Radioactivity Measurements for Some Building Materials in Yemen and Simulation of the Annual Effective Dose

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***Abstract*—Fifty three samples of building materials were collected from two governorates in Yemen (Taiz and Hodeidah); these materials are used mostly in Yemen. Samples were measured for gamma radiation using HPGe detector. The specific absorbed dose rates due to the three natural radionuclides ^{226}Ra,^{232}Th and ^{40}K in the most used types of building materials in Yemen such as (ordinary concrete, granite stone and cement brick) were calculated. The calculations were done for a model of spherical shaped room of radius 150 cm, thickness 30cm and variable density that varies according to the supposed material in the two selected cities (Taiz and Hodeidah). Stranden model is considered here with some modification in order to fit the specifications of the room in Yemen. The calculated annual effective dose rates for the ordinary concrete in the two cities were 329.452 and 294.250 (Hodeidah and Taiz) µSv/y respectively, in the granite stone was 1029.829 µSv/y, and in the cement brick was 929.497 µSv/y.**

***Index Terms* – Activity concentrations, annual effective dose, MCNP code and Yemen radioactive contamination.**

I. Introduction

The environment in Yemen is varied between plain, desert and volcanic islands. These varieties imposed the citizens to use the available building materials. In the areas with mountains, the nature of land has imposed the Yemenis to use rocks as the basic building material. Because of the big varieties of building materials used in different cities around the Republic of Yemen and the shortage of information about the radioactivity of these materials, we did our research in order to make a regulation of the building materials in Yemen. Some very common building materials like granite stone and Cement brick were found of high value of the activity concentrations. A theoretical model was set for a Yemeni room with approximate specification of the room in Yemen to calculate the indoor exposure dose rate.

This modeled room was established using MCNP code (Monte Carlo N-particle transport computer code) and some mathematical treatments [1].

II. Experimintal Work

Fifty three samples were collected randomly from two governorates; Taiz and Hodeidah in Yemen. Taiz represents the mountainous areas located between latitudes 14 ° and 12° to the north of the equator, and between longitudes 45° and 43° to the east of Greenwich, However Hodeidah represents the plain areas, it lies the west of red sea cost in the area between latitudes 14° and 16° to the north of the equator, and between longitudes 42° and 43° to the east of Greenwich. Some of the raw building materials were collected from the places where they sold and some were collected from their original resources (mining places) or from actual building sites. The artificial building materials were collected from the places they were sold in either from shops or from factories so that the collected samples covered the most citizens' use of these materials.

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III. Sample Preparation

The collected samples were saved in plastic bags. Then they were crushed by hummer, and sieved through 0.8 mm mesh sieve. Each sample was weighted and stored in a sealed marinelli beaker for more than four weeks to reach the secular equilibrium between ^{226}Ra and its short lived products.

IV. Experimental Results

We have used the HPGe detector to measure the activity concentrations in our samples in order to assess the individual exposure dose rate and to estimate the risks from spending most of our lifetimes inside buildings. The activity concentrations for raw materials were ranged between (1.858 ±0.333-154.216±6.974),(0.288±0.165-229.141±3.398),(3.38 9± 0.266-1701.338±59.572) Bq/Kg for ^{226}Ra, ^{232}Th and ^{40}K respectively, whereas the activity concentrations for the industrial materials were ranged between(0.209±0.155 -180.950±6.922),(0.491±0.088-252.854±3.939) and (2.480 ±0.958-1017.220±12.080) Bq/Kg for ^{226}Ra,^{232}Th and ^{40}K respectively. The highest value of the activity concentrations was in the cement brick (180.950±6.922 and 252.854±3.94) Bq/Kg for ^{226}Ra and ^{232}Th respectively, and granite stone (154.216±6.974 and 229.141±3.398) Bq/Kg for ^{226}Ra and ^{232}Th Radionuclides, the concentration of these radionuclides increases the risks from these radionuclides inside buildings, as these bricks are used as the main building materials in most of the buildings around the country and especially in the two areas under study in this research.

V. Activity Analysis

A. The Radium Equivalent

The radium equivalent Ra_{eq} was calculated for all samples. Because the distribution of ^{238}U,^{232}Th and ^{40}K in nature is not uniform, the radium equivalent Ra_{eq} is proposed to comparing the specific activity of material containing different amount of ^{238}U, ^{232}Th and ^{40}K, and it is defined as a weighted sum of the activity concentrations of the ^{238}U, ^{232}Th and ^{40}K.The measured specific activity (Bq/Kg) of ^{238}U, ^{232}Th and ^{40}K for each sample are used to calculate Radium equivalent Ra_{eq} using the following equation [2] :

$$Ra_{eq} = C(Ra) + 1.43C(Th) + 0.077C(K) \quad (1)$$

where C(Ra), C(Th) and C(K) are the activity concentrations in Bq/Kg. For the limitation of the annual effective dose to be 1mSv for the population, the maximum value of this index must be less than 370Bq/Kg.

B. The External Hazard and the Internal Hazards

For the safe use of the materials in the Yemeni buildings and to limit the annual effective dose to be 1mSv for the population the external hazard H_{ex} and the internal hazard indices H_{in} which are given by [2-3]:

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \quad (2)$$

And

$$H_{ex} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \quad (3)$$

Should be less than unity.

TABLE I: THE CALCULATED RADIUM EQUIVALENT Ra_{eq}, THE INTERNAL HAZARD H_{in} AND THE EXTERNAL HAZARD H_{ex} IN INDUSTRIAL AND RAW MATERIALS

Index	Industrial materials (Bq/Kg)	Raw materials (Bq/Kg)
Radium equivalent	1.340±0.349–603.698±13.463	5.718±1.747 - 593.177±12.856
Internal hazard	0.004±0.001- 2.120±0.055	0.023±0.007 – 2.019±0.054
External hazard	0.004±0.001-1.630±0.036	0.006±0.001-1.602±0.035

From the “Table. I” the values of Ra_{eq} , H_{in} and H_{ex} are almost twice world average value.

C. The Absorbed Dose

The absorbed dose rate in air (D) in nGy/h, resulting from the natural specific activity concentration of ^{238}U, ^{232}Th and ^{40}K in Bq/Kg, at a height of 1 m above the ground was calculated according to this formula [4]:

$$D(nGyh^{-1}) = 0.429\,^{226}Ra + 0.666\,^{232}Th + 0.42\,^{40}K \quad (4)$$

where the contribution from the ^{238}U has been replaced with the decay product ^{226}Ra. For the industrial materials the absorbed dose ranged [13.734±1.559-279.393±9.834] Gy/h and for the raw material it ranged [2.60±0.62– 279.47±10.60] Gy/h. Some samples has absorbed dose higher than the estimated average global terrestrial radiation of the range 24-160 nGy/h [5]. It is clear that the absorbed dose in the granite stone and cement brick collected from Taiz and Hodeidah are (279.470±10.602 Gy/h) and (279.393 ±9.834 Gy/h) respectively, are higher than the calculated values for some soil and stones samples collected from Juban town in Yemen [6].

D. The Investigative Level

Another hazard index called the investigative level was determined for all the samples according to [7]:

$$I = \frac{C_{Ra}}{300Bq/Kg} + \frac{C_{Th}}{200Bq/Kg} + \frac{C_K}{3000Bq/Kg} \quad (5)$$

The investigative level was ranged between [0.020±0.006 – 2.142±0.045] for the raw materials, and ranged between [0.005±0.001–2.132±0.047] in the industrial material. According to the European commission the activity concentration shall not accede the following values depending on the dose criterion, the way and the amount the material used in a building [7]:

TABLE II: DOSE CRITERION RANGE

Dose criterion	0.3mSv a-1	1mSva-1
Materials used in bulk amount,e.g. concrete	I≤ 0.5	I≤ 1
Superficial and other materials with restricted use: tiles ,boarded	I≤ 2	I≤ 6

VI. MODELING

Our model is a developed for Mustonen model [8], although it is a modification of Stranded model [9]. The indoor exposure dose rate at a point in dwelling is written as following:

$$x^{\cdot} = \frac{kc\rho}{4\Pi} \sum_i E_i N(E_i) \mu_a(E_i) \int \frac{B_D(Ei,s)}{l^2} e^{-di} dV \quad (6)$$

where x. the exposure dose rate, ρ is the density of the material, C is the activity per unit weight, k is the coefficient to change the exposure in to Roentgen unit ;(k = 1.462 X10^{-2} R/Mev.cm^3) , E is the photon energy, $N(E_i)$ is the number of photons with energy E_i emitted per unit primary disintegration, $\mu_a(E_i)$ is the linear absorption coefficient in air $\mu_m(E_i)$ is the attenuation coefficient in the material $B_D(E_i,s)$ is the build-up factor, S is the distance the photon travels in the material, L is the distance from the source point, V is the volume of the room and di is the optical distance between the source and the detection point which is given by:

$$di = s\mu_m(E_i) + (L - s)\mu_a \quad (7)$$

The linear attenuation coefficients (μ_m) for the mostly used building materials in the selected cities (ordinary concrete, granite and cement brick) have been calculated, by using MCNP code. Our summation in “(6)” is done over only 18 selected energy lines used in this simulation model to calculate the exposure dose rate.

VII. CALCULATION OF THE LINEAR ATTENUATION COEFFICIENTS

A theoretical model was built to calculate the linear attenuation coefficients for the selected energy lines using MCNP code [1]. MCNP code is a Monte Carlo N-particle transport computer code created and developed by Los Alamos National Laboratory that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport. The selected geometry for the theoretical model here is a sphere. We detected the flux resulting from the radionuclides inside the spherical layer of the supposed material that we want to calculate the linear attenuation coefficient for it by a standard tally in MCNP code named (F5).

This sphere has a thickness of 30 cm, where the detection is performed using a ring detector of radius of 50 cm in centre of the room in about 150 cm from the internal wall (F5 tally). We used a matrix of group of the gamma energies of ^{238}U,^{232}Th and^{40}K in each running of MCNP. We supposed that the sphere layer built of concrete, and the initial flux ϕ_0 was detected first inside a vacuum sphere, after that we filled the sphere with the ordinary concrete, got the attenuated flux ϕ resulting from existing of the concrete material. By using the simple relation of the photon attenuation equation:

$$\phi = \phi_0 e^{-\mu x} \tag{8}$$

where x is the distance from the entire wall to the detection ring applied by (F5) tally in the MCNP input, x=150.We got the values of the linear attenuation coefficients µm "Table III.", and these values of concrete are in a good agreement with the published values by Mustonen [8]. We repeated the same steps to calculate the linear attenuation coefficients µm of granite stone and cement brick. Each time we changed only the chemical compositions of the studied material in the input file and all their densities. The attenuation coefficients for concrete, granite stone and cement brick listed also in Table. III.

TABLE III: THE ATTENUATION COEFFICIENTS FOR THE ORDINARY CONCRETE, GRANITE AND CEMENT BRICK

E (Mev)	µ concrete (μ cm^{-1})	µ granite (μ cm^{-1})	µ cement brick (μ cm^{-1})	E (Mev)	µ concrete (μ cm^{-1})	µ granite (μ cm^{-1})	µ cement brick (μ cm^{-1})
0.063	0.370	0.580	0.081	0.351	0.240	0.320	0.150
0.092	0.280	0.350	0.071	0.583	0.180	0.230	0.070
0.186	0.230	0.260	0.078	0.609	0.190	0.250	0.120
0.209	0.195	0.260	0.0128	0.860	0.160	0.200	0.100
0.238	0.220	0.290	0.0120	0.911	0.170	0.210	0.120
0.277	0.220	0.280	0.075	0.968	0.170	0.210	0.110
0.295	0.220	0.270	0.123	1.120	0.160	0.170	0.090
0.300	0.240	0.290	0.158	1.464	0.140	0.170	0.090
0.338	0.210	0.260	0.107	1.760	0.140	0.160	0.090

VIII. THE SPECIFIC EXPOSURE DOSE RATE

From "(6)," the specific exposure dose rate per unit activity concentration (Q) is given by the following relation:

$$Q = \frac{k\rho}{4\Pi} \sum_i E_i N(E_i) \mu_a(E_i) \int \frac{B_D(Ei,s)}{l^2} e^{-di} dV \tag{9}$$

The supposed geometry of a spherical shaped modelled room of 150 cm radius and wall thickness of 30cm is shown in " Fig. 1", this is the easiest for modeling since the sphere is one dimensional, and the spherical shape is compatible with some houses in Yemen which have been domed the roof. According to Koblinger [10], the good agreement of the data from this approximation with those obtained for rectangular shaped room shows that the shape of the room hardly affects the dose rates, so for the simplicity we have chosen the spherical shaped room. The area of windows and doors in our supposed room was taken in to consideration however they act as shields against gammas coming from terrestrial sources or walls of other rooms. We use in our calculation the Berger's formula of the build-up factor has the simplicity of the linear form but fits the buildup Factor data over a long range, and it is given by [11].

$$B(E_i, s) = 1 + a(E_i)\mu_m(E_i) s \exp(b\mu_m s) \tag{10}$$

Our assumption is based on a spherical shaped room of 150 cm and thickness of 30 cm. These specifications are compatible with the design of the Yemeni room. For the calculation of the flux at a point in the centre of the room, or any other point from a volume source like concrete, or granite room we supposed that the gamma radiation source as a point source inside the material wall "q", then the contribution from all point sources to the total flux is added in the integral over the thickness of the room, while the integration was done using the spherical coordinates.

$$dV = r^2 \sin\theta d\theta d\phi dr \tag{11}$$

"Fig.1"shows the geometry used in our calculations, from this figure we can see that:

$$l = r (12)$$

$$r = r_p - r_Q (13)$$

$$s = r - r_0 (14)$$

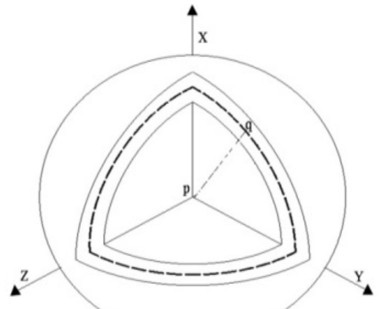

Fig. 1. Modeled room

, r_0 is the distance from the internal wall of the spherical room to the detection point (p) in the centre. By substituting in "(9)" and the integrated part using MATHEMATICA 5.2

soft ware, we got the specific exposure dose rate inside the sphere.

TABLE IV: SPECIFIC EXPOSURE DOSE RATE

The material	The specific exposure rate in μRh-1 / $Bq^{-1}Kg^{-1}$		
	226Ra	232Th	40K
Concrete	0.046	0.096	0.008
Granite	0.043	0.087	0.008
Cement brick	0.044	0.099	0.005

IX. THE ANNUAL EFFECTIVE DOSE RATE IN THE MIDDLE OF A ROOM BUILT WITH DIFFERENT TYPES OF BUILDING MATERIALS

The annual effective dose rate is calculated according to this relation [12]:

$$E_{wall} = YT(C_{Ra}Q_{Ra} + C_{Th}Q_{Th} + C_K Q_K)m \quad (15)$$

where Y is the factor that converts the absorbed dose in air to effective dose in humans (Sv/Gy), T is the indoor occupancy factor and C_{Ra},C_{Th} and C_K are radioactivity concentrations for ^{226}Ra, ^{232}Th and^{40}K, respectively. The quantities Q_{Ra}, Q_{Th} and Q_K are the respective specific absorbed dose rates which have been calculated for a typical Yemeni room built with concrete, granite stone and cement brick, and m is the fraction of the wall is made up of the material type (concrete, granite or cement brick), it is supposed here to be equal to (32%, 58% and 51%) for concrete, granite and cement brick respectively.

TABLE V: ANUUAL EFFECTIVE DOSE RATE FOR DIFFERENT TYPES OF BUILDING MATERIALS

City	Type of material	The total annual effective dose rate of whole room (μSv/y)
Hodeidah	Concrete	329.452
Taiz	Concrete	294.250
Distributed around Yemen	Granite stone	1029.829
Distributed around Yemen	Cement brick	929.497

The annual effective dose for concrete in Hodeidah and Taiz 329.452 and 294.250 μSv/y respectively, is less than that in Jordan (470 μSv/y) [13] ,Nigeria (400 μSv/y) [12], Cuba (429.2 μSv/y) [14] and less than the dose in typical building in Hong Kong (1459 μSv/y) [15] but lied within this range of the total (outdoors plus indoors) annual effective dose equivalent from terrestrial gamma radiation, averaged over the world's population (30 μSv/y -400 μSv/y) [16].In granite stone the annual effective dose(1029.829 μSv/y)is higher than that obtained in Jordan (520 μSv/y) [13] ,but within the range of the effective dose rate calculated for granite stone in Iran (480-1050 μSv/y) [17],whereas it is twice the world average range .The effective dose rate calculated for cement brick in this work is higher than that dose calculated in Jordan (442 μSv/y) [13] , Cuba (258.59 μSv/y)[14], and also is twice the world average range.

X. CONCLUSION

We observed widespread use of building materials like cement brick and granite with high values of the activity concentrations of the three studied radionuclides and their resulted absorbed dose. We intend to make guideline for those responsible to make a regulation for the specifications of the building materials in Yemen.

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REFERENCES

[1] X-5 Monte Carlo Team, MCNP — A General Monte Carlo N-Particle Transport Code, Los Alamos laboratory,Version 5, April 24, 2003 (Revised 10/3/05).

[2] J. Bereteka and P. J. Mathew, "Natural radioactivity of Australian building materials, industrial wastes and by-products", *Health Physics*, vol. 48,no 1, pp. 87-95, 1985.

[3] S. Roy, M. S. Alam, F. K.Miah and B. Alam, "Concentrations of naturally occurring radionuclides and fission products in brick samples fabricated and uses in and around greater Dhaka", *Radiation Protection Dosimetry* vol. 88, no 3, pp. 255-260, 2000.

[4] N. N. Jibiri and I. P. Farai., "Assessment of dose rate and collective effective dose equivalent due to terrestrial gamma radiation in the city of Lagos", *Radiation Protection Dosimetry*, vol.76, no.3. pp.191-194, 1998.

[5] Nations Scientific Committee on the Effects of Atomic Radiation, Sources and effects of ionizing radiation(UNSCEAR), report to the general assembly with scientific Annexes,vol. 1:sources, 2000.

[6] A. I. Abd El-mageed ,A. H. El-kamel, A. Abbady, S. Harb, A. M. M. Youssef, and I. I. Saleh, "Assessment of natural and anthropogenic radioactivity levels in rocks and soils in the environments of Juban town in Yemen", *Radiation Physics and Chemistry,* Vol.80, pp.710-715, 2011.

[7] Radiological protection principles concerning the natural radioactivity of building materials,Report of European Commission, no. 112, pp.8, 1999.

[8] R. Mustonen, "Methods of evaluation of radiation form building materials", Radiation Protection Dosimetry, vol. 7, pp. 235–238, 1984.

[9] E.Stranden,"Radioactivity of building materials and the gamma radiation in dwellings", *Physics in Medicine and Biology* , vol.24,pp.921–930 , 1979.

[10] L. Koblinger, "Calculation of exposures rates from gamma sources in walls of dwelling rooms", *Health Physics*, vol.34, pp.459–463, 1978.

[11] A. B Chilton, J. K. Shultis, and R. E. Faw, "Principle of Radiation Shielding" (Englewood Cliffs, NJ: Prentice-Hall Inc.), 1984, pp.196.

[12] J. A. Ademola, and I. P. Farai, " Annual effective dose due to natural radionuclides in building blocks in eight cities of south western Nigeria", *Radiation Protection. Dosimetry*, vol. 114, no. 4, pp. 524–526, 2005.

[13] N. Ahmad, A. J. A. Hussein, and Aslam. "Radiation dose in Jordanian dwellings due to natural radioactivity in construction materials and soil", *Journal of Environmental Radioactivity*. vol. 41, pp. 127–136, 1998.

[14] O. Brígido Flores, A. Montalván Estrada, R. Rosa Suárez, J. Tomás Zerquera, A. Hernández Pérez, "Natural radionuclide content in building materials and gamma dose rate in dwellings in Cuba". *Journal of Environmental Radioactivity*.vol. 99, pp. 1834-1837, 2008.

[15] K. N. Yu, Z. J. Guan, M. J. Stokes, E. C. M. Young, "The assessment of the natural radiation dose committed to the Hong Kong people", *Journal of Environmental Radioactivity*, vol. 17, no 1, pp. 31-48, 1992.

[16] Nations Scientific Committee on the Effects of Atomic Radiation, Ionizing radiation (UNSCEAR), sources and biological effects, report to the general assembly with scientific Annexes, AnnexB, exposure to natural radiation sources, pp.32-33, 1982.

[17] A. Jahangiri, S. Ashrafi, "Natural radioactivity in Iranian granites used as building materials", *Journal of Environmental Studies*. vol.36, no. 56, March, 2011.