum Detectable Concentrations (MDC) using gamma spectrometry, as indicated in Table 2. Probably gamma spectrometry is not sensitive enough for activity concentrations in foodstuffs (Saïdou *et al.*, 2008). Moreover, the small quantity of samples collected for measurements, leading to the use of Semadeni D5 (40 ml) instead of more voluminous containers (250 ml or 500 ml), also contributed to making the activity concentrations of ^{226}Ra and ^{210}Pb below the MDC. Alpha spectrometry is strongly advisable for radioactivity in foodstuffs because of its low detection limit (Saïdou *et al.*, 2008).

^{210}Po activity concentrations range from 14.3–27.5 Bq.kg^{-1} in three species of fish and 122 Bq.kg^{-1} in shrimps. ^{210}Pb and ^{210}Po present in seafood could partially stem from ^{226}Ra contained in formation water found during operations in offshore production platforms. ^{210}Pb and ^{210}Po are highly radiotoxic and present in relatively high concentrations in the marine biota due to their enhanced bioaccumulation and strong affinity for binding with certain internal tissues (Díaz-Francés *et al.*, 2012). Consequently, ^{210}Pb and ^{210}Po are the main contributors to the radiation dose received by marine organisms as well as by humans consuming seafood. For the pair ^{210}Po-^{210}Pb behavior previously described in the literature with a common pattern is thus observed: activity concentrations of ^{210}Po are greater than activity concentrations of ^{210}Pb in marine organisms (Carvalho, 2011). Taking into consideration that the ^{210}Pb/^{210}Po activity ratios in seawater are in the range 0.5–1.0 (Fowler, 2011), it is straightforward to conclude that ^{210}Po has a higher bioaccumulative behavior than ^{210}Pb in the marine trophic chain (Díaz-Francés *et al.*, 2012).

Ingestion intake of natural radionuclides depends on the consumption rates of food and water and on the radionuclide concentrations. Unfortunately, although tap water was sampled in the Bakassi Peninsula, radioactivity measurements were not performed. Thus, a partial dietary pattern of people living in Bakassi localities based on their alimentary habits was elaborated, as shown in Table 3.

A global review of ^{210}Po in marine food has suggested that representative concentrations are 2.4 Bq.kg^{-1} in fish, 6 Bq.kg^{-1} in crustaceans and 15 Bq.kg^{-1} in mollusks (UNSCEAR, 2000). Representative consumption rates are 13 kg.y^{-1} of fish and 1 kg.y^{-1} each of mollusks and crustaceans, and yield a polonium intake of 52 Bq.y^{-1}. In the Bakassi peninsula, seafood is the only aliment available locally. Most other food items come from Nigeria and sometimes from the continental part of Cameroon. Thus, the representative consumption rates of inhabitants of the Bakassi Penisula are 73 kg.y^{-1} of fish and 18.25 kg.y^{-1} for shrimps,

Table 3. Partial diet model of Bakassi based on the alimentary habits of inhabitants.

Daily consumption (dry weight)
400 G OF TAPIOCA (CASSAVA BY- PRODUCT)
200 G OF FISH
50 g of shrimps
50 g of waterleaf
50 g of eru leaf
20 G OF COWPEA

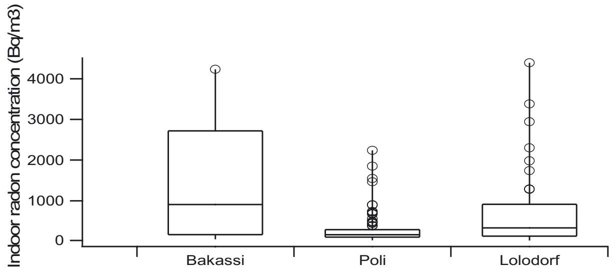

Fig. 3. Indoor radon concentrations in Bakassi compared with the regions of Poli and Lolodorf.

as shown in Table 3. These values are significantly higher than the world average values. These values come from surveys in the field and from the World Bank survey in coastal regions of Cameroon (Koppert, 1994).

Based on the daily consumption and the ^{210}Po values found in this work, using the ingestion dose coefficient of 1.2 μSv.Bq^{-1}, a corresponding ingestion dose of 4.8 mSv.y^{-1} was found for the inhabitants of the surveyed area of Bakassi Peninsula. This radiation dose is greater than the corresponding world average value of 0.7 mSv.y^{-1} (UNSCEAR, 2000). The difference is essentially attributable to the dietary habits of the local populations, whose main items of food are sea products. It should be noted that ^{210}Po is volatile above 100 °C. Thus, cooking aliments may possibly reduce ^{210}Po concentrations in foodstuffs.

The contribution of ^{226}Ra and ^{210}Pb was not taken into account because most of their concentrations are lower than the corresponding MDCs. Activity concentrations of ^{40}K range between 111−1880 Bq.kg^{-1} in foodstuffs. High concentrations are observed in leafy vegetables. Nevertheless, the homeostatic regulation of ^{40}K in the human body makes a calculation of the ^{40}K ingested dose meaningless.

3.3 Indoor radon concentrations and corresponding inhalation dose

Figure 3 displays the distribution of indoor radon concentrations in 15 dwellings of the Bakassi Peninsula, precisely in Jabane and Idabato. Indoor radon concentrations range between 51−4230 Bq.m^{-3} with respective median and average values of 907 Bq.m^{-3} and 1280 Bq.m^{-3}. In a previous work in the uranium regions of Poli and Lolodorf, indoor radon concentrations range, respectively, between 29−2240 Bq.m^{-3} and 24−4390 Bq.m^{-3} with corresponding median values of 165 Bq.m^{-3} and 331 Bq.m^{-3} and average values of 294 and 735 Bq.m^{-3} (Saïdou *et al.*, 2014). Thus, dwellings in the surveyed area of Bakassi have significantly higher radon concentrations.

Considering the latest scientific data, the World Health Organization (WHO) proposed a reference level of 100 Bq.m^{-3} to minimize health hazards due to indoor radon exposure (WHO, 2009). However, if this level cannot be reached under the prevailing country-specific conditions, the chosen reference level should not exceed 300 Bq.m^{-3}. Taking account of the new findings, the ICRP has also reduced the upper reference value for radon gas in dwellings from 600 Bq.m^{-3} to 300 Bq.m^{-3} (ICRP, 2011).

There is not yet a regulation to protect people against radon exposure in Cameroon, so reference levels fixed at the international level can be used. 60% of dwellings have an indoor radon concentration above the reference level of 300 Bq.m^{-3}. This level of exposure probably has an impact on human health, leading to an increase in the probability of developing lung cancer (Darby *et al.*, 2005). The high level of indoor radon could be explained by the building construction (building materials, ventilation and floor type) because dwellings are not sufficiently ventilated. By updating the dose conversion coefficient of radon given in ICRP Publication 65 (ICRP, 1993) corresponding to 4.35 10^{-6} mSv/(Bqh/m^3), using the average indoor time (occupancy factor of 0.6) and the average radon level in dwellings of the Bakassi Peninsula, an inhalation dose of 29.3 mSv.y^{-1} was calculated. This value is much higher than the world average inhalation dose of 2 mSv.y^{-1} and should be considered cautiously because measurements were performed in only 15 dwellings.

The preliminary results of this study showed that ^{232}Th concentrations in soil samples are higher than the ^{238}U. Although only ^{222}Rn concentrations were measured in the surveyed area, for a proper dose assessment ^{220}Rn will be considered shortly using Raduet detectors.

Finally, as displayed in Table 4, a total dose of 34.6 mSv.y^{-1} received on average by each of the 11000 inhabitants living in Jabane and Idabato was assessed following radioactivity measurements in foodstuffs, soil and indoor radon measurements in Bakassi Peninsula. This value is very high compared with the world average total dose of 3.2 mSv.y^{-1}, updated using the new dose conversion coefficient of radon. This difference is explained by the high level of indoor radon exposure and the dietary habits of the population of Bakassi Peninsula, having seafood, locally available, as the main aliment. In the case of confirmation of the results of this study, countermeasures must be taken into consideration to avoid such a high level of exposure, to reduce the radiation dose to the population.

4 Conclusion

A pilot study on radioactivity measurements in soil and foodstuff samples and indoor radon measurements was carried out in the oil-bearing region of Bakassi. Elevated indoor radon concentrations were found, and relatively high levels of ^{210}Po in seafood (fish and shrimps) and leafy vegetables were measured, yielding a high dose exposure to the public of 34.6 mSv.y^{-1} compared with the world average value of 3.2 mSv.y^{-1}. This could be explained by the high consumption

Table 4. Components of the total dose for members of the public in the Bakassi Peninsula; the world average inhalation dose is updated by using the new dose conversion coefficient of radon. World average values of the effective dose are taken from the UNSCEAR report (UNSCEAR, 2000).

Exposure pathway	Location	Effective dose ($mSv.y^{-1}$)
External irradiation (ground)	Bakassi	0.27
	World	0.5
External irradiation (cosmic rays)	Bakassi	0.27
	World	0.4
Inhalation	Bakassi	29.3
	World	2
Ingestion	Bakassi	4.8
	World	0.3
Total	34.6 $mSv.y^{-1}$	

of seafood and by the building construction in Bakassi. No radioactive contamination was evidenced due to the presence of offshore production platforms in the area according to radionuclide concentrations found in the surveyed area. Only 15 soil samples, 9 foodstuff samples and 15 dwellings were considered to assess radiological exposure within the framework of the present study. Thus, more data are needed for better statistical analysis of the results obtained. This will help provide an appropriate judgment of the study. Alpha spectrometry is strongly advisable for radioactivity in foodstuffs because of its low detection limit. The most urgent action is to extend the study area to all localities of Bakassi. Only after this action is carried out should recommendations to protect people against the harmful effects of natural radiation be addressed.

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