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Original Article

Assessment of Radiation Exposure Levels and Associated Health Risks in Calabar Free Trade Zone, Nigeria

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Abstract

Introduction
Exposure to chronic levels of ionizing radiation could be detrimental to health even at very low doses. Calabar free trade zone (CFTZ) was established to promote export business in Nigeria and it is yet to produce exposure data of the Zone.
Materials and Methods
The Zone was divided into three categories depending on the type of business. Category A had facilities with manufacturing businesses, Category B was service providers while Category C was oil and gas businesses. Exposure levels within the CFTZ were measured with exposure meter and results obtained were converted to annual effective dose in mSv/yr. The evaluated doses were used to estimate health risks to workers in the Zone in terms of lifetime cancer incidence and mortality for persons aged between 18 – 65 years using the conversion factors in BEIR VII.
Results
Category B facilities had dose values between 0.21 – 0.31 mSv/yr followed by Category A with dose values between 0.23 – 0.35 mSv/yr. Category C facilities had the highest dose values between 0.33 – 0.40 mSv/yr. The evaluated cancer incidence and mortality rates were generally less than 2 persons in 1,000 persons for both male and female workers.
Conclusion
The study shows that the exposure levels in business facilities within the CFTZ were higher than the background radiation level. The effective doses were not uniform for the different categories. The estimated cancer incidence and mortality were low, and simple linear equations were generated to relate cancer incidence to mortality.

Keywords: Effective Dose, Health Risk, Cancer, Oil and Gas

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1. Introduction

The human environment is always bombarded with ionizing radiation from radionuclides within the environment and cosmic rays. Exposure of man to ionizing radiation in the environment is continuous and occurs both indoor and outdoor. The source of this radiation could be natural or artificial. Natural radiation exposure is contributed from radionuclides found in the various geological formations in soils, rocks, plants, water and air[1,2]. The radionuclides in these media are the naturally occurring radioactive materials (NORM) such as ^{238}U, ^{232}Th, and ^{40}K, with potassium being the most abundant [3]. Exposure of man to ionizing radiation is of great concern to regulatory authorities for radiation protection, management and emergency [4,5]. Agba et al [6] reports that 85% of background radiation from natural sources is due to man activities, while the remaining 15% is from cosmic rays and nuclear processes. Several studies indicate that naturally occurring radioactive materials (NORM) are also present in building materials [7], vegetables, fruits and staple food stuffs[8-10] and timbers[11]. There is evidence on enhanced levels of gamma radiation within shelters (indoors) due to building materials used in the construction of the buildings [7]. Coal ash used as additives in the production of cement and concrete is also a known cause of elevated levels of radiation exposure [12].

Enhanced levels of radiation exposure at dumpsites constitute sources of ionizing radiation to the environment, which could be hazardous to human health [13-15]. Evidence abound elsewhere showing that the levels of ionizing radiation in automobile mechanic centres are higher than the environmental background [16, 17]. Mining industries and mining products are other possible sources of gamma radiation to the environment [6]. Industrial activities have been observed to be another source of elevated levels of environmental radiation [18]. Contributions to environmental radiation level through production and application of fertilizer has also been reported [19].

Exposure to radiation, if not regulated and properly monitored could cause detrimental health effects. The main health effect, especially at low levels of radiation doses, is the increase in the probability of inducing cancer [20]. Ionizing radiation transmitted through the human body is capable of transferring some or all of its energy to the tissues which could cause damage to the cells. The damaged cells could be repaired or eliminated from the body through natural body defense mechanism [20]. This defense mechanism used by the body in repairing cells damaged by low levels of radiation doses notwithstanding, repairs of irradiated cells could sometime be difficult or imperfect, thereby causing mutation. Cell mutation is known to cause changes in the characteristics of the cell which could result in uncontrollable cell proliferation and cancer.

Low doses (near 0 – 100 mGy) of radiation with low linear energy transfer (LET) such as gamma rays and x-rays are capable of causing late effects (cancer) several years after the person had been exposed [21]. In essence, exposure to low levels of radiation doses could increase the chances of the exposed person developing cancer in the future [20]. Factors such as age, sex, time ethnicity and exposure to environmental agents such as ionizing radiation have been identified as factors that can influence the occurrence of cancer [20]. In view of this, BEIR [21] has developed models and risk factors for the estimation of lifetime risk for cancer incidence and mortality resulting from a single dose of 0.1 Gy at several specific ages, 1 mGy per year throughout life and 10 mGy per year for ages from 18 – 65 years. It should be noted that these models and factors are for 100,000 people while the doses could be extrapolated to reflect values obtained in different situations.

It has been observed that occupationally exposed persons could be exposed to other sources of radiation that should require regulatory control in addition to the well known sources of exposure at work [4, 7]. These other sources of occupational exposures are usually not included in any form of radiological protection [22]. Industrial activities in the Calabar Free Trade Zone (CFTZ) include oil and gas business, building materials and metal processing which are known sources of enhanced levels of radiation [22]. However, to the best of our knowledge, the business facilities in CFTZ are yet to come under regulatory control, or evaluate the levels of radiation exposure to ascertain compliance with set limits.

This study was therefore set up to measure the levels of exposure at the different facilities in CFTZ and evaluate the associated health risk of cancer incidence and mortality to workers in the Zone. Results obtained from this study could form baseline data for future comparison to ascertain the possible impact of industrial activities to changes in the radiation exposure levels in the zone.

2. Materials and Methods

The Calabar free trade zone (CFTZ) is an industrial area located in Calabar, longitude $5^0$1'18''N and latitude 8^0 19' 13''E. The zone is set aside for export free trade by government of Nigeria. It is occupied by companies and industries engaged in manufacturing, assembling, trading, oil and gas related activities and service providers. The CFTZ is located in Esuk Utan, Calabar Municipal, Cross River State, Nigeria. It is the premier free trade zone which commenced operations in November 2001. It occupies a total land mass of 220 hectares with 78 registered companies of which 34 is in full operations, 16 companies are in different stages of installations and test running of equipment/machineries, 17 are at different stages of construction and 11 companies yet to mobilize to the free trade zone.

A preliminary survey of the trade zone was conducted to mark out the areas for measurements and to obtain permission from the management of the free trade zone to undertake the study. The facilities within the zone were assured that the study was not meant for regulatory assessment and would not be used in the future for any business transaction. This assurance notwithstanding, and the endorsement of a nondisclosure of facilities identities agreement by the researchers, some facilities were still reluctant to grant the researchers adequate cooperation for the study.

The response of the survey meter to environmental radiation was tested according to the method proposed by Uwah and Inyang [23] between the hours of 9.00 and 17.00 on a bright sunny day. The results are given in Table 1. The radiation exposure level within the area of study was measured using a portable gamma radiation survey exposure monitor RADEX model (RD 1212 manufactured by Quart-Rad Inc, United States of America). The survey meter which was factory calibrated to measure radiation effective dose in µSv/hr was held at 1 m above the ground level following the method described by Inyang et al[11] and Uwah and Inyang[23]. Measurements were taken 10 times at each location between the hours of 13.00 to 15.00 during which time the survey meter showed optimal response.

Forty (40) measurement sites were selected and were divided into three categories depending on the industrial activities within the facilities. These categories included: Category A for manufacturing industries, Category B for Service providers, trading and residents and Category C for Oil and gas industries. The measurements were conducted indoors between the hours of 13.00 to 15.00 daily for 30 days. The measured doses were converted to effective dose per year using a method similar to that of Inyang et al [7], by assuming that each worker spends 8 hours a day on duty for 5days a week and 48 weeks in a year, while the remaining 4 weeks were used for vacation. This brought about a conversion factor of 1,920 hr/yr.

The risks of lifetime attributed cancer incidence (LCI) and lifetime attributed cancer mortality (LCM) were calculated using the risk factors presented in BEIR [21] for males and females exposed to 10 mGy/yr from 18 to 65 years which was regarded as the ages for the worker in the zone. The dose value of 10 mGy/yr stated here was extrapolated to reflect the dose values obtained from measured and evaluated effective doses (EED) before the results were interpreted in terms of 100,000 persons used by BEIR [21] in calculating the risk factors. Even though the risk factors were presented for several types of cancer, the risk factor for all cancer was used since its value was the sum of the risk factors for the different types of cancer.

3. Results

The results of the exposure meter response during different hours of the day are presented in Table 1. The meter showed varied responses with a threshold between 13.00 and 15.00 hours. Other measurements in this study were taken within these hours. The average background radiation in an open space about 6 meter from any known building was 0.09±0.03 µSv/hr.

Table 1. Effective dose rates showing the exposure meter response

Time (hr)	Mean exposure (µSv/hr)
09:00	0.09
10:00	0.09
11:00	0.10
12:00	0.11
13:00	0.12
14:00	0.12
15:00	0.12
16:00	0.10
17:00	0.09

Radiation exposure values obtained in Category A facilities ranged from 0.23 – 0.35 mSv/yr, with most of the values above 0.30 mSv/yr (Table 2). Category B facilities had effective dose values in the range of 0.21 - 0.31 mSv/yr (Table 3) while category C which represented facilities involved in oil and gas had values between 0.33 – 0.40 mSv/yr (Table 4).

Table 2. Annual effective dose values for Category A facilities

Category A	Measured effective Dose rate (µSv/hr)	Annual effective dose (mSv/yr)
A01	0.16 ± 0.04	0.31
A02	0.18 ± 0.03	0.35
A03	0.16 ± 0.05	0.31
A04	0.16 ± 0.04	0.31
A05	0.17 ± 0.03	0.33
A06	0.14 ± 0.05	0.27
A07	0.18 ± 0.04	0.35
A08	0.12 ± 0.03	0.23
A09	0.13 ± 0.05	0.25
A10	0.16 ± 0.03	0.31
A11	0.15 ± 0.05	0.29
A12	0.15 ± 0.04	0.29
A13	0.17 ± 0.03	0.33

Table 3. Annual effective dose values in Category B facilities

Category B	Measured effective dose rate (µSv/hr)	Annual effective dose (mSv/yr)
B01	0.11 ± 0.05	0.21
B02	0.12 ± 0.04	0.23
B03	0.13 ± 0.03	0.25
B04	0.16 ± 0.04	0.31
B05	0.14 ± 0.03	0.27
B06	0.14 ± 0.05	0.27
B07	0.14 ± 0.06	0.27
B08	0.12 ± 0.03	0.23
B09	0.13 ± 0.04	0.25
B10	0.14 ± 0.03	0.27
B11	0.11 ± 0.05	0.21
B12	0.11 ± 0.05	0.21
B13	0.13 ± 0.04	0.25
B14	0.11 ± 0.03	0.21
B15	0.12 ± 0.05	0.23

Table 4. Annual effective dose values in Category C facilities

Category C	Measured effective dose rate (µSv/hr)	Annual effective dose (mSv/yr)
C01	0.19 ± 0.03	0.36
C02	0.20 ± 0.03	0.38
C03	0.19 ± 0.05	0.36
C04	0.19 ± 0.03	0.36
C05	0.18 ± 0.04	0.35
C06	0.18 ± 0.03	0.35
C07	0.18 ± 0.04	0.35
C08	0.21 ± 0.02	0.40
C09	0.17 ± 0.04	0.33
C10	0.18 ± 0.05	0.35
C11	0.18 ± 0.03	0.35
C12	0.19 ± 0.03	0.36

Table 5. Lifetime attributed solid cancer incidence and mortality for category A facilities

Category A	AED (mSv/yr)	LCI (male)	LCM (male)	LCI (female)	LCM (female)
A01	0.31	95	53	133	74
A02	0.35	107	60	150	84
A03	0.31	95	53	133	74
A04	0.31	95	53	133	74
A05	0.33	101	56	142	79
A06	0.27	83	46	116	65
A07	0.35	107	60	150	84
A08	0.23	70	39	99	55
A09	0.25	76	43	107	69
A10	0.31	95	53	133	74
A11	0.29	89	49	126	69
A12	0.29	89	49	126	69
A13	0.33	107	60	150	84

Table 6. Lifetime attributed cancer incidence and mortality for category B facilities

Category B	AED (mSv/yr)	LCI (male)	LCM (male)	LCI (female)	LCM (female)
B01	0.21	64	36	90	50
B02	0.23	70	39	99	55
B03	0.25	76	43	107	60
B04	0.31	95	53	133	74
B05	0.27	83	46	116	65
B06	0.27	83	46	116	65
B07	0.27	83	46	116	65
B08	0.23	70	39	99	55
B09	0.25	76	43	107	60
B10	0.27	83	46	116	65
B11	0.21	64	36	90	50
B12	0.21	64	36	90	50
B13	0.25	76	43	107	60
B14	0.21	64	36	90	50
B15	0.23	70	39	99	55

Table 7. Lifetime attributed cancer incidence and mortality for category C facilities

Category C	AED (mSv/yr)	LCI (male)	LCM (male)	LCI (female)	LCM(female)
C01	0.36	110	61	154	86
C02	0.38	116	65	163	91
C03	0.36	110	61	154	86
C04	0.36	110	61	154	86
C05	0.35	107	60	150	84
C06	0.35	107	60	150	84
C07	0.35	107	60	150	84
C08	0.40	122	68	172	96
C09	0.33	101	56	142	79
C10	0.35	107	60	150	84
C11	0.35	107	60	150	84
C12	0.36	110	61	154	86

Table 5 presents results for lifetime risk of cancer incidence and mortality for Category A facilities which comprised different manufacturing businesses. The range of lifetime cancer incidence risk for male workers in Category A facilities was 70 – 107 persons in a total of 100,000 persons with a corresponding male cancer mortality of 39 – 60 persons out of 100,000 persons. Similarly, the female cancer incidence and mortality risks were in the range of 99 – 150 and 55 – 84 persons respectively out of 100,000 persons.

The lifetime cancer incidence and mortality for male workers in Category B facilities ranged from 64 – 95 and 36 – 53 persons respectively per 100,000 persons (Table 6). The values of female cancer incidence and mortality had ranges between 90 – 133 and 50 – 74 persons respectively in every 100,000 persons available. The cancer risk values obtained in Category B facilities were mostly lower than those observed in Categories A and C facilities.

The cancer risk incidence and mortality for both males and females working in Category C facilities had most of the highest values with the cancer incidence ranging from 101 – 122 persons and 142 – 172 persons for males and female workers respectively in 100,000 persons (Table 7). The corresponding cancer mortality for males and females in category C facilities were 56 – 68 and 79 – 96 persons respectively in every 100,000 persons.

4. Discussion

The estimated effective doses in all the Categories (A, B, C) of facilities in operation within the CFTZ were in the range of 0.21 – 0.40 mSv/yr (Tables 2 – 4). These values were generally lower than 1.00 mSv/yr dose limit for public exposure which is also the value for EC control limit [22]. The doses in Category C facilities were mostly higher than those from facilities in other categories. The higher levels of doses observed in Category C facilities could be attributed to the type business they are involved in. Most of facilities in Category C were importers of refined petroleum products which are stored within those facilities for distribution to retailers. It is a known fact that petroleum oil and gas have some traces of radionuclides in them when extracted from the earth crust and very minute quantities of these radionuclides might still flow into the refined products resulting in higher dose values within the facilities.

Category C facilities were followed closely by Category A facilities which were involved in manufacturing business using scrap metals and other raw materials that could contribute to enhance levels of environmental radiation. The observed effective doses in Category A facilities could be attributed not only to the building materials but also to the materials the use in the manufacturing processes. Category B facilities had most of the lowest observed doses, except in facility B04 which had an estimated effective dose of 0.31 mSv/yr. The doses in Category B facilities could be attributed to the building materials used in the construction of the facilities buildings since these facilities did not involve in business activities using materials that may cause enhance levels of environmental radiation. However, based on the limited access to facilities granted the researchers by facilities managers, due to fear of possible regulatory implications of the study, it was not possible to ascertained the possible causes of the high dose observed in facility B04.

Results of this study presented in Tables 5 – 7 show that cancer incidence and mortality were generally higher in females than in males. This observation, it is believed, is due to the assumptions in the model that was used by BEIR [21] in deriving the factors that were used in determining the cancer incidence and mortality in this study. A further analysis shows that it is possible to get about 2 females cancer incidence within 1,000 females in some of the facilities, especially Category C facilities. Male cancer incidence was estimated to be about 1 male in every 1,000 males in the facilities. The estimated cancer mortality rate for males and females in this study were generally under 1 person for every 1,000 persons in the Zone.

Simple linear relationships developed to investigate the possible relationships between male cancer mortality M_m and male cancer incidence I_m, female cancer mortality M_f and female cancer incidence I_f are shown in Figure 1(a and b) with the appropriate equations inserted within the figures.

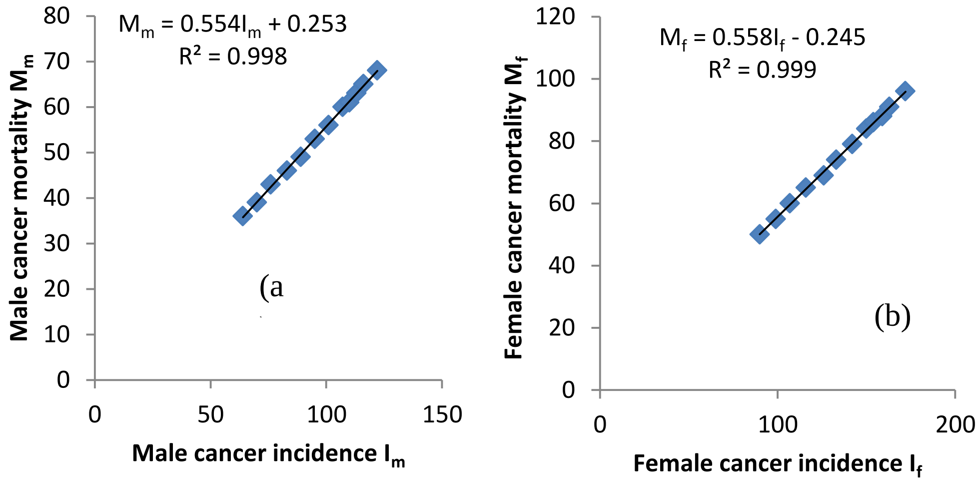

Figure 1. Plots of (a) male cancer mortality M_m against male cancer incidence I_m and (b) female cancer mortality M_f against female cancer incidence I_f

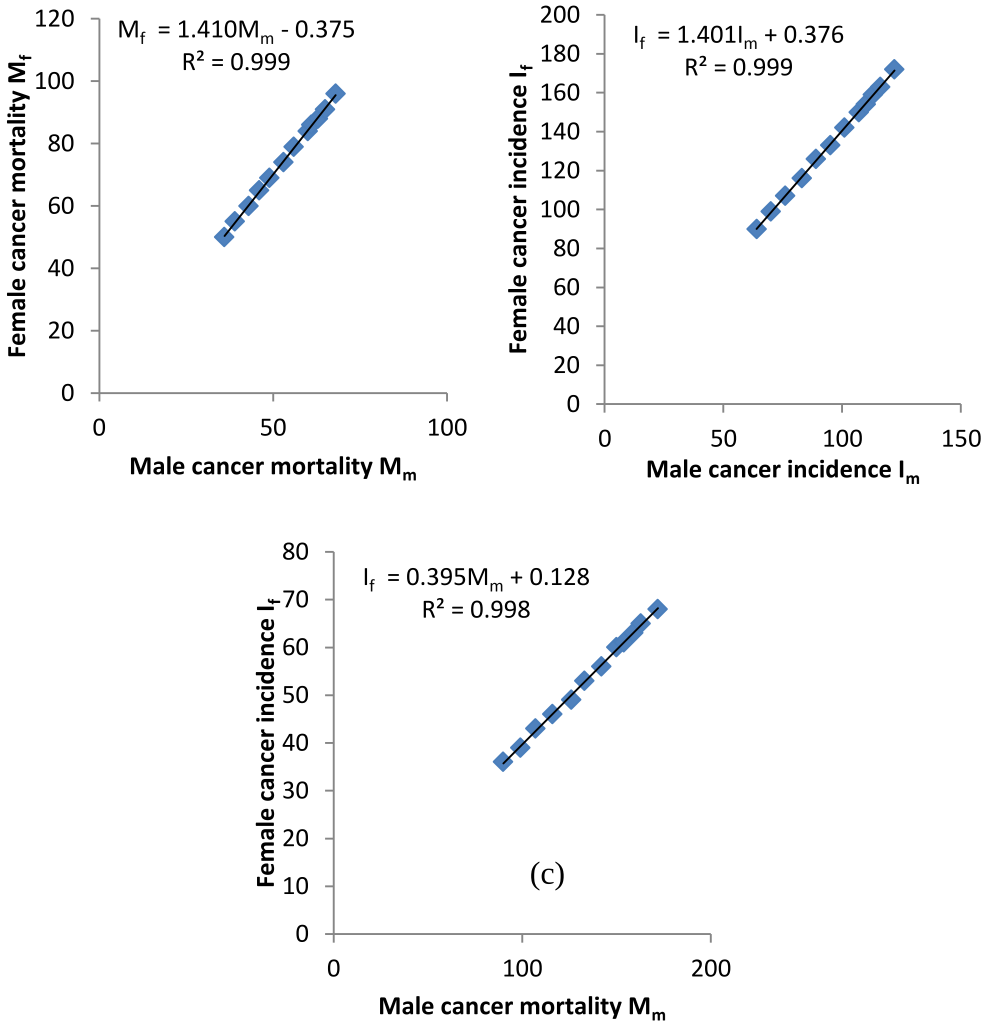

Figure 2. Plots of (a) female cancer mortality M_f against male cancer mortality M_m, (b) female cancer incidence I_f against male cancer incidence I_m and (c) female cancer incidence I_f against male cancer mortality $M_{m.}$

Similarly, the plots of female cancer mortality M_f against male cancer mortality M_m, female cancer incidence I_f against male cancer incidence I_m and female cancer incidence I_f against male cancer mortality M_m are given in Figure 2 (a, b, c) with their associated linear relationships inserted in the figures.

Each equation obtained from the different plots showed good linear relationship with R^2 not less than 0.998. In essence, these equations could be used in obtaining the cancer mortality when the incidence is calculated and vice versa.

5. Conclusion

Calabar free trade zone (CFTZ) was established in South-South Nigeria to promote export trade and has existed without any baseline data on background radiation or possible radiation due to business activities going on in the Zone. The radiation dose levels within the Zone have been measured and the annual effective dose rates evaluated. The evaluated effective doses for facilities in the manufacturing sector (category A) have values ranging from 0.23 – 0.35 mSv/yr while Category B which included services providers have estimated effective dose that ranged from 0.21–0.31 mSv/yr. Category C which comprised oil and gas facilities had the highest estimated effective dose with values from 0.33–0.40 mSv/yr. Evaluation of possible health risk due to lifetime attributed cancer, showed that in 1,000 males and 1,000 female about 1 and 2 cancer incidences respectively could be observed. The evaluated lifetime cancer mortality for males and females was below 1 in every 1,000 persons. The equations obtained can be used to obtain cancer incidence from mortality and vice versa when either of them is known.

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