3.7 Ramsar Hot Springs: How Safe is to Live in an Environment with High Level of Natural Radiation

S. M. J. Mortazavi

Medical Physics Department, Rafsanjan University of Medical Sciences, Rafsanjan, Iran

Abstract

Ramsar in northern Iran is among the world's well-known areas with highest levels of natural radiation. Annual exposure levels in areas with elevated levels of natural radiation in Ramsar are up to 260 mGy y^{-1} and average exposure rates are about 10 mGy y^{-1} for a population of about 2000 residents. Due to the local geology, which includes high levels of radium in rocks, soils, and groundwater, Ramsar residents are also exposed to high levels of alpha activity in the form of ingested radium and radium decay progeny as well as very high radon levels (over 1000 MBq m^{-3}) in their dwellings. In some cases, the inhabitants of these areas receive doses much higher than the current ICRP-60 dose limit of 20 mSv y^{-1}. As the biological effects of low doses of radiation are not fully understood, the current radiation protection recommendations are based on the predictions of an assumption on the linear, no-threshold (LNT) relationship between radiation dose and the carcinogenic effects. Considering LNT, areas having such levels of natural radiation must be evacuated or at least require immediate remedial actions. Inhabitants of the high level natural radiation areas (HLNRAs) of Ramsar are largely unaware of natural radiation, radon, or its possible health effects, and the inhabitants have not encountered any harmful effects due to living in their paternal houses. In this regard, it is often difficult to ask the inhabitants of HLNRAs of Ramsar to carry out remedial actions. Despite the fact that considering LNT and ALARA, public health in HLNRAs like Ramsar is best served by relocating the inhabitants, the residents' health seems unaffected and relocation is upsetting to the residents. Based on the findings obtained by studies on the health effect of high levels of natural radiation in Ramsar, as well as other HLNRAs, no consistent detrimental effect has been detected so far. However, more research is needed to clarify if the regulatory authorities should set limiting regulations to protect the inhabitants against elevated levels of natural radiation.

Address for Correspondence:
SMJ Mortazavi, Ph.D
Vice-Chancellor for Education and Research
Rafsanjan University of Medical Sciences
Imam Ali Blvd.
Rafsanjan
Iran

Tel: +98-391-8220097
Fax: +98-391-8220092
E-mail: jamo23@lycos.com

1. Introduction

Humans, animals and plants have been exposed to cosmic radiation since the beginning of life. The level of cosmic radiation varies in different parts of the world due to differences in elevation and the geomagnetic latitude, and of terrestrial radiation due to geochemical diversity. About 4 billion years ago, when the living organisms appeared on the Earth, the level of natural radiation was about 3-5 times higher than its current level (Jaworowski 1997, Karam 1999, Karam 2001). The annual level of radiation from internal potassium-40 has decreased to 1/8 while the external radiation from geologic materials has decreased from about 1.6 mGy to 0.66 mGy since the beginning of life. Thus, the annual background radiation exposure from these two sources has decreased from about 7.0 to 1.35 mGy (Karam and Leslie 1999). The annual per caput effective dose from natural and man-made sources for the world's population is currently about 2.8 mSv. Nearly 85% of this dose (2.4 mSv) comes from natural background radiation (UNSCEAR 2000). People who live in high-altitude areas such as Tibet in China, Andes in South America, or cities like Denver, Colorado, are exposed to higher levels of cosmic radiation due to a thinner atmosphere than people living in areas at sea level. Also astronauts, pilots and cabin crew are exposed to higher than normal levels of cosmic radiation. The study of these population groups may reveal information on adaptive responses (AR) induced by exposure to higher than normal levels of natural radiation.

When living organisms are exposed to a variety of DNA damaging stresses such as UV, alkylating or oxidizing agents and heat, adaptive responses (AR) are induced which cause resistance to the agent (Samson and Cairns 1977). The early investigations of Olivieri and his colleagues (1984) showed that cultured human lymphocytes, which were exposed to a low dose of ionizing radiation had fewer chromatid aberrations induced by a subsequent high dose as compared to the lymphocytes that have not been exposed to a low dose. Since 1984, many investigators have demonstrated AR in plant cells (Cortes et al. 1990), insects (Fritz-Niggli and Schaeppi-Buechi 1991), Chinese hamster V79 cells (Ikushima 1987), cultured human lymphocytes (Wiencke et al. 1986, Shadley and Wolff 1987, Wolff et al. 1988, Shadley and Wiencke 1989, Sankaranarayanan et al. 1989), human embryonic and HeLa cells (Ishii and Watanabe 1996), occupationally exposed persons (Barquinero et al. 1995, Gourabi and Mozdarani 1998), cultured animal lymphocytes (Flores et al. 1996), and *in vivo* studies on laboratory animals (Wojcik and Tuschl 1990, Cai and Liu 1990, Liu et al. 1992, Farooqi and Kesavan 1993). Mortazavi et al. (2003c) have recently reported that the inter-individual variability of adaptive response in humans is much greater than what is usually expected. Recent data on different aspects of adaptive response, obligate us to reevaluate the current conservative radiation protection regulations (Pollycove and Feinendegen 2001, Mortazavi et al. 2002, Mortazavi 2002). In this paper, studies on adaptive responses related to natural radiation levels are shortly reviewed.

2. Adaptation after Exposure to Cosmic and Terrestrial Radiation

2.1. Underground Studies

Early experiments carried out on single cell organisms shielded against background radiation showed that at the levels of natural radiation lower than normal, the proliferation of these organisms can be inhibited. Interestingly, this inhibitory effect disappeared when shielded cells were exposed to very low doses of gamma radiation close to background levels (Planel et al. 1987). Later it was shown that yeast cells cultured in a low background environment were less protected from mutational damage induced by methyl methane sulfonate than the cells grown in a normal background radiation environment (Satta et al. 1995). The results of a recent study on mammalian cells showed an increase in both the basal *hprt* mutation frequency and sensitivity to the mutagenic effects of gamma rays in cells grown in an underground laboratory, compared to the cells grown in a laboratory with natural radiation environment (Satta et al. 2002).

2.2. High Altitude Areas

The people who live in Tibet, "the roof of the world", are exposed to high levels of cosmic radiation. At the mean elevation of about 4000 meters above the sea level, the atmosphere is less thick, and the residents are exposed to external annual radiation doses up to 2.12 mSv (Shouzhi 2000). This dose is 3.5 times higher than that at the sea level. Recently the Glycophorin A-based somatic mutation assay was carried out on the residents of high-altitude areas and on those who lived at low-altitude. The life time cumulative doses for the high-altitude and low-altitude areas were 111 mSv and 27 mSv respectively. This study showed no significant difference between the Glycophorin A-based somatic mutation frequencies in these two populations (Jensen et al. 1997). An epidemiological study on mortality due to cancer (Xin 1983) showed that the standardized mortality of cancer (56.26×10^{-5}) in the high-altitude area of Tibet was lower than those of the whole country (66.92×10^{-5}). The mean annual dose equivalent for high altitude area was 1.8 mSv that is a few times higher than that of areas at sea level. The mortality from leukemia in the high-altitude area was lower than those of the whole country either.

In an old paper, Frigerio and Stowe (1976) reported that in the United States they found a consistent and continuous inverse relationship between levels of natural background radiation and cancer mortality-rates in 50 states. Again in the Unites States a negative correlation of normal background radiation with overall cancer death was observed in a more recent study. In Rocky Mountain States, where the level of natural radiation is 3.2 times higher than that in Gulf States, the age adjusted overall cancer death was 79% of that in Gulf States (Jagger 1998).

2.3. Flights and Space Journeys

Zwingmann *et al.* (1998) recently measured the DNA damages in 23 flight engineers. Despite that oxidative DNA damage in flight engineers was higher than the control ground personnel, it was observed that DNA damage in flight engineers who had a relatively longer flight time (>7,500 hr) and a higher cumulative radiation dose (53.6 mSv) was less than that of the flight engineers with a shorter flight history (<7,500 hr) and a lower cumulative radiation dose (30.7 mSv). They also observed that frequencies of hprt mutations and micronuclei also tend to be higher in flight engineers with a shorter flight history. These findings are in keeping with the results of another study that was performed on flight crew using the chromosomal aberrations as the end point (Zwingmann *et al.* 1998). It was indicated that pilots and stewardesses with a flight history of only 1-6 years had more chromosome aberrations compared to crew with more than 20 years of intercontinental flights. The frequency of chromosome aberrations in the pilots and stewardesses who were exposed to cosmic radiation for a long-term, i.e.

more than 20 years of intercontinental flights, and those who had been flying only 1-6 years were 1.4×10^{-3} and 3.2×10^{-3}, respectively.

In a recent study on the frequency of chromosome aberrations in eighteen supersonic Concorde pilots (Heimers 2000), it was indicated that the dicentric yield in pilots who were employed over 28 years was about 50% of that observed in pilots with 16-26 years of occupation ($1.3\pm0.5 \times 10^{-3}$ and $2.9\pm0.5 \times 10^{-3}$ respectively). Also the frequency of cells with translocations in pilots with 28-34 years of flight occupation was 78% of that in pilots with 16-26 years of flight occupation ($2.8\pm0.7 \times 10^{-3}$ and $3.6\pm0.6 \times 10^{-3}$ respectively). Despite the fact that there are statistical uncertainties in these data, this kind of adaptive response has been well documented in eukaryotes such as yeast. Deorukhakar and Rao (1995) investigated the radiation induced genetic damage in yeast by culturing the cells continuously at a radiation level of 0.383 – 1.275 μSv h^{-1} by selecting appropriate concentrations of tritiated water in the growth medium. It was shown that cells which were incubated at higher radiation levels and for longer duration had a higher conversion frequency. However, when subculturing continued beyond 900h, the gene conversion frequency reverted back to normal value. Such a response could not be detected when the cells were exposed to an acute high dose. The authors concluded that chronic exposure of yeast to low dose radiation might induce an AR.

In a recent study on 6061 male cockpit personnel which yielded 105,037 person-years of observation it was shown that cockpit crew had a low overall and cancer mortality (Zeeb et al. 2002). This result is consistent with the results obtained from previous studies on Canadian (Band et al. 1996) and British Air Ways pilots (Irwin et al. 1999). That this is not a healthy worker effect, suggests mortality from all cancers, which in cabin crew who received 5-14.99 mSv cumulative radiation dose, was lower than in those who received either 0-4.99 or 15-29.99 mSv (Zeeb et al. 2002).

Results of a cytogenetic study on 22 cosmonauts who stayed on average 4-6 months in MIR station shows that the after mission percentage of chromosomal aberrations in 6 cosmonauts is less than that of the scored frequency before the mission (Fedorenko et al. 2001). Also the after mission frequency of the cells with dicentrics and centric rings in four cosmonauts was less than that of before mission. Interestingly, in one case, the after mission frequency of chromosomal aberrations was about 1/3 of the before mission value.

2.4. Very High Levels of Natural Terrestrial Radiation

People in some areas around the world live in dwellings with radiation and radon levels as much as 100 times the global average. Inhabited areas with high levels of natural radiation are found in different areas around the world including Yangjiang, China; Kerala, India; Guarapari, Brazil and Ramsar, Iran. (Figure. 1).

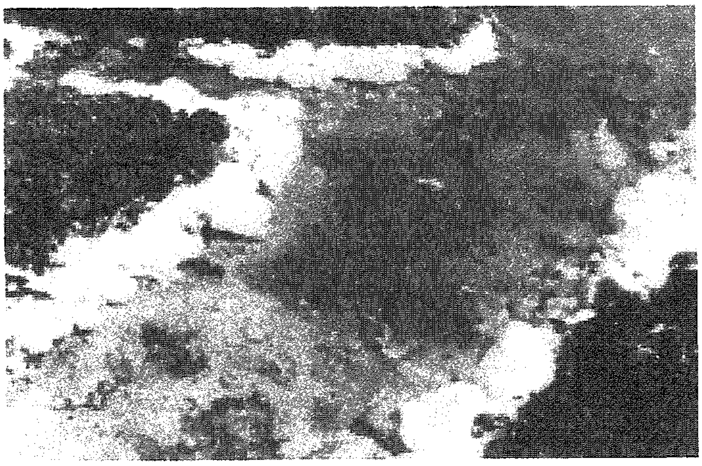

Figure 1. Ramsar hot springs. White-colored sediments at the streams' bed have high concentrations of Radium-226. In some cases, residents of these hot areas have used the residue of the hot springs as building materials to construct their houses.

Ramsar in northern Iran is among the world's well-known areas with highest levels of natural radiation. Annual exposure levels in areas with elevated levels of natural radiation in Ramsar are up to 260 mGy y^{-1} and average exposure rates are about 10 mGy y^{-1} for a population of about 2000 residents.

Biological Findings on HLNRAs of Ramsar

- **Chromosome Aberrations.** Preliminary results showed no significant difference even in the case of the inhabitants who lived in houses with extraordinarily elevated levels of natural radiation.
- **Dose-Effect Relationship.** There is a great controversy about the dose-effect relationship in published reports on the frequency of chromosome aberrations induced by chronic exposure to elevated environmental levels of radiation. This controversy exists in studies of residents in areas with elevated levels of natural radiation as well as the residents of areas contaminated by nuclear accidents. Using chromosomal aberrations as the main endpoint, an experiment to assess the dose-effect relationship in the residents of high level natural radiation areas of Ramsar was carried out. A cytogenetical study was performed on 21 healthy inhabitants of the high level natural radiation areas and 14 residents of a nearby control area. Preliminary results showed no positive correlation between the frequency of chromosome aberrations and the cumulative dose of the inhabitants.
- **Hematological Alterations.** It has been reported that in mice and rats total body exposure to moderate doses decreases the number of circulating erythrocytes, platelets, granulocytes, lymphocytes etc. However, data on hematopoieses as a result of exposure to very low doses of ionizing radiation are scarce. Hematological parameters such as counts of leukocytes (WBC), lymphocytes, monocytes, granulocytes, red blood cells (RBC), hemoglobin (Hb), hematocrit (Ht), MCV, MCH, MCHC, RDW, PLT, and MPV were studied in all of the individuals. The results of this study indicated that there was no any statistically

significant alteration in hematological parameters of the inhabitants of HLNRAs of Ramsar compared to those of the neighboring control area.

- **Immunological Changes.** It is well known that high doses of ionizing radiation suppress the activity of the immune system. On the other hand, the low-level whole body irradiation (WBI) can enhance the immunological response. To assess whether relatively high doses of natural radiation can alter humoral immune parameters, an experiment was conducted on the inhabitants of HLNRAs of Ramsar, permanently living in houses with elevated levels of natural radiation. Immunological factors such as the concentration of serum immunoglobulins of IgA, IgG, IgM and C3, C4 components of the complement system in healthy donors from HLNRAs and a neighboring NBRA were studied. Preliminary findings indicate that there is a slight increase in IgA and IgG levels of the inhabitants of HLNRAs compared to those of matched controls. IgM, C3, and C4 complements were in the normal range. In spite of the fact that the increase in IgA and IgG were not so marked to show probable enhanced immunological capability, it can be concluded that relatively high doses of natural radiation are not immunosuppressive. More research is needed to clarify the immunological alterations induced by different levels of natural radiation.
- **Radioadaptive Response** It has been shown that in high level natural radiation areas (HLNRAs) of Ramsar, the blood cells of inhabitants whose cumulative radiation doses were 170 times higher than of those living in a nearby control area (2,550 mSv and 15 mSv respectively) were significantly more radioresistant to chromosomal damage when subjected to 1.5 Gy challenge dose (Ghiassi-nejad et al. 2002, Mortazavi et al. 2002, Mortazavi 2002). The relationship between the degree of AR (as indicated by the k-value[2]) and cumulative lifetime dose is an important finding. The AR of the residents of Iranian HLNRAs is more pronounced at higher cumulative doses, except for 2 residents, whose cumulative doses are much higher than those of the others (Mortazavi et al. 2002).

The results of the adaptive responses observed in the residents of high level natural radiation areas of Ramsar are summarized here:

- Individuals whose cumulative radiation doses were up to 950 mGy, showed a significant AR after exposure of their cultured lymphocytes to 1.5 Gy gamma radiation . These doses are much higher than those received by astronauts during a six-month space mission that has been reported to be 90 mGy absorbed dose and 180 mSv equivalent dose. The radiation dose of these astronauts ranged 95-455 mGy (Testard et al. 1996).

---

[2] The k-value is the coefficient of induced adaptive response (k) that shows the magnitude of the adaptive response and can be calculated as the ratio of the observed frequency to the expected frequency of chromosome aberrations.

- There is a controversy over the induction of AR in resting cells (Cai and Liu 1990, Shadley et al. 1987, Azzam et al. 1992). Ramsar results showed that high levels of natural radiation might enhance radiation-resistance in non-cycling lymphocytes. Since the majority of the lymphocytes in the body are in the resting phase of the cell cycle (G_0), any implication of AR strongly depends on the possibility of induction of AR in G_0 stage.
- ARs have been usually observed in experiments by exposing the cells to a low dose radiation in the range of 10-100 mGy. These doses are considerably lower than the lifetime doses that induced AR in the inhabitants of HLNRAs of Ramsar.
- It was suggested that aging could cancel the AR (Gadhia 1998). This is contrary to findings in Ramsar population which show that aging does not influence the induction of AR.

The cumulative doses and the magnitudes of the induced adaptive response in cultured lymphocytes of residents of Ramsar HLNRAs are shown in Figure 2.

2.5. Potential Implications of Radioadaptation in Radiation Protection

It was generally believed that the presence of AR does not mean that the low dose radiation is beneficial to living organisms (Sagan 1989, Wolff 1989). Even in its 1994 report on adaptive responses to radiation in cells and organisms (UNSCEAR 1994), after reviewing experimental and epidemiological studies showing increased longevity and lower-than-expected incidence of tumors, UNSCEAR stated that "it would be premature to conclude that cellular adaptive response could convey possible beneficial effects to the organism that would outweigh the detrimental effects of exposure to low doses of low-LET radiation". However, more recent worldwide studies on the different aspects of AR, have lead to recognition of its positive health effects, and to a more realistic assessment of the risk of radiation. The preliminary studies of the Ramsar residents (Mortazavi et al. 2001), suggest that the induced AR might have considerable implications for radiation protection, and that the chronic low dose radiation may be protective against accidental high dose radiation (Pollycove and Feinendegen 2001).

2.6. Radioadaptation and Deep Space Manned Missions

Based on Ramsar findings, it has been recently reported that adaptive response studies may have implications in radiation protection. It was proposed that individuals who failed to show an adaptive response would not be good candidates for space travel (Mortazavi et al. 2003a, Mortazavi et al. 2003b). These authors suggested that all potential crew members for a deep space mission had their adaptive response measured. The space crew should show a high magnitude of adaptive response. The chronic exposure to elevated levels of space radiation during a long-term mission can considerably decrease their radiation susceptibility and protect them against the unpredictable exposure to sudden and dramatic increase in flux due to solar flares and coronal mass ejections.

References

Azzam E.I., S.M. de Toledo, G.P. Raaphorst and R.E.J. Mitchel. Radiation-induced radioresistance in a normal human skin fibroblast cell line, In Low Dose Irradiation and Biological Defense Mechanisms (T. Sugahara, L.A. Sagan and T. Aoyama, Eds), pp. 291-294, Amsterdam: Excerpta Medica, 1992.

Band PR, Le ND, Fang R, Deschamps M, Coldman AJ, Gallagher RP, Moody J. Cohort study of Air Canada pilots: mortality, cancer incidence, and leukemia risk. Am J Epidemiol, 143(2):137-43,1996.

Barquinero J.F., L. Barrios, M.R. Caballin, R. Miro, M. Ribas, A. Subias and J. Egozcue, Occupational exposure to radiation induces an adaptive response in human lymphocytes., Int. J. Radiat. Biol. 67, 187-91 (1995).

Cai L. and S.Z. Liu, Induction of cytogenetic adaptive response of somatic and germ cells *in vivo* and *in vitro* by low dose X-irradiation. Int. J. Radiat. Biol. 58, 187-194 (1990).

Cortes F., I. Dominguez, S. Mateos, J. Pinero and JC. Mateos, Evidence for an adaptive response to radiation damage in plant cells conditioned with X-rays or incorporated tritium. Int J Radiat Biol, 57, 537-41 (1990).

Deorukhakar V.V. and B.S. Rao, Induction of gene conversion in yeast cells continuously cultured at high radiation background. Radiat Environ Biophys. 34, 185-90 (1995).

Farooqi Z.and PC. Kesavan, Low-dose radiation-induced adaptive response in bone marrow cells of mice. Mutat. Res. 302, 83-9 (1993).

Fedorenko B, Druzhinin S, Yudaeva L, Petrov V, Akatov Y, Snigiryova G, Novitskaya N, Shevchenko V, Rubanovich A. Cytogenetic studies of blood lymphocytes from cosmonauts after long-term space flights on Mir station. Adv Space Res. 27, 355-9 (2001).

Flores M.J., J. Pinero, T. Ortiz, N. Pastor, J.C. Mateos and F. Cortes, Both bovine and rabbit lymphocytes conditioned with hydrogen peroxide show an adaptive response to radiation damage. Mutat. Res. 372, 9-15 (1996).

Frigerio N.A., and Stowe R.S. Carcinogenic and Genetic Hazard from Background Radiation, in Biological and Environmental Effects of Low-Level Radiation, International Atomic Energy Agency, Vienna, Austria, pp.385-393, 1976.

Fritz-Niggli H. and C. Schaeppi-Buechi, Adaptive response to dominant lethality of mature (class A) and immature (class B) oocytes of D. melanogaster to low doses of ionizing radiation: effects in repair-proficient (yw) and repair-deficient strains (mei 41D5 and mus 302D1). Int J Radiat Biol. 59, 75-84 (1991).

Gadhia PK., Possible age-dependent adaptive response to a low dose of X-rays in human lymphocytes. Mutagenesis. 13, 151-2 (1998).

Ghiassi-nejad M, Mortazavi SMJ, Cameron JR, Niroomand-rad A and Karam PA, Very High level natural radiation areas of Ramsar, Iran: Preliminary Biological Studies. Health Physics. 82, 87-93 (2002).

Gourabi H. and H. Mozdarani, A cytokinesis-blocked micronucleus study of the radioadaptive response of lymphocytes of individuals occupationally exposed to chronic doses of radiation. Mutagenesis. 13, 475-80 (1998).

Heimers A., Chromosome aberration analysis in Concorde pilots. Mutat Res. 467, 169-76 (2000).

Ikushima T., Chromosomal responses to ionizing radiation reminiscent of an adaptive response in cultured Chinese hamster cells. Mutation Research. 180, 215-221 (1987).

Irvine D, Davies DM. British Airways flightdeck mortality study, 1950-1992. Aviat Space Environ Med. 70(6):548-55, 1999.

Ishii K.and M. Watanabe, Participation of gap-junctional cell communication on the adaptive response in human cells induced by low dose of X-rays. Int. J. Radiat. Biol. 69, 291-9 (1996).

Jagger, J. Natural background radiation and cancer death in Rocky Mountain states and Gulf Coast states. Health Phys. 75:428-430, 1998.

Jaworowski Z., Beneficial effects of radiation and regulatory policy. Australas Phys Eng Sci Med. 20, 125-38 (1997).

Jensen R.H., Zhang S., Wang Z., Wang W.and Boice J., Glycophorin A somatic cell mutation frequencies in residents of Tibet at high altitudes. Health Phys. 73, 663-7 (1997).

Karam PA, Leslie SA. Calculations of background beta-gamma radiation dose through geologic time. Health Phys. 77(6):662-7, 1999.

Karam P. A. (2001) Changes in background cosmic radiation dose during the history of life on Earth. Ph.D. thesis, Ohio State University.

Liu S.Z., L. Cai and S.Q. Sun, Induction of a cytogenetic adaptive response by exposure of rabbits to very low dose-rate gamma-radiation. Int. J. Radiat. Biol. 62,187-90 (1992).

Mortazavi S.M.J., M. Ghiassi Nejad and M. Beitollahi. Very High level natural radiation areas (VHLNRAs) of Ramsar: Do We Need any Regulations to Protect the Inhabitants? Proceedings of the 34th midyear meeting, Radiation Safety and ALARA Considerations for the 21st Century, California, USA, 177-182, (2001).

Mortazavi S.M.J., M. Ghiassi-nejad, A. Niroomand-rad, P.A. Karam and J.R. Cameron, How should governments address high levels of natural radiation and radon? Lessons from the Chernobyl nuclear accident, Risk: Health, Safety and Environment. 13, 31-36 (2002).

Mortazavi, SMJ, Karam P.A. High Levels of Natural Radiation in Ramsar, Iran: Should Regulatory Authorities Protect the Inhabitants? Iranian Journal of Science (Germany), 2 (2): 1-9, 2002.

Mortazavi, SMJ., Risk Assessment: Extraordinary Levels of Natural Radioactivity in the Environment and the Problems Associated with Induced Radioresistance, In: Proceedings of the International Conference on Radioactivity in the Environment. Borretzen P, Jolle T, and Strand P. Eds, pp. 110-113, 2002.

Mortazavi SMJ, Cameron JR, and Niroomand-rad A. Adaptive response studies may help choose astronauts for long-term space travel, Advances in Space Research, 31 (6): 1543-1552, 2003a.

Mortazavi SMJ, Cameron JR, and Niroomand-rad A. Is the Adaptive Response an Efficient Protection Against the Detrimental Effects of Space Radiation. Proceedings of the 28th International Cosmic Ray Conference, Universal Academy Press, pp 4299-4302, 2003b.

Mortazavi SMJ, Ikushima T, and Mozdarani H. Variability of chromosomal radioadaptive response in human lymphocytes. IJRR, 1(1): 55 - 61, 2003c.

Mortazavi SMJ, Ghiassi-Nejad M, Ikushima T, Assaie R, Heidary A, Varzegar R, Zakeri F, Asghari K, and Esmaili A. Are the Inhabitants of High level natural radiation areas of Ramsar More Radioresistant? Scope of the Problem and the Need for Future Studies. Iranian Journal of Radiology, 1(1), 37-43, 2003d.

Olivieri G., Bodycote J. and Wolff S., Adaptive response of human lymphocytes to low concentrations of radioactive thymidine, Science, 223, 594-597 (1984).

Planel H, Soleilhavoup JP, Tixador R, Richoilley G, Conter A, Croute F, Caratero C, Gaubin Y. Influence on cell proliferation of background radiation or exposure to very low, chronic gamma radiation. Health Phys.;52(5):571-8, 1987.

Pollycove M. and LE. Feinendegen. The Journal of Nuclear Medicine. 42, 26N-37N (2001).

Sagan LA., On radiation, paradigms, and hormesis. Science. 245, 574, 621 (1989).

Samson L. and J. Cairns, A new pathway for DNA repair in *Escherichia coli*. Nature. 267, 281-282 (1977).

Sankaranarayanan K., A. Von Duyn, M. Loos and A.T. Natarjan, Adaptive response of human lymphocytes to low level radiation from radioisotopes or X-rays. Mutat. Res. 211, 7-12 (1989).

Satta L, Augusti-Tocco G, Ceccarelli R, Esposito A, Fiore M, Paggi P, Poggesi I, Ricordy R, Scarsella G, Cundari E. Low environmental radiation background impairs biological defence of the yeast Saccharomyces cerevisiae to chemical radiomimetic agents. Mutat Res. 347(3-4):129-33, 1995.

Satta L, Antonelli F, Belli M, Sapora O, Simone G, Sorrentino E, Tabocchini MA, Amicarelli F, Ara C, Ceru MP, Colafarina S, Conti Devirgiliis L, De Marco A, Balata M, Falgiani A, Nisi S. Influence of a low background radiation environment on biochemical and biological responses in V79 cells. Radiat Environ Biophys. 41(3):217-24, 2002.

Shadley J.D. and S. Wolff, Very low doses of X-rays can cause human lymphocytes to become less susceptible to ionizing radiation, 2, 95-96 (1987).

Shadley J.D. and J.K. Wiencke, Induction of the adaptive response by X-rays is dependent on radiation intensity. Int. J. Radiat. Biol. 56, 107-118 (1989).

Shadley J.D., V. Afzal and S. Wolff. Characterization of the adaptive response to ionizing radiation induced by low doses of X rays to human lymphocytes. Radiat Res. 111, 511-7 (1987).

Shouzhi Z., Current status of space radiation research in China, In Exploring Future Research Strategies in Space Radiation Science, (H.J. Majima and K. Fujitaka, Eds), pp. 99-103, Tokyo: Iryokagakusha, 2000.

Testard I., M. Ricoul, F. Hoffschir, A. Flury-Herard, B. Dutrillaux, B. Fedorenko, V. Gerasimenko and L Sabatier, Radiation-induced chromosome damage in astronauts' lymphocytes. Int J Radiat Biol. 70, 403-11 (1996).

UNSCEAR, Sorces and Effects of Ionizing Radiation, Report to the General Assembly, United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations, New York, NY, 1994.

UNSCEAR, Sources and Effects of Ionizing Radiation, Report to the General Assembly, United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations, New York, NY, 2000.

Wiencke J.K., V. Afzal, G. Olivieri and S. Wolff, Evidence that the [3H] thymidine induced adaptive response of human lymphocytes to subsequent doses of X-rays involves the induction of chromosomal repair mechanism. Mutagenesis. 1, 375-380 (1986).

Wojcik A. and H. Tuschl, Indications of an adaptive response in C57BL mice pre-exposed *in vivo* to low doses of ionizing radiation. Mutat. Res. 243, 67-73 (1990).

Wolff S., Are radiation-induced effects hormetic? Science. 245, 575, 621 (1989).

Wolff S., Afzal V., J.K. Wiencke and G. Olivieri, Human lymphocytes exposed to low doses of ionizing radiation become refractory to high doses of radiation as well as to chemical mutagens that induce double strand breaks in DNA. Int. J. Radiat. Biol. 53, 39-48 (1988).

Xin X.F., Cosmic radiation levels and the status of mortality from malignant tumors in Tibet. Chin. J. Radiat. Med. Prot. 3, 1-31, (1983).

Zeeb H, Blettner M, Hammer GP, Langner I. Cohort mortality study of German cockpit crew, 1960-1997. Epidemiology, 13(6):693-9, 2002.

Zwingmann I.H., I.J. Welle, van M. Herwijnen, J.J. Engelen, P.A. Schilderman, T. Smid and J.C. Kleinjans, Oxidative DNA damage and cytogenetic effects in flight engineers exposed to cosmic radiation. Environ Mol Mutagen. 32, 121-9 (1998).

SESSION Ⅳ

NATURALLY OCCURRING RADIATION/RADIOACTIVITY AND ITS USE

TUESDAY, AUGUST 24