Documented optimum and threshold for ionising radiation

T.D. Luckey

1719 Brandon Woods Drive, Lawrence, KS 66047, USA
E-mail: tdl108@sunflower.com

Abstract: A concept of the complete dose-response curve of ionising radiation will allow us to live in harmony with this ubiquitous agent. Convincing data show ionising radiation is essential for life. Ambient levels of ionising radiation (about 2 mSv/y without medical and cosmic radiation) are adequate for life but insufficient for abundant health. We live with a partial deficiency of ionising radiation. Thousands of people have lived for generations with 2–20 times the ambient levels of radiation without showing ill health. A conservative threshold, the maximum safe level of radiation, was estimated from abundant rodent data to be about 8000 mSv/y. When human and rodent data were collated, a conservative optimum of 60 mSv/y was obtained. Radiation levels greater than the threshold are harmful. The facts suggest that radiobiologists and governments should abandon the 'linear no threshold' (LNT) paradigm and accept natural and industrial low level sources of ionising radiation in order to promote abundant health.

Keywords: ambient radiation; cancer; deficiency; essential agent; health; nurture; optimum level; safe level; threshold.

Reference to this paper should be made as follows: Luckey, T.D. (2007) 'Documented optimum and threshold for ionising radiation', *Int. J. Nuclear Law*, Vol. 1, No. 4, pp.378–409.

Biographical notes: Sir Samurai T.D. Luckey, PhD, is Professor Emeritus of the University of Missouri and Honorary Professor of the Free University at Herborn, Germany. He has a BSc in chemistry from Colorado State University and both MSc and PhD in nutrition and biochemistry from Wisconsin University. He spent eight years as Research Professor in gnotobiology at Notre Dame University and 30 years as Professor of Biochemistry in the Medical School of the University of Missouri. In 1979 he received a Humboldt award for Senior Scientists to study in Germany. In 1984 he was knighted, *Ritter von Greifenstein,* for his international leadership in microecology. In 2003 he became an honorary Samurai for bringing radiation health to Japan. He is a member of the Board of Directors for Radiation, Health and Science and is an honorary member of the International Society of Hormesis and the Environmentalists for Nuclear Energy.

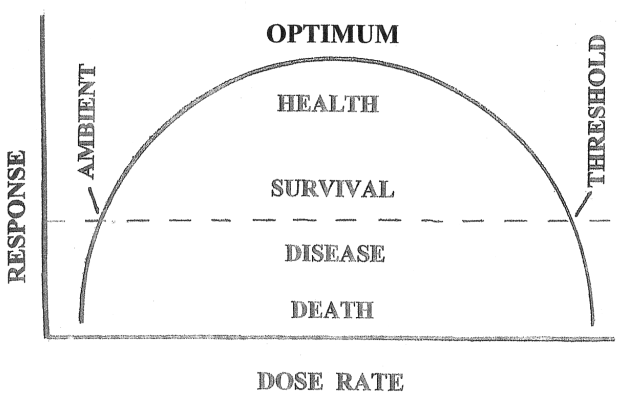
1 Introduction

To live in harmony with ionising radiation we must consider the complete dose-effect relationships for continuous exposures. The average background level of ionising radiation for the world is about 2 mSv/y; this does not include medical or cosmic radiation (Luckey, 1991). Most population centres occur on coasts which have low levels of ionising radiation.

Dose rate is tremendously important. Large and small doses elicit opposite effects. For example, most of the pills we take daily provide reasonable health; if we took a years supply in one day, we would be in great danger. This truth applies to ionising radiation.

Physiological responses to different dose rates are formidable (Figure 1). Death and disease characterise both doses below ambient levels and doses greater than the (second) threshold, the zero equivalent point (ZEP). Ambient radiation provides reasonable health. This is a minimum; less than this would induce a radiation deficiency. Dose rates between ambient and the threshold are considered to be 'low doses'; these are biopositive. Un-imagined health is promised for increased amounts of irradiation. The optimum is that level which produces the most abundant health. At the threshold, any parameter measured is comparable with that at ambient levels. The threshold is the highest level that can be reasonably considered to be safe. Radiation levels greater than the threshold are harmful. Information will be reviewed to provide a quantitative estimate of deficient, optimum and safe (threshold) levels for chronic exposures of ionising radiation. Such information is necessary in order to live in harmony with ionising radiation. There are no significant studies in English which show harm (increased cancer mortality rates or decreased average lifespan) from low dose irradiation of humans or rodents with normal genetic constitutions.

Figure 1 Complete dose-response curve for an essential agent



Without significant evidence of harm in normal humans or other vertebrates, national and international committees promulgate the concept that 'all radiation is harmful' and the paradigm of a linear no threshold (LNT) response to ionising radiation. For half a century, radiobiologists have refused to accept scientific evidence and remove LNT as their guide. The concept and the paradigm are challenged by data showing biopositive effects induced by low dose irradiation in 3000 scientific studies (Luckey, 1980; Muckerheide, 2000) and, as documented here, many thousands of humans live with more than 4 mSv/y of radiation. It is time to accept the findings of the elite committee from the French Academies of Sciences and the National Academy of Medicine: 'In conclusion, this report doubts the validity of using LNT in the evaluation of the carcinogenic risk of low doses (<100 mSv) and even more for very low doses (10 mSv)' (Aurengo et al., 2005), and finally, 'With regard to radiation leukaemias, the dose-effect relationship is statistically incompatible with an LNT relationship'. The collective mass of data and sentiment against LNT show that the biopositive effects of low dose irradiation need to be expressed in rational revisions of national and international laws. National laws should not abrogate natural law.

2 Characterisation of an essential agent

The characteristics of an essential agent are outlined graphically in Figure 1. Beginning at the left side, disease and death characterise a deficiency of an essential agent. Supplementation with a specific material identifies the deficient agent. Ambient levels of the agent establish an 'ambient threshold' which may involve a partial deficiency. From these, optimum and safe levels can be established. The second threshold is the threshold of contention; it is called the 'zero equivalent point' (ZEP) because the examined parameter at this does is equivalent to that found with no added radiation. As the dose increases beyond the second threshold, an excess of the agent induces an acute toxicity and death ensues. This threshold varies with the conditions of the study as well as the parameter being studied.

The complete dose-response curve applies to about 40 essential nutrients (Luckey, 1977). For each of these a deficiency was well defined, a specific agent was found to cure the deficiency, an optimum established and safe and harmful levels were determined. These characteristics of an essential agent are pivotal to our understanding of the role of ionising radiation in our lives.

The term nurture and the complete dose-response curve apply to other essential agents of our environment. Examples include heat, gravity and light as well as ionising radiation. There is adequate information for quantitative estimates of deficient, ambient, optimum, threshold and toxic levels of ionising radiation for humans. Evidence of ionising radiation as an essential agent is reviewed.

3 Radiation as an essential agent

Studies with a variety of species have consistently shown that ionising radiation is essential for life (Table 1). In one example, a heterotrophic bacterium, *Escherichia coli,* (#1, Table 1) showed a decreased growth rate when it was deprived of internal ionising radiation from natural potassium; the non-radioactive ^{39}KCl was substituted (Luckey, 1983).

Swiss researchers worked for a decade to prepare a special 'low cosmic radiation' room (almost 3000 m underground) with steel boxes (to reduce background radiation) and aged water and air (lowered radon content) to determine the effect of a deficiency of ionising radiation in plants and an invertebrate (Eugaster, 1964). Their three experiments (#2, an alga; #4, barley; and #8, shrimp eggs, shown in Table 1) are impressive because they continued until the deficient cultures had zero viability. They used natural (radioactive) potassium in the media.

Table 1 Evidence of a deficiency of ionising radiation

				% success		
Organism		*Days*	*Effect*	*Deficient*	*Control*	*Ref*
1	bacteria	0.6	growth	25	100	Luckey (1983)
2	alga	30	viability	0	50	Eugaster (1964)
3	alga	5	growth	75	100	Planel et al. (1987)
4	barley	180	viability	0	85	Eugaster (1964)
5	paramecium	8	growth	42	100	Planel et al. (1987)
6	paramecium	7	growth	6	100	Luckey et al. (1978)
7	protozoan	6	growth	41	100	Luckey (1986)
8	shrimp eggs	263	viability	0	65	Eugaster (1964)
9	rat	30	growth	~50	100	Kuzin and Krymskya (1994)
10	mouse	42	growth	<50	100	Kuzin and Krymskya (1994)

Notes: 1 *Escherichia coli* – these experiments were performed in ambient levels of ionising radiation at Argonne National Laboratory (ANL) with non-radioactive potassium, ^{39}K, in the medium (Luckey, 1983)

2 *Mastigocladus laminosus* – experiments #2, #4 and #8 were performed within a 10 cm steel box with light in a room at the middle of the Simlon Tunnel, about 8000 feet below Mt Leone-Massive, France (Eugaster, 1964)

3 *Synechococcus lividus* – when housed in a 10 cm lead box with light in a surface laboratory, the level of ionising radiation was only 17% that of the control (Planel et al., 1987)

4 *Hordeum bonus* – the conditions were those described in #2 (Eugster, 1964)

5 *Paramecium tetraurelia* – conditions were as in #3, without light and with bacteria as a food source (Planel et al., 1987)

6 *Paramecium bursaria* – cultures were maintained in a surface laboratory within a 10 cm lead box inside an incubator (Luckey et al,. 1978). The medium was sterilised wheat extract and contained unidentified bacteria as a food source

7 *Tetrahymena pyriformis* – ambient radiation was reduced with a 1 cm lead box, within a room with 21 cm old-steel walls; this was under 3 m dirt and 21 cm special cement at Argonne National Laboratory. Pure cultures of this protozoan were fed a chemically defined medium with non-radioactive ^{39}KCl and low radon air and water (Luckey, 1986)

8 Brine shrimp, *Artemia salina* – the conditions were as described in #2 (Eugster, 1964)

9 *Rattus rattus* – rats were reared within a 9 cm lead box which reduced background radiation to about 15% of ambient. Weaned rats were fed diets with ^{39}KCl in place of naturally radioactive KCl (Kuzin, 1984)

10 *Mus sp* – Kuzin and associates kept young mice in about 15% of ambient radiation (with low radon and within a 9 cm lead box). They were fed diets with ^{39}KCl in place of naturally radioactive KCl (Kuzin, 1984; Ruda and Kuzin, 1991)

Planel et al. (1987) led the French team at Toulouse to explore the effects of subambient levels of ionising radiation. Under full illumination, the blue-green alga (#3, Table 1) grew at a reduced rate when grown in lead boxes. The protozoan (#5, Table 1) grew less than that of the control cultures outside the box ($p < 0.001$). They ignored radon, used natural (radioactive) KCl in their media and took no precautions to reduce radon.

The experiments of Luckey and associates (1978) showed reduced replication in protozoa (#6, Table 1); these were performed, with medical students, in a 10 cm lead box at the University of Missouri, Columbia, MO (Luckey *et al.*, 1978). The media contained natural KCl and no precautions were taken to reduce radon.

More sophisticated experiments with pure cultures of the paramecium *Tetrahymena pyriformis* (#7, Table 1), were performed in the low radiation laboratory at ANL (Luckey, 1986). The decreased growth ($p < 0.01$) in this 30-fold reduction of ambient radiation was eliminated in control cultures maintained in the same box, behind a lead barrier, with radiation from a $^{137}CsNO_3$ source. In the absence of human data 'Experimental data from laboratory organisms must be used' (p. 94, BEIR III, 1980).

Data from early Russian research have been neglected. Planel et al. (1987) reported that, when compared with unshielded controls, the protozoa *Colpoda* grew at a lower rate when shielded from ambient radiation (Kozlov, 1972). The experiments reported in Table 1 followed previous studies with rats and mice (Kuzin, 1984, Ru 91). The radiation deficient rats and mice (#9 and #10, Table 1) were fed with the non-radioactive potassium-39 (Kuzin and Krymskaya, 1994).

The results of Eugster (#2, #4, and #8, Table 1), Planel et al. (#3 and #5, Table 1) and Luckey (#1 and #7, Table 1) indicate natural potassium is inadequate as the sole source of ionising radiation. The data from paramecia (#7, Table 1) and mammals (#9 and #10, Table 1) indicate radioactive potassium can counteract a radiation deficiency.

The consistency of the phylogenetic evidence from bacteria, algae, land plants, protozoa, invertebrates and mammals (Table 1) allows extrapolation to suggest that humans require ionising radiation. Further evidence of such a requirement can be inferred from the very positive response of humans to increased levels of ionising radiation. As shown in the next section, the good health of humans exposed to unusual levels of ionising radiation is evidence of a partial deficiency at ambient levels. These data support the hypothesis that humans require ionising radiation.

4 Life with increased radiation

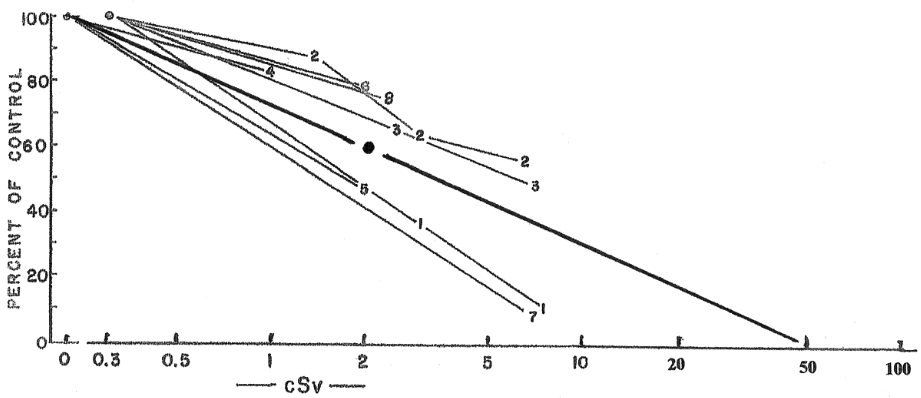
In contrast to the above data showing a deficiency of radiation, hundreds of thousands of people have lived in good health with unusually high levels of ionising radiation. These come from four unrelated arenas:

- Many populations have lived, in apparent good health, through many generations with ten times the world average radiation. Many thousands of people in small villages receive five, ten, and up to 100 times the world average of 2 mSv/y. Documentation of these people shows they come from all over the world (Appendix). No studies show unusual health problems or reduced average lifespan for any of these people.
- Cohen (1995) measured radon in 272,000 homes in 1729 counties selected to represent 90% of the population of the US. There was a strong negative correlation between radon concentration and lung cancer mortality. Although smoking was an independent variable, none of over 50 socioeconomic variables could account for the results. High levels of home radon protect humans from lung cancer ($p < 0.0001$). Several studies concluded that the leukaemia death rate in was inversely proportional to background radiation in the US (Craig and Seidman, 1961; Frigerio and Stowe, 1976; Saur, 1980; Webster, 1983).

- Radiation contaminated nuclear workers had cancer death rates which decreased in direct proportion to the dose (Figure 2). An estimate of the most healthy dose for continuous human exposure to ionising radiation involves meta analysis of these cohorts which involve over seven million person-years. Eight studies, with some overlap, compared the cancer death rate in 123,846 exposed nuclear workers with that of carefully selected unexposed control workers for a weighted average of 34.2 years. There was no 'healthy worker effect'. The weighted average cancer death rate at 2 cSv lifetime radiation dose was used to extrapolate to zero cancer deaths. This value is about 50 cSv lifetime exposure. This extrapolation indicates that 15 mSv/y would eliminate cancer mortality as a major cause of death.
- Rowland (1997) noted that radium dial painters with less than 16 Gy total intake had no bone tumours. The great majority of radium dial painters, those who were exposed to less than the threshold dose of 16 Gy, lived in health. During the next 48 years they had a death rate which was only 88% that of controls. This indicates that persons who received up to 33 mGy/y had a somewhat longer average lifespan (p = 0.05) than the control group. Those who received more than the threshold value, a lifetime dose of about 20 cGy, had bone cancers in proportion to the dose. This study of radium dial painters is unique in showing a threshold with continuous exposure to ionising radiation in humans.

This wide range of evidence showing no harm from increased radiation levels has not gone unnoticed. Statements from independent researchers are provided in the discussion.

Figure 2 Ten year lagged cancer mortality rates of contaminated (film badge record) nuclear workers as a percent of unexposed controls from the same plant with each judged to have the same socio-economic characteristics (Luckey, 2000). There is some duplication within almost eight million person-years experiences: 1 – 3,237,378 person-years at British weapons plants (Kendall et al., 1992), 2 – 419,467 person-years included in the data of #1 (Beral et al., 1988), 3 – 705,395 person-years at Oak Ridge National Laboratory (Gilbert et al., 1989), 4 – 286,320 person-years at Canadian power plants (Gribbin et al., 1983), 5 – 291,130 person-years at Oak Ridge National Laboratory (Wing et al., 1991), 6 – 1,591,832 person-years in nuclear shipyards (Matanoski, 1991), 7 – 268,320 person-years at a Canadian nuclear power plant (Abbatt et al., 1983), 8 – 456,637 person-years at Los Alamos National Laboratory (Wiggs et al., 1994)

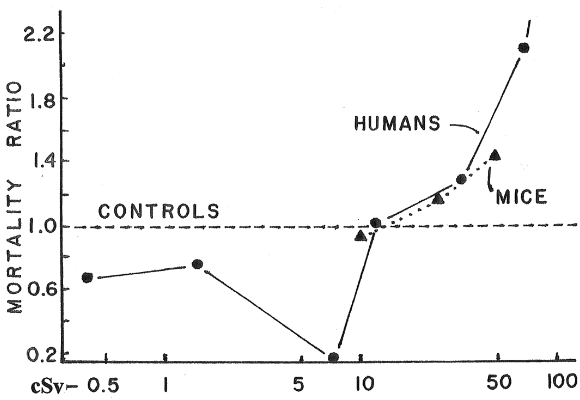


5 Threshold

The threshold is the zero equivalent point (ZEP), the dose at which any given parameter is indistinguishable from the control group at ambient levels. Since there is no bionegative effect at any dose greater than the ZEP, this is the maximum safe level for exposure to ionising radiation.

Excepting the radium dial painter study, there are no data showing a threshold for continuous exposure to ionising radiation in humans. Of many studies which show a threshold with acute doses of ionising radiation, some show how closely human and rodent values match (Figure 3) (Luckey, 1991, 2003). In this example, the thresholds for humans and mice were both about 10 cSv. This agreement indicates it is reasonable to collate rodent and human data to estimate a threshold for chronic radiation exposure in humans. In the absence of human data 'Experimental data from laboratory organisms must be used' (p. 94, BEIR III, 1980).

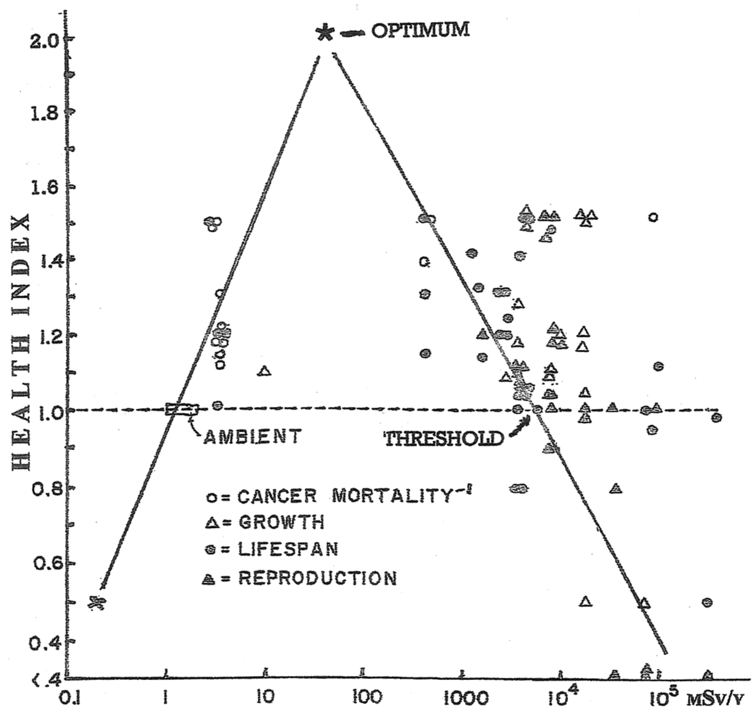
Figure 3 Leukaemia mortality following acute irradiation of humans and mice. The human data are from Japanese atomic bomb survivors (Shimizu et al., 1992). The mice were exposed to acute doses of gamma radiation (Upton et al., 1970)



The effects of daily irradiation in rodents is plotted on the right side of Figure 4. Each experiment has been reported separately (Luckey, 1991). The parameters are cancer mortality (inversion makes decreased cancer a biopositive effect), growth, average lifespan and reproduction. In contrast to the rainbow curve in Figure 1, the abscissa in Figure 4 provides radiation as a logarithmic function. Since the effects of radiation are directly proportional to the logarithm of the dose, the average can be expressed as a straight line. A least squares approach would make the threshold about 10 Sv/y.

There is a more acceptable alternative to the least squares approach. It is usual to set limits for health effects at a most conservative condition. When a very conservative line is drawn, the threshold is 8000 mSv/y. Therefore, 8000 mSv/y is the value of choice for a conservative, maximum safe level of ionising radiation for humans. This provides a safety factor of about 4000 times ambient radiation levels.

Figure 4 Collated human and rodent data showing major effects of radiation: deficiency, ambient, hormesis, threshold and excess



6 Optimum

A documented optimum is obtained by collating human and rodent data. Of the many examples of people living with increased levels of ionising radiation, few have been examined with specific evaluation of cancer mortality, growth, average lifespan or reproductive capacity. The few data available (Luckey, 1991) are combined with information about deficiencies to provide an important element for an estimate of the optimum for humans with continuous exposure to ionising radiation (Figure 4). The straight line on the left side of the figure represents the human data. Extension of this line to its intersection with the line from right, the rodent data, forms a lambda curve. The tip of this lambda curve represents the optimum dose, a minimum yearly radiation allowance (MYRA), for humans.

Using the least squares method or the mean of all the data from each side, the optimum is about 90 mSv/y. A more viable alternative, with concern for a most conservative estimate, places the peak of the lambda curve at about 60 mSv/y. This is a best estimate. Luckey (1997) previously suggested 'The evidence supports a minimum yearly allowance (MYRA) of seven centiGrey/year (70 mGy/y) for adult males.'

The safety factor between the conservative optimum (60 mSv/y) and a conservative maximum safe level (8000 mSv/y) for ionising radiation is 133. This is considerably more than the safety factors for some of our essential nutrients: vitamin A, 5; iron, 7; and selenium, 9 (Luckey, 1981).

7 Discussion

Collated evidence from humans and rodents shows that ionising radiation is beneficial. Appreciation of the complete dose-response curve will allow us to live in harmony with ionising radiation. The complete dose response curve indicates:

- a radiation deficiency can be induced
- we live in a partial deficiency of ionising radiation
- the optimum for ionising radiation is 60 mSv/y, about 30 times ambient levels
- the threshold, the maximum safe level, is 8000 mSv/y, about 4,000 times the ambient level for most people.

The complete dose-response curve indicates most people live with a radiation deficiency. Supplementation would produce bountiful health (Luckey, 2003). The main mechanism is the activation of the immune system by ionising radiation. Luckey (1991) discussed the increased efficiency of cellular immunity and Liu (1997, 2003), Ina and Sakai (2004) and Shawn et al. (2006) show increased enzymes and cytokines following low doses of irradiation in rodents. The benefits have been enumerated previously: better health, increased fertility, activated immune system, lower death rates from cancer and infectious disease and longer average lifespan. For example, adequate ionising radiation may decrease the cancer death rate to below 5% of that of today. This example of abundant health is promised by extrapolation of the data in Figure 2 and evidence from Taiwan (Chen et al., 2004); three US weapons plants (Gilbert et al., 1989); the Canadian nuclear workers (Abbatt et al., 1983); England nuclear workers (Beral et al., 1985, 1988; Kendall et al., 1992); and home radon in Saxony, Germany (Becker, 2002).

The many studies presented here negate the LNT paradigm which has no scientific data based upon low dose irradiation of whole, normal individuals. For half a century radiobiologists have advised governments and governments responded with laws based upon the paradigm, ‘all radiation is harmful’; these are without factual support. You are challenged to find one study in English in which the leukaemia death rate, the solid cancer death rate or the average lifespan of human populations or normal laboratory animals show significant harm from chronic exposures to low dose irradiation.

Many scientists suggest that government regulations should conform to the amounts of radiation to which populations are exposed whether the radionuclides occur naturally or were manipulated in the workplace. Each of the following comments was based upon factual information. Luckey (1980) wrote: ‘Thousands of individual observations of stimulation by ionising radiation fit a single concept.’ Luckey (1991) also noted: ‘Ionising radiation appears to be required for maximum physiologic functions in microbes, invertebrates and vertebrates, including humans.’ In his book, *Health Effects of Low Dose Radiation,* Kondo (1993) stated ‘The collected data strongly suggest that low-level radiation is not harmful and is, in fact, frequently beneficial for human health.' Jaworowski (1994) called 'all radiation is harmful' a false dogma: 'This is the greatest hoax of the twentieth century.' Muckerheide (1995) noted that government standards, which are not based upon protecting public health, cost taxpayers over $1 trillion. Muckerheide and Rockwell (1997) noted that government radiation policies spent about a trillion dollars to 'decontaminate locations that are well below the natural radiation levels where people have lived healthily for generations'. Luckey (1997) stated: 'Low doses of ionising radiation promote optimal health'. Commenting on the activities of WHO, IAEA and ICRP, Luckey (1998) stated: 'Their recommendations are counterproductive for the environment, industry, medicine and humanity.' Becker (2003) noted: 'The benefits in the adequate use of low-dose radon exposure far exceed the hypothetical lung cancer risk attributed to the inhalation of low radon concentrations'. Due to the ignorance of officials about 'the mistaken attribution of many ill health conditions to radiation exposure', about seven million persons are still receiving government compensation from the Chernobyl accident (Kinley, 2005). Hattori and Sakai (2005) discussed raising the dose for exemption of members of the public from 0.01 mSv/y to 0.1, 0.5 or 1.0 mSv/y. Mortazavi and Karam (2005) state: 'Given the apparent lack of ill effects to the populations of these high dose rate areas, these data further suggest that the current dose limits are overly conservative.' Mortazavi and Karam (2005) also stated: 'We further suggest that the lack of apparent ill effects in Ramsar inhabitants may indicate that the current standards are too stringently set and may be relaxed without detriment to public health'. Indeed, Dr B. Comby (2007) noted that the structures of one home in Ramsar emitted over 1300 mSv/y. He estimated the residents received about 100 mSv/y with no known cancer deaths. Steinhausler (2005) suggests levels up to 10 mSv/y be considered normal exposure and levels 2–220 mSv/y be acceptable. A definitive study by the French Academy of Science and Medicine unanimously accepted the concept that low dose irradiation was beneficial (Aurengo et al., 2005).

Various professional groups have protested the use of LNT in limiting worker and public radiation. The Health Physics Society: 'Below this dose, 10 rem, estimation of adverse health effects is speculative.'(Mossman, et al., 1996). 'It is the position of the American Nuclear Society that there is insufficient scientific evidence to support the use of the Linear No Threshold Hypothesis (LNTH) in the projection of the health effects of low-level radiation'. American Nuclear Society (2001). An elite French committee stated: 'These data show that the use of a linear no-threshold relationship is not justified for assessing by extrapolation the risk of low doses (Aurengo et al., 2005). They also state: 'However, the use of LNT in the low dose or dose rate range is not consistent with the current radiobiological knowledge'.

These experts speak from a wealth of evidence. This is in stark contrast to repeated dogma with no evidence from long established committee proclamations and government regulations. The information presented here makes it obvious that restrictive laws need to be changed in order to increase the health of most people.

Radiation supplementation should be encouraged. Nuclear wastes provide a ready source of radiation (Luckey, 1999). Other proposals include: convert old nuclear power plants into well supervised radiation health centres, encourage use of radiation spas (this has been done in Europe for centuries (Becker, 2003)) and add artificial radiation spas to existing hospitals.

Documentation of the elements of the complete dose-response curve for ionising radiation has included:

- a deficiency below ambient levels
- a partial deficiency for most people
- increased health with more radiation
- an optimum for maximum health
- the threshold, the maximum safe exposure
- harm with exposures greater than the threshold.

In order to attain the goal of greater health with increased ionising radiation, a massive educational programme must begin and laws must be changed. People need to be freed from radiobiologist, medical, media and government policies that bind them to live in a partial deficiency of ionising radiation.

Acknowledgements

The author thanks Dr Donna Luckey, Jane Luckey, Jim Muckerheide, Lew Pitchford and Roy Stewart for their help in the preparation of this manuscript.

References

Abbatt, J.D., Hamilton, T.R. and Weeks, J.L. (1983) 'Epidemiological studies in three corporations covering the nuclear fuel cycle', in: *Biological Effects of Low Level Radiation,* Vienna: IAEA, pp.351–356.

Akerblom, G., Hardell, L., Fredriksins, M. and Axelson, O. (2005) 'On the circumstances and some further risk estimates regarding leukemia in ages 0–19 years and exposure to ionising radiation in homes of uranium containing alum shale-based concrete', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.77–84.

Akiba, S., Sun, Q.F., Tao, Z.F. and Gabgadharan, P. (2002) 'Child risk in high background radiation areas, in: K. Burkart, M. Sohrabi, and A. Bayer (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.283–287.

American Nuclear Society (2001) 'Health effects of low-level radiation', *Am. Nucl. Soc. J.*, Vol. 135, pp.1–12.

Annanmaki, M., Oksanen, E., Venelampi, E. and Markkanen, M. (2005) 'Radon in Finnish mines – regular monitoring since 1972', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.657–664.

Aoshima, H., Hashiguchi, Y., Morizumi, J., Yoshioka, K., Kim, Y.S. and Iida, T. (2005) 'A study of atmospheric radon transport as a tracer of pollutants over the Japanese Sea', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.567–572.

Arvela, H. (2002) 'Population distribution of doses from natural radiation in Finland', in: K. Burkart, M. Sohrabi and A. Bayer (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.9–14.

Arvela, H. (2005) 'Review of seasonal variation in residential indoor radon concentrations', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.612–617.

Aurengo, A., Averbeck, D., Bonnin, A., LeGuen, B., Masse, R., Monier, R., Tubiana, M., Valleron, A. and de Vathaire, F. (2005) *Dose-Effect Relationships and Estimation of the Carcinogenic Effects of Low Doses of Ionising Radiation,* Paris: Academies of Sciences and Medicine.

Auvenin, A., Maekelaeinen, I. and Hakama, M. (1996) 'Indoor radon exposure and risk of lung cancer: a nested case-control study in Finland', *J. Nat. Cancer Instit.*, Vol. 88, pp.966–972.

Band, P., Nhu, D., Frang, R., Deschamps, M., Goldman, A.J., Gallagher, R.P. and Moody, J. (1996) 'Cohort study of Air Canada pilots: mortality, cancer incidence and leukemia risk', *Am. J. Epidemiol.*, Vol. 143, pp.137–143.

Baverstock, K.F., Papworth, D. and Vennert, J. (1989) 'Risks of radiation at low dose rates', *Lancet,* Vol. 8217, pp.430–433.

Becker, K. (2002) 'Residential radon and the LNT hypothesis, in: K. Burkart, M. Sohrabi and A. Bayer (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.259–266.

BEIR III (1980) *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation*, Washington: National Academy Press.

BEIR VI (1990), *Health Effects of Exposures to Low Levels of Ionising Radiation*, Washington: National Academy Press.

Beral, V., Fraser, P., Carpenter, L., Booth, M., Brown, A. and Rose, G. (1988) 'Mortality of employees of the atomic weapons establishment', *Brit. Med. J.*, Vol. 297, pp.757–769.

Beral, V., Inskip, H., Fraser, P., Booth, M., Coleman, D. and Rose, G. (1985) 'Mortality of employees of the United Kingdom Atomic Energy Authority, 1940–1979', *Br. Med. J.*, Vol. 291, pp.440–450.

Binu, V.S., Gangadharan, P., Jayalekshmi, P., Nair, R.R.K., Nair, M.K., Rajan, B. and Akiba, S. (2005) 'The risk of lung cancer in HBR area in India – a case control study', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects*, Amsterdam: Elsevier, pp.236–237.

Blot, W.J., Zu, Z.Y., Boice, J.D., Zhao, D.Z., Stone, B.J., Sun, J., Jing, L.B. and Fraument, J.F. (1990) 'Indoor radon and lung cancer in China', *J. Natl. Cancer Inst.*, Vol. 82, pp.1025–1030.

Chen, W.L., Luan, Y.C., Shich, M.C., Chen, H.T., Kung, H.T., Soong, K.L., Yeh, Y.C. and Chou, T.S. (2004) 'Is chronic radiation an effective prophylaxis against cancer?', *J. Am. Physc. Surg.*, Vol. 9, pp.6–10.

Cohen, B.L. (1995) 'Test of the linear no-threshold theory of radiation carcinogenesis for inhaled radon decay products', *Health Phys.*, Vol. 68, pp.157–174.

Comby, B. (2007) email Jan. 8.

Conrady, J., Martin, K., Lembeke, J. and Martin, H. (2002) 'The true size of the lung cancer risk from indoor radon: hidden behind a smoke screen', in: K. Burkart, M. Sohrabi and A. Bayer, (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.253–258.

Craig, L. and Seidman, H. (1961) 'Leukemia and lymphoma mortality in relation to cosmic radiation', *Blood*, Vol. 17, pp.319–322.

Deetjen, P. and Falkenbach, A. (Eds) (1999) *Radon and Health*, Berlin: P. Lang Verlag.

Delpoux, M., Leonard, A., Dulieu, H. and Dalebroux, M. (1997) 'Experimental study of the genetic effects of high levels of natural radiation in South-France', in: *High Levels of Natural Radiation – Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.397–406.

Deme, S.C., Apathy, I., Reitz, G. and Akatov, Y. (2005) 'Twenty years of TLD measurements on board space vehicles by the Hungarian 'Pille' system', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII*, Amsterdam: Elsevier, pp.916–925.

Eisenbud, M. (1977) 'Summary report', in: T.L. Cullen and E. Penna Franca (Eds) *International Symposium on Areas of High Natural Radioactivity*, Rio de Janeiro: Acad. Brasileira de Cienciaas, pp.167–179.

Eisenbud, M. and Gesell, T. (1997) *Environmental Radioacivity*, 4th edition, San Diego: Academic Press.

Elizabeth, C. (2005) 'Commentary on information that can be drawn from studies of areas with high natural radiation', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.118–123.

Eugster, J.C. (1964) 'Subradiation experiments concerning the concept of the natural radiation environment', *Aerospace Med.*, Vol. 35, pp.524–562.

Frigerio, N.A. and Stowe, R.S. (1976) 'Carcinogenic and genetic hazard from background radiation', in: *Biological and Environmental Effects of Low Level Radiation, Vol. 2*, Vienna: IAEA, pp.285–290.

Fuchs, V.R. (1981) 'Low-level radiation and infant mortality', *Health Phys.*, Vol. 40, pp.847–850.

Funtua, I.I. and Elegba, S.H. (2005) 'Radiation exposure from high-level radiation area and related mining and processing activities of Jos Plateau, central Nigeria', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects.,* Amsterdam: Elsevier, pp.401–402.

Gardner, M.J., Hall, A.J., Downs S. and Terrell, J.D. (1987) 'Followup of children born elsewhere but attending schools in Seascale', *Brit. Med. J.,* Vol. 295, pp.219–222.

Ghiassi-Nejad, M., Beitollahi, M.M., Fujinami, N. and Morishima, H. (2002) 'Radiological parameters of a house with high levels of natural radiation, Ramsar, Iran', in: K. Burkart, M. Sohrabi and A. Bayer (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.33–37.

Gilbert, E.S., Fry, S.A., Wiggs, L.D., Voelz, G.L. and Cragle, D.L. (1989) 'Analysis of combined mortality data on workers at the Hanford Site, Oak Ridge National Laboratory and Rocky Flats Nuclear Weapons Plant', *Rad. Res.*, Vol. 120, pp.19–35.

Giovani, C., Cappelletto, C., Garavaglia, M. and Villalta, R. (2005) 'Radom concentration survey of schools of the Fiuli-Venezia Giulia region, north-east Italy', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.520–527.

Green, B.M.R., Hughes, J.S., Lomas, P.R. and Janssens, A. (1992) 'Natural radiation atlas of Europe', *Rad. Protect. Dosm.,* Vol. 45, pp.491–493.

Gribbin, M.A., Weeks, J.L. and Howe, G.R. (1983) 'Cancer mortality (1956–1985) among male employees of Atomic Energy Limited with respect to occupational exposure to external low-linear-energy-transfer ionising radiation', *Rad. Res.,* Vol. 133, pp.375–380.

Hanes, R.M. (1988) 'The distribution of domestic radon concentrations and lung cancer mortality in England and Wales', *Radiat. Protect. Dosim.,* Vol. 25, pp.93–96.

Hattori, T. and Sakai, K. (2005) 'New approach to dose optimization for members of the public, in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects*, Amsterdam: Elsevier, pp.432–433.

Hayata, I., Wang, C.Y., Zhang, W., Minamihisamatsu, M., Chen, D.Q., Morishima, H., Yuan, Y.L., Wei, L. and Sugahara, T. (2002) 'Chromosome translocation in residents of high background radiation area in China', in: K. Burkart, M. Sohrabi and A. Bayer (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.199–205.

HBRRG (High Background Radiation Research Group) (1981a) 'Aspects of environmental radiation and dosimetry concerning the high background radiation areas in China', *J. Rad. Res. (Tokyo),* Vol. 22, pp.88–90.

HBRRG (High Background Radiation Research Group) (1981b) 'Aspects of environmental radiation and dosimetry concerning the high background radiation areas in China', *Science,* Vol. 209, pp.877–879.

Heribanova, A. and Tomasek, L. (2005) 'Czech study on lung cancer risk from residential radon', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.381–388.

Iacob, O. and Grecca, C. (2005a) 'Public exposure to radon and thoron progeny in Romania', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier.

Iacob, O., Greccea, C. and Botezatu, E. (2005b) 'Population exposure to inhaled radon and thoron progeny', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.232–237.

Ina, Y. and Sakai, K. (2004) 'Prolongation of life span associated with immunological modification by chronic low-dose-rate irradiation in MRL-*lpr/lpr* mice', *Rad. Res.*, Vol. 161, pp.168–173.

Irvine, D. and Flower, D.J.C. (2005) 'Practical considerations for implementation of the EU directive in the field of cosmic radiation exposure', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.876–884.

Janowski, J., Skubalsky, J., Olszewski, J., Szalanski, P. and Zak, A. (2003) 'Comparison of contemporary and retrospective radon concentration measurement in dwellings in Poland', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.358–359.

Jaworowski, S. (1994) 'Hormesis: the beneficial effects of radiation', *21st Century*, Vol. 7, pp.22–26.

Kendall, G.M., Muirhead, C.R., MacGibbon, J.A., O'Hagan, A. and Conquest, A.J. (1992) 'Mortality and occupational exposure to radiation: first analysis of the National Registry for Radiation Workers', *Br. Med. J.,* Vol. 304, pp.220–225.

Ketchum, L.E. (1987) 'Lessons of Chernobyl: SNM members try to decontaminate the world threatened by fallout, *J. Nucl. Med.*, Vol. 28, pp.413–414.

Kinley, D. (2005) *Chernobyl's Legacy: Health, Environmental and Socio-economic Impacts*, Vienna: IAEA.

Koestinger, C. (2006) email 9/28/06.

Kondo, S. (1993) *Health Effects of Low-Level Radiation*, Osaka: Kinki University Press.

Kozlov, A.A. (1972) 'The role of cosmic rays in the regulation of the division rate of protozoa', *Proc. Acad. Sci. Georgian, USSR,* Vol. 66, pp.425–429.

Kuzin, A.M. (1984) 'The characteristics of the effect of low doses of gamma radiation', *Radiolbiol.,* Vol. 24, pp.415–416.

Kuzin, A.M. and Krymskaya, V.P. (1994) 'The significance of the radioactive isotope potassium-40 for the normal development of the animal organism', *Radiats. Biol. Radioecol.,* Vol. 34, pp.73–78.

Liu, S.Z. (1997) 'Cellular and molecular basis of the stimulatory effect of the low dose radiation on the immune system', in: L. Wei, T. Sugahara and Z. Tao (Eds) *High Levels of Natural Radiation*, Amsterdam: Elsevier Science, pp.341–352.

Liu, S.Z. (2003) 'On radiation hormesis expressed in the immune system', *Crit. Rev. Toxicol.,* Vol. 33, pp.431–441.

Luckey, T.D. (1977) 'Activity spectrum of ingested toxicants', in: M. Rechcigl (Ed.) *Comparative Animal Nutrition,* Vol. 2, Basel: S. Karger, pp.144–178.

Luckey, T.D. (1980) *Hormesis with Ionising Radiation*, Boca Raton: CRC Press.

Luckey, T.D. (1983) 'A growth inhibitor of *E. Coli* K-12 in a sample of ^{39}KCl', Ann. Rept. Env Res. Div. ANL-83–100JU:70–76, Argonne.

Luckey, T.D. (1986) 'Ionising radiation promotes protozoan reproduction', *Rad. Res.,* Vol. 108, pp.215–221.

Luckey, T.D. (1991) *Radiation Hormesis*, Boca Raton: CRC Press.

Luckey, T.D. (1997) 'Estimation of a minimum yearly radiation allowance (MYRA)', *J. Clean Technol. Environ. Toxicol. and Occup. Med.*, Vol. 6, pp.239–252.

Luckey, T.D. (1999) 'A novel application for radioactive waste – as a nutritional supplement', *Am. Nucl. Soc., Symp.*, Jackson.

Luckey, T.D. (2000) 'Low dose response – hormesis', in: J.H. Lehr and J.K. Lehr (Eds) *Standard Handbook of Environmental Science, Health, and Technology,* New York: McGraw-Hill, pp.12.40–12.48.

Luckey, T.D. (2003) 'Radiation for health', *Rad. Protect. Manag.*, Vol. 20, pp.:13–21.

Luckey, T.D., Johnson, W., Krueger, S., Tolo, D. and Vandenboom, E. (1978) 'Ionising radiation required for optimum reproduction in *Paramecium bursaria*, *Bact. Abst*., p.94.

Matanoski, G.M. (1991) *Health Effects of Low-Level Radiation in Shipyard Workers*, Final Report E 1.99 DOE-ACO2–79EV10095, Dept. Energy, Washington.

McLaughlin, J.P., Kellcher, K., Jimenez-Napoles, H. and Leon-Vintro, L. (2005) 'Retrospective radon assessments in a high radon dwelling in Ireland', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.399–400.

Meenakshisundaram, V., Laakshmi, K.S., Malathi, J. and Selvasekarapandian, S. (2005) 'Measurement of primordial radionuclide distribution in the soil samples along the east coast of Tamilnadu, India', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.325–326.

Metivier, P. (Ed.) (1996) *Chernobyl, Ten Years on Radiobiological and Health Impact*, Paris: Nuclear Energy Agency.

Mifune, M., Sobue, T., Arimoto, H., Komotom, Y., Kondo S. and Tanooka, H. (1992) 'Cancer mortality survey in a spa area (Misasa, Japan) with a high radon background', *Jpn. J. Cancer Res.,* Vol. 83, pp.1–5.

Miller, A.B., Howe, G.R., Sherman, G.J., Lindsay, J.P., Yaffe, M.J., Dinner, P.J., Risch, H.A. and Preston, D.L. (1989) 'Mortality from breast cancer after irradiation during fluoroscopic examination in patients being treated for tuberculosis', *N. Engl. J. Med.*, Vol. 321, pp.11285–11288.

Mjones, L. and Falk, R. (2005) 'Cancer risks from radon in indoor air and drinking water in Sweden', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.604–611.

Mortazavi, S.M.J. and Karam, P.A. (2005) 'Apparent lack of radiation susceptibility among residents of the high background radiation area in Ramsar, Iran: can we relax our standards?', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.1141–1147.

Moss, W. and Eckhardt, R. (1995) 'The human plutonium experiment', *Los Alamos Sci.*, Vol. 23, pp.177–223.

Mossman, K.L., Goldman, M., Masse, F., Mills, W.A., Schlanger, K.J. and Vetter, R.J. (1996) 'Radiation risk in perspective; Health Physics Society position paper', *Health Phys. Newsl.,* Vol. 72, pp.1–2.

Muckerheide, J. (1995) 'Radiation protection policies to protect public health', *Nucl. News*, Vol. 5, pp.1–4.

Muckerheide, J. and Rockwell, T. (1992) 'The hazards of US Policy on low-level radiation', *21st Century,* Autumn, pp.16–22.

Nambi, K.S.V. and Soman, S.D. (1987) 'Environmental radiation and cancer in India', *Health Phys.*, Vol. 52, pp.653–657.

Nikolopoulos, D., Louizi, A., Serefoglou, A. and Malamitsi, J. (2005) 'Radon exposure of Greek population', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.425–427.

NRPB (1992) *First Analysis of the National Registry for Radiation Workers*, Chilton.

Penna Franka, E. (1977) 'Review of Brazilian investigations in areas of high natural radioactivity. Part II: internal exposure and cytogenic survey', in: Cullen, T.L. and Penna Franca, E. (Eds) *International Symposium on Areas of High Natural Radioactivity, Rio de Janeiro: Acad. Brasileira de Cienciaas,* pp.29–49.

Planel, H., Soleillhavoup, J.P., Tixador, R., Richoilley, G., Counter, A., Croute, F., Caratero, C. and Gaubin, N.Y. (1987) 'Influence on cell proliferation of background radiation or exposure to very low chronic gama radiation', *Health Phys.*, Vol. 52, pp.571–578.

Puch, K.H., Bialucha, R. and Keller, G. (2005) 'Natural occurring radioactivity in industrial by-products from coal-fired power plants, from municipal waste incineration and from the iron and steel industry', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.996–1008.

Ramola, R.C. (2005) 'Levels of indoor radon, thorium amd their progeny in Himalaya', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Elsevier, Amsterdam.

Robbins, E.S. and Harley, N.H. (2005) 'Dose to the fetus from ^{222}Rn in maternal drinking water', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.749–755.

Rowland, R.E. (1994) 'Radium in humans: a review of US studies', *Rep. ANL-ER3*, Argonne National Laboratories, Argonne.

Ruda, V.P. and Kuzin, A.M. (1991) 'The occurrence of hormesis during gamma-irradiation of developing rat pups', *Radiobiologiia*, Vol. 31, pp.345–347.

Saur, H.T. (1980) 'Geographic patterns in the risk of dying and associated factors, ages 35–74 years', *DHHS Publ. PHS 80–1492*, Public Health Services, Washington.

Shawn, V.X., Jin, S.Z., Liu, X.D., Liu, Y. and Liu, S.Z. (2006) 'Ionising radiation stimulates secretion of pro-inflammatory cytokines: dose-response relationship, mechanisms and implications', *Rad. Environ. Biophys.*, Oct 27.

Shimizu, Y., Kato, H., Schull, W.J. and Mabuchi, K. (1992) 'Dose-response analysis among atomic-bomb survivors to low-level radiation', in: T. Sugahara, L.A. Sagan and T. Aoyama (Eds) *Low Dose Irradiation and Biological Defense Mechanisms,* Amsterdam: Excerpta Medica, pp.71–74.

Sohrabi, M. and Babapouran, M. (2005) 'New public dose assessment from internal and external exposures in low- and elevated-level natural radiation areas of Ramsar, Iran', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.169–174.

Sohrabi, M. and Esmaili, A.R. (2002) 'New public dose assessment of elevated natural radiation areas of Ramsar (Iran) for epidemiological studies', in: K. Burkart, M. Sohrabi and A. Bayer (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.15–24.

Steinhausler, F. (2005) 'The significance of the natural environment in radiation protection', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterda: Elsevier, pp.18–26.

Steinhausler, F. and Paschoa, A.S. (2005) 'The impact on man and the environment from the military use of depleted uranium: worst case scenario', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.1047–1055.

Streffer, C., Kryscio, A., Muller, W.U. and Kotschy-Lang, N. (2002) 'Genomic unstability in uranium miners after high radiation exposures', in: K. Burkart, M. Sohrabi and A. Bayer (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.223–227.

Tempfer, H., Schober, A., Hofmann, W., Leetner, H. and Steger, F. (2005) 'Biophysical mechanisms and radiation doses in radon therapy', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.640–648.

Thampi. M.V., Cheriyan, V.D., Kurien, C.J., Ramachandran, E.N., Karuppasamy, C.V., Koya, P.K., Das, B., George, K.P., Rajan, V.K. and Chauhan, P.S. (2005a) 'Cytogenic studies in the high level natural radiation areas of Kerala', in: K. Burkart, M. Sohrabi and A. Bayer (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, 2002, pp.207–211.

Tietjen, G.L. (1987) 'Plutonium and lung cancer', *Health Phys.,* Vol. 52, pp.625–628.

Tokarskaya, Z.B., Okladnikova, N.D., Belyaeva, Z.D. and Drozhko, E.G. (1997) 'Multifactorial analysis of lung cancer dose-response relatiolnships for workers in the Mayak nuclear enterprise', *Health Phys.,* Vol. 73, pp.899–905.

Tomasek, L., Muller, T., Kunz, E., Heribanova, A., Matzneer, I., Placek, V., Burian, I. and Holecek, J. (2002) 'Czech residential radon study', in: K. Burkart, M. Sohrabi and A. Bayer (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.239–245.

Trautmannsheimer, M., Schindlmeier, W. and Hubel, K. (2002) 'Radon exposure levels of the staff in the drinking water supply facilities in Bavaria, Germany', in: K. Burkart, M. Sohrabi and A. Bayer (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.81–86.

Upton, A.C., Randolph, M.L. and Conklin, G.S. (1970) 'Late effects of fast neutrons and gamma-rays in mice as influenced by the dose rate of irradiation: induction of neoplasia', *Radiat. Res.,* Vol. 41, pp.467–471.

Uzunov, I., Steinhausler, F. and Pohl, E. (1981) 'Carcinogenic risk of exposure to radon daughters associated with radon spas', *Health Phys.,* Vol. 41, pp.807–813.

Veiga, L.H.S. and Koifman, S. (2005) 'Pattern of cancer mortality in some Brazilian HBRAs', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.110–113.

Voelz, G.L. and Lawrence, J.N.P. (1991) 'A 42-year medical follow-up of Manhattan project plutonium workers', *Health Phys.,* Vol. 61, pp.181–190.

Voelz, G.L., Grier, R.S. and Hempelmann, L.H. (1985) 'A 37 year followup of Manhatten project workers', *Health Phys.,* Vol. 48, pp.249–252.

Voelz, G.L., McInroy, J.F., Wilkinson, G.S., Tiejen, G.L. and Healy, J.W. (1983) 'Mortality study of Los Alamos workers with high exposure to plutonium', *Proc. Midyear Top. Meet.*, Albuquerque.

Walchuk, M. (1996) 'Astronauts and radiation risk', *The Health Phys. Newsl*., Vol. 24, p.1, p.5.

Wang, Z. (2002) 'Natural radiation environment in China', in: K. Burkart, M. Sohrabi and A. Bayer (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.39–46.

Wang, Z., Zhang, W., Minanihisamatsu, M., Morishima, H., Yuan, Y., Jiang, Y., Chen, D., Wei, L., Sugahara, T. and Hayata, I. (2005) 'Chromosome study in high background radiation area in Southern China', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.3–7.

Webster, E.W. (1983) 'The effect of low doses of ionising radiation', *J. Tenn. Med. Assoc.,* Vol. 76, pp.499–502.

Wei, L.X. and Sugahara, T. (2002) 'Risk assessment based on epidemiological study with a high background radiation area. A China-Japan cooperative research', in: K. Burkart, M. Sohrabi and A. Bayer (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.267–275.

Wichmann, H.E., Heinrich, J., Gerken, M., Kreuzer, M., Wellmann, J., Keller, G. and Kreienbrock,L. (2002) 'Domestic radon and lung cancer – current status including new evidence from Germany', in: K. Burkart, M. Sohrabi and A. Bayer (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.247–252.

Wiggs, L.D., Johnson, E.R., Cox-de Vore, C.A. and Voelz, G.L. (1994) 'Mortality through 1990 among white male workers at the Los Alamos National Laboratory: considering exposures to plutonium and external ionising radiation', *Health Phys.,* Vol. 67, pp.557–588.

Wing, S., Shy, C.M., Wood, J.L., Wolf, W., Cragle, D.L. and Frome, E.L. (1991) 'Mortality among workers at Oak Ridge National Laboratory', *J. Am. Med. Assoc.,* Vol. 265, pp.1397–1402.

Yoshinaga, S., Tokonami, S. and Akiba, S. (2005) 'Residential radon and childhood leukemia in meta-analysis of published studies', in: T. Sugahara, H. Morishima, M. Sohrabl, Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.430–431.

Zhukovsky, M. and Termechikova, R. (2005) 'Exposure to radon in the northern part of the Republic of Kyrgyzstan', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.706–714.

Zou, J., Tao, A., Sun, Q., Akiba, S., Zha, Y., Sugahara, T. and Wei, L. (2005) 'Cancer and non-cancer epidemiological study in the high background radiation area of Yangjiang, China', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.97–101.

Zunic, Z.S., Fujimoto, K. and Yarmoshenko, I.V. (2005) 'A comparison of human exposure to natural radiation and DU in parts of the Balkan region', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.141–144, pp.215–216.

Bibliography

Brucer, M. (1999) *A Chronology of Nuclear Medicine*, St. Louis: Heritage Publications, Inc., p.19.

Cohen, B.L. (2000) 'Radon in air', in: J.H. Lehr and J.K. Lehr (Eds) *Standard Handbook of Environmental Science, Health and Technology,* New York: McGraw-Hill, pp.15.7–15.19.

Cullen, T.L. (1977) 'Review of Brazilian investigations in areas of high natural radioactivity, PART I: radiometric and dosimetric studies', in: T.L. Cullen and E. Penna Franca (Eds) *International Symposium on Areas of High Natural Radioactivity*, Rio de Janeiro: Acad. Brasileira de Cienciaas, pp.49–64.

Gegner, M. and Irlweck, K. (2005) 'Uranium concentrations and isotopeic ratios in Austrian drinking waters', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.135–139.

Georgia, T. and Heleny, F. (2005) 'Radiological impact in an area of elevated natural radioactivity background: the case of the island of Ikaria, Greece', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.390–391.

Ghiassi-Nejad, M., Beitollahi, M.M., Fujinami, N. and Morishima, H. (2005) 'New findings in the very high natural radiation area of Ramsar, Iran', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.13–16.

Hajek, M., Berger, T., Vana, N. and Mukherjee, B. (2005) 'Neutron dosimetry onboard aircraft using superheated emulsions', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.941–947.

Luckey, T.D. (1998) 'Impressions of the IAEA/WHO conference: the Good, the Bad, and the Ugly in Seville', *Rad. Protect. Manag.,* p.1–2.

Luckey, T.D. (2006) 'Improved health from Chernobyl', *Int. J Low Radiation*.

Makelainen, I., Moisio, S., Reisbacka, H. and Turtiainen, T. (2005) 'Indoor occupancy and radon exposures in Finland', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.687–693.

Malathi, J., Brahmanandham, G.M., Khanna, D. and Selvasekarapandian, S. (2005) 'Study of primordial radionuclide distribution in sand samples of Agastheeswaram taluk of Lantakumaei district, India', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.321–322.

Marenny, A.M., Shinkarev, S.M., Penezev, A.V., Saavkin M.N. and Hoshi, M. (2005) 'Assessment of exposure to the population of Russia from radon', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.352–355 and pp.356–357.

Monfared, A.S., Jalali, F., Mozdarani, H., Hajiahmadi, M. and Samavat, H. (2005) 'Living in high natural background radiation areas in Ramsar, India. Is it dangerous for health?', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.438–430.

Mosavi-Jarrahi, A., Mohagheghi, M., Akiba, S., Yazdizadeh, B., Motamedi, N. and Monfared, A.S. (2005) 'Mortality and morbidity from cancer in the population exposed to high level of natural radiation area in Ramsar, Iran', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.106–109.

Muckerheide, J. (2000) *Low Level Radiation Effects: Compiling the Data. Radiation Science and Health, Inc.*, Needham.

Paschoa, A.S. and Pohl-Rulling, J. (2005) 'Early thoron concentration levels in Guapari: dosimetric implications', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.678–686.

Paschoa, A.S. and Steinhausler, F. (2005) 'Orphan sources of NORM/TENORM throughout the world', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.1017–1024.

Rowland, R.E. (1997) 'Bone sarcoma in humans induced by radium: a threshold response', *Radioprotection*, Vol. 32, pp.CI-331–338.

Rowland, R.E., Lucas, H.F. and Schlenker, R.A. (1989) 'External radiation doses received by female radium dial painters', in: D.M. Taylor, C. Mays, B. Gerber and R.G. Thomas (Eds) *Risks from Radium and Thorotrast, BIR Report 21,* London: British Inst. Radiology, pp.67–72.

Saez Vergara, J.C., Romero Gutierrez, A.M. and Jimenez, R.R. (2005) 'Monitoring of the cosmic radiation on IBERIA commercial flights: one year's experience of in-flight measurements', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.885–893.

Samavat, H., Seaward, M.R.D., Aghamiiri, S.M.R. and Monfared, A.S. (2005) '^{210}Po and ^{210}Pb content in environmental and human body samples in the Ramsar area, Iran', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.225–226.

Sengupta, D., Mohanty, A.K., Das, S.K. and Saha, S.K. (2005) 'Natural radioactivity and radiation exposure in the high background area of Chhatrapur beach placer deposits of Orissa, India', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.1148–1151.

Sevostyanov, V.N. (2005) 'Some aspects of the radon problem in Kazakhastan', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.409–419.

Shaw, R.F. and Smith, A.P. (1970) 'Strontium-90 and infant mortality in Canada', *Nature,* Vol. 228, p.667.

Shlein, B., Slaback, L.A. and Birky, B.K. (Eds) (1998) *Handbook of Health Physics and Radiobiological Health*, 3rd edn., Philadelphia: Lippincott Williams & Wilkins.

Thampi. M.V., Cheriyan, V.D., Kurien, C.J., Ramachandran, E.N., Karuppasamy, C.V., Koya, P.K., Das, B., George, K.P., Rajan, V.K. and Chauhan, P.S. (2005b) 'Cytogenic studies in the high level natural radiation areas of Kerala', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.8–12.

Tokarskaya, Z.B., Zhuntova, G.B., Scott, B.R., Khokhryakov, V.F., Belyaeva, V.E., Vasilenko, E.K. and Syrchikov, V.A. (2006) 'Influence of alpha and gamma radiations and non-radiation risk factors on the incidence of malignant liver tumors among Mayak workers', *Health Phys.,* Vol. 91, pp.296–310.

Tokonami, S., Yonehara, H., Akiba, S., Thampi, M.V., Zhui, W., Nrazaki, Y. and Yamada, Y. (2005) 'Natural radiation levels in Tamil Nadu and Kerala', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.554–559.

Tomasek, L. (2005) 'Czech study on uranium miners – evaluation of temporal factors in a 50 year follow-up', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.389–396.

Toussaint, L.F. (2005) 'Measurements to determine the radiological impact of uranium and thorium in the darling scarp', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.93–96.

Yarar, Y., Gunaydr, T. and Kam, E. (2005) 'A radon survey in some regions of Turkey', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.385–386.

Yarmoshenko, I.V., Kirdin, L.A., Zhukovsky, M.V. and Astrakhantseva, S.Y. (2005) 'Meta-analysis of twenty radon and lung cancer case-control studies', in: J.P. McLaughlin, S.E. Simopoulos and F. Steinhausler (Eds) *The Natural Radiation Environment VII,* Amsterdam: Elsevier, pp.762–771.

Yasuoka, Y., Ishii, T., Tomonami, S., Ishikawa, T., Narazaki, Y. and Shinogi, M. (2005) 'Radon anomaly related to the 1995 Kobe earthquake in Japan', in: T. Sugahara, H. Morishima, M. Sohrabl, L.Y. Sasaki, I. Hayata and S. Akiba (Eds) *High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects,* Amsterdam: Elsevier, pp.426–427.

Appendix

Humans in levels of ionising radiation above background

International

- Homes in northern Europe (Helsinki, Stockholm, Hamburg and Frankfurt) have almost two times more radon than those in southern Europe (Arvela, 2005).
- Over one billion persons are exposed to radiation from consumer products – Pa05.
- Radiation from coal is >100 times higher than that from oil, gas or nuclear fuel (Steinhausler and Paschoa, 2005). The use of coal ash in buildings produces insignificant radiation above natural sources (Puch et al., 2005).
- From the mother's drinking water, the fetus receives about 25% of the external radon concentration (Robbins and Harley, 2005).
- Cosmic neutrons dominate all commercial aviation radiation, up to 0.001 mSv/h – Ha05.
- Crews of supersonic jets receive about 3 mSv/y from cosmic radiation (Steinhausler and Paschoa, 2005). Regular jet crew members receive 2–4 mSv/y (Irvine and Flower, 2005).
- Astronauts in low space orbit, about 300 Km, receiveabout 0.2 mSv/d; in deep space they receive about 1 mSv/d (Walchuk, 1996). During extravehicular activity, astronauts receive 0.06–0.2 mGy/h from cosmic radiation (Deme et al., 2005).
- Men involved with depleted Uranium (DU) buildings or vehicles may receive 500 mSv per entry (Steinhausler and Paschoa, 2005).

Austria

- A maximum of radon is absorbed from bathing in warm radon waters in 20 min; maximum absorption from radon in air took about 40 min (Tempfer et al., 2005). Effective radon doses (in mSv) for thermal/vapor baths are skin 0.8/1.3, lung 0.13/1.87 and kidney 0.04/0.1, respectively.
- The average radon dose to underground miners was 3.5 mSv/y in 1975; this was reduced to 2.4 in 1985 and was further reduced to 1.7 in 1995 and 0.9 in 2001 (Annanmaki et al., 2005).

- Drinking water has 0.02 mg/l of U – Ge05. Bockstein spa had 0.8 mg/l of U.
- Air radon in Bad Gastein is 2–10 pCi/l indoors (Uzunov et al., 1981).
- Bad Gastein mine attendants work where the mean concentration of radon is 3000 pCi/l; this may expose them to 40 WLM/y (280 mSv/y) (Uzunov et al., 1981).
- Film badges show the staff at Bad Gastein receive a maximum of 20 mSv/y (Koestinger, 2006). Added to this is about 10 mSv/y (6 WLM/y) at home, a total of 30 mSv/y (Uzunov et al., 1981).

Australia

- The Darling scarp area, east of Perth, is a high radiation area; the average exposure rate is 4.56 mSv/y which compares with 1.87 mSv/y on the coastal plain – To05.

Balkans

- Human exposures to natural and depleted uranium (DU) in soil near towns are: Han Pjesak, 1.6; Borovac, 2.0; Uzice, 2.4; Kalna, 4.7; Gornja Stubla, 17; and Niska Banja, 29 mSv/y (Zunic et al., 2005).

Brazil

- Several towns receive 2–20 mSv/y from radon. Due to monazite sands underlying its surface, Guarapari has an average radiation level of 6 mSv/y (Penna Franka, 1977). Some of the population receives more than 9–11 mSv/y – Cu77, (Eisenbud and Gesell, 1997). A few hundred workers at the monazite mantle works receive 12 mSv/y. No unusual sickness or mortality is reported (Eisenbud and Gesell, 1997).
- Monazite releases ^{220}Rn with progeny having short half-lives. Homes in Guarapari have 55 mSv/y – Pa05.
- Excluding aneuploid cells and chromatid aberrations, the people of Guarapari had more chromosomal breaks than controls (Penna Franka, 1977).
- When compared with control populations, the cancer standard mortality rates (SMR) are high for Guarapari (SMR = 1.09 with 6 mSv/y) and Pocos de Caldas (SMR = 1.41 with 7.2 mSv/y) and not for Araxa (SMR = 1.00 with 1–6 mSv/y) which is in a high natural radiation area (Veiga and Koifman, 2005), see also Elizabeth (2005).
- Although exposed to 13–67 mSv/y, rats living in tunnels at Moro do Ferro showed no gross or cellular lung pathology (Eisenbud and Gesell, 1997).

Canada

- During nuclear bomb tests, there was an inverse relationship between ^{90}Sr from fallout and infant mortality rates (Shaw and Smith, 1970).
- Several years of multiple x-ray treatments for tuberculosis in 31,700 women clearly shows 15 cGy provided protection ($p < 0.01$) from breast cancer (Miller et al., 1989).

- No increase in cancers was found in 46,700 pilots exposed to 1.5–6 mSv/y (Band et al., 1996).
- The cancer mortality rate of 4000 nuclear energy workers (7 cSv/lifetime) was only 2% that of the controls, 21,000 workers in hydro-energy plants (Abbatt et al., 1983).
- In Canadian nuclear workers, the SMR (standard mortality rate) was found to be 0.6 for leukemia and 0.75 for solid cancer mortality rates – Gr93.

China

- The average natural radiation level in China is 2.4 mSv/y, about the world average (Wang, 2002).
- About one million people live in caves where the average radiation is ten times that of the homes of China (Wang, 2002). Radon in caves in Shaanxi znd Shanxi provinces average about 5.4 pCi/l with many as high as 16 pCi/l – To05.
- In a three decades long study, 74,000 peasants receiving 3.3 mSv/y were found to be as healthy as 77,000 peasants receiving 1.04 mSv/y (HBRRG, 1981). Air radon concentration was seven times higher in the high background group than in the controls.
- Excepting the age at involution of the thymus (20± years), leukaemia death rates were definitely lower in the high background group (Luckey, 1991), see also Akiba et al. (2002). The cancer mortality rate was somewhat less in the high background group, $p < 0.04$ (Kondo, 1993). When compared with 27,900 controls who received 0.68 mSv/y from external sources, the relative rate (RR) of cancer deaths of 23,718 people who received 2.46 mSv/y external radiation was 0.91 (Wei and Sugahara, 2002). There was no statistically significant increase in either total cancer or non-cancer mortality attributable to radiation (Zou et al., 2005).
- All abnormal cell types showed a downward trend with an odds ratio of 0.7 for the high radon group (≥8 pCi/l) (Blot et al., 1990). Down's syndrome and chromosomal abnormalities were higher in the high background children – Ko93. Radiation does not contribute to the induction of chromosomal aberrations and/or congenital diseases (Hayata et al., 2002; Wang et al., 2005; Wei and Sugahara, 2002).
- Infertility, spontaneous abortions and neonatal fatalities were lower in the high background women (Kondo, 1993).

Czech Republic

- The discovery of cancer in Joachimsthal miners was based on two false premises (Luckey, 1991). Firstly, cancer incidence in retired miners (all over 65 years old) was compared with that of the general population where the average lifespan was 55 years. Secondly, there were no cancers in the 323 active miners.
- The standard mortality risk (SMR) from residential radon was: lung cancer, 1.10; other cancers, 0.81; all cancers, 0.88 and all causes, 0.94 (Tomasek et al., 2002).
- There appears to be a linear relationship between residential radon and lung cancer for both non-smokers and smokers (Heribanova and Tomasek, 2005). Dusts and noxious gases were not considered.

- There appears to be a linear relation between radon in mines and miner lung cancer – To05.
- Produce from the Czech Republic is banned due to detectable levels of radioactivity from U depleted bombs in the fields. Compare this with the tons of fertilisers taken from Morro do Ferro which has 100 Gy/y of gamma radiation at its surface (Eisenbud and Gesell, 1997).

Egypt

- People in the Nile valley receive twice the world average radiation, 5 mSv/y (Luckey, 1991).

England

- The average radiation of England is about 2 mSv/y (Green et al., 1992).
- When controlled for smoking, diet, social class and population density, there was a negative correlation between Rn in homes of England and Wales and lung cancer mortality rates (Hanes, 1988).
- The burned reactor at Sellafield produced no leukemia and, when compared with children who moved into the area after the burnout, no excess thyroid cancer mortality (Gardner et al., 1987).
- A 33 year study of 3154 plutonium contaminated workers found statistically significant fewer ($p < 0.01$) cancer deaths than in the general population (Beral et al., 1985).
- Given a 15 year lag period between 1946–1979, the total cancer mortality rate of 39,546 employees of the UK Atomic Energy Authority decreased with increasing exposure; the 1759 employees who received >100 mSv had only 1.7% the cancer death rate as carefully selected unexposed workers (Beral et al., 1985).
- The cancer death rate decreased linearly with dose for 59,000 exposed nuclear workers (Kendall et al., 1992).
- When corrected for age, 70,600 nuclear workers, who were exposed to more than 2 cSv (lifetime), had significantly less, $p < 0.001$, total cancer mortality than 24,500 unexposed workers in the same plants (Kendall et al., 1992).
- The leukaemia death rate in nuclear workers exposed to >20 mSv was less than 5% that of selected controls (Beral et al., 1988). When exposed to >5 cSv (lifetime), the leukemia death rate in 32,000 exposed nuclear workers was only 2.5% that of 59,000 unexposed workers – Ke92. No leukaemia deaths were found among 22,552 nuclear workers who were exposed for 2–30 years to >10 mSv Pu (Beral et al., 1988).
- Radium dial painters had no leukaemia (Baverstock et al., 1989). Women who worked ≤2 years (average lifetime dose = 40 cGy) had an SMR for non-cancer deaths of 0.72, $p < 0.01$ (Kondo, 1993).

Europe

- Over 100,000 radiophobia abortions followed detectable radiation from Chernobyl (Ketchum, 1987).
- About 75,000 patients per year undergo radon therapy for a variety of diseases (Becker, 2002). Double-blind studies show the effectiveness of radon therapy (Deetjen and Falkenbach, 1999).

Finland

- Drilled wells have 2–30 ug U/kg; some have almost 2 mg/l (McLaughlin et al., 2005).
- The average background radiation for the people of Finland is 7 mSv/y (Green et al., 1992).
- Many people receive >20 mSv/y (range 0.3–27) from indoor radon – Ma05.
- Radon levels in homes were inversely proportional with lung cancer deaths from 1.1–11 pCi/l; above this Rn may have adverse effects (Auvenin et al., 1996). More than 10% of the homes have indoor radon concentrations of 3 mSv/y; 5% have 4 mSv/y; the range is 0.2–350 (Arvela, 2002).
- The average gamma radiation in homes is 0.47 mSv/y; the range was 0.2–1.0 mSv/y (Arvela, 2002).

France

- Gamma radiation in south-west France is about 2.6 mGy/y (Delpoux et al., 1997).
- The French Academies of Sciences and Medicine note that epidemiologic studies of populations exposed to less than 100 mSv ‘have not been able to detect significant (cancer) risk even in large cohorts or populations’ (Aurengo et al., 2005).

Germany

- Non-smoking women living in high radon areas had lower lung cancer death rates than the controls in studies in Saxony, Schneeberg and Sheniang – Be03.
- About 10% of the Bavarian water supply workers received >20 mSv/y from radon (Trautmannsheimer et al., 2002).
- Genomic instability, a decreased micronuclei with centromeres in lymphocytes develops in uranium miners after decades of exposure to mine dust and high levels of radiation (Streffer et al., 2002).
- Using a few case-controlled homes, the high radon levels in both East and West Germany were found to be associated with increased risk of death from lung cancer (Wichmann et al., 2002). Another small case-control study showed under-estimation of smoking was a major confounding factor; low levels of radon caused no lung cancer (Conrady et al., 2002).

- No childhood leukaemia occurred in Schneeberg where gamma radiation is 1–7 mSv/y and radon levels are 10–100 mSv/y – Be02.
- Although radon in homes of southern Saxony exceeded 400 pCi/l, lung cancer death rate was less than 0.5% before cigarette factories started in Germany – Be02.

Greece

- Only 1% of the population lives with more than 11 pCi/l radon (Nikolopoulos et al., 2005).
- Residents near the spa in Ikaria receive 0.2–3.3 mSv/y – Ge05. Attendants receive 5–35 mSv/y.

Himalaya

- Indoor radon, thorium and progeny expose residents to an average of 8.4 mSv/y; the high level was 16.6 mSv/y (Ramola, 2005).

India

- Cancer death rates in state hospitals are inversely related to background radiation levels, $p < 0.05$ (Nambi and Soman, 1987).
- Villages in Kerala have background radiation levels of 4–13 mSv/y (Luckey, 1991).
- The effective dose of gamma rays plus radon in Tamil Nadu and Kerala was 4–22 mSv/y (average = 9.3) – To05.
- The people of Kerala are the most healthy of any Indian state with the lowest sterility and the lowest neonatal death rate (Luckey, 1991).
- Over 14,000 newborn babies in Kerala with 1.5–35 mSv/y radiation from thorium and progeny were comparable in all respects with almost 20,000 control babies from low radiation areas – Th02.
- Summarising the Kerala results, Eisenbud stated: 'These studies did not reveal any statistically significant differences in fertility index, sex ratio among offspring, infant mortality rate, pregnancy terminations, multiple births or gross genital abnormalities,' (Eisenbud, 1977). There was no correlation between background radiation and chromosomal aberrations in lymphocytes or constitutional anomalies (Th02, Thampi et al., 2005).
- When exposed to >2 mSv/y, no significant increase in lung cancer was reported in a case control study for males in Karunagappally in Kerala (Binu et al., 2005; Elizabeth, 2005).
- Down's syndrome was associated with the age of the mothers but not with background radiation – Th02. Down's syndrome in not unusually high in the monazite area around New Delhi (Eisenbud, 1977).
- Small areas on the southeast tip of India, Kanyakumari District, have high levels of gamma radiation; the average is 4.8 mSv/y with the maximum about seven times that value – Ma05.

- Thorium in the soil of the southeast coast of India records an average effective gamma ray dose of 101 cGy/y (Meenakshisundaram et al., 2005).
- People on the beach of Chhatrapur in Orissa receive up to 10 mSv/y – Se05.

Iran

- Nine spas and 50 hot springs provide 30% of the population of Ramsar with an average of 1–5 mSv/y; 20% receive 5–20 mSv/y (Sohrabi and Esmaili, 2002). Gamma radiation adds about 0.85 mSv/y to 77% of the people. The mean effective dose is 6 mSv/y (the range is 0.7–131 mSv/y).
- Individuals in Ramsar receive up to 132 mSv/y; some may receive twice this amount – So02.
- When compared with residents in normal background radiation areas (NBRA), people in HBRA have normal immune functions, average lifespan and no increased leukaemia, solid cancer, hereditary diseases, congenital malformations or chromosomal aberrations – Mo05.
- Radon exposures (mSv/y) of different areas of Ramsar are: Katalom, 2.38; Chaboksar, 2.48; Lamtar, 2.76; Tonekabon, 2.78; Javaherdeh, 2.82; Sefid Tomeshk, 3.52; Lapasar, 3.54; Sadat Maahalleh, 7.14; Ghaemieh, 7.96; Chaparsar, 11.1; Ramak, 14.1; and Telesh Magalleh, 71.7 (Sohrabi and Babapouran, 2005). Radium levels in the bedroom of one home averaged 237 mSv/y (Ghiassi-Nejad et al., 2002).
- The average air/water intakes of ^{210}Po and ^{210}Pb are 4.4 pCi and 6.5 pCi, respectively – Sa05.
- Physicians see no evidence of any health hazard in Ramsar – Gh05. Residents of Ramsar had no increased death, malignancies, abortion, mental disability, mental depression and no physical disabilities – Ha05.
- Male cancer mortality in high radiation areas of Ramsar was no greater than that of controls; the slight increase in female cancer rates was not significant – Mo05.

Ireland

- A retrospective study of ^{210}Pb and ^{210}Po of an old dwelling in Castleisland indicated the residents were exposed to 1.5 Sv/y (McLaughlin et al., 2005).

Italy

- Several schools in northern Italy have high radon concentrations (Giovani et al., 2005). Some exceed 100 mSv/y assuming continuous occupancy.

Japan

- Radon in the air mass from China is less important than local sources of radon (Aoshima et al., 2005).
- Atmospheric radon increased precipitously for two months prior to the January 17, 1995, earthquake at Kobe – Yan05.

- The cancer mortality rate of radon rich Misasa was only 67% that of surrounding villages which had no unusual Rn concentrations (Mifune et al., 1992).
- Although only five studies were available in this meta-analysis, we conclude that there is no evidence for an association between residential radon and childhood leukaemia (Yoshinaga et al., 2005).

Kazakhstan

- Air in some homes exceeds160 pCi/l of radon; air in some mines exceeds 5 Sv/l – Se05.

Kosovo

- Soils with 1 g depleted uranium (DU) per kg soil may provide 15 mSv/ y by geophagia (McLaughlin et al., 2005). Water and stock from these fields will have some U from DU in them.

Kyrgyzstan

- Urban homes average 5.2 mSv/y from radon and thoron; due to more thoron, rural homes receive 7.4 mSv/y (Zhukovsky and Termechikova, 2005).

Malaysia

- Miners receive up to 180 mSv/y – St05.

Nigeria

- Mine workers at the Jos Plateau were exposed to levels as high as 180 mSv/y (Funtua and Elegba, 2005).

Poland

- Indoor exposure to radon in the Kowary region is 9.5 mSv/y (Jankowski et al., 2005).

Romania

- The average exposure of the population is 2 mSv/y (1.65 from radon progeny and 0.35 from thoron progeny (Iacob and Grecca, 2005). The revised total radon component was 22 mSv/y (Iacob et al., 2005).

Russia, Ukraine and Belarus

- The average exposure to radon is 1.4 mSv/y – Ma05. About one million people receive <5 mSv/y. External gamma radiation is 0.75 mSv/y.
- A study of contaminated Mayak nuclear workers and controls concluded: 'We find no evidence that chronic low doses of gamma rays are associated with liver cancer occurrence' – T006. Workers at the plutonium plant had significantly lower lung cancer mortality rates than the general population of Mayak (Tokarskaya et al., 1997).

- The 1986 Chernobyl accident showed little harm in lightly exposed adults. 'Direct radiation-epidemiological studies performed since 1986 have so far revealed no radiation-induced increase in mortality of the general population due, in particular, to causes such as leukaemia and solid cancer (other than thyroid cancer in children (some received > 1 Sv (Aurengo et al., 2005)) or non-cancer diseases above the spontaneous level' (Kinley, 2005, p.11).
- The rate of congenital malformations 'does not appear to be radiation related' (Kinley, 2005, p.14). In contrast, fear of all radiation caused over 100,000 deaths by suicide and abortions over northern Russia and Europe (Ketchum, 1987).
- Elite international committees from IAEA, WHO, FAO, UNDP, UNEP, UN-OCHA, UNSCEAR and World Bank Group have evaluated Chernobyl's legacy: health, environmental and socio-economic impacts (Kinley, 2005). The focus was on two decades of the health experiences of the people of Belarus, The Russian Federation and Ukraine. The committee concluded: except for increased thyroid tumors, socio-economic disruptions and much psychologic harm, doses up to 5 cGy/y were without observable harm. For persons who received <1 Gy 'follow-up programmes are unlikely to be cost effective or beneficial to patients' (Kinley, 2005, p.39). 'Experience with protection of the public after the Chernobyl accident has clearly shown the need for further international harmonisation of appropriate radiological and safety standards' (Kinley, 2005, p.45).
- The present (2005) average exposure to Russians from radon is much greater than that from external gamma radiation – Ma05. About 4300 people in Moscow receive >5 mSv/y.
- People who receive <3 mSv/y have less lung cancer than the control population – Ya05.

Scotland

- Because they had barely detectable levels of radionuclides in them, over 4 million sheep were slaughtered in southwest Scotland (Metivier, 1996, p.76).

Serbia

- Soils with 1 g depleted uranium (DU) per kg soil may provide 15 mSv/y by geophagia (McLaughlin, 2005). Water and stock from these fields will have some U from DU in them.

Spain

- The average exposure of IBERIAN flight crews is 1.3–2.2 mSv/y – Sa05.

Sweden

- No increased lung cancer was found for persons living with <3 pCi/l radon (Mjones and Falk, 2005).
- Excess leukemia in young people was 1.26 cases per 100,000 person years in U-shale concrete homes; this yields 1.5–6 mSv/y from radon (Akerblom et al., 2005).

Taiwan

- When children and students were excluded, the cancer death rate of people exposed to 1–5 mSv/y for 9–20 years was only 2.7% that of the general population (Chen et al., 2004).

Thailand

- Miners receive up to 180 mSv/y – St05.

Tibet

- Absorbed cosmic radiation is 1.02 mGy/y, four times the world average (Wang, 2002).

Turkey

- Radon exposures in spa areas of Turkey varied between 1.7 and 3.1 mSv/y – Ya05.

United States of America

- Both leukaemia and total death rates in the contiguous 48 states are inversely proportional to background radiation levels, $p < 0.003$ (Craig and Seidman, 1961; Frigerio and Stowe, 1976; Luckey, 1991; Saur, 1980; Webster, 1983).
- The total infant death rate fell during the increased radionuclide fallout from nuclear bomb testing, 1955–1965 (Fuchs, 1981).
- Radium dial painters who received <30 Gy had a longer average lifespan than the population around them; the SMR was 0.88 for all causes of death, $p < 0.05$; 0.75 for all circulatory diseases, $p < 0.01$ and 0.48 for cardiovascular diseases, $p < 0.01$ (Rowland, 1994). Radium dial painters who received less than 30 Gy (the lifetime threshold) had no increased cancer death rate and a leukaemia death rate which was only 20% that of a control population – Ro98. 'However, the great majority of exposed individuals went through life with no recognisable consequences of their exposures. They lived as long as and apparently in as good health as their unexposed neighbors' – Ro98.

- The total cancer death rate of plutonium contaminated workers was 57% that of the general population – Vo87. None of the 17 women contaminated with Pu died with cancer (Voelz, 1983). A 33 year followup of 241 heavily contaminated plutonium workers found the total cancer mortality rate was about 50% that of the general population (Voelz et al., 1985).
- Lung cancer deaths in plutonium workers who were exposed to about 10 mSv/y were below the national average – Te87.
- The 18 'terminally ill' patients who were injected with up to 0.9 mCi Pu lived 2–44 years. None died from cancer (Moss and Eckhardt, 1995).
- Voelz and Lawrence found remarkable health among 26 nuclear workers who were contaminated with 7–230 nCi of Pu for 40 years (Voelz and Lawrence, 1991). Their SMR was: 0.41 for all deaths, 0.45 for all cancer deaths and 0.21 for all circulatory deaths.
- In 2935 contaminated nuclear workers at Los Alamos Nuclear Laboratory, the total cancer mortality rate was 77% that of carefully selected controls; the leukaemia mortality rate was 35% that of controls (Wiggs et al., 1994).
- The SMR for lung cancer deaths in different nuclear weapons laboratories were: Rocky Flats Nuclear Weapons Plant, 0.14; Los Alamos Nuclear Laboratory, 0.20 and the Hanford site, 0.29 (Tietjen, 1987).
- The cancer mortality rate of 38,000 contaminated nuclear shipyard workers (up to 7 cSv lifetime from film badges) was 65% that of 32,000 carefully selected control shipyard workers (Matanoski, 1991). The total death rate was 24% that of the controls ($p < 0.001$).
- Between 1941 and 1984, the total death rate of 5868 contaminated nuclear workers (mean dose = 17 mSv) at Oak Ridge National Laboratory was 37% that of 2129 carefully selected uncontaminated workers; the cancer death rate was 50% of controls (Wing et al., 1991). The total death rate of 321 workers who received 0.1–1.1 Gy was 34% that of unexposed workers.
- Over 15,000 exposed workers had a cancer death rate that was 60% that of 20,619 unexposed workers at three nuclear weapons plants (Gilbert et al., 1989). Note, the 1412 workers exposed to 20 cSv (lifetime) had a cancer death rate which was only 2.35% that of the controls.
- Lung cancer death rates are inversely proportional with the log of the Rn concentration in almost one million homes in the United States, $p < 0.0001$ (Cohen, 1995). Except for smoking, none of over 50 other parameters showed any correlation.
- Radon concentrations show no correlation with lung cancer deaths in US and other mines (BEIR, 1990).
- Attendants at the Free Enterprise Radon Health Mine at Boulder, MT, receive an estimated 150 mSv/y – Le06. The radon concentration in the mine is 2200 pCi/l.

Conversion factors used here

1 WL = 100 pCi from short lived ^{222}Rn progeny (Beral et al., 1988, p.585)
1 WLM = 170 hr at 1WL = 1 rad = 10 mGy (Eisenbud and Gesell, 1997, p.29)
1 WLM~5 mSv (ICRP)
1 WLM/y = 250 Bq/m^3 = 7 pCi/l air with ^{222}Rn progeny (BE99, p.12)
1 Bq/m^3 = 0.233 mSv/y (whole body) (Eisenbud and Gesell, 1997, p.156)
1 mSv = 37 Bq
SMR = standard mortality rate, a comparison with the general population.