RADON IN THE ENVIRONMENT: FRIEND OR FOE?

A. S. Hussein

Nuclear Power Plants Authority, Cairo, Egypt

ABSTRACT

Radon-222 is a naturally occurring radioactive gas that is part of the Uranium decay series. Its Presence in the environment is associated mainly with trace amounts of uranium and its immediate parent, radium-226, in rocks, soil and groundwater. About one-half of the effective doses from natural sources is estimated to be delivered by inhalation of the short lived radon progeny. Owing to this fact, radon is the most popular subject of studies on environmental radioactivity. The presence of high level of radon in indoor environment constitutes a major health hazard for man. The radon progeny is well established as causative agents of lung cancer and other types of caners.

Radon’s unique properties as a naturally radioactive gas have led to its use as a geophysical tracer for locating buried faults and geological structures, in exploring for uranium, and for predicting earthquakes. Radon has been used as a tracer in the study of atmospheric transport process. There have been several other applications of radon in meteorology, water research and medicine.

This paper summarizes the health effects and the potential benefits of radon and its progeny.

***KEYWORDS**: RADON, EFFECTIVE DOSE, HEALTH HAZARD, GEOLOGICAL STRUCTURES, EARTHQUAKES PREDICTION.*

INTRODUCTION

In literature there are several reports dealing with radon in our environment [1-6].The radiation dose from radon inhalation constitute a major part of the total natural background dose received by man. The United Nation Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reports that nearly half of dose received by man from natural sources is due to breathing radon and its progenies in the indoor environments as shown in figure 1[7,8].

Radon is a colorless, odorless and tasteless gas produced by radioactive decay of uranium and thorium. There are two main isotopes of radon in nature: – ^{222}Rn ($T_{1/2}$=3.82d, here after caller radon) and its short-lived decay products: ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb, ^{210}Bi, ^{210}Po (uranium series), – ^{220}Rn ($T_{1/2}$=55.6s, also called thoron) and its decay products: ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po, ^{208}Tl (thorium series) [8,9]. The radioactive decay chain of radon is shown in Figure 2[10].

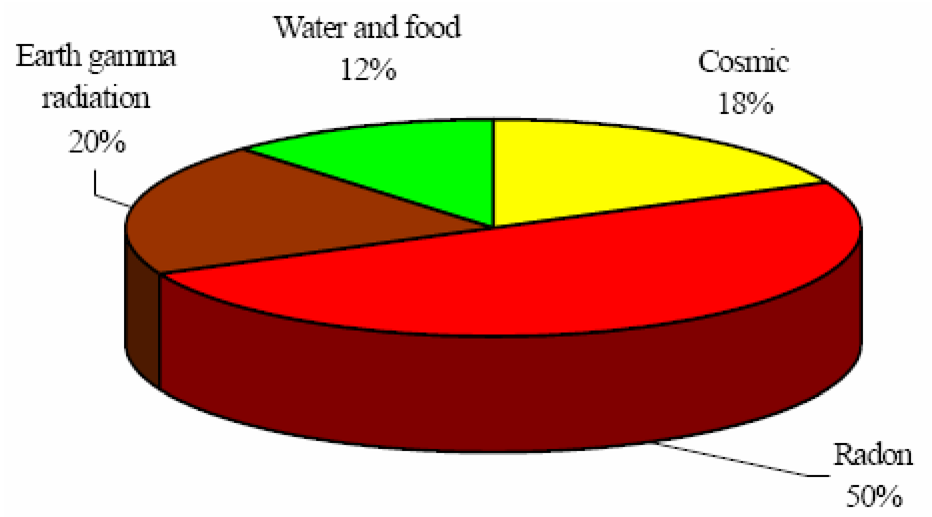

Figure 1 :" Sources and average distribution of natural background radiation for the world population[7]. "

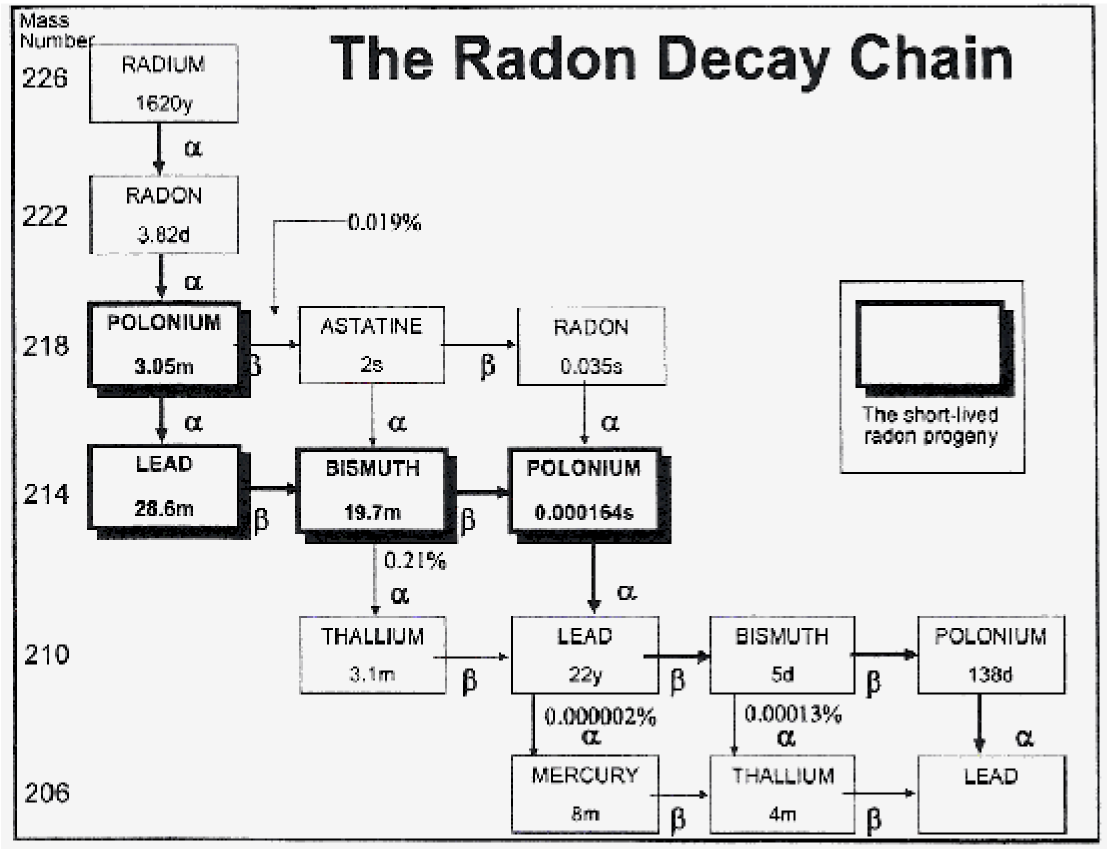

Figure 2 :" The radon decay chain [10] . "

The radon content of outdoor air 1 metre above ground typically gives 4 to 15 Bq·m^{-3}. The average indoor air concentration of radon varies from location to location, depending upon the uranium content and physical characteristics of the soil, moisture, winds and building materials. In most countries the average indoor radon concentration is a few tens of Bq·m^{-3}, however, during the surveys hundreds and even thousands could be found. The International

Commission on Radiological Protection (ICRP) therefore recommended action levels 200–600 Bq·m^{-3} for homes and 500-1500 Bq·m^{-3} for workplaces which correspond to annual doses of 3–10 mSv in either case [6-9].

There are several techniques that have been used for radon measurements .These techniques include scintillation cells, ionization chambers , solid state nuclear track detectors(SSNTDs) , solid state surface barrier detectors, thermoluminescent dosimeters , electret ion chamber , and electrostatic precipitation technique [9]. For developing countries wishing to undertake national survey programs in order to monitor environmental radon levels, the most appropriate techniques are those making use of SSNTDs (CR-39 and LR-115) because they are versatile, simple in handling and processing, low cost and insensitive to beta and gamma radiation. Also these detectors incorporate the effects of seasonal and diurnal fluctuation of radon concentrations due to physical and geological factors as well as meteorological conditions [9,12].

During recent years , numerous papers have appeared in literature demonstrating the ever interest in monitoring radon in the indoor environments in Egypt [13-21].

Radon has to facts. It has a major health hazard for man. The radon progeny is well established as causative agents of lung cancer and other types of cancers [6,7,22-25].On the other hands, it has a potential benefits in earth sciences[1,9].This paper summarizes the health effects and the potential benefits of radon and its progeny

HARMFUL EFFECTS OF RADON

Until the late 1970s , radon and its progenies were regarded as radiation health hazards only encountered in the mining and milling of uranium .This dramatically changed as a result of widespread indoor measurements of radon in parts of the world [2,6,7,22]. Attention to the problem of radon exposure and the associated health risks has thus been growing around the world [22,25]. Nowadays radon and its progeny, known to be carcinogenic in a high radon concentration places, if it is poorly ventilated and if the radon input from its sources is high, such as mines such as mines, caves, cellars, ancient tombs and energy conserved air tight houses. The inhaled radon and its progenies pass from lungs into the blood and body tissues and may indicate many types of soft tissue cancers such as lung cancer, kidney cancer and prostatic cancer [22-33]. Some radon may be dissolved in body fats, and its daughter products transferred to the bone marrow. The accumulated dose in older people can be high, and may give rise to leukaemia. Radon has also been linked with melanoma and some childhood cancers [30,34] . There is a positive association between coronary heart disease and radon exposures where an elevated risk of mortality from coronary heart disease was observed among miners with accumulative radon exposure exceeding 1000 Working Level Month (WLM) [37]. Radon daughters ^{218}Po and ^{214}Po could be regards as potential carcinogenic agents for the induction of skin cancer [36]. It is also noticed that the combination of inhalation of radon gas and smoking increases the risk of lung cancer [22,35].

The principal health effect in breathing air containing ^{222} Rn is due to its daughters ^{218}Po , ^{214}Pb and ^{214}Bi (^{214}Po). Their contribution to the radiation dose to the lung is 2- 3 orders of magnitude greater than that of ^{222}Rn [38].

Ingested radon dissolved in drinking water is a health risk, because it may cause a stomach cancer. The risk caused by drinking water containing dissolved radon is extremely much lower than inhaling radon [26].

Radon and its daughters are a significant health threat linked to thousands of preventable death each year [39]. Radon is the second leading cause of lung cancer after cigarette smoking. It may cause about 15,000 lung cancer deaths per year in the US [22,25]. The World Health Organization (WHO) says radon causes up to 15% of lung cancers worldwide [25].

The health threat from radon can be addressed by identifying geographic areas that could produce elevated levels of indoor radon, developing strategies to reduce exposure, conducting research on effective remedial measures to be taken in buildings , and providing educational programs for health officials and the public [5-9,25].

To the contrary, Reports exist on various epidemiological studies demonstrating a negative correlation of lung cancer risk with radon in dwellings, which shows that exposure to low level ionising alpha radiation has apparently resulted in positive health effects [40-43]. Also, it was reported that there was no association between residential radon and risk of childhood acute myeloid leukemia AML[44].

Recognizing the importance of radon as a public health issue, large-scale national and international Radon-programmes were initiated world-wide, such as the IAEA co-ordinate research programme CRP 'Radon in the Human Environment' involving over 50 countries [2] and The International Radon Project (IRP) by WHO on public health aspects of radon exposure. This project enjoys high priority with WHO´s Department of Public Health and Environment. The key elements of the IRP include[25] :

1. Estimation of the global burden of disease (GBD) associated with exposure to radon, based on the establishment of a global radon database
2. Provision of guidance on methods for radon measurements and mitigation
3. Developing evidence-based public health guidance for Member States to formulate policy and advocacy strategy including the establishment of radon action levels
4. Development of approaches for radon risk communication.

RADON BENEFITS IN OUR ENVIRONMENT

There is more and more information cumulating on the benefit effects of radon at cell biological level known as radon therapy [5,9,46-49]. radon measurements can be used to solve radiation safety problems at nuclear and industrial facilities [5,9,11,50-54]. In addition to that radon is very important for many applications in earth sciences .It can be used as a geological tool in mineral exploration [9,11] ,earthquake [9,55-62] and volcanic activity prediction [9] ,search for geothermal energy source [9]. Radon also can be used in atmospheric studies [63,64].

RADON AS MEDICINE (RADON SPAS AND RADON THERAPY):

Rather early, the stimulation of DNA repair was observed upon radon exposure .Similar DNA repair was indicated in lymphocytes of people living in increased radon concentration and also the adaptive response reaction was provoked under 10 mSv "priming" dose [9,45]. The spas evidently containing radon have been used with success for hundreds of years for special illnesses mainly in the pain therapy of chronic rheumatic illnesses. Radon spas are wide-spread in USA, Japan and Europe (Greece, Germany, Austria, Czech Republic, Hungary, Romania, Slovenia, Russia, etc). Clinical experience has shown that the long-lasting pain of the patients was considerably reduced with less analgetic pharmaceuticals. The presence of radon in spas, accordingly, can not be considered as risky to health, just the opposite, more and more information cumulate on its positive health effects completing the other beneficial factors present in health spas [5,9,46-49]. The Environmental Protection agency states that there is no safe level of radon and that any exposure poses some risk of cancer. Others support the positive or neutral effects of low dose radiation. The question is whether or how much the radon impacts or damages the tissue [(49]. So that any radon spa treatments should given by a medical practitioner [5].

RADON AND RADIATION SAFETY IN NUCLEAR AND INDUSTRIAL FACILITIES:

In recent years , problems of radiation and nuclear safety have been multiplied rapidly due to the release of natural alpha-radioactivity from waste material produced by power plants, chemical and metallurgical industry. Therefore the measurements of radon concentration , as well as , radon progenies in air, soil and water ,have been of great concern for radiological safety [5,9,11,50-54].

RADON AND MINERAL EXPLORATION:

Over the years, large number of techniques and methods have been developed to measure radon concentration in the "soil gas' and in ground water in selected areas of interest. These measurements can yield a lot of information regarding the subsurface geological features and the presence of mineral and oil / gas reserves [9,11].

RADON AND EARTHQUAKES PREDICTION:

The real time radon monitoring is an extensively studied area in order to give premonitory signs prior to earthquakes. The strain change that occurred within the earth surface during earthquake is expected to enhance the radon concentration in soil gas and in groundwater. In addition to continuous radon monitoring in groundwater other geochemical parameters such as electrical conductivity and water temperature should be performed [9,55-62].

RADON AND VOLCANIC SURVEILLANCE:

Radon has been recognized for long time as a detectable component of fluids associated with volcanoes (fumaroles, ground waters ,or soil gases). It was reported that radon measurements should be definitely supplemented by measurements of other physical or chemical parameters .Under such circumstances , knowledge of the geochemistry of volcanoes could rapidly increase in the immediate future [9].

RADON AND GEOTHERMAL ENERGY PREDICTION;

A geothermal source may be defined as the natural heat of the earth trapped close enough to the earth's surface to be extracted economically. Normally, geothermal sources are associated with volcanic regions. Hot water springs and vapors emanation may suggest prospecting geothermal energy sources. The observation of exceptionally high radon levels may indicate the possible existence of a geothermal energy sources lying deep underneath the earth's surface. The method of using radon signal for locating geothermal energy sources has met some success in countries such as New Zealand , Mexico and USA [9].

RADON APPLICATION TO ATMOSPHERIC STUDIES:

The keen interest in environmental radon monitoring can be attributed to its attractive characteristics as a tracer of atmospheric processes. Radon is primarily of terrestrial origin and its predominant sink is by radioactive decay, since it is a noble gas it does not react chemically with other species. Furthermore, since radon is relatively insoluble in water and does not attach to aerosols, it is not highly susceptible to dry or wet atmospheric removal processes. The half-life of radon (3.8 days) is comparable to the lifetimes of short-lived atmospheric pollutants (e.g. NO_x, SO_2, CO, O_3), and atmospheric residence time of water and aerosols. This time scale is also comparable to many important aspects of atmospheric dynamics, making radon a useful tracer at local, regional or global scales.

The characteristics of radon make it a reliable indicator of the extent of air mass contact with land. This is more accurate information than can be derived from back trajectories alone. Furthermore, the simulation of radon transport is currently one of the best tools for the evaluation of transport schemes in regional and global models. Due to its short half-life, the vertical distribution of radon in the atmosphere shows great sensitivity to sub-grid scale processes. It has also been demonstrated that trace gas emissions originating from large land areas can be estimated using radon as a marker for emission from soil. With the automated detectors, changes in radon concentration can be measured to high precision and temporal resolution a either permanent stations or on board ships [63,64].

CONCLUSION AND RECOMMENDATIONS

In the recent years, radon monitoring and indoor radon concentration levels have been of scientific and technological interest due to its health hazards, not only to underground miners but also to people in dwellings and workplaces with high radon levels , and their multiple applications; as a useful tool in studies in hydrology, geology, ocean logy and earth quake prediction . In addition to that, radon measurements can be used to solve radiation safety problems at nuclear and industrial facilities. It has proved to be a good friend and a powerful enemy at the same time or it is both a hazard and a help.

I recommend to :

- Carry out a national program for estimating radon levels and effective doses tp persons in the indoor environments in Egypt and regrouping all efforts dealing with it and turn to a collective work.
- Use the educational programs to inform health officials and the public about the health threat from radon and about associated risk factors , such as smoking.
- Apply the Geographical Information System (GIS) technology in the analysis of radon data and the creation of an indoor radon map of Egypt.
- Promote scientific researches dealing with radon applications in earth sciences and radiation safety at nuclear and industrial facilities.

REFERENCES

[1].Khan, H .A., Radon : A friend or a foe ? International Journal of Radiation Applications and Instrumentation, Part D, Vol.19,Issues1-4, pp.353-362(1991).
[2].Ahmed, J.U.,International Atomic Energy Agency ,IAEA BULLETIN ,Vol.2, pp32-35(1994).
[3] Jonsson, G., Radon gas – where from and what to do? Rad. Meas., Vol.28,pp.537(1995).
[4] M.O'rirdan, riddle of radon, J.Radiol.Prot.Vol.16, pp.269-273(1996).
[5] IAEA Safety Reports Series No.33, Radiation Protection against Radon in Workplaces other than Mines(2003).
[6] ICRP 65, International commission on Radiological Protection , Protection Against Radon-222 at Home and at Work ,Pergamon Press, Oxford ,1994.
[7] UNSCEAR, Sources and Effects of Ionizing Radiation, Report to the general Assembly, New York, United Nations(2000).
[8] UNSCEAR, Sources to Effects Assessment for Radon in Homes and Workplaces, Report to the general Assembly, New York, United Nations(2006).
[9].Durani, S.A. and.Illic, R., Radon Measurements by Etched Track Detectors, World Scientific, Singapore(1997).
[10] Darby, S. C. “Radon in homes and lung cancer risk.” In: Radon risk (2006), http://www.ibcglobal.com/
[11].Eisenbud, M. and.Gesell, T., Environmental Radioactivity From Natural , Industrial and Military Sources , Academic Presss (1997).
[12] Gomaa, M.A. , Hafez, A.F. and.Hussein, A.S., Quality Assurance for Environmental Radon Measurements by LR115 Nuclear Track Detectors, Eighth Conference of Radiation Physics and Protection, Bani Sueif, Egypt, 12-17 Nov(2006).
[13] Hafez, A.F. ,Hussein, A.S.and Rasheed, N.M., Radon measurements in underground metro stations in Cairo city, Egypt. Seventh Conference of Nuclear Sciences and Applications, Cairo, Egypt, 6-10 February (2000).
[14] Hafez, A.F. ,Hussein, A.S.and Rasheed, N.M., A study of radon and thoron release from Egyptian building materials using polymeric nuclear track detectors. Appl. Rad.. Isot., Vol 54,pp. 291-298(2000).
[15] Hafez, A.F. and Hussein, A.S., Radon activity concentrations and effective doses in ancient Egyptian tombs of the Valley of the Kings. Appl. Rad . Isot., Vol. 54,pp. 355-362(2001).
[16].El-Hussein, A.,.Mohamed, A.,.Abd El-Hady, M , Ahmed, A.A.,.Ali, A.E and.Barakat, A., Diurnal and seasonal variation of short –lived radon progeny concentration and atmospheric temporal variations of 210Pb and 7Be in Egypt, Atmospheric Environment, Vol.35,pp.4205-4313(2001).
[17] Hafez, A.F., Bishara, A.A.,.Kotb, M.A and Hussein, A.S., Regular radon activity concentration and effective dose measurements inside the Great Pyramid with passive nuclear track detectors. Health Physics,Vol. 85(2),pp. 210-216 (2003).
[18] Gomaa, M.A., AHussein, .S. and.El-Arabi, A.M., Radon measurements in Egypt using passive etched track detectors: a review, Seventh Conference of Radiation Physics and Protection, Ismaelia, Egypt, 27-30 Nov.(2004).
[19] El-Bahi, S.M .,Assessment of radioactivity and radon exhalation rate in Egyptian cement, Health Physics,Vol. 86(5),pp.517-522(2004).
[20] Hussein, A.S., Radon concentrations in some Egyptian dwellings using LR115 detectors, Eighth Conference of Radiation Physics and Protection, Bani Sueif, Egypt, 12-17 Nov.(2006).

[21] Abo-Elmagd, M.,.Metwally, S.M.,.El-Fiki, S.A.,.Eissa, H.M. and Salama, E. Passive and active measurements of radon-related parameters inside ancient Egyptian tombs in Luxer, Rad.Meas.,Vol.42,PP.116-120(2007).
[22] BEIR VI , Biological Effects of Ionizing Radiation , the Health Effects of Exposure to Indoor Radon, The National Academy of Science (NAS- USA)(1999).
[23] Boice, J.J. and.Lubin, J., Occupational and environmental radiation and cancer, Cancer-Causes –Control, Vol.8, pp.309(1997).
[24] Phillips, P. and Denman, A., Radon : a human carcinogen,Sci-Prog. Vol.80, pp.317(1997).
[25] World Health Organization(WHO), Radon and cancer(www.WHO.org).
[26] Ayotte,P.,Levesque, B., Gauvin, D.,.McGregor, R., Martel, R.,.Gingras, S., Walker, W.B. and Letourneau, E,G., Indoor exposure to ^{222}Rn: A public health perspective, Health Phyics,Vol.75, 297(1998).
[27] Eatough, J.P. and Henshew, D.L, Radon and prostate cancer. Lancet. Vol.335,pp.1292(1990).

[28] Eeva, R., Ilona, M Tapio, R, Timo, H. and Matti, H., Radon and lung cancer in Finland. Health Physics,Vol.71,pp. 185(1996).
[29] Facchini, U.,Sesana, L., Agostoniand, G. and Testa, V. ,The radon risk in Lombardy. Radio. Med. Torino.Vol. 94,pp. 376(1997).

[30] Henshaw, D.L., Eatough,J.P. and Richardson, L.B.,Radon as a causative factor in induction of myeloid leukemia and other cancers. Lancet.Vol. 335,pp. 1008(1990).
[31] Pershagen, G,.Akerblom, G.,Axelson, O., Clavensjö, B., Damber, L., Desai, G., Enflo, A., Lagarde, F., Mellander, H.,.Svartengren, M. and Swedjemark, G.A., Residential radon exposure and lung cancer in Sweden. N. Engl. J. Med. Vol.330,pp. 159(1994).

[32].Pawel, D.J and.Puskin, J.S., The U.S.Environmental Protection Egency's assessment of risks from indoor radon,Health Physics, Vol.87(1),pp.68-74(2004).

[33] Nghiep, T.D. and.Anh, V.T, Correlation between radon levels and lung cancer mortality rates: experimental and theoretical problems, Int.J.Low Radiation,Vol.2,No.1/2(2006).

[34] Wei, L., Zha, ,Y., Tao, Z., He, W., Chen, D. and Yuan, Y., Epidemiological investigation in high background radiation areas in Yangjiang China. In Proc. Int. Conf. on High Levels of Natural Radiation, Ramasar,IAEA, Vienna, pp. 523-547(1993).
[35] Villeneuve, P.J. and Morrison, H.I., Coronary hart disease mortality among newfoundland fluaspar mins. Scand-J. Work. Environ. Health ,Vol.23, pp.221(1997).

[36] Eatough, J.P., Alpha particle dosimetry for the basal layer of the skin and the radon progeny ^{218}PO and ^{214}P, Phys-Med-Biol., Vol. 42, pp.1899(1997).

[37] Leenhouts, H.P. and Brugmans, M.J.P.,Calculation of the 1995 lung cancer incidence in the Netherlands and Sweden caused by smoking and radon : risk implications for radon. Radiat. Eniveron. Biophys.,Vol. 40,pp.11(2001).

[38] Ruzer, L and Sextro, R. , Measurement of radon decay products in air by alpha and beta spectroscopy. Radiat. Prot. Dosim. Vol.72,pp. 43(1997).

[39] Boschi, N. , A risk management strategy from radon: the US experience. Radiat. Prot. Dosim. Vol..78,pp. 6(1998).
[40] Alevanjia, M.C.R., Brownson, R.C., Lubin, J.L., Beger, E., Chiang, J. and Boice, J.D., Residential radon exposure and lung cancer among non-smoking Women. J. Nat. Cancer Inst.Vol.86,pp. 1829(1994).

[41] Auvinen, A.,.Maekelaeinen, I.,.Hakama, M.,.Castren, O., Pukkala, E., Reisbacka, H.and Rytoemaa, T. , Indoor radon exposure and risk of lung cancer: A nested case-control study in Finland, J. Natio. Can. Inst. Vol.88,pp.966(1996).
[42] Cohen, B.L, Questionnaire study of the lung cancer risk from radon in homes. Health Physics, Vol. 72, pp.615(1997).
[43] Averbeck, D., Testard, I., and Boucher, D. "Changing views on ionizing radiation-induced cellular effects." Int. J. Low Radiat.,Vol. 3,pp.117–134(2006)..
[44] Steinbuch, M.,Weinberg, C.,Buckley, J.,.Robinson, L. and Sandler, D., Indoor residential radon exposure and risk of childhood acute myeloid leukaemia. Br. J. Cancer,Vol. 81,pp. 900 (1999).
[45] Masoomi, J. R., Mohammadi, S., Amini, M., and Ghiassi-Nejad, M. "High background radiation areas of Ramsar in Iran evaluation of DNA damage by alkaline single cell gel electrophoresis." J. Env. Rad.,Vol. 86,pp.176–178 (2006).
[46] Vagiannis,E.,Nikollopoulos,D.,Louizi,A. and Halvadakis,C.P. ,Radon variation during treatment in thermal spas of Lesvos Island (Greece), J.Env.Rad.,Vol.76,pp.283-294,(2004).
[47] Vaupotic,I. and Kobal,I., Radon exposure in Solovenian SPAS, Rad.Prot.Dos., Vol.97,No.3,pp.265-270,(2001),
[48] Erickson,B.E., Radiation and Health : An overview of radon therapy in the United state and Europe, California State Unversity , Fullerton,USA.
[49] American Nuclear Society(www.ANS.com): Radon Spas.
[50] Bondarenko,O.A, a, Korneevb, A. A. . Onishchukc, Yu. N , Berezhnoya, A. V. , Aryasova, P. B. ,Antonyuka, D. and Dmitrienkob, A. V., Application of SSNTD for maintenance of radiation and nuclear safety of the Sarcophagus, Rad.Meas.,Vol.30,Issue 6,pp.709-714(1999).
[51] Steinhavsler,F., Radon risk management : the future challenge for the nuclear community, Science of the Total Environment ,Vol.272 pp.7-22(2001),.
[52] Tyogi,T.,Ueda,S.,Hisamatsue,S.,Kondo,K.,Sakurai,N. and Inaba,J., Radon concentration in indoor occupational environments, J.Env.Rad.,Vol.67,pp.91-108(2003).
[53] Gaso,M.I.,Segovia,N. and Morton,O., Environmental impact assessment of uranium ore mining and radioactive waste around storage center from Mexico, Radioprotection, Suppl.1,Vol.40.pp.739-745(2005).
[54] Kumar,R.,Mahur,A.K.,Sengupta,D. and Prasad,R. , Radon activity exhalation rates measurements in fly ash from a thermal power plant, Rad.Meas.,Vol.409,pp.638-641(2005).
[55] Igarashi,G and wakita,H , Groundwater radon anomalies associated with earthquakes ,Tectonophysics, Vol.180 ,Issues 2-4,pp.237-254(1990).
[56] Zmazek,B.,Italiano,F.,Zivcic,M.,Vaupotic,J.,Kobal,I and Martinelli,G ,Geochemical monitoring of thermal waters in Slovenia: relationships to seismic activity, Appl.Rad.Isot.,Vol.57,pp.919-930(2002).
[57] Zmazek,B.,Todorovski,L.,Dzeroski,S.,Vaupotic,J. and Kobal,I , Application of decision trees to the analysis of soil radon data for earthquake prediction, Appl.Rad.Isot.,Vol.58,pp.697-706(2003).
[58] Zmazek,B.,Zivcic,M.,Todorovski,L.,Dzeroski,S.,Vaupotic,J. and Kobal,I, Radon in soil gas: How to identify anomalies caused by earthquakes, Applied Geochemistry,Vol.20,pp.1106-1119(2005).
[59] Zmazek,B.,Todorovski,L.,Zivcic,M., Dzeroski,S.,Vaupotic,J. and Kobal,I, Radon in a thermal spring: Identification of anomalies related to seismic activity, Appl.Rad.Isot.,Vol.64,pp.725-734(2006).
[60] Das,N.K., Choulhury,H., Bhandari,R.K., Ghose,D., Sen,P. and sinha,B., Continuous monitoring of 222 Rn and its progeny at remote station for seismic hazard surveillance, Rad.Meas.,Vol.41,Issue 5,pp.634-637(2006).

[61] Crockett,R.G.M., Gillmore,G.K., Phillip,P.S., Deman,A.R. and Groves-kirkby,C.J., Radon anomalies preceding earthquakes which occurred in the UK in summer and autumn 2002 , Science of The Total Environment,Vol.364,Issues 1-3 pp.138-148(2006).
[62] Ghosh,D., Deb,A., Sengupta,r., Patra,K.K. and Bera, S., Pronounced soil-radon anomaly – Precursor of recent earthquakes in India , Rad.Meas.,Vol.42,Issue 3,pp.466-471(2007).
[63] zahorowski,w., Chambers,S.D . and Henderson-Sellers,A , Ground based radon-222 observations and their application to atmospheric studies, J.Env.Rad.,Vol.76,pp.3-33(2004).
[64] Tateda,Y and Iwao,K ,High 210 Po atmospheric deposition flux in the subtropical coastal area of Japan, J.Env.Rad., Vol.99,pp.98-108 (2008).