ASSESSMENT OF CANCER RISK AND HEREDITARY GENETIC DAMAGE TO BAGHDAD'S POPULATION RELATED TO RADIOLOGICAL EXPOSURE TO NATURAL BACKGROUND RADIATION

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ABSTRACT

The risk of cancer incidence (morbidity) and mortality to individuals in Baghdad's population related to external exposure to ambient gamma radiation is evaluated in this study by using linear, no-threshold (lnt) dose-response model. Exposure rate measurements are carried out outdoors and in a house built from bricks and a building constructed from concrete by using BGS-4 gamma-ray scintillation counter (Scintrex, Canada). Absorbed dose rates in air and in human tissues are determined by applying typical conversion factors available in the literature. Age-dependent radiation dose is calculated for infants, children, and adults. Dose-to-risk conversion factors are applied to estimate potential risk to various body organs and tissues as a result of exposure to ambient gamma radiation. The effective dose equivalents to individuals living in houses and in buildings are found to be less than the allowable dose limit for the public. However, the results indicate that there is one cancer risk incident (morbidity) expected for every 329 individuals (0.3%) exposed to ambient gamma radiation. The lifetime fatal cancer probability (mortality) is found to be occurs at a rate of 0.21% (1 per 473 exposed individuals). Other consequences of radiation injury (genetic effects transmitted to succeeding generations) are expected to occur at a rate of 0.0325% in the offspring of Baghdad population as a result of changes transmitted via the genetic mechanisms due to irradiation of gonads.

Key words: Cancer risk, Hereditary genetic damage, Background radiation.

تقدير مخاطر الإصابة بالأورام السرطانية والتأثيرات الجينية الوراثية لسكان مدينة بغداد بسبب التعرض للنشاط الإشعاعي الطبيعي

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الخلاصة

أجرى في هذه الدراسة تقدير خطورة الإصابة بالسرطان المميت لسكان مدينة بغداد بسبب التعرض الخارجي للنويدات المشعة الطبيعية المنشأ بإستخدام نظرية LNT. تم قياس معدلات التعرض للنشاط الإشعاعي الطبيعي بإستخدام جهاز BGS-4. أستخدمت معاملات تحويل الجرع في تقدير معدلات الجرع الإشعاعية الممتصة في الهواء وفي جسم الإنسان للأشخاص البالغين والأطفال. كما أستخدمت معاملات تحويل الجرع – إلى – الخطورة في تقدير مخاطر الإصابة بالأورام السرطانية لمختلف أعضاء وأنسجة جسم الإنسان. وبينت النتائج أن معدلات الجرع الإشعاعية المكافئة للأشخاص الساكنين في البيوت والشقق هي أقل من الحدود المسموح بها. أظهرت النتائج احتمالية حصول عيوب وراثية بمعدل 0.0325% من الأجيال القادمة لسكان مدينة بغداد كنتيجة للأضرار الجينية التي قد تلحق بالجينات الوراثية بسبب تعرض الغدد التناسلية للنشاط الإشعاعي الطبيعي.

INTRODUCTION

Gamma energy is a high-energy electromagnetic radiation that can penetrate most substances. Because of its high energy, gamma radiation can penetrate the human body from the outside and damage cells, which would lead to cancer later in life (1). Humans are exposed to many sources of radiation in the environment of which natural sources are the most important ones (2). Natural sources deliver the highest radiation dose that people normally receive. The average annual dose from natural sources is 2.4 mS_v, which is a reference level representing the average 1-5 mS_v, and in extreme cases to 1 S_v or more (3).

The term natural radiation background is used to designate naturally occurring radioactive materials and high-energy radiations. The various members of the uranium, thorium families and a radioactive isotope of potassium are the most important naturally occurring radioactive materials. Naturally occurring radiations are due partly to these natural radioactive materials and partly to the cosmic radiation. The total background radiation levels to which people may be exposed are of considerable interest. Measurements are usually made with ionization chambers and the results expressed in milli roentgens per year, i.e. in terms of the rate of energy absorption. The sea-level value is about 0.01 mR/h (88 mR/y) in regions of low background but will be considerably higher in many places (4).

The aims of this study are:

Make quantitative estimations of the biologically damaging effects associated with exposure of Baghdad inhabitants to natural background radiation by using a hypothetical linear no threshold (LNT) statistical model. The specific risks concerned in this study focus on the ionizing radiation as the cause, cancer morbidity, mortality (an abnormal process in which cells begin a phase of uncontrolled growth and spread) and genetic effects transmissible to progeny as the response. The assessed harmful consequences of ionizing radiation include somatic effects (risk of cancer, leukemia, sterility, cataracts, reduction in lifespan) and genetic damage (increasing the mutation rate in chromosomes and genes, affects future generations).

Investigate the effect of the type of dwellings (single family house or flat) and materials of construction on the dose received by its occupants.

To determine which population group (infants, children or adults) should be the primary target for radiation protection.

Risk, may be defined as the chance of encountering the potential adverse effects of human or ecological exposures to environmental hazards. In general terms, risk is the probability of harm or loss, which may also be considered as a product of probability and the severity of consequences (5). Four steps have been defined by both the National Academy of Sciences and the U.S. Environmental Protection Agency (EPA) for the assessment of risk from hazardous wastes (6,7):

1. Hazard identification: the chemicals present at the site and their characteristics; i.e., source analysis.
2. Exposure assessment: potential transport of the chemicals to receptors and levels of intake; i.e., pathway analysis.
3. Toxicity assessment: including the determination of numerical indices of toxicity; i.e., receptor analysis.

4. Risk characterization: involving the determination of a number that expresses the risk, such as one in one hundred (0.01), or one in one million ($1x10^{-6}$).

Radiation causes ionizations in the molecules of living cells. These ionizations result in the removal of electrons from the atoms, forming ions or charged atoms. The ions formed then can be go on to react with other atoms in the cell, causing damage. An example of this would be if a gamma ray passes through a cell, the water molecules near the DNA might be ionized and the ions might react with the DNA causing it to break (8).

MATERIALS AND METHODS

Human Exposure Assessment

The exposure rates were measured 1m above the ground in Baghdad city (all measurements are carried out in 2002) by using BGS-4 Gamma-ray Scintillation Counter (Scintrex, Canada), which is a thallium-activated sodium iodide detector (ownered by Ministry of Science and Technology-Iraq). The instrument was calibrated with a thorium standard source (TS-3 thorium oxide source) supplied by the manufacturer and Cs-137 standard source (Amersham). The display in c.p.s was converted to exposure rates in μR/hr as measured by the instrument by using equation below (9):

$$c.p.s \times \frac{1}{8.27} = mR/hr \qquad \ldots (1)$$

One roentgen (R) of exposure dose to a specific volume of air at standard conditions results in the absorbed dose of 0.87 rad(10). One rad (radiation absorbed dose) is equivalent to 0.01 Gray (Gy). A coefficient of 0.7 Sv/Gy is used to convert absorbed dose rate in air to effective dose equivalent. UNSCEAR 1993 report provides coefficients for exposure to terrestrial gamma rays for adults (0.72 Sv/Gy), children (0.80 Sv/Gy) and for infants (0.93 Sv/Gy) as reported from UNSCEAR (11).

The exposure rate measurements were carried out inside and outside of two types of dwellings located in Baghdad city (Baghdad Al-Jadeda region):

1. Building constructed from concrete, consists of five stories,
2. Single family house consists of two stores, constructed from bricks.

The standard error of the arithmetic mean $S.E(\overline{x})$ for the exposure rate readings is estimated by using equation below (12):

$$S.E(\overline{x}) = \frac{S_x}{\sqrt{n}} \qquad \ldots (2)$$

where S_x is the standard deviation of the exposure rate readings of size (n).

Exposure is defined as contact of an organism, such as humans or endangered species with a contaminant. Exposure assessment is the estimation of the magnitude, frequency, duration, and route of exposure (13). The purpose of exposure assessment is the estimation of the contaminant concentrations and dosages to the population at risk (5).

Observed radiation affects (or effects the other types of noxious agents) may be broadly classified into two categories, stochastic and non-stochastic effects. In the context of radiation protection, the main stochastic effects are cancer and genetic effects. The results of exposure to a carcinogen or to a mutagen are an increase in the probability of occurrence of the effect with the increase in probability being directly proportional to the size of the dose (14). Radiation doses to exposed individuals in Baghdad population are estimated by using equation below:

$$\text{Radiation dose rate}\,(\overline{H}_i)\left(\frac{mSv}{y}\right)\text{for adults} = \text{Exposure rate}\left(\frac{\mu R}{hr}\right)\times 10^{-3}\times 0.87\left(\frac{rad}{R}\right)\times 0.01\left(\frac{Gy}{rad}\right)\times 0.7\left(\frac{Sv}{Gy}\right)\times 24\left(\frac{hr}{day}\right)\times 365\left(\frac{day}{y}\right) \quad \ldots (2)$$

The collective effective dose equivalents S_E (human-Sv/y) were assessed according to the following expression (17):

$$S_E = \overline{H}_i . N(\overline{H})_i \quad \ldots (3)$$

where $\overline{H}_i$ is the effective dose equivalent and $N(\overline{H})_i$ is the number of individuals in population subgroup i receiving an average dose dose equivalent of $\overline{H}_i$.

Toxicity assessment and risk characterization

The final step in a risk assessment is to bring the various studies together into an overall risk characterization (15). The radiation risk to individual members in Baghdad population is estimated in this study by using the following expression:

$$\text{Risk} = \text{Dose}\left(\frac{mSv}{y}\right)\times 10^{-3}\left(\frac{Sv}{mSv}\right)\times \text{Lifetime (y)} \times \text{Risk Factor}\left(\frac{Risk}{Sv}\right) \quad \ldots (4)$$

where Risk = the probability of carcinogenic risk (dimensionless), lifetime exposure is taken to be 70 y (standard exposure duration for an adult exposed to a carcinogen) as reported in Masters and Gilbert(15).

Estimation of the potential risk from low levels of ionizing radiation requires application of dose-to-risk conversion factors to an estimate of the dose. For external sources of linear energy transfer (LET) radiation that provide nearly uniform irradiation of the body, the risk of cancer incidence (morbidity) and mortality as a function of external dose can be closely approximated using the conversion factors of 8×10^{-2} and 6×10^{-2} risk per sievert (Sv), respectively (16). Morbidity and mortality risks to specific body organs and tissues can be estimated by means of the risks factors listed in Table(1). Lethality is that fraction of cancer incidence that results in fatality, while survivability is that fraction of cancer incidence that does not result in a fatality (Survivability=1–Lethality). The risk coefficient for genetic effects in all generations following the radiation exposure of adults is 0.01 Sv^{-1}(18).

Table (1): Risks factors to various body organs and tissues (Sv=100 rem). IAEA(20)

Cancer	Radiation mortality (risk per rem)	Radiation incidence (risk per rem)	Lethality	Survivability
Bladder	0.00003	0.00006	0.5	0.5
Bone surface	0.000005	0.00001	0.7	0.3
Breast	0.00002	0.00004	0.5	0.5
Colon	0.000085	0.00015	0.55	0.45
Leukemia (Bone marrow)	0.00005	0.00005	0.99	0.01
Liver	0.000015	0.00002	0.95	0.05
Lung and Bronchus	0.000085	0.00009	0.95	0.05
Oesophagus	0.00003	0.00003	0.95	0.05
Ovary	0.00001	0.00001	0.7	0.3
Skin	0.000002	0.001	0.002	0.998
Stomach	0.00011	0.00012	0.9	0.1
Thyriod	0.000008	0.00008	0.1	0.9
Remainder	0.00005	-	-	-

Genetic damage of radiological exposure

The genetic injury or damage to Baghdad population from radiation exposure is estimated in this study from the total number of human-sieverts delivered to the gonads. This may be premature death, inability to produce offspring, susceptibility to disease, or any number of changes of lesser or greater importance (20). The genetic risk coefficient for gonads is taken to be $4x10^{-3}$ Sv^{-1} for the first 2 generations (22) and 0.01 Sv^{-1} for all generations (18).

RESULTS AND DISCUSSION

Multi-step risk assessment process is used in this study to predict the biologically damaging effect of public exposure to natural background radiation. The 1st step is making quantitative measurements of the ability to produce ionization in air or the exposure dose to individuals in Baghdad population living in the area of the study by using BGS-4 Gamma-ray Scintillation Counter (SCINTREX, Canada) and the results are expressed in micro roentgen per hour $(\mu R / hr)$. Extensive measurements of the natural γ-radiation background in the indoor and outdoor air spaces are made. The 2nd step is estimation of the absorbed dose rate in air (in μrad/hr) and biological dose in human tissues and organs (in mSv/y) for local inhabitants by using a series of conversion factors available in the literature. The last step is making a correlation between the dose administered and the radiation injury produced by using a linear, no-threshold (LNT) dose-response statistical model. The exposure rates measurement were carried out outdoors and in the indoor air space of a house built from bricks and a building constructed from concrete located in Baghdad city, Baghdad Al-Jadida region. The annual individual whole body dose to members in Baghdad population from external sources of ionizing radiation originates from cosmic rays and from γ-emitting radionuclides in the atmosphere, earth's crust and earth-derived building materials. The standard error of the exposure rate readings listed in Table(2) for indoor exposure (house and flat) and for outdoor exposure is estimated to be 0.133, 0.170, and 0.184 μR/h, respectively. The contribution of outdoor γ-radiation sources (such as soil containing naturally occurring radioactive materials and cosmic ray) is insignificant. Step-by-step computation of the effective dose equivalent from the exposure rates.

Table (2): Exposure rates, effective doses, morbidity and mortality risks from lifetime (70 years) external exposure to indoor and outdoor ambient gamma radiation.

Parameters	Dwelling Type	
	House (Bricks)	Building (Concrete)
Ambient γ-radiation level, outdoor(μR/hr)	7.01 (6.77 – 7.37)	
Ambient γ-radiation level, indoor(μR/hr)	10.592 (9.431-11.279)	9.158 (7.617-10.761)
Absorbed dose rate in air (μrad/hr)	8.591772	7.593708
Absorbed dose rate in air (μGy/hr)	0.085918	0.075937
Effective dose equivalent (mSv/y)	0.541	0.465646
Lifetime morbidity risk (whole body)	1 per 329	1 per 372
Lifetime mortality risk (whole body)	1 per 439	1 per 497

The actual doses to Baghdad's population inferred from measurements cover a somewhat narrow range owing to the fact that most occupants live in habitable structures less variable in their radioactive content. The natural background γ-radiation level in Baghdad City (7.01μR/hr) is comparable to that in the USA, 8μR/hr (8). Accordingly, Baghdad City is situated in an area of low background radiation since ambient γ-radiation level is <10 μR/hr. The environmental γ-radiation background level in Baghdad City is classified as "excellent" since the mean γ-radiation exposure rate inferred from measurement (9.302 μR/hr) is found to be less 10% of the U.S. Environmental Protection Agency (EPA) external gamma radiation criterion of 20μR/hr (23).

The whole body dose inferred from measurement (0.503mSv/y) is found to be greater than the annual effective dose equivalent of 0.01mSv, which corresponds to the National Council on Radiation Protection and Measurement (NCRP) concept of negligible individual risk level (24). This result indicates that public exposure to natural background radiation causes considerable possible long term bioeffects include increased incidence of somatic and hereditary genetic effects (increased incidence of genetic abnormalities in humans) to a large number of individuals in Baghdad population.

A series of conversion factors are applied to convert the observed exposure rates to lifetime morbidity and mortality risks. The effective dose equivalents were weighed for indoor and outdoor occupancy factors (20% outdoors and 80% indoors). Effective dose equivalent to infants, children, and adults arising from external exposure to indoor and outdoor gamma radiation are listed in Table(3).

Table(3): Ranking of exposed groups in Baghdad population on the basis of the radiation dose administered (age-dependent radiation dose).

Rank	Group	Dwelling type	
		Single family house	Flat
1	Infants (1<age(y)<2)	0.699	0.618
2	Children (2<age(y)<18)	0.602	0.532
3	Adults (age(y)>18)	0.541	0.478

The radiation dose administered is correlated with response or damage produced by using a statistical linear, no-threshold (LNT) dose-response model (Eq.4). The biological effects of natural background radiation are expressed in statistical terms due to biological variability accounts for a difference in sensitivity among individuals and a wide variation in susceptibility to radiation damage exists among different types of cells and tissues. The results of quantitative risk assessment are written in Table (4) in the following form (Risk = Number of injuries or deaths per number of people exposed to hazard).

Table (4): Lifetime (70 years) possible cancer mortality and morbidity risks to various body organs and tissues as a result of external exposure to indoor and outdoor gamma radiation.

Cancer	Radiation Risk			
	Single family house		Flat	
	Mortality (per million	Morbidity (per million	Mortality (per million)	Morbidity (per million)
Bladder	113	227	100	200
Bone surface	18	37	16	33
Breast	75	151	66	133
Colon	321	568	284	501
Leukemia(Bone marrow)	189	189	167	167
Liver	56	75	50	66
Lung and Bronchus	321	340	284	301
Oesophagus	113	113	100	100
Ovary	37	37	33	33
Skin	7	3787	6	3346
Stomach	416	454	368	401
Thyriod	30	302	26	267
Remainder	189	-	167	-
Whole body	2272	3029	1935	2604

The health risk estimations are carried out by using the linear, no-threshold (LNT) dose-response model (Eq.4) and the risk factors listed in Table(1). The risk of developing blood cancer (leukemia) as a result of the irradiation of the bone marrow is calculated to be 1 in 5434 exposed individuals, while the risk of developing bone cancer is calculated to be 1 in 55555. The likelihood of developing fatal cancer in Baghdad population associated with natural background radiation exposure (0.21%) is equivalent to the risk of dying of lung cancer or heart disease related to cigarette smoking at a rate of 1 cigarette per 6 days. If the entire breeding Baghdad's population received a radiation dose of $0.503 mSv.y^{-1}$ from external exposure to ambient gamma radiation, then the probability of having hereditary genetic damage (increasing the mutation rate in chromosomes and genes, affects future generations) is estimated to be occurs at a rate of about 1 per 2838 or 352 per million in parents who were irradiated before conception occurred. The extent of occupants risks are mainly influenced by the type of residential building and materials of construction since occupants spend most of their time indoor and because indoor γ-exposure level is greater than outdoor level.

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