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Radiological Quality and Dangerousness of Ferrous and Non-ferrous Metals Waste in Cotonou (Benin)

Francis Théotime Mahudjro Hounsou[1,2,3], Haziz Sina[2], Alphonse S. Avocefohoun[2,3], Pepin Aina[4,5], Ahotondji Bertin Gbaguidi[3], Kuassi Marcellin Amoussou-Guenou[1] and Lamine Baba-Moussa[3*]

[1]Laboratoire de Radio-Immuno-Dosage, Faculté des Sciences de la Santé de Cotonou, Bénin.
[2]Laboratoire de Biologie et de Typage Moléculaire en Microbiologie, Faculté des Sciences et Techniques (FAST), Université d'Abomey-Calavi (UAC), Benin.
[3]Laboratoire de Recherche en Biologie Appliquée (LARBA), à l'Ecole Polytechnique, Université d'Abomey-Calavi (UAC), Benin.
[4]Laboratoire de la Surveillance Environnementale du Ministère du Cadre et de l'habitat, Benin.
[5]Laboratoire des Sciences et Techniques de l'Eau (LSTE), Institut National de l'Eau (INE), Université d'Abomey-Calavi, Benin.

Authors' contributions

This work was carried out in collaboration among all authors. Authors FTMH, HS, ABG, KMAG and LBM designed the study, performed the analysis, wrote the protocol and wrote the first draft of the manuscript. Authors FTMH, ASA, PA, HS and KMAG managed the analyses of the study. Authors FTMH, HS and LBM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The peoples in Cotonou give themselves to sorting and recycling activities of scrap metal for lack of financial means. The uncontrolled use of this scrap metal has effects on the health of users (waste pickers, sorters, recyclers …). It was to assess the radiological quality and the degrees of dangerousness of this scrap metal waste that we conducted a study on the urban scrap storage site in Cotonou. Thus, this study is a contribution to improving the health of scrap metal collectors, sorters and recyclers in Cotonou.

**Corresponding author: E-mail: laminesaid@yahoo.fr;*

To achieve this objective, measurements of the dose rates of ionizing radiation from scrap metal were measured using a radiation survey meter. Measurements are made on contact and from a distance. In addition, analyzes of the waste of the powder samples by gamma spectrometry were also carried out.
It emerges from this study that the quantities of ionizing radiation doses vary ranging from 7.14 msv for simple copper to 7.17 msv for iron per year. Thus the quantities of ionizing radiation doses increase with burnt copper 22 msv per year and stainless steel 53 msv per year. These doses are significantly higher than the standard of the dose threshold accepted by the IAEA, which is 100 msv over 5 years for workers or on average 20 msv on contact. Ionizing radiation emitted by scrap metal, engine batteries and battery cells cannot be detected by our survey meter beyond 95 cm. In the case of powder waste, it appears that the powder waste contains radionuclides such as K40, Pb 214 and Ra 226, which give off variable energies and exhibit various activities.
These effective doses being clearly above the thresholds accepted by the IAEA confirms the fact that scrap metal is dangerous to the health of workers.

Keywords: Scrap metal waste; ionizing radiation; low doses; Benin.

1. INTRODUCTION

Trafficking in scrap metal is an income-generating activity, which is developing more and more in the big cities of the world and especially in Africa because of the high demand for the needs of recycling and recovery of metals [1]. Indeed ferrous and non-ferrous metals are traditionally recycled economically and ecologically without loss of quality by many entrepreneurs [2]. Thus, for example, the recovered aluminum is oriented towards the application of foundry of molded parts, spinning and rolling (windows, facades of buildings ...), lead is mainly channeled towards the manufacture of batteries, and decoration of roof [3]. Recovered scrap metal (car wrecks, railway equipment, structural steel elements, naval scrap, end-of-life household appliances) which are recycled for the manufacture of toys for children [4]. It seems essential to remain attentive to variations in the metal market prices.

In Benin, especially in the city of Cotonou, there are several scrap metal trafficking sites, one of the most important of which is that of the former SONICOG Company located in Akakpa, Cotonou. Many expatriates such as Nigerians, Nigerians, Indians and more and more Beninese are involved in scrap metal trafficking [5]. In the very recent past, the high cost of extracting various raw materials is a primary reason for the recovery or recycling of certain materials such as iron, aluminum, copper, lead, bronze [5-6].

In 2009, almost 19,358,627 tons of iron waste and scrap "were exported to Asia (China, India, etc.) and Europe (Belgium, Netherlands, Germany, etc.) professional export of scrap, Kg of iron [5-7]. Non-ferrous metals are more profitable for exporters. Copper and aluminum are sold under tonnage [8]. According to metallurgical professionals, income from the sale of metals varies according to the fluctuation of the cost of the dollar [9].

Given the above and the importance of this traffic in Benin on the one hand and the other hand the sorting system of this mainly manual scrap without any protection which however may constitute a health risk [10], we have examined the potential risk of this waste. Especially if we know that a study on 77,000 children of parents exposed during the bombings has also been set up, this is the F1 study to study the hereditary effects [10-11]. Besides, studies on the survivors of the Hiroshima and Nagasaki bombings have also shown an increased dose-related risk for mental retardation in individuals exposed in utero and cataracts [12].

For example, in the 2003 analysis of cancer deaths from 1950 to 1997 in Hiroshima and Nagasaki, the relationship remained significant and linear, over the range of 0-150 msv (average dose 40 msv) [13]. The question of the risk of low doses, by definition lower than 100mSv, is therefore essential in radiation protection. This risk is not highlighted by major epidemiological studies, either because it does not exist or because it is too low to be detected, drowned in the background noise of the risk of Cancer [14]. But analyzes have been used by the ICRP to define the border of low doses towards 100 msv, while the debates of the United States Academy of Sciences set it lower (10-50msv), in particular, because of the taking into account other studies such as those on prenatal exposures [15]. The health effects of radiation depend mainly on the amount of energy received called "absorbed dose"; it is expressed in joule per kilogram of living matter. The effective dose is assumed to measure the health risk of radiation and is expressed in sievert (sv). For a homogeneous irradiation of the whole organism, for example by X or gamma rays, the absorbed dose and the effective one [14]. This evolution of the founding concepts of radiation protection led following the ICRP recommendations for a progressive lowering of the annual exposure standards, which went from 600 msv in the 1930s to today 20 msv for the worker and 1 msv for the general population [16]. This is why this transverse analytical study was initiated to assess the radiological quality and the dangerousness of scrap metal waste in Cotonou.

2. MATERIALS AND METHODS

2.1 Collecting Samples

The samples were collected in two times in Cotonou (Benin) between September 2017 and March 2018. First, it was asked the workers to sort us manually, as they used to, ferrous and non-ferrous waste [17]. Thus, the results of the survey allow targeting pure iron, aluminum, batteries, motor batteries, bronze, copper and stainless steel. The selection of the collected samples was based on such a primary investigation. Secondly, we wore a lead apron and leaded gloves and with the help of a pearl hold on a distance of one meter, we took very fine ferrous and non-ferrous waste in powder form. This waste was pooled and labeled into five according to their bulk. Once collected, from the samples collection area (Fig. 1), the waste was subsequently analyzed in the environmental monitoring laboratory to allow us to know its composition in terms of radioactive element (nature and quantity).

2.2 Sample Processing and Data Collection

2.2.1 Dose rate measurements on scrap metal

Six sample classes (El: iron, E2: aluminum; E3: motor batteries; E4: bronze; E5: battery cells; E6: copper and this for the needs of identification) have been processed for the determination of ferrous (pure iron and copper) and non-ferrous (engine batteries, bronze, batteries and aluminum) metals. The measurement of the dose rate was made with a calibrated radiation meter of the AUTOMEX type. This measurement was made by slowly moving the AUTOMEX around each sample and recording the highest dose rate at observation and a distance. The radiation measurements without scrap metal: measure background noise and that of on-site waste with background noise were carried out. Finally, for these measurements, an assessment of the annual dose limit (ADL) was made from the contact dose rate for each sample, taking into account a working time of 4 hours per day, ie 20 hours per week and 1040h per year for a recuperator according to the formula:

$ADL = D * 20 * 52$ where D is the dose rate of the sample per year

2.2.2 Measuring dose rates of powder samples

These measurements were carried out on five mixture samples contained in plastic containers closed by a stopper. These samples were marked respectively with S1 (Ø≤0.02), S2 (0.02≤Ø≤0.04), S3 (0.04≤Ø≤0.06), S4 (0.06≤Ø≤0.08), S5 (0.08≤Ø≤0.10) for identification purposes. The dose rate measurement was done by slowly walking the Automex around each sample and reading the highest dose rate on contact [18]. Subsequently, the dose rate was measured for each of the samples at different distances. An assessment of the annual dose limit (ADL) was made from the contact dose rate for each sample, taking into account a working time of 4 hours per week for a worker: ADL= Dx220 where D is the rate sample dose.

2.2.3 Analysis of samples by spectrometry

The radionuclides present in the five samples (S1, S2, S3, S4 and S5) were determined qualitatively and quantitatively by analysis using gamma spectrometry. To carry out this work, small quantities of these samples were taken from small plastic tubes closed with scotch tape, to avoid the influence of cosmetic radiation. These samples will then be passed to the gamma spectrometer.

The samples were counted using a hyper pure germanium (Ge-HP) gamma spectrometry chain with nitrogen cooling. This chain is controlled by a computer and the software used is engineering 2000. The detector consists of a lead castle to prevent radiation other than that of the samples

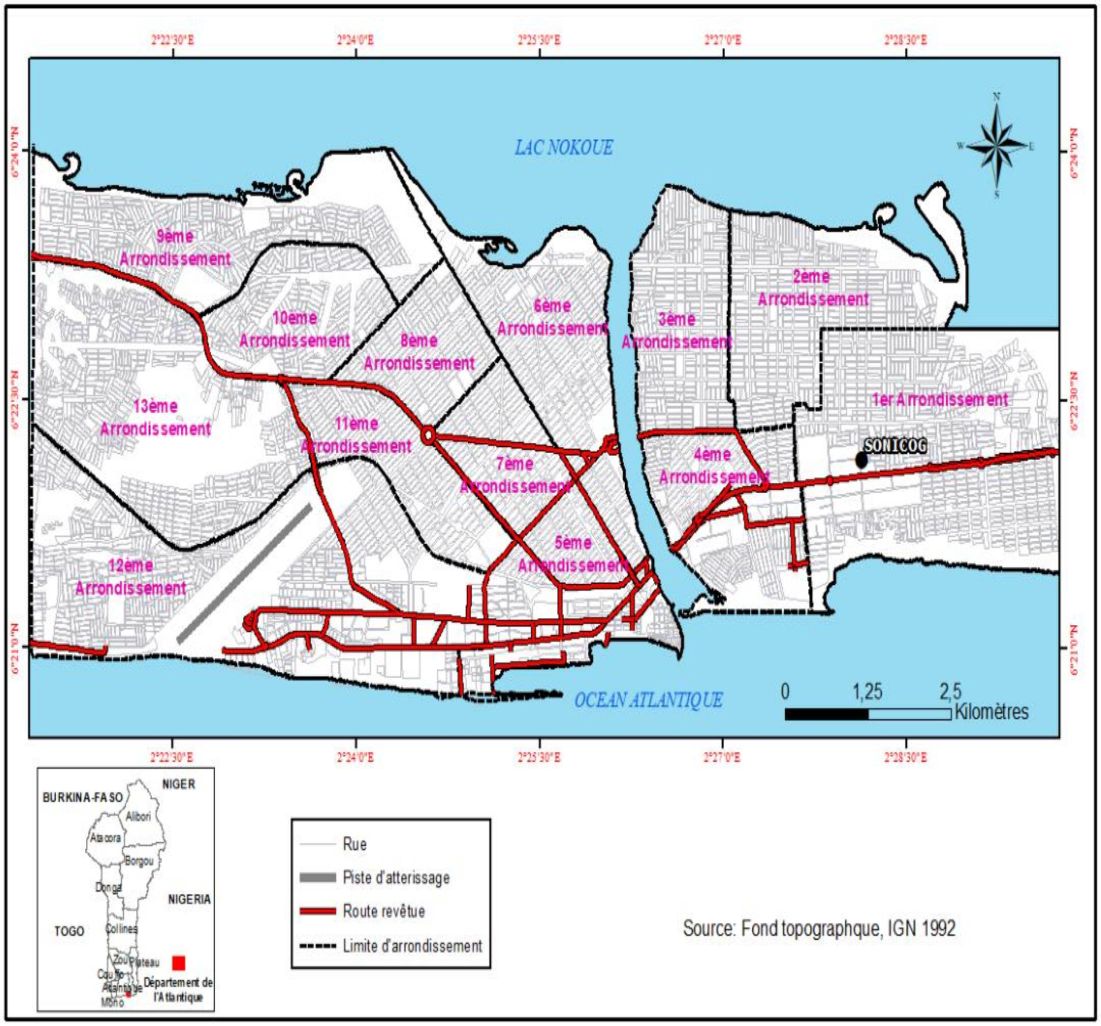

Fig. 1. Map showing the sample collection site (SONICOG)

from being counted. Before counting, Calibrate the energy and efficiency chain so that it can produce good results. Energy calibration consists of associating each channel. For this calibration, we have a source of Cs-137, Am-241, Co-60 and Europium contaminated with earth (NORM). The efficiency calibration is an operation that aims to allow the detector to be able to separate two close energies. The samples are passed in turn through the detector after calibration. The counting time chosen is 30 min taking into account the fact that we only wanted to have an idea about the activity and also the fact that the samples are very active.

2.3 Data Analysis

Data were recorded and analyzed with MS Excel 2016 Spreadsheet. The Graph Pad Prism 7.00 software was used for the graphs. The threshold of statistical significance was set at $p < 0.05$.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Direct measurement of low doses of ionizing radiation from scrap metal

Measurements of ionizing radiation low doses show that the amount of received dose per day and year by each recycler sorter and scrap metal scrap collector (Table 1). Thus, Table 1 indicates that the radiation doses are high on contact and decrease with distance. According to Table 1, the same radiation emitted by the burnt copper waste recovered during the sorting of scrap metal on the site of the former SONICOG company can be detected up to 6 m by our radiation survey meter and by 1, 02 msv or 1.02 msv per year for the surrounding population.

Table 2 shows that the contact radiation doses received by recuperators and recycling of burnt copper waste and stainless steel are 22 msv for copper and 53 msv for stainless steel per year on contact.

3.1.2 Analyses of powder samples

The analysis in Table 3 indicates that dose rates measured from the powder samples vary, not only depending on the sample but also depending on where the values are taken. Thus, overall, the values taken in contact are the larger and the further away, the smaller the values recorded. The dose rates at different distances and ADL for 220h for the powder samples vary from 0.11 msv (samples S5) to 1.78 msv (samples S2).

The radiochemical analysis of the powder samples by gamma spectrometry reveals three kinds of radionuclides: K-40, Pb-214 and Ra-226. The radiochemical parameters were measured and relate to the degree of energy released by the radionuclides and the level of activity in Bq / g that they emit. These activities and energies (Fig. 2) vary depending on the sample.

3.2 Discussion

The results of the dose rates emitted by the radiation of the waste samples found on the sites of the former company of SONICOG presented in this work showed that the annual dose in msv/h for the workers on site is greater than the dose limit that is 1msv / h according to ICRP [16]. However, an exception made to the stack sample that was at 0.93 msv/y. These amounts of radiation doses by exposed workers are 7.14 msv / year (for simple copper), 7.17 msv / year (for iron) and 4.70 msv / year for aluminum (Table 1).

The contact radiation doses received by recuperators and the recycling of burnt copper and stainless steel waste are 22 msv / year for copper and 53 msv / year for contact for stainless steel. These doses are above the threshold standard according to the International Atomic Energy Agency (IAEA) that is 100msv over 5 years for workers, or on average 20msv on contact [19]. It should be noted that in addition to the radiation emitted by scrap metal (iron), aluminum, bronze, engine batteries and battery cells are not detectable by our radiometer beyond 95cm. On the other hand, the radiation emitted by stainless steel waste is perceptible by our radiation meter up to 6 m and is 3.06 msv per day, ie 3 msv per year for the surrounding population greater than the dose limit for the population which is 1mSv according to the ICRP [16].

The radiation emitted by the burnt copper waste recovered during the sorting of scrap metal on the site of the former SONICOG company can be detected up to 6 m and 1.02 msv per year for the surrounding population. This dose is higher than the population dose limit of 1 msv per year recommended by the IAEA [19]. It emerges from the analysis of the results of the radiation doses emitted by the waste that we have two categories of radiation from our ferrous and non-ferrous metals. These are ionizing radiation that is not perceptible beyond 25 cm and ionizing radiation that is detectable up to 6 m from the waste site.

However, according to the literature, γ rays can be detectable at a distance of 6 m in the air and β rays over a few meters in the air [20-21]. As a result, we can already admit that battery cells, motor batteries, aluminum and bronze emit β ionizing radiation. The waste from stainless steel and burnt copper probably emits γ ionizing radiation. This attests that the collectors, unloaders and loaders of this scrap coming from Nigeria and Central Africa are ionized as well as the surrounding populations within a radius of 6 m from the site [22].

Table 1. Measurements of dose rates of on-site scrap samples as a function of distance

Surface dose rate (µsv)	Iron	Aluminum	Motor batteries	Bronze	Battery cells	Copper and the needs of identification
On contact	3.95	2.70	1.25	1.57	0.70	8.3
At 10 cm	1.31	0.9	0.41	0.52	0.23	1.62
At 20 cm	0.43	0.3	0.1	0.17	0.07	0.54
At 30 cm	0.14	0.1	0.04	0.05	0.025	0.018
At 40 cm	0.04	0.03	0.012	0.019	0.008	0.06

Table 2. Calculation of the maximum annual dose due to external exposure

Samples	Iron	Aluminum	Motor batteries	Bronze	Battery cells	Copper and the needs of identification
Dose rate at the surface (µsv)	6.90	4.51	1.75	2.23	0.9	14
Annual effective dose (msv)	7.17	4.70	1.82	2.32	0.93	7.4

Table 3. Measurement of dose rates for powder samples

Sample	D (µsv/h) at contact	D (µsv/h) at 10cm	D (µsv/h) at 20cm	D (µsv/h) at 30cm	D (µsv/h) at 40 cm	ADL (msv) for 220h
S1 (Ø≤0.02)	5.90	1.47	0.50	0.36	0.28	1.29
S2 (0.02≤Ø≤0.04)	3.55	1.34	0.39	0.33	0.25	1.78
S3 (0.04≤Ø≤0.06)	0.53	0.37	0.29	0.25	0.17	0.12
S4 (0.06≤Ø≤0.08)	3.43	1.20	0.50	0.24	0.10	1.75
S5 (0.08≤Ø≤0.10)	0.51	0.24	0.18	0.16	0.01	0.11

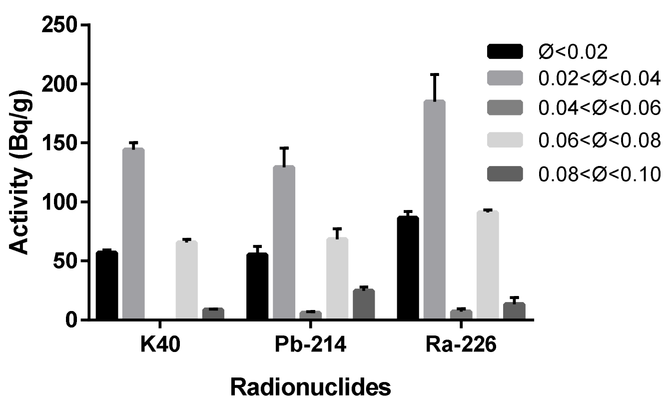

Fig. 2. Representation of the activity of radionuclides in powder by gamma spectrometry

The dose measurement results of ferrous and non-ferrous waste presented in this work showed doses above the threshold recommended by the IAEA. Thus, almost all ferrous and non-ferrous solid waste and powders emit ionizing radiation greater than the WHO standard [23]. The other samples such as scrap metal (car wrecks, railway equipment, structural steel elements, naval scrap metal, appliances out of order) indicate a dose rate on contact ranging from 1.01 to 6.90 usv / h and 7,1 msv / h per year. It appears that this scrap provides information on a radiation dose higher than that of the ICRP, which is 1 msv / h to the population [16].

In addition, non-ferrous metals such as aluminum, largely from the demolition and recovery of end-of-life objects, have a radiation dose / dose rate ranging from 0.9 to 3.6 usv / h on contact. The copper identified in waste electrical connections, fittings and files and cables has a dose rate on contact of 2.6 usv / h to 14 usv / h. The engine batteries and the battery cells indicate dose rates ranging from 0.75 usv/h to 1.75 usv/h (for the engine batteries) and from 0.51 usv/h to 0.9 usv/h (for battery cells). These batteries contain heavy metals such as mercury, nickel or cadmium that constitute a real danger for the environment and health. Burnt copper and stainless steel indicate a contact dose per hour of 4.1 usv to 25 usv / h for burnt copper and 4.6 usv / h to 56.4 usv / h for stainless steel. The average doses per year are 22 msv (copper) and 53 msv (stainless steel). From the analysis of the results of the dose rate measurements of ferrous and non-ferrous metals, we deduce the points that the contact dose rates emitted by all of our samples are higher than that of the WHO, the IAEA and the

IPRC [24]. On the other hand, French regulations fix at 1 msv per year the maximum admissible effective dose resulting from human activities outside of natural radioactivity and from the doses received in medicine [25]. This limit of 1 msv/year concerns the general public. The dose at a point represents the ratio between the energy disposed in this element divided by the mass of this element. The dose is thus above all a local value. Therefore when a subject is exposed to a source of ionizing radiation, the dose rate represents the ratio between the radioactive doses is one of the essential parameters in predicting the occurrence of acute radiation syndrome and its severity. Failure to observe proven acute syndromes does not mean an absence of ionizing radiation effects. It simply means that these effects are too weak to manifest openly. Besides, there are no tools to attribute a pathology about radioactivity exposure. Nevertheless, the exception was that the thyroid cancers that affected children and adolescents near Chernobyl are very rare at this age of life [26].

Long-term effects may then appear after exposure to low or very low doses of radiation. These long-term effects or stochastic effects are without threshold dose and lead to thyroid cancer leukemias [27]. In France, the radiation protection program of the regulations proves that up to 1 msv per year there is a specific monitoring procedure [28-30]. From 1 to 6 msv per year, dose assessment is required by workplace surveillance or individual surveillance. Beyond 6 mvs per year, mandatory surveillance of the area and the individual. In Belgium, the case of Wallonia as soon as the measured dose exceeds 5 us / h, a safety perimeter should be set up. If the limit of 5 µsv / h is exceeded, transport vehicles may in no case leave the parking place and a security perimeter of 5 µsv / h is established (delimited with a tape).

4. CONCLUSION

This study clearly showed the presence of radioactive waste from ferrous and non-ferrous metals from Nigeria, Central Africa and Benin found on the sites of the former SONICOG Company. We also deduce that the collectors, recyclers, unloaders, and loaders of this scrap metal and the population around these sites are indeed exposed to a gradual risk of poisoning linked to this radioactive waste. Efforts remain to be done to further reduce these risks of gradual exposure by raising awareness of the effective use of gantry cranes and the wearing of dosimeters by recyclers and recuperators. It is thus recommended to take maximum protection during the manipulation of both ferrous and nonferrous waste instead of avoiding being in contact with it.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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