UNIVERSITI PUTRA MALAYSIA

NATURAL VENTILATION IN REDUCTION OF INDOOR RADON CONCENTRATION IN HIGH BACKGROUND RADIATION AREA DWELLINGS RAMSAR, IRAN

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By

LOTF ALI MEHDIPOUR NASAB

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy.

September2013

This thesis dedicates to
My dear wife (Nahid), and
My dear niece, (Dr. Sahar)

Abstract of thesis presented to the Senate of Universiti Putra Malaysia, in fulfillment of the Requirement for the degree of Doctor of Philosophy

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Chairman : Professor Elias Bin Saion, PhD

Faculty : Science

Recent studies show that radon inhalation even at low concentrations poses a risk of developing lung cancer. Additionally, there are reports representing that natural radon exposure may be a risk factor for squamous cell carcinoma or chronic obstructive pulmonary disease mortality. It has been reported that the radon health risk is proportional to its concentration down to the Environmental Protection Agency of US's action level of 148Bq/m^3. Although naturally occurring isotopes of radon in indoor air are identified as the second leading cause of lung cancer after tobacco smoking, there is limited consequenceof data on the incidence of radon-related lung cancers in Iran.

Ramsar, a northern coastal city of Iran, has some areas with the highest levels of natural radiation background to date. They are considered the high level natural radiation areas (HLNRAs) of Ramsar, in particular in Talesh-Mahalleh district, in which the effective dose equivalent is a few times higher than the International Commission on Radiological Protection (ICRP)recommended radiation dose limits for radiation workers. According to U.S. Environmental Protection Agency (EPA) estimation, Radon is the first leading cause of lung cancer among non-smokers. In addition, directand indirect radon-induced lung cancer health care has cost the USA over 2 billion dollars annually. Although radon reduction systems including architectural considerations can reduce the radon levels in buildings by up to 99 percent, architectures are often unaware of the risk of radon inhalation and how to reduce the radon levels. Furthermore, radon exposureand consequent of health effect are not part of building regulation in Iran to be considered into the building construction, construction materials and building utilization by regulatory authorities.

In this study after reviewing the meteorological data of Ramsar during 1955-2005, the soil sampling was done in the radon prone area of Ramsar at four levels of activities classified as extremely hot, severely hot, very hot, and hot. The samples were placed in a model house one after another and the radon concentrations were measured with and without intervention conditions using a Prassi portable radon gas survey meter.

For the extremely hot soil samples, the mean radon concentrations measured for 24 h inside the model house wasabout 1615 Bq/m^3 when all windows were closed. When the windows were openedin the wind direction the radon level decreased to 89 Bq/m^3(96% reduction)and when the windows were opened in the opposite of wind direction the radon level decreased to 139Bq/m^3 (91% reduction). Interestingly, when crossed windows were opened for the same 24 h duration, the radon level was about 144 Bq/m^3(91%). For simulation of cold seasons, when all windows were usually closed, the chimney effect reduced the radon level to around 323Bq/m^3(80%). For the other severely hot, very hot and hot soil samples, the natural ventilation interventions effectively reduced the radon concentration in proportion with their radon concentration.

The annual equivalent dose of man and the annual effective dose of human lung associated with the radon intake in radon prone areas of Ramsar were also studied before and after ventilation interventions. For extremely hot soil samples, the mean annual equivalent dose and the annual effective dose inside the model house before intervention or when windows closed were about925 and 111 $mSvy^{-1}$respectively. When windowswere opened in the wind direction, the annual equivalent dose of man and the annual effective dose of human lung decreased to20.50and 2.46 mSv y^{-1}, respectively. When windows were opened in opposite of the wind direction the annual equivalent dose of man and the annual effective dose of human lung decreased to 34.70 and 4.16mSv y^{-1}respectively. When crossed windows were opened in silent condition(no wind), these two values were reduced to 45.33and

5.43mSv y^{-1}respectively. For the other severely hot, very hot and hot soil samples, the natural ventilation interventions effectively reduced the annual equivalent dose of man as well as the annual effective dose of human lung accordingly.

The results of the natural ventilation of HLNRAs show that these simple cost-effective interventions can significantly reduce the radon concentration, the annual equivalent dose of man, and the annual effective dose of human lung to about of 90% of their initial values.These techniques are highly recommended to be used by residents and inhabitants of radon prone areas of Ramsar.

Key Words: Radon, Ramsar, Natural Ventilation, House Design, Dwellings, annual effective dose, annual absorbed dose

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGURANGAN ASLI DALAM PENGURANGAN INDOOR RADON KEPEKATAN DALAM TINGGI LATAR BELAKANG KEDIAMAN SINARAN KAWASAN RAMSAR, IRAN

Oleh

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Kajianterkinimenunjukkanbahawa pernafasan mengandungi radon walaupun pada kepekatan yang rendah menimbulkan risiko mendapat kanser paru-paru. Tambahan pula, terdapat banyak laporan yang menunjukkan pendedahan radon semulajadi boleh menjadi faktor risiko untuk sel karsinoma skuamus, atau penyakit paru-paru obstruktif kronik (COPD) penyebab kematian. Ia telah dilaporkan bahawa, risiko kesihatan radon adalah berkadar kepada kepekatannya sehingga ke tahap 148 Bq/m^3 daripada Agensi Perlindungan Alam Sekitar. Ia telah dilaporkan bahawa risiko kesihatan radon adalah berkadar dengan kepekatan sehingga ke peringkat tindakan Agensi Perlindungan Alam Sekitar 148 Bq/m3.Walaupun isotop radon semulajadi pengudaraan dalaman yang dipastikan sebagai punca kedua utama kanser paru-paru

selepas merokok tembakau, tidak ada data secara besar-besaran terhadap kejadian kanser paru-paru yang berkaitan dengan radon di Iran.

Ramsar, sebuah bandar pantai di utara Iran, terdapat beberapa kawasan yang mempunyai sinaran asli latarbelakang yang tertinggi setakat ini. Kawasan ini diiktiraf sebagai kawasan Ramsar yang mempunyai sinaran semula jadi yang tinggi (HLNRAs), khususnya di daerah-Talesh Mahalleh, dimana dos setara berkesan adalah beberapa kali lebih tinggi daripada yang dicadangkan had dos sinaran untuk pekerja sinaran oleh ICRP. Menurut anggaran Agensi Perlindungan Alam Sekitar Amerika Syarikat (EPA), radon adalah punca utama penyebab kanser paru-paru di kalangan bukan perokok. Tambahan pula, kos penjagaan kesihatan secara langsung dan tidak langsung di Amerika Syarikat adalah lebih daripada 2 bilion dolar setahun. Walaupun sistem pengurangan radon termasuk pertimbangan seni bina boleh mengurangkan tahap radon di dalam bangunan sehingga 99 peratus, ahli seni bina sering tidak menyedari risiko pernafasan mengandungi radon dan bagaimana untuk mengurangkan paras radon. Tambahan pula, dedahan radon dan kesan kesihatan akibatnya tidak menjadi satu peraturan pembinaan bangunan di Iran untuk diambil kira dalam membina bangunan, bahan binaan, dan pengunaan bangunaan oleh pihak berkuasa.

Dalam kajian ini selepas mengkaji perubahan kajicuaca Ramsar semasa 1955-2005, persampelan tanah dilakukan di kawasan terdedah radon Ramsar dengan empat tahap yang dikelaskan sebagai yang terlalu tinggi, amat tinggi, sangat tinggi, dan

tinggi kepekatan radonnya. Sampel secara berasingan telah diletakkan di sebuah rumah model dan kepekatan radon telah diukur dengan menggunakan meter gas radon mudah alih Prassi.

Untuk sampel yang terlalu tinggi kepekatan radonnya, kepekatan radon purata diukur dalam tempuh 24 jam dalam model rumah ialah 1615 Bq/m^3apabila semua tingkap ditutup. Apabila tingkap ditutup pada arah angin bertiup kepekatan radon berkurangan kepada 89 Bq/m^3 (96%pengurangan)dan apabila tingkap ditutup pada arah bertentangan dengan arah angin paras radon berkurang kepada 139 Bq/m^3(91%pengurangan).Yang menarik, apabila tingkap-tingkap bertentangan ditutup dalam tempuh sama 24 jam paras radon ialah 144 Bq/m^3(91%pengurangan).Untuk simulasi musim sejuk, apabila semua tingkap ditutup, kesan serombong menunjukkan paras radon berkurang kepada323 Bq/m^3(80%pengurangan). Untuk sampel-sampel tanah lain yang amat panas, sangat panas dan panas kepekatan pengudarae semulayidi mangurangkan kepekatan radon dengan kadar kepekatan radon masing-masing.

Dos setara tahunan bagi manusia dan dos berkesan tahunan bagi paru-paru yang dikaitkan dengan pengambilan radon di Ramsar yang terkenal kawasan kepekatan radon tertinggi telah dikaji sebelum dan selapas campur tangan pengudaran. Untuk sampel tanah yang paling tinggi kepekatan radon didapati dos setara tahunan bagi manusia dan dos berkesan tahunan bagi paru-paru dalam model rumah sebelum campur tangan atau ketika tingkap ditutup masing-masing 925 and 111 $mSvy^{-1}$. Apabila tingkap ditutup pada arah angin bertiup didapati dos setara tahunan bagi

manusia dan dos berkesan tahunan bagi paru-paru masing-masing berkurangan kepada 20.50 dan 2.46 mSv y^{-1}. Apabila tingkap ditutup bertentangan arah angin bertiup didapati dos setara tahunan bagi manusia dan dos berkesan tahunan bagi paru-paru masing-masing berkurangan kepada 34.70 dan4.16mSv y^{-1}.Apabila tingkap bertentangan ditutup dalam keadaan senyap (tiada angin) kedua nilai masing-masing berkurang kepada 45.33 dan5.43 mSv y^{-1}. Untuk sampel-sampel tanah lain yangamat tinggi, sangat tinggi dan tinggi kepekatan radonnya campur tangan pengudaran secara berpadanan mengurangkan dos setara tahunan bagi manusia dan dos berkesan tahunan bagi paru-paru.

Keputusan yang diperolehi dalam kajian ini jelas menunjukkan bahawa cara mudah dan murah melalui campur tangan pengudaraan boleh mengurangkan kepekatan radon, dos setara tahunan bagi manusia dan dos berkesan tahunan bagi paru-paru manusiakepada kira-kira 90% daripada nilai awal mereka. Kaedah-kaedah ini sangat disyorkan untuk digunakan oleh penghuni dan penduduk di Ramsar yang terdedah kepada kepekatan radon yang amat tinggi.

Kata Kunci: Radon, Ramsar, Pengudaraan Asli, Design House, Kediaman, dos tahunan yang berkesan, dos tahunan diserap

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Lotf Ali Mehdipour

September 2013

I certify that a Thesis Examination Committee has met on 18.09.2013 to conduct the final examination of Lotf Ali Mehdipour Nasab on his thesis entitled "NATURAL VENTILATION IN REDUCTION OF INDOOR RADON CONCENTRATION IN HIGH BACKGROUND RADIATION AREA DWELLINGS, RAMSAR, IRAN" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis was submitted to the senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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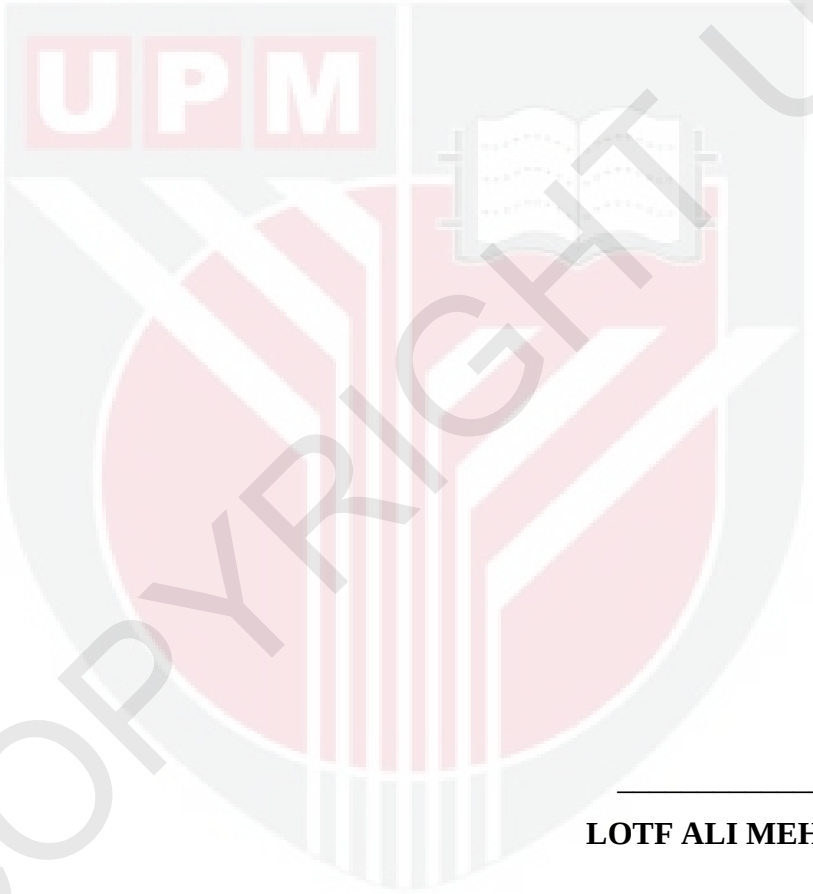
DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at University Putra Malaysia or at any other institution.



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ALARA	As Low As Reasonably Achievable
amu	atomic mass unit
BG	Background
Bq	Becquerel
Bq/m^3	Becquerel/meter cubic
$^{\circ}C$	degree centigrade
COPD	Chronic Obstructive Pulmonary Disease
DNA	Deoxyribonucleic Acid
ELNRA	Elevated-level Natural Radiation Area
EPA	Environmental Protection Agency
eV	electron volt
$^{\circ}F$	degree Fahrenheit
GRS	Gamma Ray Spectrometry
HLNRAs	High Level of Natural Radiation Areas
HNBRAs	High Natural Background Radiation Areas
IAEA	International Atomic Energy Agency
ICRP	International commission on RadiologicalProtection
KeV	Kilo electron Volt
Kpa	Kilopascal
LET	Linear Energy Transfer
LLRDs	Long Lived Radon Daughters

mbar	millibar
mBq	milli Becquerel
MeV	Million electron Volt
MDA	Minimum Detectable Activity
MDD	minimum Detectable Dose
mGy	milligray
mSv	milli Sievert
mSv y^{-1}	milli Sivert/ year
ms	millisecond
NORMs	Naturally occurring radioactive materials
pCi	Pico Curie
QF	Quality Factor
Ra	Radium
Rad	Radiation Absorbed dose
Rem	Roentgen Equivalent Man
Rn	Radon
SCC	Squamous Cell Carcinoma
SLRDs	Short Lived Radon Daughters
Sv	Sievert
TENORM	TechnologicallyEnhanced Naturally Occurring Radioactive Materials
Th	Thorium
U	Uranium

UK	United Kingdom
USA	United State of America
U.V	Ultra Violet
UNSCEAR	United Nation Scientific Committee on the Effects of Atomic Radiation
W.H.O	World Health Organization
μCi	micro Curie
μS	micro second

CHAPTER 1

INTRODUCTION

1.1 General introduction

According to WHO (W.H.O, 2009a), cigarette smoking is the foremost cause of lung cancer and radon exposure is the main contributor to the total internal radiation absorption which also contributes to lung cancer. Our world environment is full of radioactive activities since it was created(Jaworowski, 1997). The human life is constantly exposed to natural and artificial sources of ionizing radiation(Knoll, 1986). The natural sources of radiation include the cosmic rays from extraterrestrial spaceand radiation emitting from the soil and rocks and the artificial radiation is coming from man-made sources for different types of nuclear applications(Paschoa & Steinhäusler, 2010). Radionuclides used in industries, medical application and agriculture, are some of the radiation sources which humans are exposed to man-made radiation.

1.1.1 A brief history of radiation and radioactivity

Man is exposed to various types of radiation consisting of ionizing and non ionizing radiation. Alpha and beta particles, neutrons, gamma-andX-rays are ionizing

radiation which causes health hazards due to ionization of atoms or molecules whereas the UV, visible, and radio waves are non ionizing radiation which may cause health hazards by heating of atoms or molecules. Ionizing radiation from cosmic rays and naturally radioactive elements such as uranium, thorium, and radium have always been present on earth.The main sources of radiation to the environment are the natural sources and this consistsof cosmic rays and other terrestrial radiation (UNSCEAR, 1988). The discoveries of x-ray by Roentgen in 1895, uranium radioactivity by Becquerel in 1896 and electron by Thomson in 1897(Williams, 2008)were regarded as the beginning of man's foray into the use of ionizing radiation for many purposes and the exposure can cause potential health hazards.

The first radiation injury to human was reported a few months after Roentgen's discovery(Evens, 1955). Unfortunately the first detrimental effect of radiation happened to its pioneers. Some radiation injuries from exposure to X-rays noted in 1896(Lambert, 2001).Becquerel and Pierre Curie were two famous pioneers who have been injured by radiation in 1906. At the beginning of 1925, luminescent paint containing radioactive radium was used as consumer products(Clark, 1997). This leads to illnesses such as anemia, lesions of the Maxillo-mandibular bones and mouth and subsequently bone cancer.

The entrance of radionuclides through soil and water in the food chain and their subsequent entry into human through consumption has been the subject of intense research to date. Another important source of human exposure to radionuclides is through industrial accidents. For example, large quantities of radionuclides were

released into the atmosphere during the 26th April 1986 Chernobyl nuclear disaster in Ukraine and also on 11th March 2011 when the Fukushima Daiichi nuclear power plant melted down following the earthquake and tsunami of the east coast of Japan.

A nuclear reactor and spaceflights are two important novel uses of radiation as an energy source.The first nuclear reactor in the world (Chicago Pile 1) was built in 1942 (Alario & Freudenburg, 2003) by Enrico Fermi who was a winner of the Nobel Prize. The first radiation injuries and subsequent experiments on animals were used to establish scientific knowledge of radiobiology(Meyniel, 1995).

The terrestrial radiation produced by cosmogenic radionuclides are continually being produced by the cosmic rays and primordial radionuclides which have been present since the forming of the universe about 4.5 billion years ago(Wald, 1964).The cosmogenic radionuclides are always present on the earth; however their half life is shorter than the age of the earth. More than 25 cosmogenic radionuclides such as ^{14}C have been identified(Lamarsh, 1983). The life of the earth is assumed to be a little more than 4.5 billion years(Hanks & Anderson, 1969),so the short lived radionuclides would have decayed by this time. However, some primordial radionuclides due to long half-lifehave not completely decayed and continue to exist since the earth was formed to date. The radionuclides with half- life of the order of 10^8 years are present in certain amounts today in addition to the radionuclides generated from the primordial radionuclides ^{238}U, ^{235}U and ^{232}Th of the associated decay chain.One of the decay products of these series is the radon gas which is

important to human life because of its daughters decay produces alpha particles that contribute to cancers.

1.1.2 Radioactivity atRamsar

Worldwide there are four famous places which are designated as High Level Natural Radiation Areas(HLNRAs). These include Guarapari in Brazil, Yangjiang in China, Kerala in India and Ramsar in Iran (Ghiassi-Nejad *et al*., 2002). Several places are known in Iran, India and Europe where the natural background radiation gives an annual dose of more than $50mSvy^{-1}$, and in Ramsar, it can give up to $260mSvy^{-1}$(Ghiassi-Nejad, *et al.*, 2002). Lifetime doses from natural radiation range up to several thousand millisieverts. However, there is no direct evidence of increased cancers or other health problems arising from these high natural levelradiations(Hore-Lacy, 2007).

Radon gas is a fragrance-free, tasteless and colorless gas, which is formed by disintegration of natural radioactive elements of the earth. Its continuous inhalation by human can create lung cancer. This nobel gas is a product of uranium decay and exists throughout the world in soils and rocks. Radon gas can escape into the atmosphere, enter groundwater and surface water and thus enter directly into the human system through inhalation or the food one eats. This gas is found at very low levels in outdoor air and in drinking water from rivers and lakes but it can be found at higher levels in the air in confined houses and closed workplaces, as well as in

water from underground sources, such as well water. Radon decays into solid radioactive elements such as polonium-218, polonium-214, and lead-214. As radon and radon progenies decay in the air, they emit alpha particles, a form of high-energy radiation that can damage the DNA inside the body's cells and its detrimental effects is 20 times more than X and gamma rays. Recent studies show that radon inhalation even at low concentrations poses a risk of developing lung cancer(Barros-Dios *et al.*, 2012). The average effective dose for radiation worker is $20mSvy^{-1}$ and for other than radiation workers is $1mSvy^{-1}$ whilst the annual effective dose for people in some areas of Ramsar can be up to 260mSv/year(Ghiassi-Nejad, *et al*., 2002).

It is largely accepted that the human activity modifies the earth's surface, therefore the radiation dose may be considered as an ever-changing parameter(Sajó-Bohus *et al.*, 1999) and measurement of radon concentration in soil air is a useful tool in the planning and constructing of new buildings in order to avoid high indoor radon levels(Jönsson, 1995). As the main objective of ventilation system is to provide the quality and quantity of the air flows throughout the dwellings and to ensure safe health conditions for the inhabitants of dwellings to an acceptable level which is specified by the standard regulations. It can be used as a useful way to reduce the radon level inside of houses and workplaces.

The type of natural radiation responsible for most fatalities are not cosmic rays or internal exposure by ^{40}K in the human body or building materials, but actually the inhalation of environmental radon gas and its short-lives daughters which is expected

to cause well over 5000 mortalities in comparison to other radiation sources which cause about 3000 mortalities(Cohen, 1979). The worldwide average indoor radon concentration has been estimated 39Bq/m^3(W.H.O, 2009a) which corresponds to a human lung effective dose of 2.34 mSv y^{-1}. The high levels of radon concentration in Ramsar motivates this research work in order to plan for the alleviation of the indoor radon level and reduce the radon risks for the inhabitants of Ramsar.

1.2 Significance of study

Ramsar, known also by the old name as Sakhtsar, located on the Caspian Sea coast,is one of the most attractive districts in the north of Iran. It is highly attractive for tourists' destination for Iranians and people all over the world. However it is located in one of HLNRAs and several studies were performed by Iranians and scientists from other countries on Ramsar's natural background radiation. Most of the studies have been focused specifically on the radon gas, but none of these studies established a suitable protocol for healthy living in Ramsar and its surroundings. Lung cancer risk increases linearly with long term radon exposure and there is no radon exposure threshold for this risk, even below 200Bq/m^3 which corresponds to a human lung effective dose of 12 mSv y^{-1}(W.H.O, 2009a). Assessing the role of natural ventilation (chimney effect and buoyancy effect) inindoor radon reduction of high background radiation radon prone areas of Ramsar is the objective of this study.

1.3 Problem statement

The main dangerous effect of radon gas and its progenies is the inhalation of their emitted alpha rays which goes to cause lung cancer. Furthermore, there are published reports indicating that environmental radon exposure might be a risk factor for squamous cell carcinoma(SCC)(Wheeler *et al.*, 2012) or chronic obstructive pulmonary disease (COPD) mortality(Turner *et al.*, 2012). It was recommended for all countries to set a national reference level for radon hazard as low as reasonably achievable, and the 100Bq/m^3(2.7pCi/ L) which corresponds to a lung effective dose of 6 mSv y^{-1}, is the latest scientific data on health effects of indoor radon which can be used as a reference level to prevent a lot of lung cancers(W.H.O, 2009a). However if this value cannot put into action in many countries, the established reference values should not exceed 300Bq/m^3(W.H.O, 2009a) corresponds to a lung effective dose of 18 mSv y^{-1}. Despite these recommendations, unfortunately there is not a serious effort to establish a radon reference level in many countries including Iran. Most of the people and transit inhabitants living in Ramsar are not aware of the radon hazards and they live there as in other normal cities without concern of radon health effects.

The aim of this study is to determine the effect of natural radon reduction methods as a suitable and cheap method to alleviate the indoor radon gas in the Ramsar and relevant districts based on more than last 50 years meteorological changes of the Ramsar.

1.4 Objectivesof the study

The aim of this study is to determine the effect of natural ventilation based methods in HLNRAs of Ramsar based on meteorological changes during the last decades and introducing the suitable situation for residential dwellings as well as workplaces to reduce the indoor radon gas. The objectives of this research are as follows:

- To determine the mean values of meteorological parameters in the Ramsar based on the reviewed data which have been obtained from the national meteorological organization of Iran.

- To discover and determine the environmental background radiation of Ramsar and the main source of the radon production using Gamma Spectrometry Analysis of the various top soil samples.

- To evaluate the buoyancy effect and chimney effect on the concentration of the indoor radon,annual effective dose of the lung and annual equivalent dose on man living in residential dwellings of Ramsar using the Ramsar soil samples as a radon source in a model house and Prassi Portable Radon Gas survey meter in a continuous measurement method.

- To propose appropriate window position of residential dwellings as well as workplaces in the HLNRAs of Ramsar to follow meteorological wind direction.

1.5 Outline of the thesis

This thesis is planned as follows. Chapter 2 gives a report on the previous works carried out by others and applications of the study. Chapter 3 provides a theoretical background to the thesis, which includes the theoretical aspects of radiation and natural background (BG) Radiation**,** ionization effects of radiation, interaction between radiation and materials, Gamma Spectroscopy, natural ventilation, radon and radon level reduction methods. Chapter 4 describes the materials and instrument used in the measurement of soil samples by Gamma Spectroscopy method, the method of measurement of concentration of indoor radon gas using Prassi portable radon gas surveyor. Detailed results on evaluation of meteorological parameters of Ramsar region, evaluation of various mitigation method of radon concentration using natural ventilation and discussion are given in Chapter 5. The last Chapter 6 contains the conclusion of the study and suggestions for future work.

REFERENCES/BIBLIOGRAPHY

A.K. Mohanty, D. S., S.K. Das, S.K. Saha, K.V. Van. (2004). natural radioactivity and radiation exposure in the high background area at Chhatrapur beach placer deposit of Oriss, India. *Journal of Environmental Radioactivity, 75*, 15-33 .

A.N.S. (2012). Oklo,s natural fission reactors, from http://www.news.ans.org/pi/np/Oklo

Abbady. (2004). Estimation of radiation hazard indices from sedimentary rocks in Upper Egypt. *Applied Radiation and Isotopes, 60*(1), 111-114. doi: 10.1016/j.apradiso.2003.09.012

Abbady ,*et al.* (2006). Estimation of radiation hazard indices from natural radioactivity of some rocks. *Nuclear Science and Techniques, 17*(2), 118-122. doi: 10.1016/s1001-8042(06)60023-7

Abdolwahab B, S. y., A Aly, S Elfiki, N Elenary, M Abbas. (1992). a simplecalibration of a whole-body counter for the measurement of total body potassium in humans. *international journal of radiation applications and instrumentation, 43*(10), 1285-1289 .

Al-Jundi, J., *et al.* (2004). Thorium and uranium contents in human urine: influence of age and residential area. *Journal of Environmental Radioactivity, 71*(1), 61-70. doi: 10.1016/s0265-931x(03)00141-3

Alario, M., & Freudenburg, W. (2003). *The paradoxes of modernity: scientific advances, environmental problems, and risks to thesocial fabric?* Paper presented at the Sociological Forum.

Alnour, I. A., *et al.* (2012). Natural radioactivity measurements in the granite rock of quarry sites, Johor, Malaysia. *Radiation Physics and Chemistry, 81*(12), 1842-1847. doi: 10.1016/j.radphyschem2012.08.005.

Alpine, R. M. M. (2011). photomultipliers for low bachground applications, from http://www.et-enterprises.com

Andersson, K. G. (2009). Chapter 5 Migration of Radionuclides on Outdoor Surfaces. In G. A. Kasper (Ed.), *Radioactivity in the Environment* (Vol. Volume 15, pp. 107-146): Elsevier.

Babapourian, s. (2005). *New public dose assessment from internal and external exposures in low and elevated- level nayural radiation areas of Ramsar, Iran*. international conference series .

Ballinger, P& ,.Frank, E. (2003). Merrill's Atlas of Radiographic Positions and Radiological Procedures. Mosby: Inc.

Barros-Dios, J. M., *et al.* (2012). Residential Radon Exposure, Histologic Types, and Lung Cancer Risk. A Case–Control Study in Galicia, Spain. *Cancer Epidemiology Biomarkers & Prevention, 21*(6), 951-958 .

Bavarnegin, *et al.* (2013). Radon exhalation rate and natural radionuclide content in building materials of high background areas of Ramsar, Iran. *Journal of Environmental Radioactivity, 117*, 36-40 .

Beerjurj, M., Ken, Steiger, Rudolf von. (2012). *cosmogenic radionuclides, theory and applications in the terrestrial and space environment*: Springer.

Bochicchio, F. (2005). Radon epidemiology and nuclear track detectors: Methods, results and perspectives. *Radiation Measurements, 40*(2), 177-190 .

Bondensky D., R. M. A., and Staler D.R. (1987). radon and its hazzards. washington: university of washington press.

Brookins, D. G. (1978). Eh—pH diagrams for elements from Z = 40 to Z = 52: Application to the Oklo natural reactor, Gabon. *Chemical Geology, 23*(1–4), 325-342. doi: http://dx.doi.org/10.1016/0009-2541(78)90086-4

Brown. (1981). *the inaccessible earth*. London: Allen and Unwin.

Bushong, S. C. (1977). Radiation exposure in our daily lives. *The Physics Teacher* , .144-135 ,15

Buttler, M. L. a. B., P.C. (2005). The rational and the role of filtration in optimizing radiological exposures. *Journal of Radiology Ireland, 9*(2), 23-27 .

Chen, J. (2005). A review of radon doses. *Radiation Protection Management, 22*(4 ,(.27

Chiedozie, A. (2012). The history of Radon, from http://www.ehow.com/about_5481706_history-radon.html

Clark, C. (1997). *Radium girls, women and industrial health reform: 1910-1935*: Univ of North Carolina Press.

Cohen, B. L. (1979). Radon: characteristics, natural occurrence, technological enhancement, and health effects. *progress in nuclear energy, 4*(1), 1-24 .

Connell, C. P. (2010). Radon- A Brief Discussion, from http://www.forensic-applications.com/radon/radon.html

Curtin. (2012). discovery of theOklo fission reactors, from http://www.Oklo.curtin.edu.au

Draganic, D. a. A. (1993). *Radiation and radioactivity on earth and beyond* (Second ed.). Florida- USA: CRC.

Due, *et al.* (1997). Natural radioactivity levels in bottled water in Spain. *Water Research, 31*(8), 1919-1924. doi: http://dx.doi.org/10.1016/S0043-1354(97)00038-9

Eisenbud, M. (1997). *Environmental radioactivity: from natural, industrial and military sources* (4th ed.). New York: Academic press.

EPA. (1998). Evaluation of guidlines for exposures to technologically enhanced radioactive materials 21. from http://www.epa.gov

EPA. (2003). A citizen,s guid to radon, from www.EPA.gov/radon/pubs/citguide.html

EPA. (2012a). Radiation in tobacco, from http://www.epa.gov/radtown/tobacco.html

EPA. (2012b). what is EPAs action level for radon and what does it mean? , from http://www.iaq.support,portal.com/link/portal/23002/23007/article/33915/what -is-EPA-s-action-level-for-radon-and-what does it mean

Eric, H. J. (1998). Radiation and life, from http//:www.uic.com.au/ral/htm

Evens, R. D. (1955). *The atomic nucleus*. New York: Mac Graw Hill.

Fayek, M., *et al.* (2011). The oxygen isotopic composition of uranium minerals: A review. *Ore Geology Reviews, 41*(1), 1-21. doi: 10.1016/j.oregeorev.2011.06.005

Fazidah, S. (2010). *study on indoor and outdoor radon 222 concentration in UiTM puncak alam campus area.* Bachelor, Universiti Teknologi Mara(UiTM), Shah Alam .

Forte, M., *et al.* (2007). The measurement of radioactivity in Italian drinking waters. *Microchemical Journal, 85*(1), 98-102. doi: http://dx.doi.org/10.1016/j.microc.2006.03.004

Ghiassi- Nejad, F. Z., R. Gh. Assaei and A. Kariminia. (2004). long- term immune and cytigenetic effects of high level natural radiation on Ramsar inhabitants in Iran. *Journal of Environmental Radioactivity, 74*, 107- 116 .

Ghiassi-Nejad, M., *et al.* (2002). Very high background radiation areas of Ramsar, Iran: preliminary biological studies. *Health Physics, 82*(1), 87-93 .

Gillmore, G. K., *et al.* (2012). Radium dial watches, a potentially hazardous legacy? *Environment International, 45*(0), 91-98. doi: 10.1016/j.envint.2012.03.013

Glasscoe, M. (1998). structure of the earth, from http://www.sci,gn.jpl.nasa.gov/learn/plate1.htm

Gupta, A. K. (2006). *industrial safety and environment*1) st ed. Vol. 1). New Delhi: Laxmipublications.

Hall, E. J., & Giaccia, A. J. (2005). *Radiobiology for the Radiologist*: Lippincott Williams & Wilkins.

Hallenbeck, W. H. (1994). *Radiation protection*: CRC.

Haninger, T., *et al.* (2000). Indoor air as an important source for 210Pb accumulation in man. *Radiation protection dosimetry, 87*(3), 187-191 .

Hanks, T. C., & Anderson, D. L. (1969). The early thermal history of the earth. *Physics of the Earth and Planetary Interiors, 2*(1), 19-29 .

Hayat, M. (2007). *Cancer imaging: Lung and breast carcinomas* (Vol. 1): Academic Press.

Helmenstine, A. M. (2011). bananas are radioactive, from http://www.chemistry.about.com/2011/07/10/bananas-are-radioactive-html

Hemingway, G. G. a. J. (1995). *practical gamma ray spectroscopy* 1) ed. Vol. 1). west sussex: john wiley and sons.

Hore-Lacy. (1999). *Nuclear electricity*: Uranium Information Centre Limited.

Hore-Lacy. (2007). 7 - Environment, health and safety issues *Nuclear Energy in the 21st Century* (pp. 111-125). Burlington: Academic Press.

IAEA. (1975). Oklo phenomenon (pp. 646): International Atomic Energy Agency.

IARC. (2001). IARC monograph summary. *78* .

ICRP. (1992). age dependent doses to members of the public in a raddiological emergency (pp. 4): International commission onradiological protection.

ICRP. (1993). protection against radon-222 at home and at work. In a. o. t. ICRP (Ed.), *publication 65* (Vol. 23). oxford: International commission on radiological protection.

ICRP. (1999). protection of the public in situations of prolonged radiation exposure (Vol. publication 82): Elsivier science B.V.

ICRP. (2005). Basis for dosimetric quantities used in radiological protection *draft* (pp. 59)

ICRP. (2008). *Recommendation of the international commission on radiological protection* (pp. 17-20): International Commission on Radiological Protection.

ICRP. (2011). Radiological protection against radon exposure (pp. 54)

In re TMI Litigation. (1999) *F. 3d* (Vol. 193, pp. 613): Court of Appeals, 3rd Circuit.

Iran, s. c. o. (2010). thecity,s estimated population in 1389, from http://www.amar.org.ir/portals/0/filesljamiat_mazandaran.pdf

Jawarowski. (1976). lead and radium in the lower stratosphere. *nature, 263*, 303-304 .

Jaworowski, Z. (1997). benefical effects of radiation and regulatory policy. *Australas.Phy. Eng. Med, 82*(3), 128- 138 .

Jhamnani, R. D., & Kalra, M. K. (2008). 3 - Radiation Hormesis. In M. A. Hayat (Ed.), *Cancer Imaging* (pp. 23-26). San Diego: Academic Press.

Jönsson, G. (1995). Radon gas — where from and what to do ?*Radiation Measurements*, *25*(1–4), 537-546. doi: 10.1016/1350-4487(95)00180-m

Khan, F. M. (2003). *the physics of radiation therapy* (3rd ed. Vol. 1). Philadelphia: lippincott williams & wilkins.

Khater, A. E. M. (2004). Polonium-210 budget in cigarettes. *Journal of Environmental Radioactivity*, *71*(1), 33-41. doi: http://dx.doi.org/10.1016/S0265-931X(03)00118-8

Knoll, G. F. (1986). *radiation detection and measurement* (2 ed.). New York: john willy and sons.

Kolb, W. A., & Wojcik, M. (1985). Enhanced radioactivity due to natural oil and gas production and related radiological problems. *Science of The Total Environment*, *45*(0), 77-84. doi: http://dx.doi.org/10.1016/0048-9697(85)90206-2

Kurttio, P., *et al.* (2006). Well water radioactivity and risk of cancers of theurinary organs. *Environmental Research*, *102*(3), 333-338. doi: http://dx.doi.org/10.1016/j.envres.2005.12.010

Lamarsh, J. R. (1983). *introduction to nuclear engineering* Addison- wesley publishing company.

Lambert, B. (2001). 3. Radiation: early warnings ;late effects. *Late lessons from early warnings: the precautionary principle 1896–2000*, 31 .

langimuir, D. (1978). Uranium solution mineral equilibria at low temperature with applications to sedimentary ore deposits. *Geochemica et cosmochimica acta, 42*, 54 .569-7

Lawrence. (2012), from http://www.ie.lbl.gov/education/parent/th_iso.htm

Lawrie, W. C., *et al.* (2000). Determination of radium-226 in environmental and personal monitoring samples. *Applied Radiation and Isotopes, 53*(1–2), 133-137. doi: 10.1016/s098-00168(00)8043-69

Magalhães, M. H., *et al.* (2003). Radon-222 in Brazil: an outline of indoor and outdoor measurements. *Journal of Environmental Radioactivity, 67*(2), 131-143. doi: 10.1016/s0265-931x(02)00175-3

Mc Laughlin, J. P. (2001). Approaches to theassessment of long term exposure to radon and its progeny. *Science of The Total Environment, 272*(1–3), 53-60. doi: 10.1016/s0048-9697(01)00664-7

Meyniel, G. (1995). Effects of radiation on man]. *La Revue du praticien, 45*(6 Spec No), 15 .

Milgram, S., *etal.* (2008). Cytotoxic and phenotypic effects of uranium and lead on osteoblastic cells are highly dependent on metal speciation. *Toxicology, 250*(1), 62-69. doi: 10.1016/j.tox.2008.06.003

Mortazavi, S., *et al.* (2005). *Cancer risk due to exposure to high levels of natural radon in the inhabitants of Ramsar, Iran.* Paper presented at the International Congress Series.

Mortazavi, S., *et al.* (2006). The biopositive effects of diagnostic doses of x-rays on growth of phaseolus vulgaris plant: a possibility of newphysical fertilizers. *Asian Journal of Experimental Sciences, 20*(1), 27-33 .

Nair, R. R. K., *et al.* (2009). Background radiation and cancer incidence in Kerala, India-Karanagappally cohort study. *health physics, 96*(1), 55-66 .

Nazaroff, w. w. (1988). *radon and its decay products in indoor air*. New York: John Wiley and sons.

Ngachin, M., *et al.* (2007). Assessment of natural radioactivity and associated radiation hazards in some Cameroonian building materials. *Radiation Measurements, 42*(1), 61-67. doi: http://dx.doi.org/10.1016/j.radmeas.2006.07.007

Nsiah-Akoto, I., *et al.* (2011). Indoor Radon Levels and the Associated Effective Dose Rate Determination at Dome in the Greater Accra Region of Ghana. *Research Journal of Environmental and Earth Sciences, 3* .

NTP. (2005). Report on carcinogens for radon. In t. report (Ed.), *s097 zird*: NTP.

Paschoa, A. S., & Pohl-Rülling, J. (2005). Early thoron concentration levels in Guarapari: Dosimetric implications. In E. S. Simopoulos (Ed.), *Radioactivity in the Environment* (Vol. Volume 7, pp. 678-686): Elsevier.

Paschoa, A. S., & Steinhäusler, F. (2010). CHAPTER 3 - Terrestrial, Atmospheric, and Aquatic Natural Radioactivity. In A. S. Paschoa & F. Steinhäusler (Eds.), *Radioactivity in the Environment* (Vol. Volume 17, pp :(85-29 .Elsevier.

Pavlidou, S., *et al.* (2006). Natural radioactivity of granites used as building materials. *Journal of Environmental Radioactivity, 89*(1), 48-60. doi: http://dx.doi.org/10.1016/j.jenvrad.2006.03.005

Perkins, S. (2009). Fungi thrived during mass extinction Fossil analyses hint that several species made the most of Earth's largest mass die-off. *A+ A, 176*(10), 10 .

Peter, H. (1973). *Lead inthe environment* (2 ed. Vol. 1). Norfolk England: Applied science publisher LTD.

Phil, E. (1998a). Background, from http://www.normis.com/bkgrnd/htm

Phil, E. (1998b). Geology of natrally occurring of radioactive materials, from http://www.normis.com/geo/htm

Phil, E. (1998c). Mobilization and redeposition of NORM, from http://www.normis.com/mob.htm

Pierson ,R., *et al.* (1974). Total-body potassium in health: effects of age, sex, height, and fat. *American Journal of Physiology--Legacy Content, 226*(1), 206-212 .

Poirier. (2000). *an introduction of the earth,s interior*. Cambridge: Cambridge university press.

Rafique, M., *et al.* (2008). General public's and physicians' perception of health risk associated with radon exposure in the state of Azad Jammu and Kashmir. *Public Health Nursing, 25*(4), 327-335 .

S. M. J. Mortazavi, M. G.-N., T. Ikushima, R. Assaie1, A. Heidary, R. Varzegar, F. Zakeri, K. Asghari, A. Esmaili. (2003). Are the Inhabitants of High Background Radiation Areas of Ramsar More Radioresistant? Scope of the Problem and the Need for Future Studies. *Iranian journal of radiology, 1*(1, 2), 37- 44 .

Sajó-Bohus, L., *et al.* (1999). Environmental gamma and radon dosimetry in Venezuela. *Radiation Measurements, 31*(1–6), 283-286. doi: 10.1016/s1350-4487(99)00116-x

Scheler, R., *et al.* (1998). Retrospective Estimation of Exposure to Short-lived 222Rn Progeny byMeasurements of 210Pb in the Skull. *Radiation protection dosimetry, 79*(1-4), 129-132 .

seal, r. (2012). radon levels in U.S home, from http://www.radonseal.com/radon-level.com

Seeram, E. B., Patrick, C. (2006). Diagnostic reference levels in radiology. *American Society of Radiologic Technologist, 77*(5), 373-384 .

Skwarzec, B., *et al.* (2001). Inhalation of 210Po and 210Pb from cigarette smoking in Poland. *Journal of Environmental Radioactivity, 57*(3), 221-230. doi: http://dx.doi.org/10.1016/S0265-931X(01)02-0018

Sohrabi. (1990). *Recent radiological studies on high level natural radiation areas of Ramsar*. Paper presented at the international conference of high levels natural radiation, Ramsar, Iran, Vienna.

Sohrabi. (1998). the state of the art on worldwidestudies in some environments with elevated naturally occuring radioactive materials. *App. Radiat. Isotopes, 49*(3), 169- 188 .

Sohrabi. (1999). *Environments with elevated radiation levels from natural substances*. Paper presented at the international conference on restoration of environment with radioactive residues., Arligton, Virginia, USA. STI/PUB retrieved from

Sohrabi. (2012). world high background natural radiation areas:need to protect public from radiation exposure. *Radiation Measurements*. doi: 10/10.16.j.rad meas

Somlai, J., *et al.* (2008). Connection between radon emanation and some structural properties of coal-slag as building material. *Radiation Measurements, 43*(1), 72-76. doi: 10.1016/j.radmeas.2007.10.028

Steiner, M., *et al.* (2002). The roleof fungi in the transfer and cycling of radionuclides in forest ecosystems. *Journal of Environmental Radioactivity, 58*(2–3), 217-241. doi: 10.1016/s0265-931x(01)00067-4

Stojanovska, Z., *et al.* (2010). Natural radioactivity and human exposure by raw materials and end product from cement industry used as building materials. *Radiation Measurements, 45*(8), 969-972. doi: http://dx.doi.org/10.1016/j.radmeas.2010.06.023

Strebl, F., *et al.* (2007). Behaviour of radionuclides in soil/crop systems following contamination. In S. George (Ed.), *Radioactivity in the Environment* (Vol. Volume 10, pp. 19-42): Elsevier.

Sun, H., & Semkow, T. M. (1998). Mobilization of thorium, radium and radon radionuclides in ground water by successive alpha-recoils. *Journal of Hydrology* .136-126 ,(2–1)205 ,doi: 10.1016/s0022-1694(97)00154-6

Tao, Z., Zha, Y., Akiba, S., Sun, Q., J., Li, J., Liu, Y., Kato, H., S ugahara, T., Wei, L. (2000). Cancer mortyality in the high background radiation areas of Yangjiang, China during the period between 1979 and 1995. *journal of radiation research, 41(Tokyo) (suppl)*(suppl), 31- 34 .

TDCR, D. G. M. (1996). *Principles of radiological physics* (3rd ed.). London: Churchill Livingstone.

TENORM. (2012). Background radiation, from http://www.tenorm.com/bkgrnd.htm

Turhan, Ş., *et al.* (2012). Distribution of terrestrial and anthropogenic radionuclides in Turkish surface soil samples. *Geoderma, 187–188*(0), 117-124. doi: 10.1016/j.geoderma.2012.04.017

Turner, M. C., *et al.* (2012). Radon and COPD mortality in the American Cancer Society cohort. *European Respiratory Journal, 39*(5), 1113-1119 .

Tzortzis, M., *et al.* (2003). Gamma radiation measurements and dose rates in commercially-used natural tiling rocks (granites). *Journal of Environmental Radioactivity, 70*(3), 2 .235-23doi: 10.1016/s0265-931x(03)00106-1

UNSCEAR. (1988). effects and risks of ionization radiation, sources (u. n. s. c. o. t. e. o. a. radiations, Trans.). New York: UNSCEAR.

UNSCEAR. (1993a). Sources and effects of ionizing radiation. New York: United Nation Scientific Committee on the Effects of Atomic Radiation.

UNSCEAR. (1993b). Sources, effects and risks of ionizing radiation. New York: UNSCEAR.

UNSCEAR. (2000a) Sources and effects of ionizing radiation New York: United Nations.

UNSCEAR. (2000b .(sources and effects of ionizing radiation *report to general assembly with scientific annexes*. new york: united nations scientific committee on the effects of atomic radiation.

UNSCEAR. (2009). source- to- effects assessment for radon in homes and workplaces *Annex E*. New York: United Scientific committee on the effects of atomic radiation.

USGS. (2012). Naturally occuring radionuclides in the groundwater of southern Pensylvania, from http://www.pa.water.usgs.gov/reports/fso12-00.html

Verne, J. (1995). center of the earth(voyage au cetere de la terre) lidenbrok (Ed.) *center of the earth* Retrieved from http://www.vt.edu/vt98/academics/books /verne/center_earth

Vorha, K. G. (1982). *natural radiation environment* (1st ed.). New York: John Wiley and sons.

W.H.O. (2008). WHO report on the global tobacco epidemic 2008. Geneva: Whorld Health Organization.

W.H.O. (2009a). hand book on indoor radon *Diagnostic measurements for mitigation and post-mitigation*. France: World Health Organization.

W.H.O. (2009b). Radonand cancer, from http://www.who.int/mediacentre/factsheet/fs291/en/index/html

Wade-Gueye, N. M., *et al.* (2012). Chronic exposure to natural uranium via drinking water affects bone in growing rats. *Biochimica et Biophysica Acta (BBA) - General Subjects, 1* .1127-1121 ,(7)820doi: 10.1016/j.bbagen.2012.04.019

Wald, G. (1964). The origins of life. *Proceedings of the National Academy of Sciences of the United States of America, 52*(2), 595 .

Walker, A. (2010). natural ventilation, from http://www.wbdg.org/resources/natural ventilation.php

Wallova, G., *et al.* (2012). Monitoring of radionuclides in soil and bone samples from Austria. *Journal of Environmental Radioactivity, 107*(0), 44-50. doi: 10.1016/j.jenvrad.2011.12.007

Wang, Z. (2002). Natural radiation environment in China. *International Congress Series, 1225*(0), 39-46. doi: http://dx.doi.org/10.1016/S0531-5131(01)00548-9

Wheeler, B. W., *et al.* (2012). Radon and skin cancer in southwest England: an ecologic study. *Epidemiology, 23*(1), 44 .

Wikipedia. (2012a .(Geography of Gabon, from http://www.en.wikipedia.org/wiki/geography_of_Gabon

Wikipedia. (2012b). Guarapari, from http://www.wikipedia.org/wiki/Guarapari

Wikipedia. (2012c). Kerala .

wikipedia. (2012d, 29.5.2012). stack effect, from http://www.wikipedia.org/wiki/stack_effect

Williams, W. S. C. (2008). *nuclear and particle physics* (2nd ed. Vol. 1). Oxford: Oxford science publication.

Zakeri. (2005). hormon levels associated with immune responses among inhabitants in HLNRAs of Ramsar- Iran .