Charles L. Sanders

Radiobiology and Radiation Hormesis

New Evidence and its Implications for Medicine and Society

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Preface

Don Luckey in his seminal 1980 book wrote that an added, annual, cumulative ionizing radiation dose of about 20 times the mean background dose would be optimal for health [1]. The field of radiation hormesis has been built upon the early comprehensive work of Luckey and more recent work of Ed Calabrese (Chap. 1). My previous book examined nearly a thousand published studies concerning mechanisms for epidemiology of radiation hormesis [2]. Optimal health for Luckey included prevention of cancer and a wide variety of inflammatory diseases. Why people have not acted on this provocative hypothesis is largely due to the false paradigm of the linear no-threshold (LNT) assumption and resultant radio-phobia that is built upon early fraudulent mutational studies (Chap. 3). The questioning of survivability from nuclear war, the termination of oceanic and atmospheric nuclear weapons testing, and the promotion of exaggerated health effects of radiological "dirty" bombs were all due to radio-phobia following application of the LNT assumption (Chap. 2).

There is a debate among those opposed to the LNT assumption as to whether to accept radiation hormesis as a legitimate aspect of radiobiology. All sides opposed to the LNT agree that there are thresholds in the radiation dose-response (Chap. 4). But what happens before the threshold for some seems up for debate. A plutonium threshold for lung cancer is related to spatial-temporal dose distribution as well as radiation hormesis (Chap. 5). Rejection of thresholds has enormous implications concerning the costs of radiation protection and socio-psychological aspects of resultant radio-phobia. Acceptance of radiation hormesis means that low dose radiation (LDR) is not associated with increased risk of acquiring a wide variety of inflammatory and proliferative diseases below the threshold dose, but that LDR actually prevents their occurrence below that which might be expected in unexposed control groups. This is particularly evident with exposures to radon (Chap. 6). A further disagreement among advocates of thresholds occurs with using LDR to treat people with active disease in a clinical setting. Radiation hormesis has not received significant traction among radiologists and medical physicists (Chap. 7). This may be due to a high level of ignorance, indifference, antipathy, resistance, and prejudice among most physicians and their patients.

One criticism against the clinical application of radiation hormesis is the lack of epidemiological studies to investigate the efficacy of LDR for any disease category. There are some exceptions, as in the treatment of non-Hodgkin's lymphoma

(Chap. 7) and an ongoing European study of physician patients with radon health spa prescriptions. There is a resistance to read and evaluate anecdotal cases or individual testimonials (among them are those of the author), no matter how detailed or numerous they may be. However common sense and personal experience should trump the conclusions of the epidemiological elite who may manipulate data to force fit the LNT assumption and promote preconceived conclusions of fantasy harm.

The abscopal effect was proposed by R.H. Mole in 1953 in reference to the shrinking of metastatic tumor outside the radiation field used to treat the primary tumor [3]. The bystander effect examines alterations in un-irradiated cells from signals sent out from irradiated cells [4]. There are possibilities for cellular communication of healing signals within the body, such as by very weak light photons and quantum communication that may be associated with bystander effects (Chap. 8).

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Acknowledgments

The first evidence of radiation hormesis was found within a few years after the discovery of X-rays in 1895. What followed was the application of X-rays in successful treatment of a large variety of infectious, inflammatory, and proliferative diseases. A robust industry of radium containing devices was also advertised and sold for the treatment of these diseases. Modern scientific sources have called them quackery, when in fact many were successful in their time, without a following epidemic of radiation-induced cancer resulting from their use. These sometimes life-saving applications continued up to the 1940s when they were replaced by newly discovered antibiotics and the presentation (substitution) of the linear no-threshold (LNT) assumption based upon a radio-phobia of imagined radiation--induced cancer at low doses. The last several decades have seen a renaissance of scientific inquiry amounting to thousands of published studies showing just how right the early scientists and physicians were in their observations about the benefits of ionizing radiation. These historical and continuing observations over a century are hereby acknowledged.

The assistance and contributions of Drs. Jerry Cuttler, Mohan Doss, Bobby Scott, and other members of Scientists for Accurate Radiation Information (S.A.R.I) are gratefully acknowledged. Thanks also to Dr. Juyoung Kim from Stanford University and Dr. Shoujun Wang from Colorado State University for providing helpful comments.

But shall come the day of the Lord as a thief in the night, in which the heavens with rushing noise shall pass away, and the elements burning with heat shall be dissolved, and the earth and the in it works shall be burnt up. These things then all being to be dissolved, what kind of persons ought to be ye in holy conduct and piety, expecting and hastening the coming of the God day by reason of which the heavens, being on fire, shall be dissolved, and the elements burning with heat shall melt? (2 Peter 3:10–12).

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Contents

Movers of Radiation Hormesis

1

If you can't explain it simply, you don't understand it well enough (Albert Einstein).

A mover is a person who makes formal proposals and sets things in motion and who is especially suited to effectively interact with others to get their message across. Among them were the early discoverers in atomic physics. They were followed about 50 years later with the seminal books written by Dr. Don Luckey [1, 2] that elucidated the benefits of low-dose ionizing radiation in spite of an overwhelming professional commitment in radiation protection to the linear no-threshold (LNT) assumption and an atmosphere of political correctness that borders today on scientific corruption (Fig. 1.1). A mover completes the narrative of the LNT and radiation hormesis [3].[1]

A few of the early researchers were exposed to high doses of ionizing radiation. Marie Curie isolated radium and polonium from tons of pitchblende ore. She died of aplastic anemia at the age of 67. Her daughter, Irene Joliot-Curie, continued her mother's research during which she was exposed to polonium sealed in a small

[1] Sacks (S.A.R.I.) wrote: "People tend to be more convinced by a complete narrative than by a few facts or an incomplete narrative. The relevance of this for S.A.R.I. arises in at least two ways that come to mind. For one thing we have had the disagreement among ourselves as to whether we should concentrate merely on showing that LNT is false without bringing in hormesis versus bringing in the complete narrative. Some have felt that to bring in hormesis makes it more difficult for people to be convinced by the argument because that is asking too much. It's hard enough, the argument goes, to convince people that LNT is false, let alone that hormesis is true. But the other side of the disagreement says that by completing the story by explaining hormesis it becomes more convincing, and that more people will therefore be convinced. Another relevance for us to the completion of the narrative is that by showing that LNT only considers the damage but not the biological response, i.e., LNT is incomplete, and that consideration of the biological response as well as the damage is necessary to arrive at the net effect. This completion of the narrative – damage plus response – is more convincing, if it is true that people really need completion for understanding a phenomenon."

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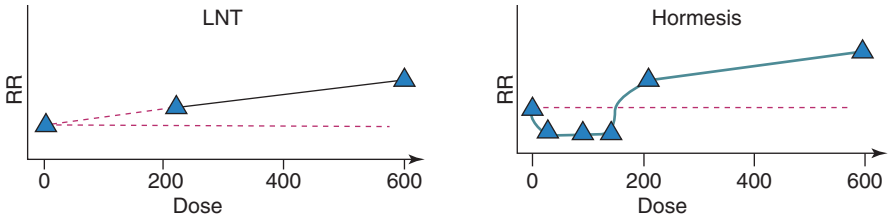

Fig. 1.1 Models of relative risk (RR) for biomedical effects following exposure to ionizing radiation: linear no-threshold (LNT) and radiation hormesis (With kind permission of Dr. Bobby Scott [42])

capsule that exploded in her laboratory. She died a few years later from leukemia at the age of 58. Previously, both Marie and Irene served as battlefield radiology nurses in World War I for about 3 years near the front lines exposing themselves to X-rays from lightly shielded machines [4].

The possibilities that ionizing radiation offered for medical diagnostics were first demonstrated by Wilhelm Roentgen, 1 month after his discovery of X-rays, by publishing in *Nature* in January 1896 an X-ray photograph of the hand of his wife. Wilhelm lived for 78 years. In 1902 Pierre Curie, [5] together with two physicians, Balthazard and Bonchard, discovered that radium rays were useful in cancer therapy. The theoretical basis for this therapy was provided in 1906 by Bergonie and Tribondeau as the result of their experiments with rats. [6] They showed that X-rays were more effective on undifferentiated cells which had a higher proliferation rate. The beneficial or hormetic effects of low doses of ionizing radiation were first described in 1898, when an increased growth rate was seen in blue-green algae exposed to X-rays [7].

Otto Hahn and Lise Meitner were exposed to radiation during their careers as they explored radioactivity and nuclear fission. Hahn was the father of nuclear chemistry. He isolated an isotope of radium that he called mesothorium. In 1912 his research institute in Germany was visited by Kaiser Wilhelm II. Hahn presented the Kaiser with an unshielded sample of mesothorium in a small box equivalent in radiation intensity to 300 mg of radium and showed the Kaiser how it produced luminous moving shapes in the dark when shown on a screen. [8] The Kaiser lived to be 82, dying in 1941 of pulmonary embolus. Hahn and Meitner both lived to the age of 90. Glen Seaborg, who discovered plutonium and other transuranic elements, lived to be 87.

Lauriston S. Taylor (1902–2004), founder and father of the early American radiation protection, was one of the most influential persons in the promulgation of radiation protection standards. Taylor founded the National Council of Radiation Protection and Measurements (NCRP) and became its first and only president for the next 48 years. It was Taylor who said: The LNT is a deeply immoral use of our scientific heritage. It was Taylor who said: No one has been identifiably injured by radiation while working within the first numerical standards set first by the NCRP and then the ICRP in 1934 [9]. Standards in 1934 were 1 mSv/day for the NCRP and 2 mSv/day for the ICRP. Lauriston Taylor

died at the age of 102 despite receiving a cumulative whole-body radiation dose of about 10 Gy when he was age 27 and several smaller doses for radiation therapy of inflammatory diseases.

Other major participants in radiation protection and hormesis were Maurice Tubiana who lived to 93, Ted Rockwell to 90, Bernard Cohen to 88, Zbigniew Jaworowski to 85, and Myron Pollycove to 92. Dr. Ted Rockwell worked on the A-bomb during World War II and then with Admiral Rickover on the nuclear navy. Later, Rockwell was a tireless campaigner for radiation hormesis [10]. Dr. Maurice Tubiana was an oncologist, radiotherapist, and member of French Academies of Science and Medicine, IARC, WHO, and IAEA. Tubiana was an early proponent of radiation hormesis. Dr. Zbigniew Jaworowski was a Polish physician and biophysicist and chair of UNSCEAR and member of IAEA. Jaworowski believed in the benefits of low-dose radiation. [11, 12] Dr. Myron Pollycove was a pioneer in the development of isotopes for use in diagnosis and therapy and professor at UCSF Medical School. His work later in life focused on radiation hormesis. Ludwig E. Feinendegen, born in 1927, is a professor in nuclear medicine at Heinrich-Heine University, Germany, and author of many publications on radiation hormesis including several in press today [13].

Bill Bair, my mentor at Battelle Northwest in Richland, WA, spent his working research life in radiobiology of transuranics; he died in 2015 at the age of 90 [14]. Allen Brodsky was exposed to a whole-body dose of about 300 mGy while recovering neutron spectrometers off Eniwetok right after the second and third US H-bomb tests. He is alive at the age of 87. Robert R. Brownlee was a navigator on a B-29 in World War II; his bomber was parked near the *Enola Gay* on the Pacific Island of Tinian. Brownlee participated in about 300 A- and H-bomb tests in Nevada and the South Pacific. A H-bomb test at Bikini Atoll was associated with an unexpected high yield and shift in winds covering him with a cloud of radioactive coral dust for 30 h. Brownlee was at Los Alamos, New Mexico, when a group of men accidentally breathed in a high level of plutonium particles. Fifty years later they were found healthier than the control group. [15] Today, Brownlee is 93, attending my church in Loveland, CO.

Don Luckey (1919–2014) carried on an active scientific life that included 282 professional publications. Following a career as a professor in Notre Dame and the University of Missouri, Luckey became interested in radiation hormesis. He continued to travel and publish after his retirement in 1984. Luckey wrote two books on radiation hormesis: *Hormesis with Ionizing Radiation* (1980) [1] and *Radiation Hormesis* (1991) [2]. He continued his work until his death. In a study of about 250,000 nuclear workers, he found an average mortality in nuclear workers that was 33% less than unexposed controls. The control groups were chosen to minimize the use of the healthy worker effect as an excuse for radiation hormesis [16, 17]. Luckey felt lifespan could be prolonged by 30% by increasing exposure to low-dose radiation [18]. He found that supplementation with low-dose irradiation decreased heart disease, sterility, infections, lung diseases, cancer, and premature deaths [18]. Luckey believed that these benefits would be cumulative if we lived with 20 times

more ambient ionizing radiation than we have now (~50 mGy per year). Ed Hiserodt called Luckey pivotal in his research; Hiserodt wrote an excellent book about the benefits of ionizing radiation [19]. Luckey was also pivotal in my research. [20] Luckey slept for many years next to a yellow radioactive granite rock; he was 95 when he died.

A policeman who survived the Hiroshima A-bomb carried a message to his fellow police officers in Nagasaki. He told them that a bright light would be followed a few seconds later by a deadly shock wave. Tsutomu Yamaguchi was the reason why a few policemen died in Nagasaki; he lived to be 93. The same duck and cover strategy was taught to school children throughout the Cold War.

Ivan Shamyanok is a 90-year-old villager who refused to leave after the Chernobyl nuclear reactor explosion in 1986. Ivan lives in the Belarusian village of Tulgovichi, which is nestled on the very edge of the exclusion zone created in 1986 to protect humans from fallout. Ivan has lived here without serious health ramifications for 30 years. He drinks a glass of vodka before every meal to boost his appetite. But for the others who left, Tulgovichi said: "they have not fared so well. My sister lived here with her husband. They decided to leave and soon enough they were in the ground." [21] Anecdotal evidence of elderly people who refused to leave the Chernobyl exclusion zone shows a consistent testimony of relief from arthritic pain and feeling much healthier than before. [22] Holly Morris did a TEDMED video presentation entitled: *Chernobyl: Flourishing lives in the dead zone*. She had visited Chernobyl and found about 100 now elderly women who refused to leave their homes in 1986. They are thriving with a longevity that is 10 years longer than women who had moved in 1986 [23]. Naoto Matsumura returned to live in the abandoned restricted zone around the Fukushima reactor accident to feed a wide range of animals. [24] Domestic and wild animals in high-radiation zones around Chernobyl and Fukushima thrive with no harmful effects from radiation [17, 23, 24].

What we as proponents of radiation hormesis write can change the way people of integrity think. James Muckerheide during his career in nuclear science was an outspoken critic of the LNT and founder of *Radiation Science and Health*, a nonprofit organization of scientists that opposed radiation protection standards based on the LNT. [25] Rod Adams is the founder of *Adams Atomic Engines, Inc.* and has made frequent comments about hormesis on his internet blog. In one he narrates how a longtime nuclear critic had changed his mind after reading my book [20]. Lawrence Solomon is a Canadian writer and columnist and a leading environmentalist for many newspapers including *The Financial Post*, *Energy Probe*, *CBS News*, and *The Wall Street Journal*. He was an advisor to President Jimmy Carter on the environment. Solomon was for 30 years an opponent of nuclear energy. Adams wrote [16]:

> Since Energy Probe adopted its anti-nuclear position in the 1970s, hundreds of nuclear plants that were on Canada's drawing boards have been cancelled and no new nuclear plants have been completed. Energy Probe is also a leading critic of nuclear power on health and safety grounds. Lawrence Solomon is one of the primary writers for Energy Probe; his anti-nuclear and pro-gas commentary is frequent and predictable [16]. With all of that background, it was therefore quite a shock to read an article from (the) Financial Post titled 'Radiation's Benefits' and to see that the by-line was no other than Lawrence Solomon [26]. Not only did the piece have an intriguing, positive headline related to nuclear energy, but it also started with a rather surprising admission. Low levels of radiation, science is increasingly telling us, are not only safe, they are actually healthful. It may be more prudent to worry about getting too little radiation than too much [26–28]. Why did Solomon change his mind? The answer comes quickly – he read a book, but not just any old book.' The latest book to question the conventional wisdom on radiation comes from Springer-Verlag, a venerable academic science publisher whose stable of writers over the years has included some 150 Nobel laureates… and its intimidating title, Radiation Hormesis and the Linear-No-Threshold Assumption [20].

Dr. Jay Lehr made several national TV news interviews after the Fukushima Daiichi nuclear disaster on March 11, 2011 that followed an earthquake-induced tsunami, flooding, and shutting down the cooling system of several coastal, Japanese nuclear reactors. Lehr is a science director of *The Heartland Institute* based in Chicago. He is an internationally renowned scientist and author of 30 books including *Wiley Interscience's Nuclear Energy Encyclopedia*. In his tweet written on May 4, 2011, Lehr says: "Charles L. Sanders latest book, Radiation Hormesis and the Linear-No-Threshold Assumption, is among the finest scientific research publications I have ever read… we have all witnessed in recent months after near-total distortion of potential harm to the Japanese population… Such distortions are fueled by proponents of the linear no threshold (LNT) assumption." Lehr interviewed Bernard Cohen about the health effects of radon in 2001 [18]. Lehr was invited to lunch by *Newsweek* magazine in New York City. He told them that one of his top three issues for the nation's environmental priorities was reducing the unwarranted fear of low-level radiation that grips most of the world's population. [29] Ann Coulter of Fox News also believes that low-dose radiation is good for you. [8] John Stossel, host of ABC's 20/20 program, dispelled the myth of health risk from low-dose radiation in a May 18, 2006 program.

Dr. Ed Calabrese, one of the nation's leading toxicologists, initially believed in the LNT (Fig. 1.2). After examining the evidence, he said: "My interpretations were pretty much wrong." Calabrese is a professor at the University of Massachusetts and author/coauthor of about 750 papers and 26 books, many on hormesis. He is the founding editor in chief of *Dose-Response* journal. In 2009 he was awarded the Marie Curie Prize for his work on radiation hormesis. Calabrese found that the fundamental dose response in toxicology, pharmacology, and radiobiology was the hormetic-biphasic dose-response relationship. It is Dr. Calabrese who is substantially responsible for the surge in interest of radiation hormesis during the last 20 years [30].

Fig. 1.2 Edward Calabrese (With kind permission of Dr. Edward Calabrese [43])

I communicated with Dr. Bobby Scott in 2005 during my first year as a professor at KAIST (Korea Advanced Institute of Science and Technology) in Daejeon, South Korea. Bobby started his hormesis research in high school (Webster High, Minden, Louisiana) by conducting a mutation induction study using the fruit fly model and β-radiation. He won first prize in a regional science fair. Bobby mentored me in basic radiation hormesis and coauthored a paper with me [31] which was presented in the 2006 dose-response annual meeting at the University of Massachusetts; the meeting was chaired by Dr. Calabrese.

In 2013, I contacted Dr. Scott, a now retired radiobiologist from Albuquerque, New Mexico, about starting a cohesive group for advocates of radiation hormesis as well as those who opposed the LNT assumption. Bobby took the idea and made it happen. The early members decided to call the group Scientists for Accurate Radiation Information (S.A.R.I.). Radiationeffects.org is a blog established to share their views. S.A.R.I. has grown to about 100 members found in a dozen countries of the world and has gained professional respect; their position letters are quoted in professional publications and news organizations. S.A.R.I. statement of purpose is: The objective of S.A.R.I. is to monitor for and counter nuclear/radiological misinformation that could adversely impact the world's ability to effectively respond to nuclear and radiological challenges to the end point of saving lives. S.A.R.I. is multidisciplinary and includes expertise in radiation source characterization, radiation transport, external and internal radiation dosimetry, radiobiological effects (both harmful and beneficial), dose-response modeling, radiation risk and benefit assessment, and nuclear/radiological emergency management. A new organization has recently been formed by S.A.R.I. members, Dr. Mohan Doss and Dr. Jerry Cuttler, called XLNT Foundation (Fig. 1.3) [32]. The *Health Physics News* for January 2017 provides a comprehensive description of the history and purpose of S.A.R.I. [33].[2]

[2] Excerpts: "Though the health effects of low-dose radiation (LDR) have been studied for many

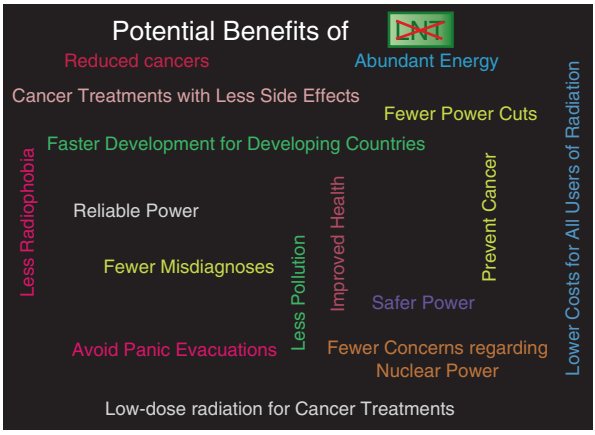

Fig. 1.3 Blog that does not support the LNT model pointing out why it should not be relied upon [32] (With kind permission of XLNT Foundation of which the author is a member)

decades, there is still considerable disagreement in the scientific community about whether LDR exposure is harmful or beneficial. The prevailing view, supported universally by international advisory bodies since the 1950s, is that LDR is harmful and can be represented by the linear no-threshold (LNT) model for radiation-induced cancers. This model has been the basis of radiation protection regulations and practices worldwide since the 1950s. In the authors' opinion, research over the past few decades has shown that the LNT model is not valid conceptually. In addition, experimental and epidemiological investigations have demonstrated its invalidity while the opposite view of radiation hormesis has proved to be conceptually valid and is supported by experimental and epidemiological observations. In view of this situation, many scientists have objected to the continued use of the LNT model. However, these objections have been overruled by advisory bodies and regulatory agencies. The main evidence usually quoted in support of the LNT model or carcinogenicity of LDR is the atomic bomb survivor data… These new data contradict the LNT model because of the significant curvature in the dose-response relationship due to the lower-than-expected cancer mortality rates in the 0.3–0.7 Gy region. Radiation hormesis, however, would be able to explain the curvature in these data. The advisory bodies and regulatory agencies have so far refused to recognize this change in the atomic bomb survivor data and continue to support the LNT model. They have also ignored much additional evidence in support of radiation hormesis. Another issue with the use of the LNT model is the calamities that result from its use, disproving the claim that it is a conservative approach to radiation safety. A case in point is the socioeconomic trauma following the nuclear reactor accidents in Fukushima in 2011. The accidents provoked fast and prolonged evacuation of the surrounding areas, causing considerable suffering and casualties, destroying the local economy, and harming Japanese society, all for no benefit. The advisory bodies have refused to modify their recommendations even after observing the tremendous amount of harm caused by the LNT model. This deplorable scenario of social harm caused by the use of the LNT model has galvanized many professionals into joining forces in an attempt to overcome the use of the LNT model in favor of a hormesis-oriented model to be applied in a public-health-relevant manner… S.A.R.I. members, and the membership has grown to over 100 professionals from a wide variety of backgrounds from 15 different countries. The group includes professionals representing a broad range of expertise, practices, and technologies involving the use of ionizing radiation. Thus, there are physicists, biologists, radiation biologists, epidemiologists, statisticians, physicians, radiologists, nuclear and other engineers, reporters, columnists, news editors, etc. S.A.R.I. is a very active group with vigorous discussions/debates on many relevant topics… An independent nonprofit organization, the XLNT Foundation, was formed in 2015 by several S.A.R.I. members in collaboration with additional interested individuals. The foundation's goal is to facilitate taking these and other additional steps to overcome the LNT model problem."

S.A.R.I. members recently made presentations at a 2015 symposium in Japan about the Fukushima accident. Earlier a S.A.R.I. document was sent to Mr. Shinzo Abe, Prime Minister of Japan [34]:

> Dear Prime Minister, We, the undersigned members of Scientists for Accurate Radiation Information (S.A.R.I.), are writing to support your efforts of calming the Japanese people and to provide a short discussion on what is known about the health effects of low-doses of ionizing radiation such as may have been received or may be received by down-wind populations of the Fukushima nuclear power plant. Casualties have already occurred among some members of the Japanese population related indirectly to radiation phobia-promoting misinformation about the health effects of low radiation doses. The misinformation mainly relates to hypothetical harm (e.g., radiation-induced cancers) based on the linear no-threshold (LNT) model. The LNT model of radiation-induced stochastic effects assumes that every dose of ionizing radiation, no matter how small, constitutes increased (linear with the dose) risk of the effect of interest. The LNT model is presently used for cancer risk assessment by advisory bodies and as such it is the basis for radiation safety regulation. The LNT model is also widely accepted by the general public. However, the scientific validity of this model has been seriously questioned and debated for many decades.

Advocates of the LNT assumption routinely avoid discussing thousands of published papers that demonstrate radiation hormesis. Newspaper op-eds are often highly negative, biased, and misleading concerning the effects of ionizing radiation. Recently the International Commission of Radiological Protection (ICRP) stated that: “While prudent for radiological protection, the LNT model is not universally accepted as biological truth, and its influence and inappropriate use to attribute health effects to low dose exposure situations is often ignored” [35]. The LNT assumption would suppose that high natural background radiation is harmful. This has been proven to be false throughout the world [36]. In fact, many studies show benefit from low-dose radiation (LDR) with less than expected cancer increased longevity and clinical efficacy (Fig. 1.4).

The Health Physics Society (HPS) position statement for 2016 says in part: “Due to large statistical uncertainties, epidemiological studies have not provided *consistent* estimates of radiation risk for whole-body equivalent doses less than 100 mSv.” This new somewhat ambiguous statement is an improvement on the previous version. One positive aspect of the statement is that it calls the LNT model questionable and another is that it refers to an adaptive response and to the French Academy of Sciences report by Tubiana [37, 38].

The question of the validity of the LNT hypothesis, in connection with radiation exposure, is very important since the LNT model has been the basis of environmental and public health policy for several decades. Inaccurate extrapolation of risks from high dose to low dose (top-down approach) is dangerous to our health [39]. The LNT is responsible for the fear of any radiation common among the general public, the reluctance seen among some individuals regarding diagnostic or screening procedures involving exposure to radiation, the fear of contamination from nuclear plant accidents or negligence, and the concerns about dirty bombs employed for terrorism. Research results clearly suggest the existence of thresholds and beneficial effects of low-dose radiation below the threshold, such that many of the concerns enumerated are unjustified. Those who believe in the LNT model regard such statements of

Fig. 1.4 From left: Dr. Jerry Cuttler, Dr. Maurice Tubiana, Dr. Myron Pollycove, and Dr. Kiyohiko Sakamoto. Dr. Sakamoto has carried out clinical trials with low-dose radiotherapy. [44] Dr. Cuttler's wife received Sakamoto's half-body low-dose radiation treatment for the prevention of cancer recurrence. Cuttler believes a single whole-body dose of 150 mGy or a continuous annual exposure of 700 mGy is safe and beneficial (With kind permission of Dr. Jerry Cuttler [45])

Fig. 1.5 Auto license plates in Ontario, Canada (with kind permission of Dr. Jerry Cuttler [14]) and in Montana, USA

benefit as heresy, reckless, and dangerous. Numerous epidemiological studies, confirmed by experimental animal studies, conducted throughout the world, show that low-dose rate of ionizing radiation is beneficial to human health [20, 40, 41].

Twenty-seven million Americans suffer from various forms of arthritis with 700,000 artificial knee replacements and 300,000 hip replacements performed each year. I greatly admire Patricia Lewis for maintaining a passion for the benefits of radon for over 20 years that has given thousands of people hope by helping them deal with a wide variety of often painful inflammatory conditions by visits to the Free Enterprise Radon Health Mine in Montana. Lewis has done this at great cost and perseverance (Figs. 1.5 and 1.6).

Examples of recent conversations by S.A.R.I. members during 2014–2016 at their blog site (radiationeffects.org) are instructive: The LNT is not a model; it is

Fig. 1.6 Patricia Lewis, a member of S.A.R.I. and previous owner of Free Enterprise Radon Health Mine, Boulder, Montana

merely a system to legislate the issue of societal and individual hazard from ionizing radiation in man, to be used for regulatory purposes only, and not for science (Mike Waligorski). I know what adaptive response means. But others do not want to use the h-word (hormesis) nor talk about beneficial effects of a low dose. Instead, they will use the term "adaptive response" (Jerry Cuttler). There has been a rapid loss of classical radiation physicists, radiation chemists, radiation biologists, and radiation toxicologists that are mostly not being replaced. As a result it has become more difficult to convince the public of the enormous benefits of nuclear energy and medical applications of ionizing radiation which far outweigh the so-called associated risks, much less the benefits in disease prevention and therapy of LDR.

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Radiological Weapons

2

We're bad at balancing risks, we humans, and we live in a world of continual uncertainty. Trying to avoid the horrors we imagine, we risk creating ones that are real [1].

2.1 Development of Nuclear Weapons

Early Nobel Prize-winning investigators of atomic physics recognized the potential of nuclear weapons [2]. Matter must be known not only as mass but also as a storehouse of energy. If a proper detonator could be found, it was just conceivable that a wave of atomic disintegration might be started through matter, which would indeed make this old world vanish in smoke (Rutherford, 1903). Soddy said in 1904: "The man who put his hand on the lever by which a parsimonious nature regulates so jealously the output of this store of energy would possess a weapon by which he could destroy the earth if he chose." There is theoretically no limit as to how large a bomb may be developed, perhaps as big as to shatter the earth into fragments, as Rutherford suggested in 1903. Einstein was alarmed enough in 1939 to write President F.D. Roosevelt about his certainty that such a bomb will be constructed. Craig Nelson in *The Age of Radiance* [3] presents these early historical discoveries leading to nuclear weapons with a "you were there" reality.

The International Solvay Institute for Physics and Chemistry hosted in Brussels the first Solvay International Conference in 1911. The conference was considered a turning point in the development of the disciple of atomic physics. The chairman was H.A. Lorentz and the conference title was *Radiation and the Quanta*. Marie Curie and Albert Einstein were present [4]. The 5th Solvay Conference was in 1927 (Fig. 2.1) [5]. The Solvay conferences continue today with the 25th conference being held in 2011 on *The Theory of the Quantum World* and the 26th conference being held in 2014 on *Astrophysics and Cosmology*.

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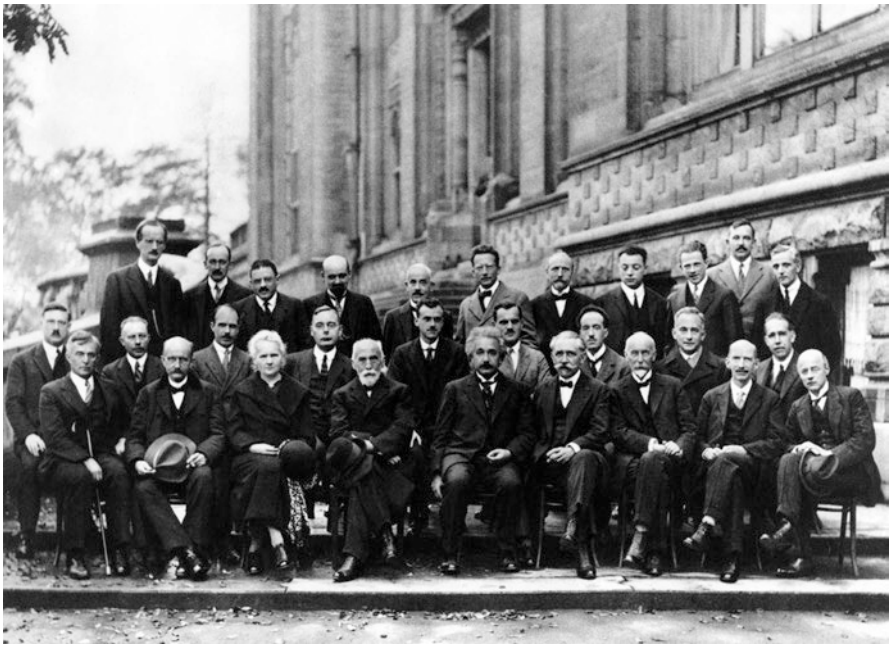

Fig. 2.1 The Fifth Solvay Conference was also held in Brussels in 1927. The subject of the conference was *Electrons and Photons*. Seventeen of the 29 participants were or later became Nobel Prize winners. Marie Curie remained as the only woman and also the only person to be awarded the Nobel Prize in two disciplines [5]. Participants for the conference were: *Back*: Auguste Piccard, Émile Henriot, Paul Ehrenfest, Édouard Herzen, Théophile de Donder, Erwin Schrödinger, JE Verschaffelt, Wolfgang Pauli, Werner Heisenberg, Ralph Fowler, Léon Brillouin. *Middle*: Peter Debye, Martin Knudsen, William Lawrence Bragg, Hendrik Anthony Kramers, Paul Dirac, Arthur Compton, Louis de Broglie, Max Born, Niels Bohr. *Front*: Irving Langmuir, Max Planck, Marie Curie, Hendrik Lorentz, Albert Einstein, Paul Langevin, Charles-Eugène Guye, CTR Wilson, Owen Richardson (Photo taken at the 1927 Solvay Conference. With kind permission of the International Solvay Institutes, Brussels, Belgium, photograph taken by Benjamin Couprie)

The grand total of deaths due to all wars involving the USA was about 850,000. Combat deaths accounted for 2% of the US population in the Civil War and 0.1% and 0.3% for World War I and World War II, respectively (Table 2.1). The number of lives in the world that can be saved and prolonged by low-dose ionizing radiation in 1 year is considerably greater than all the American combat losses in our entire history.

The golden age of triumph of the Enlightenment over darkness giving love, brotherhood, progress, and science ended in 1914. World War I saw the first development and use of large-scale poisonous gas warfare. Fritz Haber won the Nobel Prize in chemistry for finding a way to make ammonia for fertilizer. During World War I, Haber synthesized phosgene and mustard gases. The Germans first used them followed rapidly by the English, French, and Americans in the trenches of France. They included chloropicrin (vomiting gas), xylyl bromide (tear gas),

Table 2.1 American Deaths from major wars of the USA (1775–2013) [6]

War	Years	Deaths	Population (million)
Revolutionary War	1775–1783	25,000	2.5
War of 1812	1812–1815	2300	8.0
Mexican War	1846–1848	13,000	21
Civil War	1861–1865	420,000	31
Spanish-American War	1898	2900	70
Philippine War	1899–1902	4300	72
World War I	1917–1918	117,000	100
World War II	1941–1945	411,000	130
Korean War	1950–1953	54,000	150
Vietnam War	1957–1975	58,000	180
War on Terror	2001–2013	5300	310

chlorine, carbonyl chloride (phosgene), and dichloroethyl sulfide (mustard gas that penetrated rubber and leather). Mixtures were found more effective. Haber's wife committed suicide in despair over her husband's work. Of the 21 million casualties in World War I, about 5% were due to gas warfare. Most died from artillery shells and machine guns. Toward the end of the war, the Germans built large bomber aircraft such as the two-engine "Gotha" and the four-engine "Giant." They dropped 250,000 pounds of bombs on England killing 835 people. They also developed a ten-pound incendiary bomb made out of magnesium which they did not use since they felt it would destroy any hope of a negotiated peace [2]. It was also thought that 40 planes carrying tons of poisonous gases could wipe out the population of London [3]. World War II saw nearly an order of magnitude increase in deaths as compared to World War I; most of World War II casualties were found in noncombatants.

A deep fear of nuclear war and of radiation has served as containments for future wars. The potential deaths from a full-scale nuclear war between the USA and U.S.S.R. were estimated by the World Health Organization (WHO) in 1984 at about two billion people. Most would be noncombatants, and many of those were projected to have died from acute radiation exposure and a wave of cancer and other late-appearing diseases. However, the radiological estimates were deliberately exaggerated to promote radiophobia [7, 8].

On August 2, 1939, a Jewish scientist who had fled to the USA from Germany, Albert Einstein, wrote a letter to President Franklin D. Roosevelt, about the developments that had been taking place in nuclear physics, particularly by two other Jewish scientists, Leo Szilard and Eugene Wigner. They warned Roosevelt that scientists in Germany were working on the possibility of using uranium to produce nuclear weapons.

The plan to build an atomic bomb was placed under the name *Manhattan Engineer District*. About 52,000 acres of land along the Clinch River in eastern Tennessee was purchased by the US government, later known as Oak Ridge National Laboratory (ORNL). A large track of land in the desert surrounded on two sides by the Columbian River was obtained at Hanford, Washington, for the construction of uranium-fueled nuclear reactors used to produce plutonium. Another piece of property was purchased in Los Alamos, New Mexico, to be used for the construction of the first atomic bombs, both the U-235 bomb dropped on Hiroshima and the Pu-239 bomb dropped on Nagasaki. Robert Oppenheimer was its director and General Leslie Groves the military commander in overall command.

The first plutonium-producing, atomic pile reached criticality on September 26, 1944, at Hanford. Burning a nuclear reactor for 100 days transmuted about 1 atom of every 4000 U-238 atoms to Pu-239. The hot slugs were removed and placed in water for 60 days until most short-lived fission products had decayed. The slugs were then taken to a chemical facility for separation of plutonium.

Natural uranium contains >99.2% U-238 and 0.72% U-235. Low-enriched, reactor-grade uranium contains 3–4% U-235. Highly enriched, weapons-grade uranium contains ~90% U-235 [9].

On July 16, 1945, the first plutonium A-bomb was tested at Alamogordo, New Mexico, with a yield of 19 KT (Project Trinity). The uranium A-bomb was never tested. The next month a nuclear warhead was delivered from the bomb bay of a B-29, the *Enola Gay*, and detonated at an altitude of 1700 feet. The largest Catholic Church in Hiroshima was used as the target for the pilots, who were also Catholics. This uranium bomb was 28 in. in diameter and 10 feet long, weighing 9000 pounds. Charles Sweeney was the last man to drop an A-bomb (Fat Man), a plutonium bomb, this one on Nagasaki from his B-29. Sweeney's job was to drop the bomb on Kokura, but haze from a firebombing raid on a nearby city obscured the target. Low on fuel, he flew on to the alternate target, the manufacturing town of Nagasaki. The bomb detonated directly over the Christian quarter at 11:02 AM on August 9, 1945, 3 days after the Hiroshima bomb. From then on, the survivors of both Japanese cities were called "hibakusha" or "explosion-affected persons." About 20,000 enslaved Koreans also died in Hiroshima from the bomb; no one has bothered to study the health of surviving Koreans in Hiroshima and Nagasaki. In fact, very little historical study has been given to their fate. In June 1946, the US arsenal contained nine Fat Man-type bombs. In late 1949, the USA had increased its arsenal to 200 atomic bombs.

The two Japanese A-bombs were detonated by radar altimeter above grade to maximize the free expansion of the fireball, so as to set the maximum amount of these two wooden cities on fire. This created carbon soot "black rain" which may have mingled with fission-product ash particles to create hotspots of radioactivity. The second atomic weapon was so crude that only about 1% of Pu-239 mass was

burned amounting to a couple hundred grams which became actual fission-product fallout. The fireball at the Trinity site was centered only about 33 m above grade causing the fireball to touch the desert sand. The molten sand turned into plutonium-laced green glass later called trinitite.

The distribution of energy from an A-bomb is approximately 50% blast, 35% thermal, 5% prompt gamma and neutron radiation, and 10% residual radioactive fallout. The effects of a nuclear warhead detonation depend on the warhead yield and the distance from the surface of the earth at which it was detonated. In the first millisecond after a 0.5-MT nuclear warhead is detonated, the temperature of the fireball is about 400,000 °C and the overpressure is over 100,000 pounds per square inch (psi). At 50 ms, the radius of the expanding fireball has grown to 1350 feet and the fireball temperature has cooled to 75,000 °C. The overpressure shock wave is coincident with the fireball creating a wind of over 1000 miles per hour. At 1 s, the fireball has a radius of 2500 feet and a surface temperature of 6000 °C. The shock wave is now expanding faster than the fireball providing a 40 psi front at 3800 feet with a wind of 750 mph. After 10 s, the fireball has a surface temperature of 2000 °C, while the shock wave radius is 2.6 miles with a 5 psi front. Winds of over 300 mph are beginning to suck up debris from the ground into the stem of an ascending mushroom cloud. At 1 min, the characteristic cloud has grown to a radius of 1.5 miles and reached an altitude of 3.5 miles. The cloud continues to grow to over 8 miles in height and drift downwind. The prompt effects of nuclear detonations include a blast or shock wave, an initial pulse of gamma rays and neutrons, and a pulse of thermal or heat energy. Later effects are due to fallout of radioactive fission products and neutron-induced radioactive material. Blast waves can destroy the sturdiest built homes, while thermal radiation can melt the eyes and rot the flesh of those residing many miles away. The most extensive hazard from nuclear war for those residing outside the limited regions of lethal blast, thermal, and prompt radiation effects is radioactive fallout. Radioactive fallout from megaton-level detonations will carry hundreds of miles downwind.

Arthur Eddington (1882–1944) concluded that at high temperatures in the interior of a star, the nuclei in the star could penetrate other nuclei and cause nuclear fusion reactions, releasing energy. The energy would be released when fast-moving hydrogen nuclei collided with enough force to overcome their respective electrical barriers and fused together, making helium nuclei and giving up the binding energy in the process. These events were later named thermonuclear reactions. Fermi believed an atomic bomb might serve to heat a mass of deuterium sufficiently to begin thermonuclear fusion.

A bomb fusing hydrogen to helium should be many orders of magnitude more energetic than a fission bomb. Teller considered the possibility of a hydrogen bomb and made extensive calculations. He named his new hydrogen bomb, *the Super*, and used an atomic bomb for ignition and a cubic meter of liquid deuterium and an indefinite amount of tritium for the thermonuclear phase in the first H-bomb test. The design of the Super is still a secret. The first experimental thermonuclear device, coded Mike and weighing 65 tons, was detonated at Eniwetok Island in the South Pacific on November 1, 1952. Its yield was a thousand times more violent than

Little Boy dropped on Japan. The U.S.S.R. Tsar Bomba tested a 60-megaton H-bomb in the atmosphere using lithium deuteride powder.

> The 60-megaton Tsar Bomba shattered the notion in 1961 that there are any technological limits as to how big a bomb might be built; science does not impose any limits as to yield. The mushroom cloud reached to 37 miles. The ring of absolute destruction would have a 28-mi radius. The fireball was over 5 miles in diameter [10].

There was a vigorous controversy between Linus Pauling and Edward Teller 50 years ago during the height of atmospheric testing of nuclear weapons. Herman Muller's work on genetics influenced Linus Pauling (1901–1994). Pauling received Nobel Prizes in 1954 and in 1962. Other than Pauling, only Marie Curie was awarded separate Nobel Prizes in different scientific fields. Pauling was a member of the Emergency Committee of Atomic Scientists chaired by Albert Einstein. He sent a disrespectful handwritten letter to John F. Kennedy, president of the USA, in 1962 to give his adamant antinuclear views based in large part upon the false data of Muller. The letter reads:

> To: President Kennedy: Are you going to give an order that will cause you to go down in history as one of the most immoral men of all time and one of the greatest enemies of the human race? In a letter to the New York Times I state that nuclear tests duplicating the Soviet 1961 tests would seriously damage over 20 million unborn children including those caused to have gross physical or mental defect and also the stillbirths and embryonic, neonatal and childhood deaths from the radioactive fission products and carbon 14. Are you going to be guilty of this monstrous immorality, matching that of the Soviet leader, for the political purpose of increasing the still imposing lead of the United States over the Soviet Union in nuclear weapons technology? [11].

Andrei Sakharov (1921–1989) was awarded a PhD in particle physics in 1948 and immediately joined the U.S.S.R.'s nuclear weapons project; he became the key figure in the development of the Soviet hydrogen bomb. The genie unleashed by Sakharov and the other pioneering nuclear scientists will never be put back into the bottle. By 1957 Sakharov felt personally responsible for the problem of radioactive contamination from nuclear tests, writing scientific papers on *Non-threshold Biological Effects* and *The Radioactive Danger of Nuclear Tests*. Sakharov's belief in the LNT assumption played a great role in limiting testing of nuclear weapons in the air, space, and the oceans of the world. Sakharov said: the treaty has saved the lives of hundreds of thousands, possibly millions, of people who would have perished had testing continued. Today lasers and computer simulations have replaced the need for most nuclear tests [12]. Sakharov in the mid-1970s predicted the development of the World Wide Web (www), almost 20 years before it first appeared: Far in the future, more than 50 years from now, I foresee a universal information system (UIS), which will give everyone access at any given moment to the contents of any

book that has ever been published or any magazine or any fact. The UIS will have individual miniature-computer terminals, central control points for the flood of information.

2.2 Atmospheric Tests

The official stance of the USA and the U.S.S.R. with respect to nuclear tests is that they represent the development and testing of nuclear weapon reliability. In fact, such tests also suggest a surrogate nuclear war among the superpowers, a war of intimidation by proxy. Jaworowski [7] described the exaggerated fear of ionizing radiation that arose during the Cold War period with incessant testing of nuclear weapons. Radioactivity from the atmospheric tests spread over the whole planet, mostly in the northern hemisphere. People feared the terrifying prospect of a global nuclear war and "large" doses of radiation from fallout. However, it was the leading physicists responsible for inventing nuclear weapons, who instigated the fear of small doses. In their endeavor to stop preparations for atomic war, they were soon joined by many scientists from other fields. Subsequently, political opposition developed against atomic power stations and all things nuclear.

The LNT has played a critical role in influencing a moratorium and then a ban on atmospheric testing of nuclear weapons. The United Nations Committee on the Effects of Atomic Radiation (UNSCEAR) was concerned mainly with the effects of nuclear tests, fulfilling a political task to stop weapons testing. False arguments of physicists were effective in stopping atmospheric tests in 1963. However, the price paid created a radiophobia of demanding near zero radiation doses for future generations. This worldwide societal radiophobia was nourished by the LNT assumption. A video called *The Inheritance of Trauma: Radiation Exposed Communities around the World* claimed that half of background radiation comes from past nuclear weapons testing [8]. This type of fear mongering in the midst of abundant and easily available data to refute this outrageous statement is one of many that caused radiophobia in the American public. President Clinton also promoted his antinuclear campaign by grossly exaggerating the radiation risk from nuclear testing fallout based on the use of the LNT. The truth is that radiation exposure from nuclear weapons tests never amounted to more than 100 μGy per year in 1962 to those living in the northern hemisphere. The exposure from nuclear testing dramatically decreased in 1963 due to the test ban; today, test fallout contributes much less than 10 μGy per year. Mean background dose in the USA and the world today is 2500 μGy per year, with natural environmental exposures ranging up to 700,000 μGy per year in regions of Iran. In 1945, Stalin ordered the U.S.S.R. to develop its own nuclear weapons; by 1949, they had developed the A-bomb. However, this crash program cost the lives of many Soviet scientists and technicians who had ignored hazards of very high radiation doses [13].

Over 1500 nuclear weapons tests have been carried out since 1944, the majority up to 1963 in the atmosphere [14]. No evidence of cancer risk increase has been found in inhabitants of the world due to nuclear test fallout. The Standardized

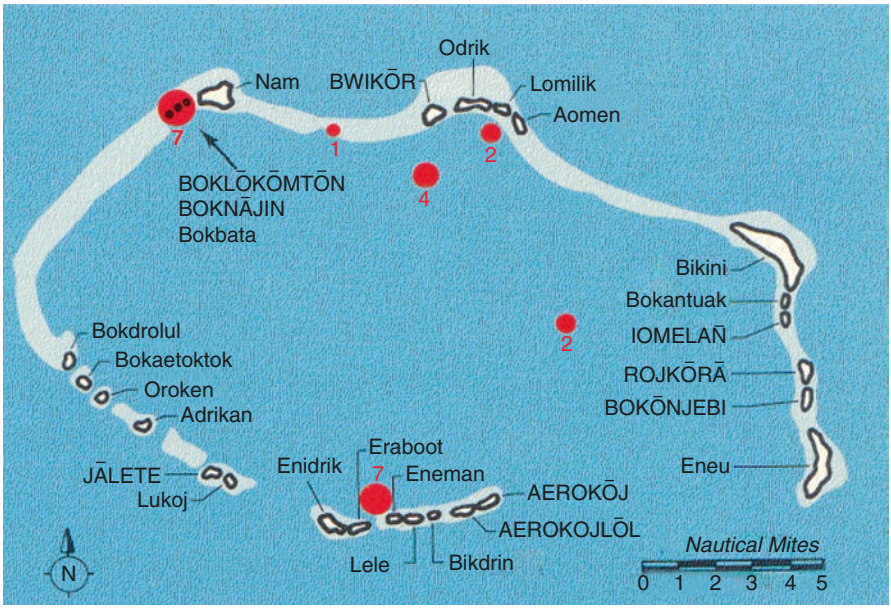

Fig. 2.2 Bikini Atolls in the South Pacific. The *red spots* indicate where nuclear tests were carried out and the *red numbers* the number of tests at that site (Committee on Radiological Safety in the Marshall Islands [17])

Mortality Ratio (SMR) for all-cause mortality and all cancer mortality was 0.71 and 0.74, respectively, for 250,000 participants at the UK and US nuclear test sites [15]; that means that about 25–30% expected mortality may have been protected by low-dose radiation from fallout.

US nuclear tests have been carried out at the Nevada Test Site, at Eniwetok and Bikini Atolls in the South Pacific, at Johnson Island, at Christmas Island, and at Amchitka, Alaska. There were 30 nuclear weapons tests at the Nevada Test Site in 1957 as part of the PLUMBOB test series. A cohort study of 12,219 military participants, who received a mean red bone marrow dose of 3.2 mGy and a maximum of 500 mGy, showed that the participants lived longer than the general population [16].

Twenty-three nuclear tests were carried out in the Bikini Atolls (Fig. 2.2). The first H-bomb test was by the USA (code named *Mike*) on October 31, 1952 at Eniwetok Atoll. It had a yield of 10.4 MT and left a crater 1 mile in diameter and 175 feet deep. Its mushroom cloud shot up to 25 miles into the stratosphere and spread out over 100 miles downwind. The largest US test (Bravo) was of a 15-MT H-bomb at Bikini Atoll on February 28, 1954, with a fireball greater than 3 miles in diameter.

Operation Crossroads in 1946 at Bikini Atoll involved 235 nuclear bomb tests which exposed about 40,000 US Navy, 6400 Army, and 1100 Marine personnel. Because available data were not considered suitable for epidemiologic analysis, a risk study was based on exposure surrogate groups [18]. There were 32,000 US observers in the later (1951–1957) nuclear tests. Both solid cancer and leukemia mortality rates decreased as exposures increased [19]. The median dose received by

military personnel was <4 mGy. The military in the late 1940s sent personnel to clean contaminated ships within a few hours after warhead detonations. The General Accounting Office rebuked the Pentagon's assertions of low whole-body doses to military personnel in Operation Crossroads tests at Bikini Atoll.

The AEC (Atomic Energy Commission) miscalculated the yield and weather conditions of its 1954, 15-megaton H-bomb test (*Bravo*) in the Bikini Atolls. As a result, 64 inhabitants of the nearby Rongelap Atoll received high radiation doses (mean γ-dose, 1.8 Gy) from fallout about 150 miles from the test site [20]. None died from acute radiation effects, although all developed beta skin burns and the children experienced thyroid damage (nodules, hypothyroidism) from uptake of I-131 into the thyroid gland. The Bikini ash also fell on a Japanese fishing boat, the *Lucky Sea Dragon*, at sea 80 miles east of the test site, causing the death of Aikichi Kuboyama among the 23 crew members, while all others experienced radiation sickness (mean γ-dose, 3 Gy). An additional 714 islanders and Americans received cumulative gamma doses of <0.05–0.8 Gy [17, 21].

Massive plutonium production reactors and extraction chemical plants at Hanford, WA; the half-mile-long uranium enrichment facility at Oak Ridge, TN; a laboratory at Los Alamos, NM, for designing and building A-bombs; a plutonium bomb building facility in Golden, CO; nuclear test sites in Nevada and the South Pacific; and scores of nuclear power plants spread over the USA employed millions of people, often for the major time of their working careers.[1] Multiple epidemiological studies of workers in the USA and over the world have failed to demonstrate a significantly increased risk of cancer or any other disease among workers at cumulative doses of <100 mGy [22].

President Eisenhower gave a speech on *Atoms for Peace* in 1953, which was followed with congressional authorization for construction of the first nuclear power plant at Shippingport based upon the light water steam reactor used in the first nuclear submarine, the *Nautilus*. That same year, Eisenhower asked the United Nations to create the IAEA to promote nuclear power.

The Russian test site at Novaya Zemlya near the city of Semipalatinsk, the Soviet equivalent to Los Alamos, was the site for 456 tests carried out from 1949 to 1989 with 700,000 people living downwind exposed to fallout. In 1957, a very large piece of land (20,000 km^2) downwind from Kyshtym, Ural Mountains, U.S.S.R., was contaminated by the release of 700 PBq from the explosion of a nuclear waste

[1] The cycle consists of: uranium mining—milling of uranium ore—conversion to U_3O_8 and then to UF_6—enrichment of ^{235}U (from natural 0.7% to 3–5%)—fuel fabrication—nuclear power plant—on site storage of spent nuclear fuel—reprocessing spent fuel to remove plutonium and other radionuclides—interim storage in tanks or in glass blocks—ultimate storage site. Transuranic elements produced in nuclear power plants include plutonium (Pu), americium (Am), curium (Cm), berkelium (Bk) californium (Cf) and einsteinium (Es)

storage tank. Twenty villages with 7500 inhabitants were permanently evacuated. Later epidemiological studies failed to demonstrate an increased mortality risk in either locations, but did show fewer than expected cancer deaths [22].

2.3 Predicted Radiation Effects of Strategic Nuclear War

Soviet Premier Nikita Khrushchev initially wanted to test a 100-megaton weapon. Miniaturization was a far more important technical hurdle for a would-be nuclear power, which needed bombs that were small and light enough to fit on ballistic missiles far more than it needed ones that produce an impressive yield. The Cuban Missile Crisis and the consequent Soviet removal of nuclear weapon delivery systems from the western hemisphere came about a year after the Tsar Bomba test. Both the USA and U.S.S.R. realized that such a bomb had no strategic significance; no further tests of such magnitude were ever attempted by either side nor by anyone else.

The National Academy of Sciences issued a report, *Long-Term Effects of Multiple-Nuclear Weapons Detonations*, in which they concluded that the impact of a nuclear war between the USA and NATO countries and the U.S.S.R. and Warsaw Pact countries would not be as catastrophic upon noncombatant countries (not directly hit by nuclear weapons) as had been previously feared. The report was kept classified in order to maintain the state of radiophobia needed to obtain the political objectives of the two military sides. The report analyzed the likely effects of a 10,000-MT nuclear exchange on populations in the northern and southern hemispheres.

Nuclear fallout would be very high in many regions of the USA (Fig. 2.3). In one attack scenario, 1440 warheads with 5050-MT surface and 1510-MT air burst

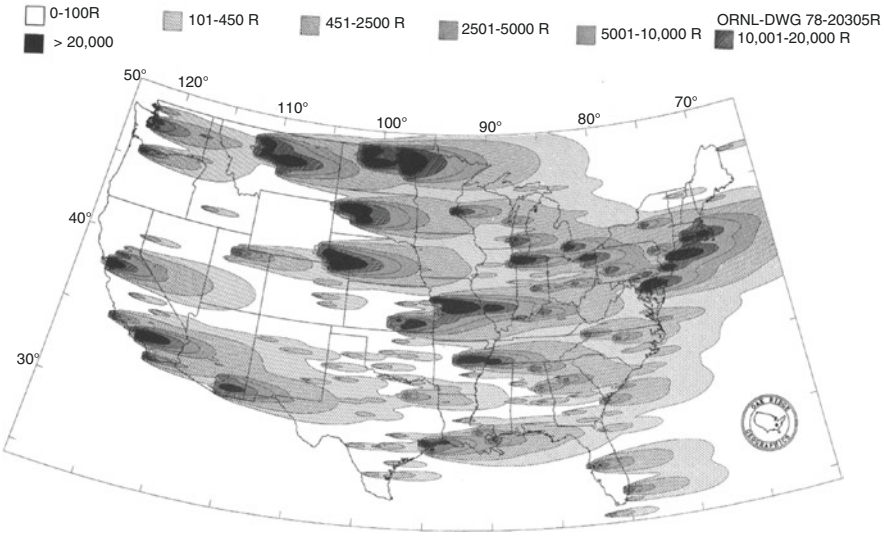

Fig. 2.3 Cumulative radiation doses resulting from a strategic nuclear strike on the USA (Oak Ridge National Laboratory [23])

total yields would potentially expose all remaining survivors to significant radiation exposures if unprotected. Nuclear fallout would be complicated by multiplicity of detonations, timing of detonations, and mix of surface and air detonations, making it difficult to predict fallout patterns in local areas of the country [24–26].

At Hijiyama High School, 51 girls were outdoors playing on the school grounds about 0.5 miles from the hypocenter of the first A-bomb detonated over Japan in World War II. All were dead within a few days from severe burns. At 1 mile, the mortality among unshielded school children was 84% and 14% among shielded children. The damage to Hiroshima, and to Nagasaki a few days later, was enormous, even by World War II standards of destruction. Overall, more than 75,000 died and 100,000 were injured in Hiroshima's 245,000 population. Of the injured survivors, 70% suffered from blast injuries, 65% from serious burns, and 30% from prompt radiation effects. About 90% of all buildings within the city limits were destroyed. In Hiroshima, 270 out of the city's 298 doctors and 1645 of its 1780 nurses were killed, while 42 of the city's 45 hospitals were destroyed [27]. The yields of the two warheads were so low as not to cause significant nuclear fallout of any immediate health hazard concern to survivors. Yet all this death and destruction was from a primitive, puny (by today's standards) uranium bomb with an equivalent explosive power of about 13 KT.

The physical effects of the atomic bomb were described in vivid detail by many authors, including this account by a Methodist missionary who was in Hiroshima right after the bomb fell:

> He was the only person making his way into the city; he met hundreds and hundreds who were fleeing, and every one of them seemed to be hurt in some way. The eyebrows of some were burned off and skin hung from their faces and hands. Others, because of pain, held their arms up as if carrying something in both hands. Some were vomiting as they walked. Many were naked or in shreds of clothing … Almost all had their heads bowed, looked straight ahead, were silent, and showed no expression whatever … It was at that moment … the sound … the lights out … all was dark … How I got out, I don't know … the sky was lost in half-light with smoke … like and eclipse … The window frames began to burn; soon every window was aflame and then all the inside of the building … There were eight of us there … The fire spread furiously and I could feel the intense heat … The force of the fires grew in violence, and sparks and smoke from across the river smothered us … and barely managed to escape [28]. Parents, half-crazy with grief, searched for their children. Husbands looked for their wives, and children for their parents. One poor woman, insane with anxiety, walked aimlessly here and there through the hospital calling her child's name [29].

Fallout radiation levels from modern nuclear warheads are very high near the site of detonation, decreasing and increasing with distance due to radioactive decay and from fallout. Prompt fallout occurs during the first day producing the greatest radiation levels. Geography, wind conditions, and precipitation can greatly influence early radiation fallout patterns, causing local "hotspots" of radioactivity, even hundreds of miles downwind. The fallout pattern of volcanic ash following the May 1980 eruption of Mount St. Helens is similar to what one might anticipate from a multi-megaton surface blast. Uncertainties in bomb effects and radionuclide fallout

patterns depend far more on local topography and weather conditions than on bomb design. For example, more than 50% of radioactivity in a cloud will be washed out by a heavy rainfall of 2-hour duration. Radioactive particles will also settle to the earth by dry deposition. Particles >10 μ in diameter settle promptly by sedimentation; smaller particles are more readily dispersed by wind updrafts and turbulence. In regions of low to moderate rainfall, dry deposition of radioactive particles may account for a greater total deposition than washout in precipitation.

The acute radiation syndrome in humans was known and described in reasonably good detail by Pfahler as early as 1918 and by others two decades later who called the syndrome "radiation sickness." The largest body of data concerning radiation sickness in humans is from the Japanese A-bomb survivors. The Japanese exposures were instantaneous to a mixture of γ-rays and limited neutrons. Fallout of fission products was minimal in the Japanese. Ionizing radiation from nuclear weapons fallout can produce a variety of biomedical effects, whether the exposure comes from external or internally deposited α-, β-, and γ-emitting radionuclides. External γ-rays cause acute radiation sickness when they are delivered over a substantial portion of the whole body.

Biological damage is related to dose and dose rate. A lethal dose of external, whole-body, Co-60, 1-MeV gamma rays delivered in 1 h is 3000–6000 mGy per hour. This is about ten million times greater than the mean background dose rate for the world of 0.20 μGy per hour. The dose rate in Japanese A-bomb survivors near the hypocenter was 6000 mGy per second, which is 2×10^{15} times greater than the highest dose rate from the Chernobyl fallout.

An acute whole-body, external γ-ray exposure to humans has rapid biological effects at a high-dose rate and as the dose increases. At 1 Gy, blood changes are observed but little or no evidence of acute radiation disease. At 2 Gy, radiation sickness occurs with few deaths. At 3.5 Gy, death occurs in 50% of the population within 60 days due mostly to failure of the blood-forming tissues in the bone marrow. At 10 Gy, death occurs in about a week in 100% of the population due to gastrointestinal damage as well as severe bone marrow failure.

For humans the median lethal radiation dose is about 4.5 Gy if given in 1 day. There is some disagreement as to what is the $LD_{50(60)}$ dose for humans exposed under the expected conditions of nuclear war. Most believe that the $LD_{50(60)}$ lies between 3.5 and 4.5 Gy, when the dose is delivered to the whole body within a period of less than a day. There is a sharp steepness in the radiation dose-lethality curve. A dose that is only 20% greater than the $LD_{50(60)}$ may result in death of over 90% of the population, while a dose that is 20% less than the $LD_{50(60)}$ may result in death of only 5% of the population.

The number of deaths from the acute radiation syndrome in the first 60 days and the number of cancer deaths during the next 50 years have been exaggerated by both the USA and U.S.S.R. to achieve a political agenda in their nuclear war scenarios. Local fallout from a 1-MT surface burst would result in a patch of about 200 square miles (oval area 6 miles at its widest and 45 miles at its longest for a continuous unidirectional wind of 15 mph) where radiation levels would be lethal to anyone not protected. It is important to remember that as radiation levels in the cloud are

decreasing due to radioactive decay, they may be increasing for a period of time on the ground due to fallout accumulation.

The $LD_{50(60)}$ is the lethal dose in humans that will kill half the exposed population within 60 days.

Radiation levels near the detonation site will be rapidly decreasing, while those hundreds of miles downwind will be increasing for the first few days (Table 2.2). In this example, the radiation dose rate would decrease to about 15 Gy/h at about 1 h to about 1.5 Gy/h after 12 h to about 0.15 Gy/h after 4 days and to about .01 Gy/h after 40 days [30]. The rate at which fallout radioactivity decreases can be estimated: The estimate is fairly accurate for times from 1 h to about 6 months after detonation, assuming the fallout is completed by $t = H + 1$. As a rule of thumb, the radiation levels from fallout will decrease by a factor of 10 for every sevenfold increase in time. This rule is applicable for the first 6 months after detonation. This means that radioactivity in fallout will decrease to 1/10th of the 1-h level by 7 h and to 1/100th at 49 h. The shape of this dose rate curve is similar to that near Fukushima, where after a week or two, dose rate had fallen to near baseline; the dose rate never reached the background dose rate at Ramsar, Iran (260 mGy/y), even at its peak which was at about 180 mGy/y.

Residual radiation results from neutron activation of elements in the soil and buildings and from fission-product fallout. Neutron-related gamma doses were negligible in Japanese cities. Gamma doses from fission-product fallout were less than 25 mGy [31]. Today Hiroshima and Nagasaki are modern cities of 2.5 million people with no residual radiation attributed to A-bomb detonation. The Life Span Study (LSS) of the Japanese atomic bomb survivors is considered the "gold standard" for radiation epidemiology; nevertheless, these studies are filled with significant limitations at low doses, which are of great interest to radiation protection agencies and the EPA [32]. The threshold based on the LSS data is very conservative, 100 mGy/y. The actual threshold is likely 200–700 mGy/y with hormesis effects being seen below these doses. It appears that there was significant misunderstanding, misinterpretation, or even possible deliberate scientific misconduct in the 1956 NAS paper concerning the use of the LNT in evaluating A-bomb survivor data [33–36].

Table 2.2 Influence of dose rate on human survival following radiation exposure from nuclear weapon fallout

Dose rate at 1 h (rad/h)	Survival prognosis
10	No acute lethality if unshielded
100	Lethal if unshielded; not lethal if taken with minimal protection
1000	Lethal unless substantially shielded
10,000	Lethal unless in best of fallout shelter

The Radiation Effects Research Foundation (RERF) data show more evidence of hormesis than adverse effects at low doses (Figs. 2.4 and 2.5). However, thresholds and radiation benefits are not considered by radiation protection agencies. The use of the RERF results for LNT modeling of harmful health effects is well known to be inappropriate, because A-bomb exposures do not apply to radiation protection for workers or for the public exposed to chronic and highly fractionated and low-dose-rate radiation, especially for extreme costly cleanup and decommissioning standards [38]. Dr. Gunnar Walinder believed the "expectation" that UNSCEAR members would manipulate the RERF data to produce "expected" results that supported the LNT [39].

The all-cause death rate in the USA for 2013 was 730 per 100,000, or about 2.2 million deaths per year. A moderate dose of radiation increases longevity [40]. Longevity is a better measure of health effects than is cancer mortality. A-bomb survivors had a small added risk of cancer at high radiation doses. And this high-dose cohort lived only a few months less than their children and those not exposed to radiation. No health effects related to radiation exposure of their parents have been found in survivors [41]. The life expectancy in Japan in 2015 was 80.5 years for males and 86.8 years for females; mean for both sexes was 83.7 years. Japan is ranked number 1 in the world for life expectancy. The USA is ranked number 31 with life expectancy of 76.9 years for males and 81.6 years for females; mean for both sexes was 79.3 years. Australia has a cancer death rate of 314 per 100,000 per year that is about 50% higher than for low-dose Japanese A-bomb survivors (201 per 100,000 per year). A-bomb survivor cancer death rates at the highest doses were comparable to living in Australia. This means that Japanese A-bomb survivors are living significantly longer than non-exposed Americans and Australians [42, 43].

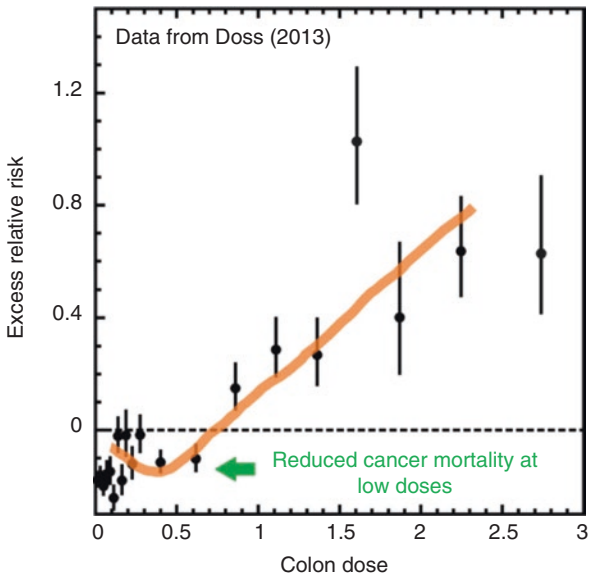

Fig. 2.4 Excess relative risk of solid cancer mortality in Japanese A-bomb survivors [6]. The threshold dose was about 500 mGy (With kind permission of Dr. Mohan Doss [2])

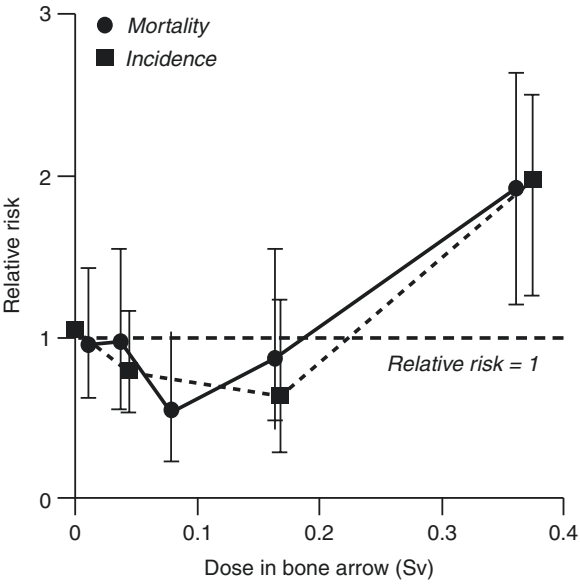

Fig. 2.5 Relative risk of leukemia in Japanese A-bomb survivors [37]. Diagram shows details of expanded view for the low-dose region. The threshold for leukemia incidence and mortality is about 200 mGy (With kind permission by Springer, Charles L Sanders: Radiation Hormesis and the Linear-No Threshold Assumption, © 2010)

Following the dropping of two A-bombs on Japan in 1945, researchers exaggerated the radiological risks as a result of politics and not science. Only about 500 of the hibakusha died a premature death from cancer (0.5% of the exposed Japanese population), and most of them received high-dose exposures. The high-dose data is primarily derived from extensive studies of the survivors of the atomic bomb exposure in Japan with doses estimated according to the distance from the epicenters of the explosions. A threshold of about 500 mGy in Japanese A-bomb survivors was found for formation of birth defects of the nervous system irradiated in utero at 8–15 weeks [44]. No hereditary disorders were found in 40,000 children of A-bomb surviving parents. No increase in adult-onset hypertension, diabetes, hypercholesterolemia, ischemic heart disease, and stroke was observed in offspring of A-bomb survivors [45].

RERF studies of Japanese atomic bomb survivor data at low doses have not been adequately evaluated [46]. Many independent studies of the RERF data contradict the official RERF analyses, even when limited to using the RERF's own processed data in the absence of the ability to access the raw data. Even BEIR V consultants were unable to obtain the data to undertake an independent analysis. BEIR V states that there are no adverse effects below a high dose, but then presumes a straight line from the high dose to zero. Atomic bomb survivor data shows a significant reduction in cancer mortality rate in the dose range of 300–700 mGy. Nevertheless, BEIR applies the linear model down to zero [47].

Leukemia incidence was initially determined in 195,000 survivors of the combined populations of Hiroshima and Nagasaki (Table 2.3). The threshold dose for radiation-induced leukemia base on 96,800 A-bomb survivors was 500 mGy [49, 50]. Ozasa claimed that the risk of cancer mortality among Japanese A-bomb

Table 2.3 UNSCEAR in 1958, p. 165, proposed a threshold of 500 mGy for leukemia induction in Hiroshima A-bomb survivors [48]

Cases	Persons	Dose (mGy)	Cases/10,000	% Controls
9	32,963	0	2.7	100
3	32,692	20	0.9	34
8[a]	20,113	500	4.0	150
33	8810	5000	37	1400
15	1241	13,000	120	4400

There were only 68 cases of leukemia found in 95,819 survivors.
[a]The cases found in the 500-mGy cohort appeared to be mostly from much higher doses. Therefore, the threshold from this "gold standard" database must be ~500 mGy [48, 49]

survivors was significantly higher for several major organs [51]. The data from low-dose groups (extrapolated to zero dose) were used in determining baseline cancer rates causing a negative bias. Correcting for this negative bias produces a J-shape curve consistent with radiation hormesis [52].

UNSCEAR (1958) reported an incidence of leukemia in Japanese A-bomb survivors that was three times lower than in controls at a mean dose of 20 mGy and with a threshold of 500 mGy. The significant reduction in leukemia incidence for the 32,692 survivors in the low-dose region was far below the leukemia incidence of the 32,963 survivors in the controls. This data disproved the LNT dose-response model, and UNSCEAR should have rejected the LNT model in its report [53]. UNSCEAR (1958) found that almost all of cases of leukemia occurred in residents that had severe radiation complaints (doses >0.5 Gy).

The 1958 UNSCEAR report on Japanese A-bomb survivors deleted the lowest exposed group from analysis to obscure a hormetic effect [53]. UNSCEAR 1958 made conflicting statements. Jaworowski states: "hormesis is clearly evident . . . in a table showing leukemia incidence in the Hiroshima population, which was lower by 66.3% in survivors exposed to 20 mGy, compared to the unexposed group." This evidence of radiation hormesis was not commented upon by UNSCEAR. Since then, the standard policy line of UNSCEAR and of international and national regulatory bodies over many decades has been to ignore any evidence of radiation hormesis and to promote LNT philosophy [7].The Hiroshima leukemia data strongly contradict the LNT model, which predicts increasing risk as the radiation dose increases. The threshold for leukemia incidence and mortality is about 200 mGy [37, 49]. Jaworowski estimated a threshold for leukemia incidence of 400 mGy for A-bomb survivors [7]. The leukemia data fit a hormetic J-curve; they do not fit a straight line. UNSCEAR (2012) did state that no radiation-induced health effects, including leukemia, have been found as a result of the Fukushima accident [54].

Global fallout is not expected to result in many survivors of blast and thermal effects exhibiting prodromal symptoms of fatal acute radiation syndrome in a 5000-MT attack because of the magnitude of cumulative acute exposure and later chronic exposure rate from fallout [55]. The projected number of radiation-induced cancers in survivors of a nuclear war would be much fewer than would be affected by acute effects of fallout if given warning of only a few minutes and if educated as to what

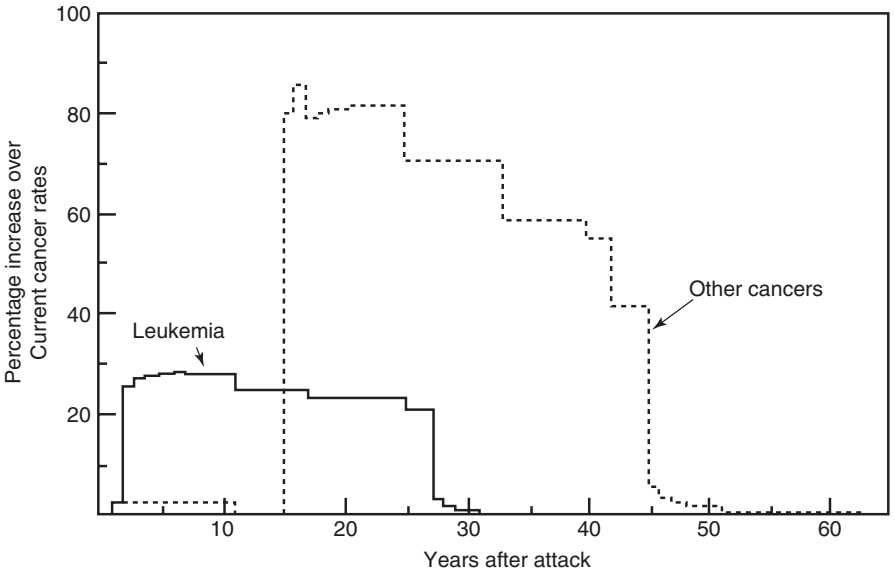

Fig. 2.6 Predicted excess deaths from leukemia and other cancers expected following a hypothetical 5000 MT nuclear attack on the USA using the LNT model (Adapted from Gant KS and CU Chester, Minimizing excess radiogenic cancer deaths after a nuclear attack, Health Physics, © 1981) [41]

to do by providing personal shielding. Leukemia would appear earlier than solid cancers (Fig. 2.6). An 8000-MT nuclear exchange between the USA and the U.S.S.R. would result in long-term residual radioactivity in the northern hemisphere that is 40 times greater than the highest level seen during the period of the most intense atmospheric weapons testing in the 1960s. A 3500-MT attack on the USA would cause only a small 1–2% increase in cancer mortality from fallout [55]. Even with a 5000-MT attack, the average reduction in American lifespan from radiation-induced cancer would be only 1.2 years, or considerably less than is experienced today by the average cigarette smoker [56].

The current maximum accepted radiation dose allowed for radiation workers is 20 mGy/y or ten times greater than that allowed for the general public. A 1-MT warhead surface burst would deliver a dose greater than 20 mGy/y at 1 year after detonation to a surface area of about 5700 square miles. A 1-MT warhead exploded on a 1000-megawatt electric nuclear power reactor would increase the inventory of radioactive fallout of mostly long-lived radionuclides. The added (from the reactor) early radiation dose would not be substantial; however, at time periods longer than 1 month after detonation, a significant portion of residual radioactivity would be contributed by reactor fission-product inventory and not from the bomb. Detonation of a 1-MT warhead on radioactive waste storage facilities, like those found at Hanford, Washington, would increase the 20 mGy/y fallout area to >100,000 square miles more than from a detonation over a nuclear power reactor [55]; this low-dose rate would be beneficial.

2.4 Nuclear Winter

The political philosophy of MAD (mutually assured destruction) deterrence doctrine has encompassed the idea of nuclear winter that will follow an all-out nuclear war involving 10,000 or more nuclear warheads. The nuclear winter scenario was anticipated in the 1964 movie, *Dr. Strangelove*, where a mountain range in the U.S.S.R. was mined with nuclear warheads, triggered to explode at the onset of nuclear war, hurling debris into the stratosphere and destroying all civilizations. The hypothesis of nuclear winter was a central fixture in the nuclear weapons debate during the 1970s. If the concept is correct, then the USA and the U.S.S.R. cannot make total nuclear war on each other without counting the environmental cost within its own borders from its own attack. To accept the worst about nuclear winter would be to conclude that civil defense would be useless and a first strike would be suicidal.

The possibility of nuclear winter was suggested by the observations of dust storms on Mars and resultant temperature changes seen with the Mariner space probe. One report predicted a drop in earth's surface temperature due to absorbance of solar light and heat by dust particles injected into the stratosphere by surface nuclear detonations. The amount of debris injected into the air from a surface burst was estimated at five million tons per MT; an air burst would cause little dust injection into the stratosphere. Dust particles absorb sunlight, reducing the temperature on the earth's surface. In the worst proposed scenario, surface temperatures would drop for a period of several months before temperatures returned to normal. The soot produced by forest fires, burning urban, and industrial centers would add an estimated 225 million tons of soot into the atmosphere in addition to ash and other particles initially entrained in mushroom clouds of surface bursts. All entrained material would fall out downwind at rates dependent upon the altitude attained, wind conditions, precipitation patterns, and particle size and density [57].

Rain and other natural scavenger processes would likely cleanse the atmosphere of 66–95% of the particulate material over a period of a few weeks. Soot may create its own defense against atmospheric cleansing. Warmed by the sun due to its higher solar absorbance than ash particles and because of its lower density, soot particles could become buoyant and rise above cleansing rain. Once in the troposphere, soot particle concentration would decrease by a factor of 3 every 180 days. Maximum summertime cooling would occur over the northern hemisphere during the first 2 weeks after a nuclear war, assuming an initial release of 170 million metric tons of smoke and soot particles [58]. The potential for nuclear winter suggests that a protracted nuclear war involving very large numbers of nuclear weapons used over a period of several months would minimize nuclear winter effects, whereas a maximum first strike and counter strike would maximize these effects. However, nuclear winter may be much less severe than originally proposed [59].

2.5 Survival of Nuclear War

The penetrating nature of γ-rays requires substantial shielding with denser materials in high-dose fallout regions. No lethality is expected from a radiation dose rate of 100 mGy/h. An initial dose rate from fallout of 1.0 Gy/h would not be lethal if minimum protection is taken (e.g., staying indoors). An initial dose rate of 10 Gy/h is lethal unless substantially shielded. A shelter providing a protection factor of 100 would suffice. A dose rate of 100 Gy/h would be lethal unless in the best of radiation shelters that give a protection factor of ≥500. However, the area downwind from a nuclear detonation with these high-dose rates would be limited.

To protect yourself from fallout, it is essential to find shelter. The dose protection factor of a shelter is the protection afforded someone inside the shelter from radiation originating from the outside. For example, a dose protection factor of 5 means that the radiation level inside the shelter is five times less than the radiation level outside the shelter at the surface of the ground. Dose protection factors vary widely according to building construction, floor level in a multistory building, and proximity to other buildings. A dose protection factor of 5 can be assumed for most wood-frame buildings. Most basements provide protection factors of about 50 in at least one area. Building a simple 6-foot trench shelter in your backyard covered with a few feet of dirt on a door would provide protection from thermal and blast effects and a protection factor of 500 from radiation fallout (Table 2.4). Provision of shelters that can withstand 100 psi blast waves, such as subway and utility tunnels, could save nearly 70% of the American urban population from a 9000-MT attack. US ICBM silos are built to withstand up to 2000 psi [60].

Americans are dreadfully ignorant on the subject of civil defense against nuclear war. Americans don't want to talk about shelters. Most who take shelters seriously are considered on the lunatic survivalist fringe. The current US rudimentary fallout shelter system can only protect a tiny fraction of the population. There are probably less than one in a 100 Americans who would know what to do in the case of nuclear war and even fewer with any contingency plans. The civil defense system should, instead, provide stockpiles of food, water, medical supplies, radiological instruments, and shelters in addition to warning systems, emergency operation and

Table 2.4 Protection factor for γ-ray exposures from nuclear fallout in various habitations structures

Structure	Protection factor
Multistory—upper	20–100
Multistory—lower	10
Frame house—ground level	2–5
Frame house—basement	10–50
Concrete with 2-foot walls and ceiling	500–1000
Six-foot-deep trench with 3-foot dirt on top	500

communication systems, and a trained group of radiological monitors and shelter managers. There is a need for real-time radiation measurements in warning the public to seek shelter and prevent panic [61].

Shelters and a warning system providing sufficient time to go to a shelter are the most important elements of civil defense. The purpose of a shelter is to reduce the risks of injury from blast and thermal flux from nearby detonations and from nuclear fallout at distances up to hundreds of miles downwind from nuclear detonations. There are several requirements for an adequate shelter:

1. Availability—Is there space for everyone?
2. Accessibility—Can people reach the shelter in time?
3. Survivability—Can the occupants survive for several days once they are in the shelter? That is, is there adequate food, water, fresh air, sanitation, tools, clothing, blankets, and medical supplies?
4. Protection Factor—Does the shelter provide sufficient protection against radiation fallout?
5. Egress—Is it possible to leave the shelter or will rubble block you?

There are several good publications that provide information for surviving nuclear war [62–64]. Two that offer good practical advice are *Nuclear War Survival Skills* by Kearny [65], and *Life after Doomsday* by Clayton [66]. Fallout is often visible in the form of ash particles. The ash can be avoided, wiped, or washed off the body or nearby areas. All internal radiation exposure from the air, food, and water can be minimized by proper ventilation and use of stored food and water. Radioactivity in food or water cannot be destroyed by burning, boiling or, using any chemical reactions. Instead it must be avoided by putting distance or mass between it and you. Radioactive ash particles will not induce radioactivity in nearby materials. If your water supply is contaminated with radioactive fallout, most of the radioactivity can be removed simply by allowing time for the ash particles to settle to the bottom and then filtering the top 80% of the water through uncontaminated clay soil which will remove most of the remaining soluble radioactivity. Provision should be made for water in a shelter: 1 quart per day or 3.5 gallons per person for a nominal 14-day shelter period. A copy of a book by Werner would be helpful for health care [67].

During the 1950s, there was firm governmental support for the construction and stocking of fallout shelters. In Eisenhower's presidency, the National Security Council proposed a $40 billion system of shelters and other measures to protect the civilian population from nuclear war. Similar studies by the Rockefeller Foundation, the Rand Corporation, and the MIT had earlier made a strong case for shelter construction. President Kennedy expected to identify 15 million shelters, saving 50 million lives. Even at that time, there were many who felt this was a dangerous delusion giving a false sense of security. However, the summary document of *Project Harbor* (Publication 1237) concerning civil defense and the testimony before the 88th Congress (HR-715) both strongly supported an active civil defense program by the US government. A latter 1977 report to Congress

concluded that the USA lacked a comprehensive civil defense program and that the American population was mostly confused as to what action to take in the event of nuclear war.

President Carter advocated CRP (Crisis Relocation Planning) as the central tenet of a new civil defense program. President Reagan in 1981 announced a new civil defense program costing 4.2 billion dollars over a 7-year period; this program included CRP and the sheltering of basic critical industries in urban and other target areas. President Reagan believed that civil defense will reduce the possibility that the USA could be coerced in time of crisis by providing for survival of a substantial portion of her population as well as continuity for the government. Stockpile, sheltering, and education could be a relatively cheap insurance policy against Soviet attack [68]. With the fall of the U.S.S.R. came a lack of continuing interest in preparation to survive a nuclear war in subsequent administrations.

The Pentagon recommended to the Reagan administration that the USA adopt a Soviet-style civil defense program, combining evacuation with fallout shelters. It was suggested that the Americans use doors wrapped in plastic to cover hastily dug trenches in their backyards. The US strategy is like poker while the Soviets' is like chess. If we bluff and lose, we lose the game. If the Soviets bluff and lose, they only lose one piece. The Soviets have prepared for "social control" following nuclear war, while many Americans believe that all would die. Thus, a prerequisite for any substantial change in US civil defense policy requires a change in popular attitude about survival. Reagan planed for a hypothetical postwar future society in almost bizarre detail. In one additional touch worthy of Dr. Strangelove himself, it was proposed that a select group of volunteers—men and women with a carefully chosen range of skills and talents—live on the continuously moving, subterranean train and that the underground community be equipped with nuclear reactors and hydroponic gardens to sustain life in what was termed "the post-attack environment" [69].

Carl Sagan called for rejecting civil defense, appearing on television to denounce SDI military weapons [70]. Some would prefer surrender to any risk of nuclear war [71]. In 1986 the states of Oregon and Washington withdrew from an emergency drill organized by the FEMA as a protest against "planning for nuclear war." The drill involved a hypothetical attack on these two states with 48 warheads. According to Oregon Rep. Wayne Fawbush:

> If you lead people to believe that a nuclear exchange can be survived, you promote the possibility of it happening. If the US was better prepared to survive a nuclear attack, then others would be less likely to launch one. Thus civil defense does not signal a willingness to wage war, but a willingness to deter war by making it less tempting to a potential aggressor. It was to the Soviets politically advantage to hyperbolically emphasize the 'dreadful' effects of nuclear weapons to promote American disarmament. The consequences of using nuclear weapons defy human imagination … all-out nuclear war would cause the death of more than 200 million people and 60 million more would be mutilated … Such a nuclear war would inevitably lead to global catastrophe … 80 percent of doctors would perish, 80 percent of hospital beds would be destroyed as would nearly all supplies of blood, antibiotics and other medicines … epidemics would start, radiation will remain a threat…Understand me well. We do not wish to frighten the world with these apocalyptic figures and facts. No, we wish to show the realities of a nuclear war and what needs to be done to prevent it [72].

The Federal Emergency Management Agency (FEMA) was formed in 1979, consolidating in one agency the various federal bureaucracies involved in disaster management. The 1986 FEMA plan calls for sheltering local, state, and federal officials from nuclear war, while everyone else will have to shift for themselves. Land records will be taken into shelters. The federal government denies that this is an elitist strategy but that it is rather to insure that emergency-management infrastructure survives to direct the recovery of the surviving general population. The FEMA admits that as many as half our citizens or more would be lost to the direct and indirect effects of the weapons themselves, and millions more would die in the chaos of the post-attack environment. Current FEMA strategy also calls for return to the traditions of the 1950s when school children were instructed to curl under their desks when they saw a bright flash of light.

The USA is woefully unprepared for nuclear war because of radiophobia (Table 2.5). The FEMA is absent before the American public about advice. To be politically correct, the FEMA just assumes that it will never happen. To educate the public in their mind is to enhance the probability of nuclear war. A false emphasis is on prevention of nuclear war not on preparation. The National Radiological Defense Agency of the FEMA is responsible for providing radiation detection instruments, training of personnel in their use, and educating large segments of the American population about radiation hazards. A low budget and even lower public visibility have made this program largely ineffectual.

The FEMA had actively promoted CRP as a method to move these more vulnerable populations prior to a war. The current goal of CRP is 80% survival of the US population following a 6559-MT attack on the USA; according to this scenario, 45 million Americans would die. During the initial phase of CRP, 150 million people would be expected to travel from 50 to 300 miles to designated low-risk areas. They will join about 75 million, totaling a shelter population of 195 million. For some the concept of CRP is flawed, unworkable, and dishonest, being in itself a

Table 2.5 Myths and facts about surviving nuclear war

Myths	Facts
Nuclear fallout will kill everyone	Common sense sheltering will protect most people
Radiation from fallout penetrates everything	All of β-particles and half of high-energy γ-rays will be shielded by 3.6 in. of dirt, less for more dense materials
H-bombs are a 1000 times more destructive than A-bombs	Destructive potential is not a linear function of warhead yield
All that live in a bombed city will die	Most in underground shelter will survive not only from radiation but from blast and thermal effects
The living will envy the dead	Life for survivors will be dismal at first but preparation will lead to more rapid recovery
An epidemic of cancer will be seen in survivors	Cumulative radiation-induced cancer risk will increase in survivors by only a few percent of population over a 50-year period
All radiation exposures are harmful	Exposures to <1 Gy may result in improved health and longer lifespan due to hormesis

significant threat to instigating a war since its implementation would be a sign to an enemy that we are preparing to fight a total nuclear war. To others it is common sense that we should plan for all contingencies. No one disagrees that to achieve 80% US survival will require several days to carry out evacuation and a whole lot more preparation, organization, and staffing than now exists. Richard Beal, former director for crisis management systems and planning under President Reagan, believes that "national security planning is a myth" because information uncertainty is the normal course in a crisis and that no one has devised a reliable system for tracking the implementation of presidential decisions in crises. The current White House executives have little or no experience with previous crises, making it very difficult to swiftly and accurately analyze crises using available intelligence and information.

Some experts believe that civil defense will have no effect on initiation or outcome of a nuclear war. Lauriston Taylor wrote:

> Nobody in his right mind believes that a nuclear war can be won by anyone-civil defense or no civil defense. No worse tragedy can befall man. Unfortunately, the worst situation that can be computed today, involving a maximum mutual attack by two opponents, will not destroy man, in spite of all the nonsense that has been written to the contrary … On the basis of the worst double attack scenario that can be visualized today, it is anticipated that about 80% of the US population would die within 30 days of the attack. That means that 20% will be left in survivable condition … in varying degrees of distress, almost beyond our imagination to comprehend. Incidentally, this is almost exactly the American population just 100 years ago … Civil defense is in no sense a preparation for war. The existence or nonexistence of civil defense preparations by any party to nuclear war will have no influence on such a war coming about [73].

Paradoxically, it was Taylor who received an accidental whole-body exposure of 10 Gy and believed that 2 mGy/d (730 mGy/y) was safe while living to 102 years (Chap. 1). Nevertheless, Taylor had gotten taken up by doomsday frenzy.

During the Cold War, the USA was wanting to exaggerate the effects of nuclear weapons testing to deter the U.S.S.R. from nuclear expansion and other countries from developing nuclear weapons. The U.S.S.R. did the same exaggeration when they had achieved the same capability as the USA, emphasizing that there would be no winners in a nuclear war. Their motivation was not to prevent radiation harm to its population but was political to discourage others to develop nuclear weapons.

Exaggerations of the effects of nuclear war will paralyze us. We could accomplish much for so little, spending only 1% of our defense budget on civil defense. The USA has carried out little public education on how to survive nuclear war. In contrast, the U.S.S.R. had carried out an extensive educational program for all its citizens on how to survive a nuclear war. Its citizens are instructed on how to construct a simple, underground trench shelter in less than a day. The Soviets had a highly organized civil defense program, with a planned-for evacuation of cities and construction of underground shelters for some of their industries and for governmental personnel. Civil defense in the U.S.S.R. was part of everyday life as well as a propaganda tool. In peacetime, the U.S.S.R. civil defense program employed 115,000 people under military control; this could be rapidly expanded during wartime to

15,000,000. The first priority of Soviet civil defense is the survival of its political leaders. Because of this emphasis, part of the US strategy was to target Soviet leaders. The CIA predicted 25–35 million deaths in the U.S.S.R. if they had less than a week to evacuate their cities prior to total nuclear war with the USA and 100 million deaths if no warning was given [74]. Only ten million Soviets would die in total war with the USA if given 7–10 days for total evacuation and preparation [75].

In general, Europeans have in the past taken a much more serious and professional view about civil defense than do Americans. American shelters are often considered socially divisive, even though Americans are the most heavily insured people in the world. The reality is that Europeans believe with much justification that simple shelters are remarkably effective in protecting from the effects of nuclear weapons. European countries have extensive civil defense programs. Before 1990 in Switzerland, nearly two-thirds of their population had been provided shelter protection; by 1990, all their population was sheltered. Civil defense training is compulsory for all Swedes with significant support from volunteer agencies [76].

2.6 Dirty Bomb

Several internet articles appeared on December 21, 2016, concerning Congress and the firing of a top DOE scientist by the Obama administration to advance climate change plans [77, 78]. That scientist was Dr. Noelle Metting, a former graduate student at the University of Washington/Tri-Cities campus in Richland, WA. Noelle was a student in my radiobiology class about 35 years ago, followed with a PhD from Harvard University. Dr. Metting went to work for DOE and in 2000 became program leader and senior radiation biologist for the Low Dose Radiation Research Program (LDDRP) which sponsored research on the biological effects of low-dose ionizing radiation. The LDRRP concentrated on biological effects at doses that were less than 100 mGy. The LDRRP had an annual budget from 1999 to 2015 of 15–20 million dollars. Sponsored researchers published over 700 papers during this time. The million man study and the Fukushima study showed preliminary results indicating fewer than expected cancers than the unexposed control groups at doses <100 mGy. Both programs had 4–5 more years until completion. The programs were terminated in 2015 and the funding given for climate change research.

In 2014 Congress introduced the Low-Dose Radiation Act to help regulate the program. In October 2014 briefing with the US House of Representatives Committee on Science, Space, and Technology (Lamar Smith, Chairman), the committee was briefed by senior DOE staff and by Dr. Metting. Less than a month later, the Obama administration officials had "removed" Dr. Metting from federal service for providing too much information in response to questions by the committee. She was dismissed from the DOE on May 2015, whereupon she appealed and was subsequently reinstated. Dr. Metting plans on retiring from the DOE in 2017. The Congressional committee filed misconduct charges against the DOE [79].

The charges against Dr. Metting by the DOE were insubordinate defiance of authority for not communicating the department's management positions and for

inappropriate workplace communication during discussions of funding and policy in her presentation before Congress; that is, she did not censor information nor give only the DOE's talking points.

The House committee conclusions were that: Instead of providing the type of scientific information needed by Congress to legislate effectively, senior department officials sought to hide information, lobbied against legislation, and retaliated against a scientist for being forthcoming. The report went on to say that: DOE management worked to kill LDRRP because it did not further the administration's goals to advance climate research. DOE deliberately withheld information from Congress and removed an agency scientist from federal service for providing complete answers to committee staff with respect to the LDRRP and H.R. 544, the Low-Dose Radiation Research Act of 2014.

In questioning the DOE staff about the LNT and possible health benefits from LDR, the staff claimed either ignorance or they did not know. One senior DOE staff member in response to a committee question stated that the DOE: have not been able to resolve a threshold level of radiation that does not cause cancer, ignoring clear evidence of thresholds and radiation hormesis in LDRRP publications.

The trigger radiation doses of 10–50 mGy for public sheltering, evacuation, and relocation were demonstrated to be beneficial in many of the former DOE's LDRRP studies (Fig. 2.7). In addition the use of the LNT assumption to predict health risk was shown to be inappropriate. The current RDD and IND dose guides will produce radiophobia hysteria and loss of life, particularly when applied to forced evacuation orders following the nefarious use of a dirty bomb, also called a radiation dispersal device.

Dirty radionuclide-containing bombs are what you may choose to build if you're unable to create a real nuclear bomb. A dirty bomb contains a conventional chemical explosive salted with radioactive isotopes in order to spew out that nuclear material and contaminate a wide area. There is little or no military usefulness of such devices. The chemical explosive in such a bomb is quite likely to be more dangerous

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Table 1 - Protective Action Guides for RDD and IND Incidents

Phase	Protective action recommendation	Protective action guide
Early	Sheltering or evacuation of public[a]	1-5 rem (.01-.05 Sv) projected dose
Intermediate	Relocation of public	2 rem (.02 Sv) projected dose 1st year, subsequent 0.5 rem/yr (.005 Sv/yr)

Fig. 2.7 Department of Homeland Security, Federal Emergency Management Agency. August 1, 2008. Planning guidance for protection and recovery following radiological dispersion device (RDD) and improvised nuclear device (IND) incidents

than the radioactive material. A dirty bomb is much easier to build than a nuclear bomb. The radiation associated with a dirty bomb is unlikely to kill anyone but would set off Geiger counters that would terrify a whole city. It is only useful as a terror weapon because radiation protection agencies believe in the LNT and ignore radiation hormesis. The low-dose levels of radiation associated with a dirty bomb are more likely to save and prolong lives. Folk should make personal decisions in case of radiological terrorism rather than depending upon radiophobic, radiation protection professionals [80].

Dirty bombs elicit mass fear reaction. Dirty bombs are weapons of mass disruption, not destruction. The cost of decontamination of a region in a large city would be very high when using the LNT, if to the levels suggested by the EPA, ICRP, and NCRP. Thus, dirty bombs become economic bombs, a political weapon, not a military weapon. The reality of nuclear terrorism, using current EPA and ICRP radiation standards, is that a tiny dirty bomb explosion in an American city would cause the evacuation of tens to hundreds of thousands of people. In response to this potential issue, EPA raised its historical radiation limit 350-fold to 50 mGy for a one-time event.

There is a strong incentive for radiological terrorism. What do you think would happen if a terrorist detonated a dirty bomb spewing gamma ray emitting radiocesium or radio-cobalt over many square blocks of the financial district of New York City? Radiophobia would cause panic, government regulators would issue evacuation orders, and the center of the American economy would be in shutdown mode. For example, President Obama recommended evacuating all American military personnel within 50 miles of the Fukushima reactor in Japan. The fact is that many of the most contaminated areas of New York City would be turned into potential health zones where therapeutic cumulative doses of less than 500 mGy may be given.

Stolen radioactive material can be used by terrorists to make a RDD (radiological dispersion device). Chechen terrorists in 1995 placed a small amount of Cs-137 in Moscow's Izmailovsky Park only as a psychological weapon. In 1998 and 1999, Chechen militants were not successful in detonating a radioactive bomb in a land mine. Old discarded radiotherapy units containing undispersed cesium-137 or cobalt-60 that emits high-energy gamma rays can have lethal effects. In 1987, a junk dealer in Goiania, Brazil, opened an abandoned radiation therapy source which contained about three ounces of Cs-137 (chloride) powder. About 250 persons were contaminated, of which four died from acute radiation sickness. They were attracted to the therapy unit because it emitted a blue glow. In 1961 some Mexican boys played with a discarded cobalt-60 medical therapy source; four died from radiation sickness.

In the 1970s, mobile radiation sources containing cesium-137 were used in Russia to stimulate plant growth and grain production. Recently, ten of these old "Gamma Kolos Factors" were found in Georgia, Moldavia, and Ukraine. The radiation sources had partial shielding and were housed in secret storage. About 900 small Russian electric generators (mobile nuclear power plants in titanium-ceramic containers about 1 cubic foot in size) were used for radio-transmission in lighthouses in remote areas; fewer than 30 have been found [81]. No one has ever

exploded a dirty bomb in anger, but there has been at least one close call. In November 1995, a security alert in Moscow unearthed a package of radioactive material, wired with explosives. The Russian authorities kept the incident from the public.

The evidence suggests up to 200 times our background radiation would be optimal for health. Predictably, over 90% of the exposed survivors of a dirty bomb will have beneficial or no detectable harmful or beneficial effects from ionizing radiation. This is the crux of triage for dirty bombs. Persons who receive low-dose irradiation become healthier and live longer than nonirradiated persons [82]. Delivery methods could also include detonation of a "smoky bomb" in a confined space or insecticide sprayer on a truck to disperse polonium-210 dissolved in water. The death of a Soviet spy, Alexander Litvinenko, resulted from a high concentration of Po-210 in his tea [17].

A very small amount of radioactive material turns into a weapon with psychological and economic impact because of radiophobia. A dirty bomb is a radiological weapon whose purpose is to contaminate and disrupt rather than destroy. It's ultimately a pure terror weapon.

2.7 Unexpected Resources

Nuclear warheads have become emblems of national power and place in the international community. Most industrial nations have considered acquiring nuclear weapons, and surely many have secretly developed simulations and efficient pathways to rapidly build them following significant provocation. Both South Korea and Japan, surrounded by the potentially belligerent countries of China and North Korea, must have made plans and simulations.

We are not distant in space or time from nuclear war. There is no evidence in history where a country who thought they had a military advantage did not eventually use it for their advantage. To this we add terrorist groups who may use nuclear weapons to promote their agendas and theological ideologies. The U.S.S.R. invasion of Afghanistan, the Cuban Missile Crisis, the shooting down of a Korean airliner by the Soviets, and a NATO field exercise each came close to triggering a full nuclear war. The belief that man's goodness or common sense will prevent nuclear war is utter foolishness. There is no historical evidence to support this notion. As long as any state has nuclear weapons, others will seek to acquire them. Those who have nuclear weapons for security reasons do not want others to have them for their security reasons. The containment of nuclear proliferation will continue to be an illusion since the hypocrisy of the "haves" is monumental. The historical conclusion is that the use of nuclear weapons by nations or terrorists is inevitable.

What are the odds that the world will experience a nuclear war, either limited or total? Most agree that nuclear war is unthinkable. Then why do most experts believe that it will happen or that it is inevitable? The human race is rushing toward its suicide. The events of history hardly justifies any other conclusion. Since 650 B.C., there have been 1656 arms races; all but 16 of them have ended in war, with these

16 countries ending in economic collapse before war could occur. In the twentieth century alone, 140 million people have perished as a result of war and its aftermath. There are only 12 nations in the entire world who have not been involved in war since 1945. In 1986, the world's total standing armies amounted to 32,000,000 persons with 570,000,000 reserves. It is sheer fantasy to believe that governments will yield their power and authority to more responsible people.

About 100 of the world's governments are ruled by some form of totalitarianism and pragmatism, having limited political constraints. Muslim terrorists and a few Islamic nations may be motivated to obtain atomic weapons for theological purposes to bring on the 12th Iman by world conflagration. Nuclear weapons have been around for 65 years since World War II, giving us a dangerous illusion that there is permanence in their deterrence and nonuse. Political instability results from highly accurate nuclear-tipped missiles, multiple methods of delivery, decision periods of a few minutes, hair-trigger readiness, and the use of computers to sort out the spurious from the real.

Writers of fiction allude to the development of nuclear weapons. Theodor Seuss Geisel in *The Butter Battle Book* writes a pictorial parable of the nuclear arms race with an ambiguous ending. The Yooks and the Zooks are enemies because the Zooks eat their bread with the down side buttered while the Yooks keep their butter side up. The trouble begins when a Zook uses a slingshot against the Yook's best weapon, a Snick-Berry Switch. A rapid arms escalation ensues, until inevitably they both come up with the Bomb, the Bitsy Big-Boy Boomeroo. At the end, there is a confrontation at the wall separating the two countries. Each is holding a pink hand-sized bomb that can obliterate the other, while a Yook grandson is watching. As the last page reads in its entirety: "Grandpa! I shouted. 'Be careful! Oh, gee! Who's going to drop it? Will you … Or will he?' 'Be patient, said grandpa. We'll see. We'll see'."

In Milton's *Paradise Lost*, Adam is told by the angel Raphael about an "absolute weapon" that the angels loyal to God had used against Satan and his followers in Heaven's Civil War after the Fall. The weapon is so powerful, according to Milton, that it "tears the seated hills of Heaven from their roots." Unfortunately, the absolute weapon is captured by Satan and turned against Heaven. If it were not for the intervention of the Deity, Paradise itself would have been destroyed. Raphael predicts that the absolute weapon would appear among men "in future days, if malice should abound." H.G. Wells in *The World Set Free* (1912) described a war where most of the world's capitals were consumed in fire from a new type of bomb. Millions of people were killed, and all forms of government came to a virtual end. Wells wrote of how "a man could carry about in a handbag an amount of latent energy sufficient to wreck half a city." Wells said:

> … the liberation of atomic energy on a large scale for industrial purposes, the development of atomic bombs, and a world war which was apparently fought by an alliance of England, France and perhaps including America, against Germany and Austria, the powers located in the central part of Europe. He placed this war in 1956, during which the major cities of the world would all be destroyed by atomic bombs.

The Bible is comprised of 66 Books, 39 Books in the Old Testament and 27 Books in the New Testament. Despite the disbelief of most scientists and politicians,

the Bible does contain descriptions of nuclear physics and nuclear war. The end-time battle described in the Book of Revelation speaks of cataclysmic judgments and battles that kill at least another order of magnitude more people on the earth than occurred in World War II. In this final war preceding the coming of Jesus Christ, billions will die [12]. The writer (John) of Revelation wrote about twenty-first-century events using first-century vocabulary. Even so the biblical events are easily understood using modern vocabulary of nuclear physics and warfare.

The Heavens and earth have been "stored for fire" for a time when the "elements will be dissolved" (melt, split) with fire (2 Peter 3:10–13). The Greek word for element, *stoicheion*, means a basic unit of matter. The text describes quite concisely fission with a release of atomic nuclear binding energy, in anticipation of the creation of a new Heaven and a new earth. It is God who holds each atom in the universe together by binding energy (Colossians 1:17) [83].

A great, powerful weapon will destroy and kill throughout the whole earth, something that has never happened before in the history of the world (Revelation 6:3–4; Isaiah 54:16). Pillars of smoke will be seen (Joel 2:30). The entire world will be involved with cataclysmic events. One of the last battles of time will last for only 1 day, but its effects will remain for 7 years (Ezekiel 39:1–16). The battle will be preceded by 30 min of silence following the opening of the seventh seal (Revelation 8:1; 18:10, 19).

The prompt effects of nuclear detonations include a blast or shock wave, an initial pulse of gamma rays and neutrons, and a pulse of thermal or heat energy. Later effects are due to fallout of radioactive fission products and induced radioactive material. A description is given by John Hersey in his book, *Hiroshima*: "There were about 20 men...all in exactly the same nightmarish state: Their faces were wholly burned, their eye sockets were hollow, the fluid from their melted eyes had run down their cheeks … their mouths were mere swollen, pus-covered wounds, which they could not bear to stretch enough to admit the spout of a teapot." These thermal effects are also described in the Bible (Zechariah 14:12–13; Isaiah 13:8; 24:6). Shock waves from nuclear blasts will push the air apart like an unrolling scroll (Revelation 6:12–14; Isaiah 34:1–4).

The slaughter will be so great that sufficient people will not be alive or available to bury the dead before they decomposed into skeletons (Jeremiah 25:31–33; 30:24; Psalm 110:5–6). Smoke and dust will turn the sun into darkness (Acts 2:16–21; Revelation 6:12; Joel 2:30–31). The dead will not be buried until a wait of 7 months (Ezekiel 39:12–15). He (John) describes how a third of mankind is killed by a "vehicle" possibly like ICBMs with multiple heads (Revelation 9:17–19) [83].

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The Harmful and Fraudulent Basis for the LNT Assumption

3

I do not hesitate to say that the LNT is the greatest scientific scandal of the twentieth century (Gunnar Walinder)

3.1 A Scientific Scandal of the Last Two Centuries

New technology and ideas can be difficult to implement. Critics of Captain Edward J. Smith of the RMS *Titanic* were fast to point out that his poor handling of wireless messages deprived Smith of vital information concerning navigation of the ship in an ice field. However, wireless technology was relatively new in 1912, and most officers of passenger ships in the North Atlantic had not considered the implications of enhanced communication capabilities that the wireless offered. Smith did not appreciate how wireless gave him the opportunity to look over the horizon and anticipate danger before it came into view. He shared this shortcoming with nearly all of his colleagues [1].

This is not a claim that can today be made for radiation hormesis. Every regulatory agency in the world, other than France, bases their policies on the LNT, in spite of the massive published scientific literature that has clearly pushed far beyond the factual horizon to demonstrate thresholds and the beneficial effects of low-dose ionizing radiation. The linear no-threshold (LNT) assumption is a dogma constructed of untruths, artful dodges, and blind faith. The LNT paradigm does not fit the facts but holds political sway for the time being. The LNT has the political power for now to ridicule, ostracize, censor, and ignore the hormesis message and the facts that underlie its contention. This is the corruption mythology of the harmful effects of low-dose ionizing radiation that costs enormous resources in money and the quality and quantity of lives. Folk today are more worried about legal and political

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Table 3.1 Contrasted characteristics of science and pseudoscience [2]

Science	Pseudoscience
Evidence obtained via experimentation informs beliefs; belief in a claim is withheld if evidence is not available; relies on entire body of evidence	Beliefs are formed first and evidence is sought to support; relies on credulity; disconfirming evidence is rejected to preserve belief
Makes conservative and tentative claims based on evidence; beliefs change with new evidence; open-mined	Makes sensational claims without evidence; rejects new evidence against belief; close-minded
Uses precise terminology to aid understanding and independent verification; rejects unverifiable claims	Uses vague language and jargon to avoid criticism and inhibit verification; accepts unverified claims
Knows, understands, and applies the rules of logic with body of evidence to make claims	Uses logical fallacies and cherry-picks evidence to make claims
Treats critics as colleagues and values criticism from a community of scientists; engages in honest debate	Does not value criticism and condemns dissent; works in isolation and dishonestly engages in debate

liabilities than they are in science-based truth. The result is a politicalized pseudoscience wound around the LNT[1] (Table 3.1).

The Merriam-Webster dictionary defines "phobia" as an exaggerated, inexplicable, and illogical fear. The result of fear is anxiety and avoidance [3]. The LNT has a wide-ranging impact on radiology, nuclear power, "dirty" bombs, nuclear waste disposal, food irradiation, home radon, and diagnostic and nuclear medicine. The societal cost of radiophobia and fear mongering is exorbitant, and those that continue to promote it stand the most to gain; just follow the money. The cost of implementation and carrying out radiation regulations does not improve plant safety or personal health; it actually costs tens of thousands of lives annually in the USA alone.

> Smoke detectors should not cross state lines according to radiation dose regulations.

[1] The ICRP, NCRP, UNSCEAR, BEAR-BEIR Reports and IAEA are national and international funded radiation protection agencies with select committees and government officials, who nearly all promote the LNT as a radiation protection model. Proponents of radiation thresholds and hormesis are not appointed to scientific committees no matter how qualified they may be. Regulators claim their findings cannot be reviewed and changed. Some of the research that has refuted the LNT and was prematurely terminated includes studies of background radiation, CHR radium dial painters, Nuclear Shipyard Workers, AEC/DOE high-dose workers, Manhattan Project dose workers, radiation deficiency studies and most recently, DOE low dose radiation studies. All showed clear evidence of radiation thresholds and hormesis. Dr. Noel Metting, director of the DOE low dose radiation program, was fired in 2014 for her challenge to the LNT; she was reinstate after appeal. Metting was just another example of what happens to a scientist who objects to the LNT inside of "closed" science venues. Critics of the LNT are readily ignored with no debate. Debate challenges are avoided. Critics of the LNT risk science careers, grants and appointments by gov't agencies. Radiation protection officials routinely suppress science objections. The nuclear industry does not assess data, does not do research, does not review scientific data, but does profit to the tune of 100's billions dollars per year from public funds used for radiation protection and useless 'clean-up' and waste disposal based upon the LNT

Deep fear of nuclear radiation is widespread, yet research on radiation's biological effects finds that the level of alarm far exceeds the actual danger. This "radiophobia" has roots in the fear of nuclear weapons, but has been significantly reinforced and inflamed by accidents at nuclear power plants. Radiophobia does far more harm to human health than the radiation released by nuclear accidents. In some cases, the harm results from disaster response. The influence of radiophobia on society's energy choices poses great additional dangers [4].

Radiation protection scientists knew in 1934 what level of radiation was harmful and what level was safe. In 1956, the US National Academy of Sciences (NAS) adopted the LNT assumption from an evaluation of genomic risks due to ionizing radiation, based in large part on the fraudulent studies by Mueller on mutations in fruit flies. In 1958, the National Council on Radiation Protection and Measurements (NCRP) generalized the LNT assumption to somatic cells and cancer risk assessment [5]. The LNT is pragmatic and not based on biological concepts or mechanistic biological research. Most of low-dose mechanistic research at low radiation doses confirms the presence of thresholds and hormesis [6] (Fig. 3.1).

It was the leading physicists of that time responsible for invention of nuclear weapons that instilled an exaggerated fear of small doses irradiating healthy tissues, during the Cold War period of massive testing of nuclear weapons. Dr. KZ Morgan (1907–1999) was a pioneer in radiation protection beginning with the Manhattan Project. He founded the Health Physics Society (1955) and the *Health Physics* journal (1958). During World War II, Morgan believed in a radiation dose threshold but

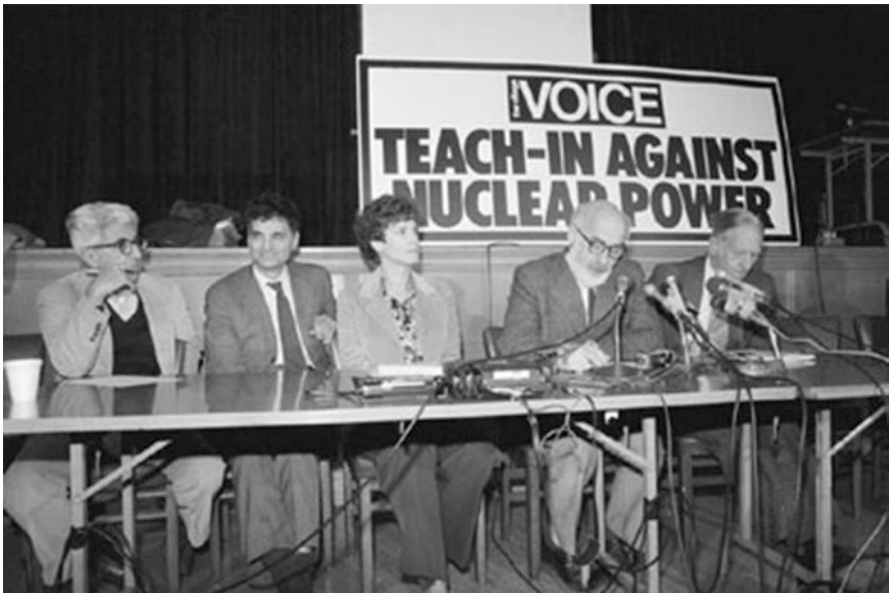

Fig. 3.1 Antinuclear advocates speaking in May 1979 at New York's Riverside Church (from *left*: Barry Commoner, Ralph Nader, unknown lady, John Gofman, and KZ Morgan) [7]

later reversed himself and became a firm believer in the LNT. He ignored the clear thresholds in radium dial painters and in Japanese A-bomb survivors and aligned himself with antinuclear activists who made absurd statements about the risks of radiation. Morgan could not give any good evidence for the LNT because it was theoretically impossible to do so [7].

John Gofman, an M.D. and nuclear physicist, was a graduate student of Glenn Seaborg at the University of California, Berkeley, from 1939 to 1943 working with cyclotrons. Gofman put a rat into a canister within a cyclotron and found it dead when he removed it later. He thought it had been killed by radiation, when in fact it had simply suffocated. The lab director, John Lawrence (1903–1991), wanted students to fear radiation and did not correct his misconceptions. Gofman (1918–2007) later wrote in his book, *Nuclear Witnesses: Insiders Speak Out*: It is not a question anymore. Radiation produces cancer, and the evidence is good all the way down at the lowest level [8].

Antinuclear activist organizations promoting radiophobia use blatant distortions. Fear mongering by antinuclear organizations such as Greenpeace has spread throughout the world. Greenpeace uses the words "birth defects, cancer, and nuclear power" in rapid succession over and over without establishing any scientific links, hoping that the repetition will become a mantra in place of the truth in the minds of its hearers. Sternglass in the 1960s predicted thousands of dead babies in the USA due to nuclear weapons testing fallout. Take this comment by a Korean organization: Relying on nuclear plants is like playing Russian roulette: the bullet-bearing chamber will come up eventually. It takes very little exposure to radiation to be fatal; the only difference between Hiroshima and Chernobyl is that in the first case hundreds of thousands of people died instantaneously and in the second, an even larger number will die of cancer over a longer, more painful period of time [9]. A 2009 review of Chernobyl finds that the earlier estimate of 50,000 deaths should be doubled to 100,000 [10]. Today, documented cases of radiation-related mortality from any cause from low-dose Chernobyl fallout are hard to come by. Is a little radiation really bad for you [11]?

Scientific American used to be known for accurate reporting on science and not for published fiction and propaganda. *Scientific American* in the June 2013 issue had an article entitled *Radioactive Danger Lurks in the Trees*. They reported that one million eventual deaths will result from deposited Chernobyl fallout due to a possible forest fire of so-called "contaminated" trees. The author believed that the risk of cancer after such a fire was 170 per 100,000 women and 18 per 100,000 men. A 2012 article in *Scientific American* says there is deadly radiation even associated with lightning strikes from the clouds [12]. The wildlife in Chernobyl evacuated zones are thriving in what is supposed to be an ecologic radiation death zone. Wildlife thrive in low-dose radiation, while only humans are supposed to be hurt by radiation. Where is the consistency of reporting facts?

The LNT assumption is based on seriously flawed and misleading epidemiological studies often conducted using phantom increased cancer risk for low-radiation doses.

The construction of a castle built upon the white cliffs of Dover was initiated by Roman conquerors and largely completed in the eleventh century by King Edward and King John. Tunnels were carved out of the rock below the castle during an invasion by Napoleon and enlarged during World War II. Vice admiral Ramsey used the tunnels of Dover as his command post to oversee the rescue at Dunkirk in 1940 and the invasion of Normandy in 1944. The tunnels were used as a secure command post in case of nuclear war with Russia and then abandoned in the 1970s. The reason was the fear of minimal radioactivity seeping into the tunnels with water from radioactive fallout.

The silliness continues today. On May 5, 2016, a spike of radiation was detected miles from the high-level nuclear waste tanks on Hanford, Washington. The EPA attributed the brief radiation to natural background radon emanation from the ground near a detector. Washington State Rep. Gerry Pollet called this meaningless spike a disaster that would result in 2102 additional fatal cancers for every 10,000 adults. This silly math and misuse of collective dose and the LNT by a Hanford agitator and politician were meant to scare, not educate, the public [13]. The latest in unbelievable science comes from Finland. The authors claim to have detected an increase in leukemia in a genetic subset of children aged 2–7 at a background dose difference of only 1 mSv [14].

An expansive, ever controlling government wants to take advantage of people's fears by promulgating regulations restricting exposure to ionizing radiation. Antinuclear NGOs thrive on fear. This radiophobia provides political power and lots of money to antinuclear activists, politicians, career radiation protectionists, and a long list of entrepreneurs who move "contaminated" soil from one place to another (even putting it into glass) and for the radon exterminator to relieve you of your own household radon gas you need for optimum health.

> There are great herds of elk and caribou in the Canadian artic. They survive in the winter by digging into the snow and eating large amounts of lichens. The lichens contain significant amounts of polonium-210 from the decay of uranium. According to the Chalk River Nuclear Laboratory in Canada, the animals typically receive an annual dose of about 1 Gy. The animal herds are not decreasing in number nor dying of cancer. Instead, they are thriving (Jerry Cuttler, S.A.R.I.).

Fear of radiation has served the political interests of countries that already possessed nuclear weapons, particularly the USA and U.S.S.R. The nuclear test ban treaty prohibited atmospheric and ocean testing; later treaties prohibited all nuclear weapons tests. However, all countries did not sign it. The idea that low-dose radiation was beneficial was anathema to their political interests. Instead they emphasized the supposed terrible cost to life from the infinitesimally small doses received by the northern hemisphere from test fallout while ignoring the higher doses received directly downwind in towns and cities of their own countries. The

hypocrisy was monumental by all sides; however, the radiation doses received by "downwinders" were beneficial.

People had good reason to worry about nuclear war. A book written in 1987 described updating of US military plans to launch a first strike war on the U.S.S.R. [15].

> The most insidious opposition comes from the radiation safety experts whose salaries, research funding, and bureaucracy depend on the status quo. They adhere to ALARA as if it were the Hippocratic Oath of their profession. According to Upton Sinclair, it is difficult to get a man to understand something when his salary depends on his not understanding it [16].

This led to political opposition to all things nuclear, including nuclear power plants. There are powerful political and vested interests in opposition to radiation hormesis today in spite of an overwhelming published literature to the contrary [17]. Not all officials believed in the LNT. George Kistiakowsky was President Eisenhower's science advisor and a former nuclear scientist who was a participant in the Manhattan Project; he believed that the use of the LNT was totally arbitrary. In his 1976 book, *A Scientist at the White House*, which he wrote in his diary in 1960 on being exposed to the idea of the LNT by the Federal Radiation Council, Kistiakowsky said: "… a linear relation between dose and effect … I still believe is entirely unnecessary for the definition of the current radiation guidelines, since they are pulled out of thin air without any knowledge on which to base them."

Critical thinking was suspended by decision makers for political agendas. The result has been an endless filing of lawsuits. Many people have thought they lived under the shadow of disease and death for decades, only because of radiophobia. Daniel Miles, who lived in St. George, Utah, in his 2008 book *The Phantom Fallout-Induced Cancer Epidemic in Southwestern Utah: Downwinders Deluded and Waiting to Die*, describes the inhabitants who called themselves downwinders and sued for their cancers. Follow the money! There are still people making claims that their "illnesses" are the result of having lived downwind of the Trinity test, even though they weren't actually "downwind" at the time of the test. Dr. Reginald Gotchy measured 700 people living near the Three Mile Island nuclear reactor accident a few months after the accident that happened on March 28, 1979 and found no increase in radionuclides. The increased radiation dose to two million people living around the plant was only 14 μGy [18]. Because we can't absolutely prove that there is no connection between their "illnesses" and radiation, radiation takes the fall. And once "victims" obtain an out-of-court financial settlement, a precedent has been set. There's no way to get the cows back in the barn. Follow the money!

A sad recent example is the US Nuclear Regulatory Commission (NRC) who granted the Vermont Yankee Nuclear Power Plant a 20-year extension of their operating license in 2011 that would keep it running until 2032. A miniscule leak of tritium from the plant, the radiophobia of the public, and the high costs of radiation

protection regulations caused the operating company to shut down a perfectly working 40-year-old plant. However, the NRC will say nothing because of politics. The Vermont Department of Health limits are 20 mrem per year. The NRC limits radiation doses for the general public to 100 mrem per year (1 mSv = 100 mrem). The EPA limit is 25 mrem per year from radioactivity in air, water, and soil. In comparison, the natural radiation background is 300 mrem per year in Vermont. The highest natural radiation levels found in the world are in Ramsar, Iran, where several thousand citizens live free from any adverse radiation effects at dose rates that are orders of magnitude greater than seen with the Vermont Yankee Plant.

Not surprisingly, radiation protectors often act in their own self-interest. Probably 90% of those employed in radiation protection are involved with "protecting" nuclear workers and the public from cumulative annual doses <100 mGy. Applying a threshold and the hormesis model would eliminate their careers. Most academics and physicians are not well informed about hormesis [19] (Table 3.2).

The whole sad story of dishonesty and misinformation and even fraud continues by radiation protection agencies and governments who want to keep the people of the world in fear of ionizing radiation [21]. The deadly outcomes resulting from radiophobia reactions have resulted in literally thousands that perished or had their livelihood destroyed due to irrational decisions to evacuate areas of low radiation levels. Michael Stabin of Vanderbilt University calls the LNT a "stupid bastard," which is not intended as a "low class slur" but a statement of fact.

A 1958 paper published in the *British Medical Journal* by Dr. Alice Stewart, *A Survey of Childhood Malignancies*, became one of the seminal influences for the LNT-based connection between low-dose X-rays during pregnancy and increased leukemia frequency in offspring. Stewart claimed an increased risk of leukemia for in utero exposures of 1–2-rad X-rays [22]. Several subsequent publications clearly showed that the human fetus exposed to doses less than 100 mGy (100 mGy = 10 rad) did not have an increased risk of leukemia or of any cancer [23]. This did not stop

Table 3.2 The supposedly ten most radioactive places on earth [20]

Ranking	Description
1	Fukushima, Japan, tsunami and nuclear reactor accident
2	Chernobyl, Ukraine, nuclear reactor accident
3	Mailuu-Suu, Kyrgyzstan, uranium mining and processing site
4	Polygon, Kazakhstan, nuclear weapons testing site and city of Semipalatinsk
5	Siberian underground liquid and solid waste storage facility and reprocessing plant at Tomsk
6	Sellafield, UK, Pu production facility for nuclear weapons
7	Pu production facility at Mayak and Techa River in Southern Ural Mountains of Russia
8	Coast of Somalia. Illegal burial of nuclear waste
9	Mediterranean Sea. Illegal dumping of radioactive waste
10	Hanford, WA, Pu supplier for most US nuclear weapons. Large mass liquid and solid nuclear waste

Stewart from becoming a spokesperson for antinuclear groups and an advocate of the LNT. Many studies have been carried out on the offspring of A-bomb survivors. These include birth defects (malformations, stillbirths, and newborn deaths), sex ratios, chromosome aberrations, blood-protein mutations, and minisatellite DNA mutations. None of these studies found any evidence for genetic effects resulting from parental exposures to radiation [24]. A recent study of women workers at Mayak, Russia, exposed in utero to γ-rays and plutonium found no risk of cancer in offspring [25].

Prof. Dr. Gunnar Walinder, former head of the Swedish Radiobiology Society and a preeminent Swedish radiation scientist, wrote about the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in his 1995 book; he stated bluntly: "I do not hesitate to say that the LNT is the greatest scientific scandal of the 20th Century." Walinder wondered if radiation protection had become a health hazard. He believed that the LNT assumption was a primitive and unscientific idea. UNSCEAR, which had later changed its view on the LNT, expected no radiation-related health effects from Fukushima. There are 192 references to radiation hormesis in Annex B of UNSCEAR (1994) along with several thousand references in Luckey's books, which list the good, bad, and ugly from either listening to or ignoring evidence for radiation hormesis [26].

> A one-time dose of 400 adult aspirins can cause the death of one person. However, a group of 400 persons each taking one aspirin does not mean that one will die [27].

There were 86,611 survivors of the Japanese A-bomb detonations. Of those who died of cancer for the next 50 years, the number of solid cancers and leukemia deaths attributed to radiation was 480 and 93, respectively, amounting to less than 1% of those initially killed by blast and thermal effects [28]. UNSCEAR (1958) reported an incidence of leukemia in Japanese A-bomb survivors that was three times lower than in controls at a dose of 20 mGy and with a threshold of 500 mGy. Many other studies have shown evidence for radiation hormesis in the Japanese A-bomb survivors [29, 30] (Chap. 2).

UNSCEAR calculated in 1993 a collective dose for the entire world's population of 650,000,000 man-Gy truncated for 50 years; they also calculated 100,000 man-Gy for nuclear testing and 600,000 man-Gy for Chernobyl fallout. The tiny individual doses are harmless or beneficial. Only utilization of the LNT would make such foolishness sound scientific.

Abel Gonzalez of the ICRP attempted to take a middle political position on the LNT. According to Gonzalez, the LNT model yields speculative, unproven, undetectable, and phantom numbers. Nevertheless, he finds the LNT model to be prudent for radiological protection. Gonzalez states that:

> While prudent for radiological protection, the LNT model is not universally accepted as biological truth, and its influence and inappropriate use to attribute health effects to low dose exposure situations is often ignored. Speculative, unproven, undetectable, and "phantom" numbers are obtained by multiplying the nominal risk coefficients by an estimate of the collective dose received by a huge number of individuals theoretically incurring very tiny doses that are hypothesized from radioactive substances released into the environment [31].

NCRP-136 wrote:

> It is important to note that the rates of cancer in most populations exposed to low-level radiation have not been found to be detectably increased and that in most cases the rates have appeared to decrease. However today, neither ICRP nor NRCP promulgates radiation dose regulations that take into account the benefits of low-dose radiation but continues to remain "prudent." (Fig. 3.2).

There is a socio-technical vanity and arrogance concerning the unreality of the LNT. The LNT has little to do with science but of the profit motive for the thousands of businesses that depend on radiophobia for their profitability. They depend on hypothetically exaggerated radiation hazards. The EPA facilitates this fear of radiation by published false estimates of annual number of Americans who will die

Fig. 3.2 Abel Gonzalez, ICRP Vice-Chairman from 2008 to 2013

View of nuclear wastes [50].

Fig. 3.3 View of nuclear wastes [33]

from cancer following exposure to radon in their homes. EPA exposure limits are orders of magnitude below levels where there is evidence of harm. The regulations cost hundreds of billions a year and accomplish nothing in radiation protection while preventing radiation that protects against cancer and other diseases [32] (Fig. 3.3).

Nations of the world spend hundreds of billions of dollars a year to maintain ridiculous radiation standards. For example, Poland spent billions of dollars on their first nuclear power plant only to have it abandoned due to politically motivated radiophobia by using the LNT to determine cancer risk. There is a near total fear of radiation in Germany causing a green energy focus and the abandonment of nuclear energy. Billions of dollars are spent each year by poor countries for phantom radiation protection; these resources could be used in much better ways to save lives [34]. Using present radiation protection regulations in the USA, it is estimated to cost 2.5 billion dollars to save one human life from so-called dangerous exposure. In contrast, it takes <$100 to save a life by immunization against a variety of communicable diseases.

Editors of major medical journals (*Lancet* and the *New England Journal of Medicine*) regularly publish papers that arrive at false conclusions about the risk of radiation.

The enormous social fear and media frenzy surrounding the release of radioactivity from the damaged Fukushima Daiichi NPP led to careful reexamination of the facts. Radiation hormesis is an excellent remedy for this affliction, and it is perhaps for this reason that this has been ignored and discredited over the past half century [35]. Today, people worry about dirty bombs, frantic evacuations, suicides, abortions, psychosomatic disorders, increased drug and alcohol use due to despair, and permanent abandonment of their home and properties from low-level radioactive contamination.

The first Earth Day, in 1970, was celebrated after a wave of environmentalism swept the nation. Many give credit to Rachel Carson's 1962 book, *Silent Spring*, which popularized the notion of large-scale chemical pollution, for igniting the movement. The enthusiasm spawned by Earth Day soon gave us brand-new regulatory agencies such as the Environmental Protection Agency. The "linear model" assumes that just a single molecule of a carcinogen or a single ionization from an X-ray can induce cancer. The linear model is rigid, absolute, and wrong. The resulting environmental regulations are having a negative impact, not only on societal costs but on our health as well (Calabrese. 2016 (go-nuclear.org)).

Radiophobia causes misappropriation of often precious resources to accommodate pseudo-dangers or made-up dangers; causes massive psychological damage in affected populations leading to depression, suicide, abortion, and unneeded stress; causes overspending on limited resources that could be used for more efficient and better purposes; and causes the avoidance of effective medical procedures such as low-dose radiation therapy (Bill Sacks, S.A.R.I.).

The grand total of the wealth and jobs created by the application of radiation technology in the USA is 420 billion dollars and 4.4 million jobs (Alan Waltar, S.A.R.I.). There have been no new nuclear power plants built in the USA since 1974. Ultralow limits have delayed and prevented the construction of new nuclear power plants, added billions to the cost of refurbishing old reactors and Superfund cleanup sites such as Hanford, and scared residents of Nevada from opening of the Yucca Mountain nuclear waste repository site. John Shanahan and the website, *Go Nuclear*, have contacts with thousands of professionals in nuclear energy and nuclear medicine in 111 countries. He believed that we need a new Earth Day dedicated to righting the past deceptions and correcting the ongoing errors in environmental regulation. It should be one that acknowledges our adaptive responses to what, in high doses, can cause cancer, but, in low doses, can improve our well-being [36]. Most members in the media and in the general public seem to believe that humans normally live lives free of natural background ionizing radiation. As a result, regulatory agencies only limit anthropogenic sources of exposures to radiation as being harmful, ignoring high doses from natural sources. Organizations like NAS and BEAR accept fraudulent, uncritical, unquestioning, and blind-faith rules put out by regulatory agencies and the scientific community [37].

3.2 The Scan that Cures

According to the *Book of Exodus*, a man who assaults another must pay a physician to heal the wounds. The thirteenth-century medieval physician and philosopher Nachmanides interprets this to mean that physicians require permission to heal, for without the warrant to treat, physicians might hesitate to treat patients . . . "in that

there is an element of danger in every medical procedure. That which heals one may kill another." This 800-year-old warning seems self-evident [38]. One should bear humility and avoid the arrogance of a know-it-all attitude when dealing with harm and benefit scenarios from CT scans. Even so, CT scans seem to be "The Scan That Cures." [39]. Diagnostic imaging is critical to effective therapy and saving and prolonging lives. Many epidemiological studies claim there is an increased risk of cancer associated with the low-dose radiation received during imaging, believing that view is the real health risk [40].

There were about 60 million CT scans in 2007 and 2008 in the USA, including four million children [41, 42]. Brenner and Hall estimated that up to 2% of cancers in the USA are attributed to CT scans. An iodine-based dye (injected) or barium solution (oral) may be administered as a contrast agent prior to CT scan to improve image quality. Severe anaphylactic reaction may occasionally occur, even to the point of being life threatening. Brenner and Hall do not address this risk in their analysis but only risk from X-ray exposure. The mean (± SD) cumulative dose from imaging procedures per patient per year is 2.4 ± 6.0 mGy; of this dose, 75% is due to CT and nuclear imaging [43]. The average dose from an abdominal-pelvic CT scan is the same as 100–250 chest X-rays [44]. There are many who want to decrease the dose received from a CT scan. The New York University Department of Radiology in 2016 was awarded an NIH grant of $3 million to work toward reducing the radiation dose from CT scans by as much as 90%.

> The general public's perception of the risks from CT scan radiation exceeds reality. Parents should agree to scans for their children with absolutely no worry or concern [45].

Computed tomography (CT) scan and computerized axial tomography (CAT) scan are procedures in which cross-sectional images (X-rays taken from many different angles) of structures of the body are created. Information is processed through a computer forming a three-dimensional image called a tomogram. The 3-D imaging makes CT scans more informative than chest X-rays. An X-ray source emitting an energy of 60–80 kv is used to make CT images. The scan time is very short, from 0.5 to 1.0 s. A higher CT radiation dose provides a higher image resolution with improved diagnostic reliability. Today, a chest X-ray gives 0.1 mGy, a chest CT gives 8 mGy, and a whole-body CT gives 10 mGy. In 2003, a chest X-ray gave 0.25 mGy and a whole-body CT gave 60 mGy. The difference in radiation dose between a chest X-ray and chest CT is today about 100-fold. Despite the apparent large dose differences, all fall in the hormetic zone.

Fear of ionizing radiation occurs in strange and unexpected places. In the midst of a combat zone, one of the concerns of a highly experienced and courageous physician is this fear. Mack Easty is a retired Army Lieutenant Colonel MD. Mack volunteered for a full year (2010–2011) tour of duty with a combat battalion

stationed in Kandahar Province, Afghanistan, just before his retirement. On one two-day patrol there were several IED (improvised explosive device) detonations. All the casualties received CT imaging, many with multiple scans with and without contrast media in Afghanistan hospitals and after transfer to medical facilities in Germany and Walter Reed Hospital. The typical CT scan is ubiquitous in combat casualties, each delivering a radiation dose of 10–20 mGy.

Mack wrote this to me in November 2011:

> I had always been taught that any amount of radiation incurs a cancer risk, especially CT scans since the radiation doses are 'massive'. As an emergency physician, I've ordered a lot of CT scans, but have always vowed to avoid them myself...I've always been taught that radiation exposures are additive and the lifetime cumulative dose determines ultimate risk...I was with a light infantry battalion and went on all the air assault missions. The guys with the worst injuries pretty much got scanned from head to toe when they made it to Kandahar … We flew 12 casualties (on this mission) and I figured out a lot of them were going to get scanned. I'm guessing these situations aren't things that Brenner and Hall [41] ever think about.

How you choose to analyze data often biases your conclusions. Epidemiologists like Brenner and Hall believe that all radiation is bad for you. This logically leads them to the use of a simple positive straight line without a threshold to represent the entire dose–response curve for cancer and radiation dose. Over 80 million Americans received a CT scan in 2011; the probability of receiving a CT scan was greater than one in ten. Brenner and Hall, using a simplistic LNT model, concluded that CT scans will be responsible for 1.5–2.0% of all cancers seen in the country [41]. Mack Easty was trained from publications by Brenner and Hall. Mack, as an emergency physician, needed to make sure to convey these "facts" to his patients before ordering these studies. There is no credible study, and it is a fantasy to support the contention that routine CT scans will cause future cancers [46, 47]. In fact, there is no epidemiologic study that has demonstrated adverse effects of radiation at doses less than about 100 mGy [6, 48].

The soldiers in the field are blest by the best medical care in the world. They are blest to be alive because of men like Mack Easty and accompanying medics. The casualties also receive a "hidden" blessing. The small doses of radiation they receive from CT scans stimulate a physiological phenomenon called radiation hormesis or benefit that enhances their healing and helps to prevent a wide variety of inflammatory and proliferative diseases in the future. Low-dose radiation is not harmful but is beneficial [6]. There is abundant scientific evidence that low-dose radiation exposures such as received by CT scans will reduce, not increase, cancer risks [46]. Mack Easty has been a member of S.A.R.I. for the last few years.

I was a professor at Korea Advanced Institute of Science and Technology (KAIST) in the Nuclear and Quantum Engineering Department in Daejeon, Korea, from 2004 to 2010. Korea obtains 40% of its electricity from nuclear power. During that time I made several presentations about the benefits of ionizing radiation. I was the keynote speaker at the annual meeting of the Korean Radiation Protection Society. I spoke at Seoul National University, Korean Nuclear Society, two nuclear

institutes in Daejeon, at KAIST, and in international meetings in Beijing and Hiroshima. The message was always the same. Low-dose radiation is good for you. Get as much as you can. If you smoke cigarettes, get an annual whole-body CT scan to limit your lung cancer risk [49]. I was probably entertaining but did not seem to make many converts.

The FDA even recommends that smokers and ex-smokers should get an annual CT scan to early detect life-threatening lung cancers. A $250 million study carried out over 5 years by the National Cancer Institute (NCI) showed I was right. Annual CT screening for lung cancer reduced lung cancer mortality in current and former heavy smokers by 20%. Also unexpectedly, annual CT screening cuts all-cause mortality by 7%. These results published in the November 2011 issue of *Radiology* triggered not an increased emphasis on causation but an early halt to the trial after the scan's benefits became obvious. The researchers assumed the benefits were due to the ability to detect tumors early when they are smaller and more treatable. This is a big issue since 220,500 new cases are diagnosed in the USA each year claiming 157,000 lives annually. Interestingly, screening studies with standard chest X-rays have not shown a screening benefit. The radiation dose from a standard chest X-ray is up to 100 times less than for a typical CT scan. The study involved 53,500 current and former heavy smokers (> one pack a day for at least 30 years) who were randomized to undergo either helical CT or a chest X-ray. By October 2010, 354 of those receiving CT scans had died from lung cancer versus 442 deaths for those receiving chest X-rays; the difference was 20.3% drop in mortality rates [50, 51]. The authors mistakenly attributed the differences to a screening effect without collaborating data rather than to radiation hormesis. Even so, a research team member, Dr. David Naidich, called the results stunning. The paper expresses angst over potential later cancers resulting from CT scans but completely ignores the possibility of radiation hormesis decreasing cancer risk.

Benefits of low-dose radiation are not only for cancer prevention but for prevention and treatment of a wide variety of other diseases that have significant pathological inflammatory components. The number of lives that could be saved, improved, and prolonged by low-dose radiation is enormous.

There is no evidence that CT scans increase the risk of cancer, in children or adults [46, 52]. Yet the experts contradictorily advocate the use of lower doses of radiation for needed CT scans as a "prudent" approach, thereby conflating the actual prudence of confining medical procedures to those that are clinically indicated by limiting radiation exposures that are clinically indicated [53]. Thus, apparently afraid to wander too far out on a limb in the face of the dominating and intimidating, but erroneous, belief in LNT, they undermine their own messages of reassurance, leaving patients and/or their parents confused as to whether there is risk or not. The number of excess cancer deaths in the USA due to CT scans has been estimated to be 29,000 per year, a figure that is patently false. There should be less than expected cancer deaths not more from CT scans. The LNT model has contributed to a widely held perception that radiation does more harm than good for patients who depend on advanced imaging to obtain correct diagnoses. Concerns over low doses of radiation from CT and X-ray scans are not only misguided but may lead to more deaths

from missed or delayed diagnosis than would supposedly be derived from radiation exposure.

In 2016, a Fox Chase Cancer Center researcher (Mohan Doss, S.A.R.I.) evaluating atomic bomb survivor data concluded that there should be no concern regarding low-dose radiation exposures to children and cancer risk from pediatric CT scans. The data on the long-term health effects of the survivors of the atomic bombings of Hiroshima and Nagasaki is generally regarded as the most important data for estimating health effects of radiation. Doss recommends the discontinuation of ALARA. We should not continue this campaign, but rather, we should educate the public to help alleviate their concerns. The ALARA principle can lead to issues with the quality of the images produced and can produce nondiagnostic scans, which can lead to a missed or incorrect diagnosis [52] (Fig. 3.4).

The use of fluoroscopic X-ray monitoring during the treatment of tuberculosis was common between 1920 and 1960. Typically, each dose was in the range of 10–100 mGy, and exposures occurred as frequently as every 2–3 weeks for 3–5 years. No significant increase in breast cancer was noted up to cumulative doses of 500 mGy [6]. The Canadian fluoroscopy study contains the second largest group listed in BEIR V and has good dosimetry documentation. Below a cumulative dose of 300 mGy, there is a highly statistically significant decrease in breast cancer. Miller wrote: The data was most consistent with a linear dose-response relationship … Our additive model of lifetime risk predicts that exposure

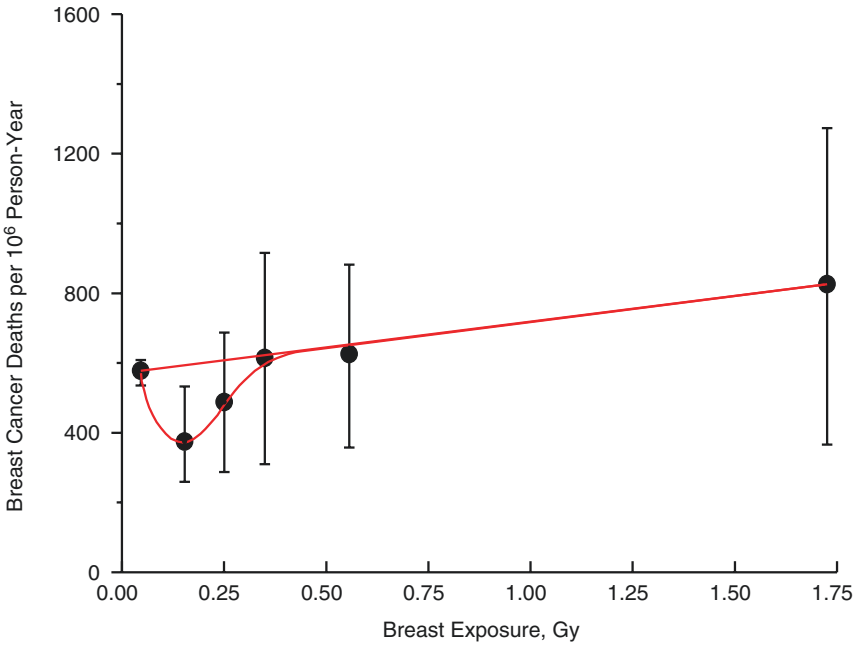

Fig. 3.4 Breast cancer mortality in Canadian tuberculosis patients given periodic fluoroscopic examinations. Figure redrawn from Miller et al. [54]

to 1 cGy at the age of 40 increases the number of deaths from breast cancer by 42 per million women [54]. Miller estimated an excess of 900 cases of breast cancer in a million women using the LNT assumption, [54] while Makinodan predicted 10,000 fewer cancers than expected in a million unexposed woman, using the same data [55]. Miller misrepresented the data to force fit an LNT response. BEIR V followed by applying a false straight line in its report; BEIR does not include any substantial studies that show the adverse effects claimed with the use of the LNT. In 1995 and 1996, NCRP continued to support the LNT assumption using this well-known straight line to zero [56]. An "update" study was published by Howe in 1996 [57]. Howe claims that the study does not show evidence of radiation hormesis. Howe graphically presents this conclusion by combining the four lowest dose groups into one group, thereby eliminating all evidence of hormesis. When challenged at the1997 National Academy of Sciences meeting in 1997, Howe said that the low-dose groups were "not informative." These low-dose groups in the Canadian breast cancer study had the largest number of cases with the smallest error bars. Subsequently, the NCRP SC 1-6 draft stated that the paper by Howe "refutes" the 1989 study [56].

Later Howe published a paper on lung cancer in the same Canadian women being treated for tuberculosis. The women had significantly lower lung cancers at cumulative doses below 2 Gy [58]. This radiation hormesis response was similar to many findings by other investigators [6, 49, 59]. The risk of childhood cancer was studied in a cohort of 92,957 children who had been examined with diagnostic X-rays in a large German hospital during 1976–2003. Newly diagnosed cancers occurring between 1980 and 2006 were determined through record linkage to the German Childhood Cancer Registry. No increase in cancer risk with diagnostic radiation was observed [60]. The low-dose radiation of medical imaging provides no pathway to poor health, whereas the LNT and ALARA most certainly do [61].

3.3 Chernobyl and Fukushima

James Muckerheide (1942–2014) spent the later part of his life trying to tell the truth about the health effects of low-dose radiation [56]. Most in government agencies throughout the world have failed to listen to James and many others. An expansive government may want to take advantage of people's fears by promulgating regulations. This is a clear and demanding problem in radiation protection. The LNT assumption is extremely simple to understand by the public and to apply in radiation risk estimates. The LNT is responsible for the radiophobia following the Chernobyl (1986) and Fukushima (2011) nuclear accidents. The accidents created an atmosphere of dread and panic by adjacent populations who had been taught that there is no safe radiation dose. Tens of thousands of cancer cases were predicted in the general population around Chernobyl [62]; no cancers or other clinical medical issues were found associated with Chernobyl radiation [27]. The incidents resulted in the loss of thousands of lives not from radiation-induced

cancer but from fear of radiation. The people of Russia and Japan would have greatly benefited by listening to the advice of James Muckerheide [56].

Kofi Annan (former United Nations Secretary-General) predicted in 2000 that three million children would require treatment because of Chernobyl, and many would die prematurely. Poor people in South America would not consume free powdered milk given by European relief agencies because they feared it was contaminated by radioactivity from Chernobyl. All these false views are the simple result of believing that even the smallest radiation exposure was harmful to health.

> We have quite a gap between scientific realities where not a single death from radiation has occurred and psychological trauma causing over 1000 deaths from the Fukushima accident (Wade Allison, S.A.R.I.).

The Chernobyl plant in northern Ukraine was a 1 GW nuclear power reactor. The Chernobyl accident happened on April 26, 1986 at the nuclear power plant in Pripyat, Ukraine[2]. The Chernobyl reactor exploded and the graphite core burned; it was about as bad as you can get. The accident was the worst nuclear power plant accident since the advent of nuclear power nearly 60 years ago. There followed a total meltdown of the reactor core, which, associated with burning graphite, produced a large, radioactive, aerosol emission for several days. The accident released 100 times more radiation than the Hiroshima A-bomb in 1945 and much more radiation than released into the environment from the Fukushima reactors. The explosion at Chernobyl went through the roof of the Reactor 4 building, spreading a radioactive cloud over areas as far away as Spain and Scandinavian countries. It also led to the relocation of 350,000 persons in Belarus and Ukraine and left an area of 100,000 square kilometers "uninhabitable." Needlessly, it may remain that way for generations to come. The results of radiophobia were untold numbers of abortions, suicides, and panic evacuation deaths.

> There were 134 cases of persons at Chernobyl that had acute radiation syndrome; of these 31 died within a few weeks. Of the 103 high-dose, long-term survivors, only 19 had died by 18 years later, mostly from cardiac disease and liver cirrhosis, often in men associated with cigarette smoking and alcoholism. Andrei Tarmozian, a 25-year-old fireman at Chernobyl in 1986, was successfully treated by a US physician, Dr. Robert Gale, for high-radiation exposure. Tarmozian survived but died at age 50, not of cancer, but from cirrhosis of the liver associated with alcoholism. Tarmozian believed that vodka protected him against the carcinogenic effects of radiation.

[2] The author was attending an IAEA conference in Vienna, Austria, at that time. The conference was about radiological hazards associated with nuclear power plant accidents.

Psychological disorders occurred in millions of people in Russia as a result of radiophobia associated with Chernobyl fallout. It was the most significant health effect observed, all because of the LNT. The Russian government evacuated and relocated 270,000 people; had they stayed they would have received from 1986 to 1995 a cumulative dose of between 6 and 60 mGy. Their mean ten-year cumulative dose from background radiation would have been 150 mGy. The Chernobyl evacuees would have received an additional 160–210 mGy had they stayed. Many places in the world experience much greater annual natural doses than these, up to 200 mGy per year. None has an increase in cancer rates. The background dose rate in Colorado is 6 mGy per year which would give a cumulative 10-year dose of 60 mGy; in Ramsar, Iran, it would have been 2000 mGy.

Mikhail Gorbachev believed that the Chernobyl accident was perhaps the real cause of the economic collapse of the U.S.S.R. One could now imagine much more clearly what might happen if a nuclear bomb exploded …one S-18 rocket could contain a hundred Chernobyl's (quoted by Jaworowski [63]). The enormous political, economic, social, and psychological impact of the Chernobyl accident was due to the irrational fear of ionizing radiation. Nuclear power is the cleanest, safest, and nearly inexhaustible supply of energy in the world. Nearly four million people living in Russia live in "contaminated" areas, receiving doses of >15 mGy. These people were declared to be "victims." They were much more victims of radiophobia [64]. According to the IAEA and other sources, from 100,000 to 200,000 abortions were performed following Chernobyl throughout Europe because of fear and the advice of physicians [65–68]; these unborn children were the ultimate victims.

UNSCEAR, the Chernobyl Forum, and many Russian and former U.S.S.R scientists believe that more than 800,000 excess deaths had resulted from Chernobyl during 1987–2004 [69]. Marvin Goldman in 1987 estimated that 53,400 people would die of radiation-induced cancer from Chernobyl fallout over the next 50 years [70]. In reality, the fatality rate per GWe-year at Chernobyl was nearly 50 times less than fatalities in hydroelectric plants [63]. Radioactive cleanup workers or "liquidators" worked in a 30-km^2 "high-" dose zone in 1986–1987. Workers were sent home when their cumulative dose reached 100 mGy to be replaced by new workers. The expected increase in cancer among these workers based on the LNT was 0.6% or about 1200 cases (BEIR 2006). The observed cancer mortality rate for the next 20 years was about 20% less than in an unexposed control population [71]. There were less than expected deaths and birth defects in populations exposed to Chernobyl fallout than seen in unexposed control populations [6, 63, 72]. Even people living in Bryansk district (the most contaminated area in Russia with a mean cumulative dose of 40 mGy) had a 17% decrease in cancer incidence [73]. Today, one can attend the "Chernobyl Festival" where for $200 you can take a tour of the reactor and enjoy a dinner. Those who travel today will feel like they are entering a nature paradise. In this area around the surrounding reactor, there are once again wolves and Przewalski's horses, European bison, and lynx which all have free range in the flourishing forests.

LNT advocates consistently proclaimed an increased risk of cancer whenever the epidemiological numbers are positive while hypocritically ignoring any negative number that indicated a benefit. The affected countries were very keen to exaggerate

the medical and environmental consequences of Chernobyl fallout because of potential western investments in future studies and aid. Research money and outside aid would dry up if their studies demonstrated benefits from ionizing radiation. Because the LNT hypothesis is very well established, and because many strong radiation protection organizations are in place, scientists and government officials are reluctant to seriously consider the implications of radiation hormesis phenomenon, which has very important public health consequences. The cost in lives and money in implementing current radiation guidelines is enormous, while the "benefit" to our health may be negative with not less but more cancer [74].

At 15:37 on March 11, 2011, a tsunami wall of water engulfed the Japanese eastern coastline, including three nuclear power reactors at Fukushima. There were about 20,000 Japanese who died from the Tohoku and resultant tsunami. No one died from direct effects of ionizing radiation (Fig. 3.5).

The operator of the stricken Fukushima Daiichi Nuclear Power Plant revealed that 600 tons of reactor fuel melted during the disaster, with the exact location of the highly radioactive blobs remaining a mystery [75]. Radiophobia covered up the real impact of the tsunami on Fukushima refugees. The only things we learned that were helpful from Fukushima are that emergency generators and cooling water pumps should be placed further up the hill and that earthquake zones are hazardous (Wade Allison, S.A.R.I.). According to the World Nuclear Association (2016), UNSCEAR (2013, 2016), and IAEA (2015), there have been no deaths from radiation sickness or any other health effect from Fukushima fallout nor are health effects likely to be detected in the future in either a nuclear plant employee or in those living nearby the facility [76].

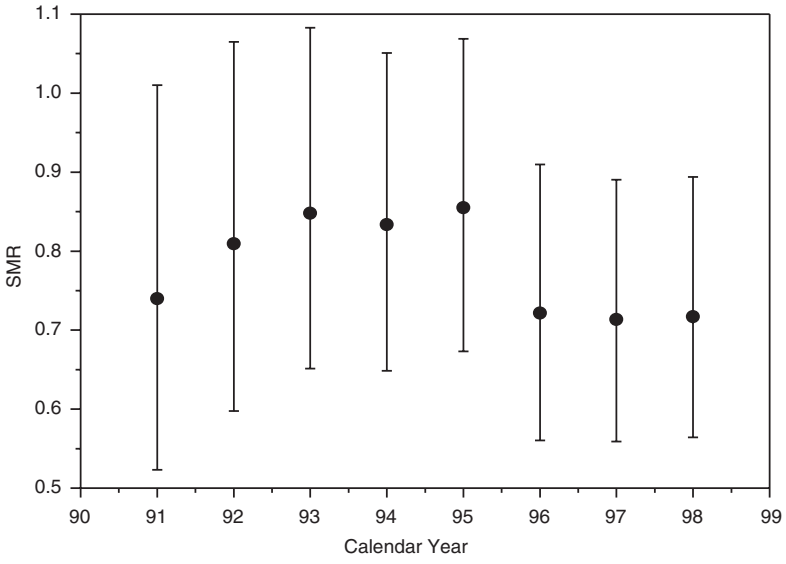

Fig. 3.5 SMR for all-cancer mortality in Chernobyl liquidators [71]. An SMR = 1.0 is expected for a similar unexposed population

Fukushima radiation levels following the 2011 nuclear power reactor accident were less than several natural, high-radiation background areas. Radiation doses received during the first year to those living in a 20-km radius were 20 mGy; 169 nuclear reactor personnel received doses of >100 mGy, mostly by inhalation (6 staff received >250 mGy and 136 received 100–250 mGy) [78]. A recent paper found that Fukushima individual radiation doses were by a factor of 4 smaller than earlier doses employed by the Japanese government [79].

The number of evacuees initially totaled 328,903 that was reduced to 263,392 as of February 13, 2014, nearly 3 years after the tsunami. Of the 132,500 Fukushima residents, about 70% experienced mental and physical disorders. Long-term refugee life spawned suicide, divorce, separation of family members, migration and settlement outside the evacuation zone, and mental illness. No one was killed by radiation alone. However, more than 1000 people died from radiophobia induced by the LNT [24].

Many people living in Tokyo did voluntary evacuations, among them members of the French embassy and many Americans. The Japanese government had forcibly and unjustifiably removed and relocated over a 1000 elderly people outside of Fukushima, similar to the relocation of American Japanese along the Pacific coast of the USA to inland "camps" in 1942. The relocation had substantial social impact: loss of homes, employment, community support and social ostracization, and isolation because of supposed radioactive contamination. As around Chernobyl there were a rash of suicides, alcoholism, and manifestations of PTSD. Stress-induced deaths in Fukushima were greater in number than from 2011 natural causes. Psychological consequences of low-dose radiation exposure may result in depression, post-traumatic stress disorder, chronic anxiety, sleep disturbance, severe headaches, alcoholism, intense anger, despair, and suicide. Societal risk was aggravated by radiophobia which is an emotional reaction that considers radiation as being unsafe no matter how low is the dose.

The Japanese government panicked and evacuated a hospital intensive care unit, taking them to a high school where many died. There were suicides among residents of nursing homes. Had the evacuees stayed home, their cumulative exposure over 4 years, in the limited and small areas of most intensely radioactive locations, would have been about 70 mGy—roughly comparable to receiving a high-resolution whole-body diagnostic scan each year. Most of the other evacuees would have received much less, about 4 mGy/y. Recently, Mohan Doss and two other researchers, Carol S. Marcus of Harbor-UCLA Medical Center in Los Angeles and Mark L. Miller of Sandia National Laboratories in Albuquerque, petitioned the Nuclear Regulatory Commission to revise its rules to avoid overreactions to what are nonexistent threats.

Nuclear Japan is a documentary film directed by Hiroyuki Kawai, a 70-year-old lawyer and filmmaker with a remarkable record of winning very high-profile cases, and elucidated the controversial issue of the nuclear power industry in Japan. The film takes you back to a few hours after the earthquake on March 11 to the shore of Namie Township, 7 km north of Fukushima No.1 nuclear power plant. The local fire brigade in Namie was desperately searching for missing persons swept away by the

disastrous tsunami. However, the next morning on March 12, the question starts to rise for the possible dissemination of radioactive material. The Japanese government consequently declares the area within 10 km from the Fukushima Daiichi Nuclear Power Plant as an evacuation zone. As a result, the fire brigade in Namie Township was forced to give up the search for tsunami victims. A month after the earthquake, the search for missing persons resumed. During the search, more than 180 bodies were found along the shore of Namie Township. If it weren't for the nuclear accident, most of those lives could have been saved [80].

Of the 17,000 killed in Japan by the tsunami and over a 1000 by the stress of emergency evacuation from Fukushima region, none has died from excess radiation exposure nor are expected from radiation-induced cancer or any other disease. Total voluntary and nonvoluntary relocations in Japan were initially estimated at 500,000. Why do much of the media misread the Fukushima meltdown and mention that no one has died of radiation exposure and no one is expected to die from it? Fukushima foolish evacuation did great harm to the elderly due to a nonexistent radiation threat emergency evacuation around the Fukushima Daiichi Nuclear Power Plants; this has been reported by the Japanese Recovery Agency.

The claims of radiation-induced disaster are mind-boggling. Dr. Gordon McDonald, executive director for research at the Koinonia Institute, claims that Japan's radiation is poisoning America. He believes that released Cs-137 from the Fukushima accident is having catastrophic effects on sea stars, killer whales, sockeye salmon, and other oceanic creatures. Even people who should know better have espoused outrageously inaccurate views. YouTube videos portray zombies following the Fukushima contamination. Yale University professor Charles Perrow warned that even humanity could be threatened for thousands of years by radioactivity from Japan. Canadian scientist, David Suzuki said: Fukushima is the most terrifying situation I can imagine. You have a government that is in total collusion with TEPCO, the energy company. They're lying through their teeth … It's bye-bye Japan and everybody on the west coast of North America should evacuate.

Several sailors serving on the aircraft carrier *Ronald Reagan* have sued the Japanese government for cancers and other diseases that have appeared among them since being exposed to radioactivity from the Fukushima nuclear accident. Radiophobia is good for lawyers. On February 10, 2014, several US naval personnel serving in the Navy off the coast of Fukushima, Japan, filed a billion dollar lawsuit against Tokyo Electric Power Company (TEPCO), claiming that they knew they were in danger of suffering from the toxic radiological exposure caused by the failure of the Fukushima Daiichi Nuclear Power Plant nuclear reactors. The exposures on the nuclear-powered aircraft carrier were a very small fraction of normal background exposures (<0.2 mGy).

In overreaction, the Japanese government is preparing to store the surface soil with a Cs-137 content of 100 Bq/kg, or about the radioactive content of the human body due to naturally occurring K-40 and C-14. The Fukushima cleanup costs by 2016 amounted to 42 billion dollars. Essentially, none of this herculean effort is needed. The radiotoxicity of naturally occurring U-238 and Th-232 and their daughter products Ra-226 and Po-210 is over 1000 times greater than for Cs-137.

Cesium-137 content found in tuna caught off the California coast was tenfold higher than found in tuna caught pre-Fukushima. The author of the "expose" failed to mention that even this "high" radioactivity is 30-fold lower than naturally occurring potassium-40 in tuna or that the radiation dose to tuna is also much higher for naturally occurring polonium-210 than for radio-cesium. On November 17, 2016, a United Nations panel found no evidence of increased cancer caused by the Fukushima reactor accident.

3.4 Statistical and Observational Malfeasance

We are suffering from a crisis of over-certainty, placing faith in meaningless statistical analyses and invalidated models, while packaging the old as new [81]. Bobby Scott (S.A.R.I.) writes of harm linked to biological-mechanisms-devoid, radiation-phobia-promoting LNT model whose use is currently justified based on seriously flawed and misleading epidemiological studies conducted by LNT profiteers that create phantom increased cancer risk for low radiation doses. Calabrese writes of abusive, falsified research used to promote the LNT [37, 82–84]. Cuttler writes of politicized science to promote the LNT [5]. "Science" today uses seriously flawed methodology that could have disastrous results [85].

Much of the scientific literature, perhaps half, may simply be untrue: Afflicted by studies with small sample sizes, tiny effects, invalid exploratory analyses, and flagrant conflicts of interest, together with an obsession for pursuing fashionable trends of dubious importance, science has taken a turn toward darkness. In their quest for telling a compelling story, scientists too often sculpt data to fit their preferred theory of the world. No one is incentivized to be right. Instead, scientists are incentivized to be productive and innovative. Our love of "significance" pollutes the literature with many a statistical fairy tale. We reject important confirmations. And individual scientists, including their most senior leaders, do little to alter a research culture that occasionally veers close to misconduct [16, 86].

> Torture numbers and they'll confess to anything (Mark Miller, S.A.R.I.).

Epidemiology studies can be a dream scenario for environmentalists, because they require no science (Robert Hargraves, S.A.R.I.). A case in point is the myriad numbers of positive and negative epidemiology studies published with respect to food consumption and cancer [87]. This demonstrates that for many epidemiology study designs, the claims in the conclusion may be as likely to be wrong as to be right. There is also a bias for publishing positive results, even though negative results are just as informative. This makes it more likely that incorrect results will end up being published, especially if they fit the researcher's preconceived notions. Preference may also be given to epidemiological studies with the highest quality of methodology and interpretation, regardless of the results and level of statistical manipulation [88, 89].

Most patients lack basic knowledge about the risks of radiation exposure from X-rays and other diagnostic imaging tests [90]. Physicians are told what to believe. Dr. Mack Easty, an emergency room physician, writes: You have my full sympathy. If you think it's tough and crazy being an emergency physician, you can only imagine how trying it is to convey accurate information to patients as a radiation oncologist. And the board exams remain rife with this overly simplified—or downright inaccurate—nonsense, or else we cannot get or maintain board certification [91].

The impact of the LNT assumption is enormous with respect to avoidance of radiation exposure to prevent and treat diseases, as well as in medical imaging technologies, costs of implementing radioprotection guidelines, radiological terrorism, and the development of improved nuclear reactors for electrical power generation. Falsely vilifying radiation hormesis, in the absence of actual confirmatory data and in apparent ignorance, or at least neglect of much contrary observational and experimental data, and particularly without regard to the risks of being wrong, can be deadly. Yet the statistical limitations and manipulations of many epidemiological studies by LNTers on radiation risk determination and the use of "tricks" to hide radiation hormesis and its benefits are legion in the radiation sciences community. Data should be transparent. The obsession for controlling variables when the results show no effect or radiation hormesis seems designed to impress rather than inform. As a result, nice linear placements seem too good to be honest (Wade Allison, S.A.R.I.).

I think it is vital for us all to realize that there is still a role that paradigm blindness played in the early promotion of LNT in the 1940s and 1950s. Trapping by false paradigms is firmly *entangled* with deliberate distortion in ways that each reinforces the other. They are often inseparable. And since paradigm blindness can catch every one of us if we are not vigilant and open to learning from others, this is at least as important an aspect of the history of LNT as the deliberate distortion and lying. In short, paradigm blindness and deliberate lying both played, and continue to play, a role in the original creation and the continued maintenance of LNT, and it is important for us not to omit the former while concentrating only on the latter. The lessons may be even more profound in the former aspect, as they apply to all of us. The LNT-promoting radiation epidemiologists are trapped in the LNT paradigm, even if there may be a tendency on the part of some, or all, of them to fudge a little as they fool themselves (Bill Sacks, S.A.R.I.).

Everything should concern biology, including epidemiology. That is, there are biological mechanisms proposed for the observed results. There is a great problem with false paradigms, unfounded assumptions, and specious statistics in radiation science. All epidemiological studies that attempt to show causal correlation between low-dose radiation and low-dose-rate radiation and cancer incidence and cancer mortality are based upon hidden circular reasoning that "removes" the impact of hormesis by using the LNT assumption while failing to account for other radiation exposures, such as natural background, medical and therapeutic exposures, etc. exposures [92]. The LNT authors routinely conflate dose with dose rate and regard cumulative dose at low-dose rates as a meaningful risk factor. Risk estimates from radiation dose delivered in small packets over time are not additive for individuals

or even large populations. It is like saying if you ingest 100 aspirin at one time, it is lethal to one person, or if 100 persons take one aspirin, it would also be lethal to one person (Bill Sacks, S.A.R.I.).

All epidemiological studies that purport to show a monotonic causal correlation between low-dose and low-dose-rate radiation and cancer (incidence and/or mortality) are based on hidden circular reasoning that erases any hormetic zone and/or threshold. Analyses usually fail to account for natural background and medical exposures. We also show that many of the LNT authors routinely conflate (fuse, combine into one entity) dose with dose rate, apparently without understanding the difference.

Does the EPA really protect the public or does it protect the established worldwide radioprotection empire that costs hundreds of billions of dollars a year [93]? It is difficult to understand why the unscientific behavior in applying the LNT is tolerated. The LNT was cleverly created to be untestable using creative statistical analyses. The LNT is un-confirmable due to statistical signal and noise issues. However, the LNTers cannot refute radiation hormesis despite an ever growing and enormous published literature that confirms the truth of hormesis. Radiation protection specialists demand statistical significance from studies associated with radiation hormesis but refrain from the same statistical fidelity from studies that promote the LNT. Epidemiologists are more likely to report, and journal editors are more likely to accept positive findings than null findings. Thus, information in the literature on populations exposed to low doses of radiation may be slanted in favor of those studies that show higher risks than the conventional estimates, since those that show estimates consistent with the accepted values would not be seen as significant [94].

Epidemiological studies utilizing the LNT hypothesis to develop a risk model commonly employ inappropriate methodology such as giving excess statistical weight to high-dose regions where most cancers occur while ignoring the absence of cancers in low-dose regions, utilization of dose lagging, shifting the dose–response curve to the left, making small doses appear more harmful than they are, attributing reduction of cancer incidence at low doses to the healthy worker effect (HWE), ignoring the presence of thresholds, averaging over wide dose intervals so that nonlinearity is removed, and ignoring radiation exposures from medical and other sources [46].

Radiation epidemiologists often play the trick of using the wrong null hypothesis, since the LNT model is assumed to be the correct null hypothesis. Then they force the intercept of the fitted linear relationship to be 1.0. I think what would be revealing is to allow both the intercept and slope to be free parameters with uncertainty assigned to RR = 1. In many cases, the intercept obtained would be significantly different from RR = 1, indicating that the LNT model is inconsistent with the epidemiology data [95]. Also, limiting the data analysis to only low radiation doses could lead to a slope of zero (threshold model) or a negative slope (hormetic response). By not considering nonlinear responses, they are able to play a "slope constraint trick" whereby negative slopes (hormetic responses) were not allowed to exceed (i.e., be more negative) than the value "−1/maximum dose." With a U- or

J-shaped response, slopes on descending arms of the dose–response curve can approach negative infinity.

Other tricks used by epidemiologists are the use of "wasted dose" by lagging. Throwing away radiation dose is common with many research groups. The thrown away dose may have stimulated the body's natural defenses [96]. A 5-year lag means that 5 years of radiation dose is thrown away. This is not consistent with the LNT assumption which assumes that each unit of dose is equally capable of causing cancer. Another trick is averaging overdose groupings and incorporation of low-dose data which may show hormesis in a high-dose group or in the control group. This can be an "effective" means of "hiding" hormesis and a threshold. A third trick is to constrain the slope of the dose–response curve to always be positive, which readily supports the LNT assumption. This causes any low-dose data showing hormesis to simply be ignored [6, 97, 98].

The problem of random error caused by sampling variability is more important for low-dose than for high-dose studies. The major determinant of error is sample size and its distribution across exposure and disease categories. This comparison emphasizes the importance of considering sampling variability in assessing the results of low-dose studies. In most studies of low-dose effects, the standard error is larger than that for high-dose studies, even if the overall sample sizes were the same.

In general, systematic biases are also relatively more important for the objectives of low-dose studies than they are for those of high-dose studies. Because of the existence of more and larger populations exposed to low doses, low-dose studies are often ecological (correlational) or case-control studies rather than cohort studies. The ecological and case-control studies are particularly prone to bias in their design. Selection bias is a major potential problem in case-control studies: The major concern is over the appropriateness of the control group. This is a particular problem for those studies in a medical setting.

Information bias leading to misclassification of either exposure or disease status, if random, leads to underestimated risk. Confounding may be more important for low-dose than for high-dose studies. All research like this is bedeviled by "confounders"—differences between populations that must be accounted for. Some are fairly easy (older people and smokers naturally get more cancer), but there is always some statistical wiggle room. As with so many issues, what should be a scientific argument becomes rhetorical, with opposing interest groups looking at the data with just the right squint to resolve it according to their needs. They give no confidence intervals to show statistical significance. And this whole scare seems to be the result of data mining—if one looks hard enough for any unanticipated outcome at all, one is bound to find one or two statistical significance; this is not necessarily clinically significant. But the real question is whether such outlying outcomes are reproducible. This kind of research is truly junk science—the goal of which is to get funding to stay alive in a research-dependent job or to reinforce one's past contentions in which a reputation is invested, and not to discover actual reality (Bill Sacks, S.A.R.I.).

The dose and dose rate effectiveness factor (DDREF) was proposed by BEIR VII only for use with the LNT assumption. DDREF essentially reduces the slope of the

LNT function (for high-dose rate) to supposedly account for dose rate effects. What is generally not recognized is that application of the DDREF essentially removes the ability to demonstrate a threshold-type or hormetic-type response so that one is still left with the notion that any radiation dose no matter how small could cause cancer. The DDREF falsely ensures that the dose response at low doses will be linear with a positive slope and is therefore scientifically meaningless. With the LNT assumption, the quantitative analyses of dose responses for carcinogenesis use a DDREF of about 2 to extrapolate to low doses from effects induced by high doses.

The HWE is a "catch-all" term that is used irrespective of the extent or degree of benefit obtained within the workplace, to avoid invoking the other obvious scientific conclusion (i.e., there is a benefit from low-level radiation) [99]. The HWE is postulated by LNT proponents to explain undesirable epidemiological results, such as reduction in all-cause mortality and all-cause cancer in nuclear workers receiving low doses of radiation during their employment. LNTers do at least admit that these "benefits" are abundant, frequent, and real. The HWE assumption is that nuclear workers had to be healthier even when hired. I can tell you from personal experience as a Hanford worker (1966–1992) that this is not true. They might say that nuclear workers received better medical examinations [6]. Those that I received at Hanford were superficial.

HWE has been attributed to preemployment medical screening examinations and annual physicals. Medical screening prior to employment does not remove those who might develop cancer decades later. That does not stop proponents of the HWE from suggesting that the preemployment physical must unwittingly identify distant cancer victims [100]. No reduction in cancer mortality was found in those who received annual medical physicals compared to those who did not [101–103]. Thus, routine preemployment medical examinations do not eliminate cancer-susceptible individuals. Routine preemployment medical examinations did not eliminate cancer-susceptible IARC workers since no genetic tests were carried out [104]. In 2011, the rate of thyroid cancer diagnosis in South Korea was 15 times that observed in 1993. Yet thyroid cancer mortality was unchanged—the cause was overdiagnosis due to widespread thyroid cancer screening. Screening identifies thyroid abnormalities that do not need to be treated [105].

One must pose the difficult question of whether there is any serious evaluation of HWE or whether the HWE is in effect a "zombie science" not supported by medical evidence but used dogmatically to "eliminate" radiation hormesis as an explanation for decreased all-cause mortality and all cancer mortality in epidemiology studies [106]. HWE is of little or no consequence in interpreting data on cancer mortality, and the healthy worker effect is relatively weak [107].

We are bombarded with radiation from space, rocks, food, and water. Our Creator has provided us with ionizing radiation to make us healthy [108]. The same is true for nuclear workers. The average mortality of nuclear workers was substantially lower than in control groups; there was a lower mortality in nuclear workers who received lifetime doses of <100 mGy [48, 109]. SMR for cancer is lower in the IARC cohort of nuclear workers and should be considered as a hormetic effect, rather than an HWE as claimed by the IARC [110].

Nuclear workers employed in 154 facilities in 15 countries were examined. The annual radiation doses received by nuclear workers are small, with the maximum annual dose being 5.3 mGy and the mean lifetime working dose being 20 mGy [6, 111]. The paper just before Cardis et al. in the same volume and number of the *Radiation Research* journal contained the "raw" un-manipulated data for all-cause mortality and all-cause cancer. The mean and range for SMRs for all 15 countries were all-cause mortality 0.62 and all cancer mortality 0.74 [112]. Cardis did not assess the confounders of smoking or other occupational exposures in her analysis [111]. Cardis explained away the large decrease in mortality and cancer in the preceding paper by Vrijheid [112] as the healthy worker effect. Fornalski and Dobrzynski published an analysis for the study by Cardis, showing why the healthy worker effect cannot explain the reduced mortalities in nuclear workers [110]. A further discussion of the healthy worker effect was done by Sanders [6].

SMRs for cancer in two Canadian cohorts of 45,468 radiation-exposed workers [113]and 206,620 dental, medical, industrial, and nuclear power workers [114], as compared to the general Canadian population, and in comparison with SMRs for cancer for badged male workers at INEEL with zero dose or positive dose [115], all showed clear evidence of radiation hormesis. UK radiologists (1897–1920) had a noncancer SMR of 0.86 compared to all other male physicians. Noncancer mortality makes up ~80% of all mortality. Post-1955 radiologists had an all-cause SMR of 0.68 compared to non-radiologist, male physicians [67]. Cancer incidence was determined in 7417 patients with hyperthyroidism treated with ^{131}I in the UK. Cancer incidence was reduced in an "unhealthy" population. The whole-body dose from ^{131}I was 280 mGy [116].

SMR values for all-cause mortality and all-malignant neoplasms mortality were significantly less in the US shipyard workers, who had received cumulative doses that ranged from 5 to 400 mGy than for nonnuclear workers who worked at the same facility and received the same medical care and screening [117, 118]. The 28,000 nuclear shipyard workers had a death rate from all causes that was 24% lower than did the 32,000 age-matched and job-matched unexposed shipyard workers. The Department of Energy news release about the study did not mention that the deaths from all causes of the nuclear workers were 16 standard deviations lower than for the controls [119–121] (Fig. 3.6).

A comprehensive study of nuclear workers at the Idaho National Engineering and Environmental Laboratory (INEEL), previously known as the Idaho National Laboratory (INL), was published not in the open peer-reviewed literature but as an "in-house" DOE/NIOSH publication. The study compared the SMR for all-cause mortality and all cancer mortality in badged workers (those who had received a measured radiation dose of ionizing radiation from the site's facilities) to those who were also badged and worked at the same facility but received zero dose. All cohorts received the same medical care [115].

All-cause mortality and all cancer mortality were significantly less in badged workers with a positive dose than in badged workers with zero dose. INEEL badged workers with a positive dose had significantly less cirrhosis of the liver even though they experienced a significantly higher frequency of alcoholism. This indicates that

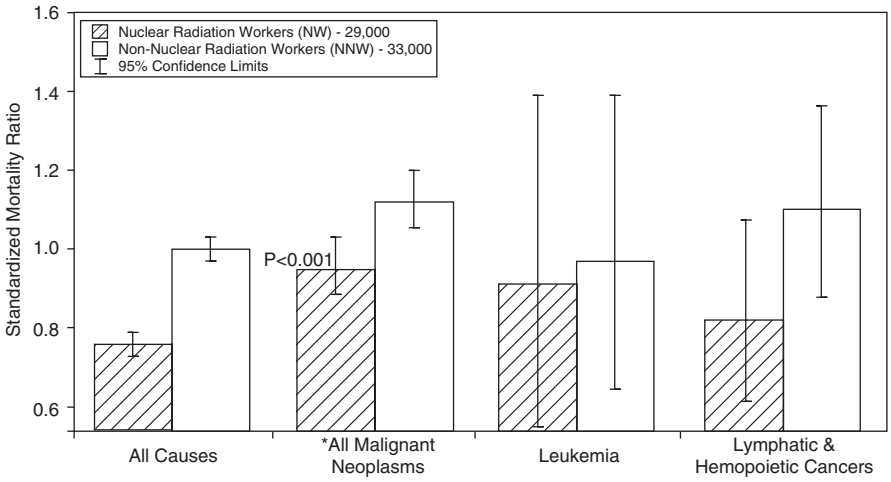

Fig. 3.6 SMR ratios for selected causes of death among nuclear and nonnuclear shipyard workers who received the same level of medical care [117, 118]

low-dose radiation protected the liver from damage due to alcohol consumption. Noncancer cardiovascular, respiratory, and GI diseases along with cancer of the respiratory and GI tract were all significantly less in badged workers with a positive dose than in badged workers with zero dose. The one exception is for myeloma which was significantly greater in workers with a positive dose. Though myeloma cases are few in number, this association has also been seen in other studies of nuclear workers, such as the Hanford site in WA. The epidemiological study design and subsequent results eliminated the so-called healthy worker effect as being the cause for significantly different observations among the two badged groups, since all workers received the same medical care. The obvious conclusion is that radiation hormesis accounted for these significant differences in health of INEEL workers. The failure to publish this work, along with failure to publish in a timely manner the nuclear shipyard worker study and radium dial painter study because of potential "political" implications, is a sad tale of academic intimidation and data suppression (Table 3.3).

Prior to the late 1990s, EPA's cancer risk assessment guidelines (CRAGs) required sufficient evidence of a cause-and-effect relationship in humans before a substance could be classified as a "known human carcinogen." However, by the late 1990s, EPA decided to classify substances as known human carcinogens without sufficient epidemiological evidence to support such a decision. As a result, EPA invented bogus human carcinogens such as dioxin, formaldehyde, and trichloroethylene. Using similar LNT methodology, it was relatively easy for the EPA to classify radon and low-dose ionizing radiations as human carcinogens.

It is probably only a matter of time before we witness the next event in which large numbers of people are exposed to ionizing radiation as a different threat has come to fore from intentional releases of radioactivity resulting in low-dose

Table 3.3 SMRs for all-cause mortality in males badged with zero dose or positive dose at INEEL [*$p < 0.05$] [115]

Cause of death	SMR badged-zero dose	SMR badged-positive dose	Ratio: positive dose/zero dose
All cause	0.96	0.86*	0.90
Diabetes mellitus	1.28	1.09	0.85
Alcoholism	**0.20**	**0.70***	**3.50**
Cirrhosis of the liver	**0.85**	**0.59***	**0.69**
Diseases of the CNS	1.32	0.92	0.70
Diseases of the heart	0.87	0.83*	0.95
Diseases of the circulatory system	0.98	0.81*	0.83
Diseases of the respiratory system	1.05	0.81*	0.77
Diseases of the GI system	0.95	0.69*	0.73
Diseases of the genitourinary system	0.85	0.79	0.93
Diseases of the blood-forming organs	0.69	0.65	0.94
All cancer	1.14	1.01*	0.89

exposure to a large population [122]. The only method for calculating the long-term so-called "stochastic" adverse health consequences of a radiation exposure is by using the LNT assumption. A stochastic system is one that is unpredictable due to the influence of a random variable. The system is randomly determined but maybe statistically analyzed but not precisely predicted. The process must be analyzed using probability theory. Epidemiologists speak of "stochastic deaths," those they predict will happen in the future because of radiation or some other risk. With no names attached to the numbers, they remain an abstraction. The millions of lives benefiting by low-dose radiation are not an abstraction but real.

The LNT assumption is widely accepted by the general public. However, the scientific validity of this model has never been proven and has been seriously questioned and debated for many decades. The absence of scientific consensus has been officially acknowledged, including by the US Congress Office of Technology Assessment [123]. Numerous studies (experimental, epidemiological, and ecological) have shown that low doses of ionizing radiation are beneficial to health [6]. The LNT assumption was adopted by the NAS in 1956 for the political purpose of creating radiophobia to impede the continuing development and testing of nuclear weapons. The LNT assumption was used to predict the risk of cancer for the very low doses associated with test fallout, even though no one had demonstrated an increased risk in epidemiological studies [124]. The NAS has misled the American public about cancer risk from ionizing radiation ever since. Truthful evidence needs to reach the public writing in clear plain language in order to lessen FUD (fear, uncertainty, doubt) about radiation risks. Science often does not drive regulations or funding decisions. Public opinion developed and manipulated by politicians can be

much more important. Few care that health risks are overestimated. They only care if risk is underestimated (Tony Brooks, S.A.R.I.).

> What might be the cost reduction and health benefit if people were allowed exposures up to 100 mGy/year?

There are serious ethical issues associated with the use of the LNT assumption. They are associated with social and medical destruction in Chernobyl and Fukushima, self-interest, economic incentives, human biases, and political pressures. Proponents claim "to be on the safe side" regarding nuclear hazards regardless of the economic or human costs. At stake are the hundreds of billions of dollars spent for "safety" around nuclear power plants and for waste storage. The extremely harmful episodes of public panic that accompany rare radiation release events such as Fukushima and Chernobyl make the projected costs for next-generation nuclear power plants to be enormous.

The ICRP 2013 Symposium in Abu Dhabi did not make any major changes in radiological protection regulations from those given in 2007. The 2007 regulations were similar to those made in 1990 by the ICRP. The ridiculously low-dose regulations do nothing to protect the public. According to the ICRP, public exposure from planned situations will not exceed 0.3 mGy per year from waste management operations, and no more than 0.1 mGy in a year for the public exposed to such operations. The occupational exposure dose limit is 20 mGy per year. The general public exposure is not more than 1 mGy per year. Below 100 mGy per year, however, no increased cancer incidence has been detected, either because it doesn't exist or because the numbers are so low that any signal gets lost in the epidemiological noise [125].

The ICRP wishes to address limitations of epidemiological studies (particularly when they appear to demonstrate radiation hormesis). The ICRP documents are of great length and even greater verbosity making them virtually useless and almost incomprehensible for informing the public. The ICRP and their adherents, such as BEIR VII, use misapplication of atomic bomb survivor Life Span Study (LSS) data like a mantra. Their analyses ignore low-dose exposures up to 100–200 mGy, to which nearly half of the survivor population received. BEIR VII was supposed to be devoted to doses <100 mGy; yet 90% of their relevant reports are devoted to much higher-dose studies.

The ICRP uses the LNT and LSS data to generate scary but false publications affecting public opinion. The current ICRP radiation dose restrictions are absurd. If the "no-threshold" part of the LNT assumption is taken seriously, and an exposed population experiences as much as a 0.5% increase in cancer risk, it simply cannot be detected. The LNT assumption operates on the unprovable assumption that the cancer deaths exist, even if the increase is too small to detect, and that therefore "no level of radiation is safe," and every extra mGy is a public health hazard. Once the LNT is explicitly discarded, we can move on to regulations that reflect only discernible, measurable medical effects. Those living in Mississippi receive 2 mGy per

year from natural radiation, while those living in Colorado receive 7 mGy per year. Utilizing the ICRP's train of thought, it would be dangerous to move from Mississippi to Colorado. Never mind that epidemiological studies clearly show that the cancer rate mortality in Colorado is 30% less than in Mississippi after correcting for confounding factors. LNTers claim they err on the safe side. They stubbornly continue to claim a relationship with any dose of radiation and potential harm. This is not just a benign difference in scientific opinion, but the radiophobia that results from application of the LNT assumption is a national security and health problem. The LNT assumption is extremely simple to teach as a fact to the public who mostly remain ignorant of the benefits of low-dose radiation.

LNT religious culture relies on emotional arguments propped up by the precautionary principle of "better to be safe than sorry." This is a powerful argument that has successfully been used by epidemiologists to shift the burden of proof away from proving an adverse effect to proving that radiation is safe. The attitude assumes one is guilty until proven innocent (John Cardarelli, S.A.R.I.). The National Nuclear Security Administration (NNSA) has been formed to help prevent unnecessary radiophobia-related deaths, morbidity, and injuries associated with nuclear (radiological) emergencies by countering phobia publications that use misinformation to spread alarmist views. The news media and other media forms are most guilty of promulgating radiophobia. I submitted letters to our local newspaper in Colorado (Loveland Reporter-Herald) concerning radon and radiation hormesis. Not being politically correct with respect to the LNT, they were not published.

Political correctness prevents advancement of science.

ICRP Task Group 94, entitled *Ethics of Radiological Protection*, was empowered to present ethical foundations for radiological protection. Task Group 94 was to provide a basis for communication on radiation risk and its perceptions. Perception of radiological risk is different for the general population. The mass media does not use the language of technical experts in addressing radiological risk. The communication gap between experts and the general public presents a great challenge [126]. The ICRP was to be benevolent (do more good than harm), prudent (keep exposure As Low As Reasonably Allowable—ALARA), and just (reduce inequities among nations and peoples), to provide dignity (involve the stakeholders), and to integrate reasonableness and tolerance. ICRP Publication 60 examines the tolerability of the current risk model (i.e., the LNT assumption) with respect to differences between unacceptable, tolerable, and acceptable risks of ionizing radiation.

A recent workshop in Daejeon, South Korea, revisited the issue of tolerability of radiation risk in relation to varying types of exposure situations. The workshop claimed to follow scientific and societal evolutions, to clarify ethical and societal values underlying the system of radiological protection and promised to maintain a separate perspective from regulatory requirements. The workshop expressed attitudes toward risks and exposure situations with terms like quietude (have

confidence in the arrangements put in place and we trust the institutions and people responsible for radiation protection), vigilance (take action to try and reduce risk in order to reassure ourselves that everything has been done), and reaction (proper responses are carried out when facing an imminent danger to protect ourselves). The principles of justification, optimization of protection, and of application of dose limits were to be explained directly in terms of ethical principles (precaution, equity, fairness, or justice). Hence, communications may be more effective when referring to ethical principles rather than to actual facts of radiological protection.

The three pillars for the Korean workshop were science, values, and experience. The science overwhelmingly tells us that low-dose ionizing radiation exhibits a threshold and is good for us. The values should express how much more healthy we would be if exposed to low-dose radiation and how much less is the cost to apply the concept of radiation hormesis. The present LNT-based regulations impose excessive costs to the society, effectively leading to loss, rather than saving, of life. According to researchers from the Harvard T.H. Chan School of Public Health, spending $100,000,000 per year on controlling radiation emissions might save one life-year per year, if the LNT model were valid, while life-saving medical program median cost is $19,000 per life-year saved. Another study concluded that costs of radiation protection are about 5000 times higher than the cost of protection of workers from all other and much more probable events [127]. Finally, individual experience and experience of hundreds of researchers show that the ICRP's promotion of the LNT assumption in determining health risk is completely wrong (Table 3.4).

There have been four fatal space flights out of a total of 126 launches or 3%. That should be the main concern about any space flight. However, radiation exposure accumulated through the entire flight and the predicted resultant small cancer risk using the LNT assumption take overriding emphasis to the point of using precious cargo weight delivery to reduce the phantom risk [128]. The predicted, mission, radiation dose accumulated on the Mar's surface is estimated at 75–150 mGy, well within the hormesis zone.

Table 3.4 Accident mortality in the workplace for 2012 from Occupational Safety and Health Administration (OSHA)

Industry	Number of fatalities
Total	4383
Trade, transportation	1152
Construction	775
Agriculture, mining	475
Manufacturing	314
Education, health services	139
Financial services	81
Radiological services	**0**
Other (mostly private industry)	1447

Data taken from the US Department of Labor, Bureau of Labor Statistics. We all die, many of us from cancer. Nobody seems to have died in 2012 who worked in the radiological services industry

There are additional aspects of human cost because of the LNT model and the associated radiophobia—an irrational fear of radiation hazards: Predictions of hypothetical cancer incidence and deaths cause some patients and parents to refuse medical imaging procedures, placing them at substantial risk by not receiving the clinical benefits of the prescribed procedures; present policy significantly dissuades the study of low-dose radiation therapies for beneficial effects in medicine, whereas animal studies have shown potential for treatment of diseases for which presently no treatments are available, such as treatment of Alzheimer's disease using low-dose radiation. Finally, the LNT assumption and its associated radiophobia motivate terrorists to use radioactive "dirty" weapons as a means of terror. Claims that the LNT model underestimates risks from low-level radiation by orders of magnitude have been vigorously expounded elsewhere and used as the basis for attacks on the nuclear industry." There is no credible, consistent evidence to support these claims" [129].

Rockwell said it concisely and with boldness when it came to the scandal of the LNT:

> It's inexcusable that with hundreds of millions of cases of chronic exposure from medical therapy, occupational exposure, high-background locations, and accidental mass exposures in Taiwan and Russia, we still look to poorly known exposures with dose rates many orders of magnitude higher, whose situation was complicated by neutrons and war conditions totally different from situations of interest … Such repeated practice in the radiation protection field raises the question of whether it is time for one or more formal charges of scientific misconduct … It is a scientific issue, tried and judged by scientists in the defendants institution. The key issues to be proved are fabrication or distortion of data and selection and omission of data for the purpose of supporting a preferred conclusion-exactly the concerns raised (but not dealt with) in radiation protection [130].

3.5 Muller's Deception and Russell's Mistake

Fraud is found in research everywhere. Bernard Kettlewell (1907–1979) claimed to show that dark-colored moths had evolved in soot-black areas of England. His published photographs of moths perching on tree trunks turned out to be dead glued ones. His case for natural selection was fiction. I learned the mantra "ontogeny recapitulates phylogeny" in my freshman biology class at the College of William and Mary (1956). This is a fancy way of saying that embryos repeat their evolutionary history by passing through to their adult forms. This idea was presented from research studies of Ernest Haeckel (1834–1919). Haeckel's peers claimed similarities in embryos were faked, and drawings and woodcuts were doctored by Haeckel. His colleagues knew he was a fraud. Yet I still had to learn it in a freshman biology class in 1956. The evolutionary deception continues today with imaginary sprouting of new stars and galaxies, retrodictions of black energy and black matter which cannot be seen or measured, "hopeful" appearance of incredibly complex life by random chance, and the total inability to find one transitional fossil, a problem that even bothered Darwin.

Science should be in the business of making observations of nature with machines and calculations, and doing experiments to test ideas and interpret the results,

hopefully without prejudice. Scientists, unfortunately, are not always as objective as one would like. Many find it difficult to completely detach themselves from the hypotheses that they espouse. They find pride in authorship and an intense personal loyalty to the ideas they have developed. As a result, there can be subjectivity, prejudice, and ignoring of opposing data. This may lead to the need to "fudge" their interpretations in favor of their preconceived hypothesis. This is *misinformation* when the scientist knows the data is correct or incorrect, yet spins the data otherwise. It is *dishonesty* when the scientist knows the data is correct yet ignores it. It is *fraud* when the scientist clearly knows the data is incorrect yet posits it to be correct.

Herman J Muller (1890–1967) was born in a working class of German-Irish home in Harlem and attended public schools in Brooklyn, NY. Muller was a socialist and eugenicist who believed in removing all class barriers and carrying out studies in human breeding to develop a "superior" class of humans. Muller attempted suicide in 1932 from an overdose of sleeping pills. Later in the 1930s, he worked in Nazi Germany at the Kaiser Wilhelm Institute and then jumped to Stalinist Russia where he attempted to convince Stalin to produce an army of supermen to conquer capitalism [131]. Eugene Fisher, anthropology professor at Kaiser Wilhelm Institute believed at that time that selected" young women should be forcibly sterilized after receiving a simple diagnostic X-ray examination. The essence of evolution is natural selection. The essence of eugenics is the replacement of "natural" selection by conscious, premeditated, or artificial selection in the hope of speeding up the evolution of "desirable" characteristics and the elimination of undesirable ones [132]. That is precisely what Nazi Germany attempted to accomplish in promoting the "superiority" of the Aryan race. Eugenicists wanted to improve the human race (gene pool) by social and political interventions and tinkering.

Ninety years of research with mutations in millions of irradiated fruit flies shows that all you get are odd-looking flies. None of the mutations are beneficial nor do any add new genetic information, just genetic mistakes. Herman Muller received a Nobel Prize in 1946 for showing that mutations in fruit flies increased in direct proportion to the dose of X-rays. In the process, Muller ignored and withheld data that showed he was wrong. The Rockefeller Foundation sponsored Herman Muller fly studies and, in 1956, awarded grants amounting to $991,000 for genetic studies, which included Muller.

Muller was also paranoid in believing that other scientists wanted to steal his ideas [131]. His actions were incredibly important because the world came to believe that if mutagenesis from ionizing radiation is true for fruit flies, then it is also true for cancer in humans. In his Nobel Prize speech, Muller said: that there is no escape from the conclusion that there is no threshold. This was a statement that he knew or should have known was not true.

Edward Calabrese recently exposed Hermann Muller's scientific dishonesty explaining how the NAS had misled the world on cancer risk assessment. Muller in published studies carried out during 1927 claimed to have shown a linear increase in mutations in irradiated fruit flies (*Drosophila*) with increasing dose of X-rays [133]. The mutation assay used was the sex-linked recessive lethal test in male flies. The radiation doses were high. Muller in his acceptance lecture for the Noble Prize

on December 12, 1946 made deceptive statements in an attempt to promote the acceptance of the LNT assumption for risk assessment from ionizing radiation. Muller also wanted to exaggerate the health risk from low-level radiation because he was opposed to aboveground nuclear weapon testing.

Questionable actions by his colleague, Curt Stern, a well-known geneticist of that time, influenced radiation protection policy and caused the policy members on the NAS and Biological Effects of Atomic Radiation (BEAR) Committee to adopt the LNT assumption in 1956, switching from a previous position of a threshold [134]. Findings of Caspari and Stern (1948) [135] demonstrated a doserate response in fruit flies. These findings along with results of Spencer and Stern (1948) [136] demonstrated both a threshold and dose rate effect. In his 1946 Nobel lecture, Muller said that the mutation rate was linear function of dose down to zero with no threshold; his test doses went from 1000 to 4000 R. Curt Stern (1948–1949) found doses <50 R or about 500 mGy did not increase the mutation rate when given continuously over a 21-day period; the results were dose rate dependent [135, 137]. Interestingly, Muller did not find linearity in mutation frequency following exposure to UV radiation in fruit flies [138].

> In a young adult, living in a low LET background of 0.1 cGy/y, the antimutagenic system of prevention, repair, and removal of DNA alterations reduces about one million DNA alterations/cell/d to about one mutation/cell/d. DNA alterations from background radiation produce about one additional mutation per 10 million cells/d [139].

Muller knew prior to his Noble lecture that data by Caspari and Stern [135] and by Uphoff and Stern [137] had demonstrated a threshold of about 50 R for mutations in fruit flies that strongly challenged the LNT [93]. Data from Caspari and Stern [135] and repeated in a note published in Science by Uphoff and Stern [137] shows a threshold for sex-linked fruit fly mutations following 50 R when the dose was given continuously for 21 days. For one group of flies, the dose rate was 13,000 lower than the high acute doses used by Muller and 80 times lower than the highest dose used by Muller. Yet Muller proudly proclaimed that one could no longer consider a threshold. Muller claimed linearity over a huge dose range. He also claimed that dose rate had no impact on his results. Muller had manipulated the data on fruit fly mutations to protect his prize and reputation and promote his ideological goal of linearity [140]. Muller in a 1930 article noted that background doses of radiation are not responsible for natural (spontaneous) mutation rates. He also failed to report that natural background levels ranged several hundredfold.

It is still the case that Muller and Stern published data that disproved their LNT contention with regard to dose rate. That's just too simple, clean, and one-sided an explanation for Muller's role, but when it rises to the level of manipulation of panels of scientists and direct payment for advocacy, paradigm becomes less contributory and deliberate lying becomes more so—even to the point of eclipsing the former almost entirely (Bill Sacks, S.A.R.I.).

More recent studies have shown that there was no effect on lifespan or on permanent gene expression in fruit flies at doses less than 10,000 r [141]. Irradiation of fruit fly spermatozoa with only 200 mGy significantly reduced mutation frequency below that observed in sham-exposed control flies [142]. Ogura later showed that the mutation frequency for sex-linked recessive lethal mutations in fruit flies was significantly reduced by a dose of only 500 μGy [143]. The threshold for fruit fly mutations was found to be 80 mGy by Shiomi [144], 800 mGy by Koana, [142] and >1000 mGy by Ogura [143]. Muller had argued that background radiation had a negligible impact on spontaneous mutations. Calabrese believed that the deliberations of the Genetics Panel of the NAS should be charged with scientific misconduct and deliberate misrepresentation of the scientific record in order to promote their ideological agenda [37]. This has led to consistently incorrect conclusions [145] (Fig. 3.7).

Numerous studies on irradiated populations of insects in the 1920s had shown beneficial effects. Flour beetles, mosquitos, crickets, codling moth, tsetse fly, housefly, and fruit flies all experienced enhanced lifespans of from 20 to 60% following radiation exposures of 1–40 kR. Exposure at egg and larval stages increased

Fig. 3.7 Hermann Muller (1890–1967)

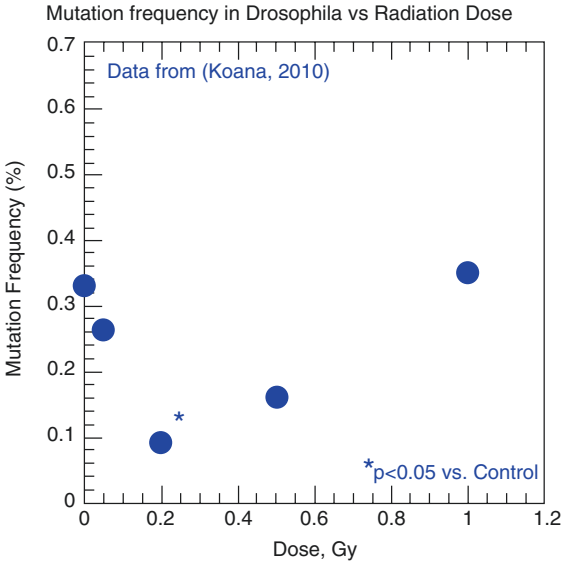

Fig. 3.8 Evidence for radiation hormesis in X-irradiated fruit flies (With kind permission of Mohan Doss) [142]

longevity in insects at much lower doses, typically from 10 to 100 R. More recent studies in fruit flies have shown that X- and γ-ray doses as low as 200 mGy to eggs significantly increased adult fly longevity, whether given as an acute or chronic dose (Fig. 3.8).

In 1996, the Department of Energy investigated allegations about the now-accepted fact that the Oak Ridge National Laboratory (ORNL) mega-mouse studies presented false data on genetic effects, starting in 1951. These mouse studies, along with Muller's fruit fly studies, were emphasized as proof of genetic effects in mammals when I was a PhD student at the University of Rochester from 1963 to 1966. ORNL underreported the number of mutations in the control animals. WL Russell was a member of the 1972 NAS, Biological Effects of Ionizing Radiation (BEIR I) Committee, and Genetics Panel which used his mega-mouse dose rate data to support the adoption of the LNT for genetic and cancer risk assessment [146].

The assumption that all mutational damage is cumulative and irreversible and that dose rate is linear at low doses was promoted by Muller. Muller provided incorrect information to ICRP (1964) in an attempt to prevent the dose rate concept offered by Russell from being adopted into risk assessment [134, 147]. Russell admitted making an error in counting the control mutation rate when he was in his 80s [148]. There was no admission of fraud, but Russell did participate in a paper that quietly revealed the error (Rod Adams, S.A.R.I.). Dr. Paul Selby was Russell's only PhD student who later became a geneticist at ORNL. Selby discovered that lower-dose rates reduced mutation rates by factors of 3 and 20 in germ cells of male and female mice, respectively. This made genetic damage highly dependent upon dose rate, while earlier results assumed that it was dependent only upon total dose. A J-curve-hormesis model would have been a better fit for Russell's data based on

Selby's findings [149, 150]. The overall weight of scientific evidence supported Selby's correction factor for underreporting of mutations in Russell's control mice. Selby alleged that the misrepresentations of the data seemed to have been intentional [84]. Mice given γ-rays for 90 days (0.0014 Gy/h) did not show an increase in mutation frequency [151]. Doug Boreham also carried out a mutation study in mice given a cumulative 12 cGy in 75 weeks and failed to find an increase in mutations [152]. International programs have now abandoned the fruit fly and mouse data and are assessing the potential effects of radiation for genetic diseases using only human data (Fig. 3.9).

Four decades of genetic research on Japanese A-bomb survivors have failed to show any heritable effect in offspring [153]. Cancer risk was reduced by 27–39%

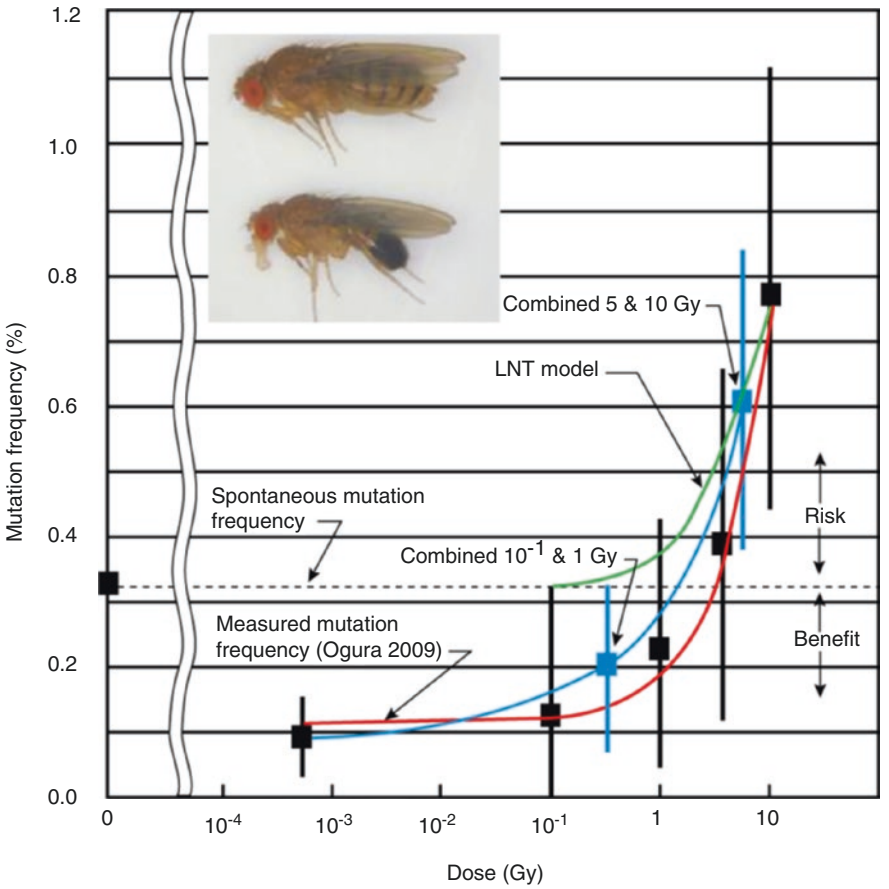

Fig. 3.9 Mutation frequency as a function of radiation dose. Error bars are two standard deviations around the mean mutation frequency. The data points at 0.3 Gy and at 7 Gy were obtained by combining data from Ogura [143] at 10 and 1 Gy and at 5 and 10 Gy, respectively. Note that mean mutation frequencies are below the spontaneous (background) level (0.32%) where the radiation dose is below 1 Gy (With kind permission of Jerry Cuttler) [125]

in downwind inhabitants of a 1957 Mayak nuclear waste tank and was not increased among Techa River residents living nearby a highly contaminated river [6, 154]. Genetic effects have not been observed in residents near the Techa River, downwind from the waste tank explosion at Kyshtym or in offspring of nuclear workers at Mayak. There have been no reports of increased mutations or birth defects in the millions of people living in Ukraine or Belarus that were exposed to fallout from Chernobyl [6]. In spite of the lack of any human data, UNSCEAR in 2001 gave a doubling dose for genetic effects in humans of 3.4–4.5 Gy. BEIR VII even lowered the doubling dose to 1.0 Gy in spite of a lack of any human confirmation data. The early epidemiological studies of populations associated with Chernobyl fallout, cleanup workers, Mayak nuclear workers, downwinders from the USSR nuclear tank explosion in 1957, and Techa River inhabitants showed abundant evidence of thresholds and radiation hormesis [6]. Subsequent later studies used ERR methodology that force fitted implementation of the LNT and typically failed to provide cancer risk estimates for each radiation dose category in the publications. Follow the money! Continued research grants were given only for those who could show increased risk and not for those who showed a threshold or hormesis.

3.6 S.A.R.I.

S.A.R.I. (Scientists for Accurate Radiation Information) and other organizations monitor for misinformation and communicate correct responses. Moral-ethical issues of the LNT and ALARA have been previously addressed by Taylor [155], Jaworowski [17], Calabrese [82], Socol, [156] and Cuttler [32]. The Society for Radiation Information (SRI) was recently founded in Japan along the lines of S.A.R.I. A large workforce and bureaucracy are needed to maintain ALARA. ALARA is like a cancer grabbing resources and manpower in an economy short of jobs (Wade Allison, S.A.R.I.). There has been a several decade of long struggle to get the nuclear power industry and the radiation health physics profession to fight against the LNT and its progeny, ALARA, which are huge job generators and money makers for companies in “cost-plus” enterprises like construction, component manufacturing, and services for government or regulated monopoly customers. They know that our assertions of cost reductions by recognizing a threshold dose model would come at their expense. One man’s cost is another man’s revenue (Rod Adams, S.A.R.I.). In other words, some don’t want to kill the goose that lays the golden eggs—even if killing the goose is the right thing to do. This whole issue is “rigged” by the industries that support much of the nuclear front-end, plant, and back-end operations and just try to get committed support of these industries for killing the LNT. Yes, lip service can be gained easily, but talk is cheap and ALARA-related systems and services are not (Charles Pennington, S.A.R.I.). Last time that there was a problem like this, it was how to stop the arms race. How was that achieved? By making everybody frightened by grossly exaggerating the dangers of radiation—and it worked. Then we were left

with a reducing weapon stockpile and now have ALARA/LNT instead today (Wade Allison, S.A.R.I.).

> More scientists involved with radiation protection today claim agnosticism about the LNT. They say that we just do not know if the LNT is true or not, but, to be safe, we must use the LNT.

In the absence of the LNT model, practice of radiation safety would be trivial: Avoid high radiation doses. There would be no need for most of the work presently done by health physicists or medical physicists relating to low radiation doses. Such work would only be needed when dealing with potentially high doses. Since excellence in the practice of radiation safety would be accomplished easily and trivially, HPS would have very little to do. If HPS wants to exist in the post-LNT era, it has to change its mission. Since the LNT model is not valid (and this was known a long time ago), work done based on the LNT model did not result in "excellence in the science and practice of radiation safety" but quite the contrary (Mohan Doss, S.A.R.I.).

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Thresholds

4

The greatest tragedy of science is the slaying of a beautiful hypothesis by an ugly fact (T.H. Huxley).

Everything has a toxic threshold: water, salt, oxygen, cyanide, lead, and ionizing radiation. We have known this for centuries. It is patently ridiculous to say radiation has no threshold. It is amazing that anyone would think otherwise. The science is overwhelming. According to Caroline Hadley, what doesn't kill you makes you stronger [1]. Hadley may have been thinking of the words of the German philosopher Friedrich Nietzsche (1844–1900). This is an adaptation of the idea that a little stress makes you stronger, while a large amount can kill you. The word hormesis is derived from the Greek word, *hormaein*, which means "to excite." The first appearance of the word "hormesis" can be traced back to 1941 where it appeared in the undergraduate thesis of Chester Southam, who reported that low doses of toxic red cedar tree extract enhanced the growth of fungi, while high doses inhibited growth [2]. Southam was not the first to note this dichotomy of dose. Hugo Schulz demonstrated that low doses of chemical disinfectants stimulated yeast growth, while high doses deterred growth. The LNT model was conceived by Lewis in1957 [3]. The BEAR IV Committee had assumed in 1956 that there was a threshold for radiation carcinogenesis [4]; Herman Muller was a key member of the committee.

Low-dose level excitation can be accomplished over a wide range of wonderful things. A Catholic and pragmatic application of hormesis concerns the use of alcoholic drinks. Low doses of ethanol protect us from cardiovascular disease, while high doses can kill from liver cirrhosis and liver cancer [5]. One of the strangest associations is with cigarette smoke and Parkinson's disease (PD); moderate smoking is good for PD patients. Ionizing radiation is harmful at high doses but is beneficial at low doses in promoting health and long lifespan. Low-dose radiation can even prevent or treat neurodegenerative diseases causing the dementias of aging [6].

C.L. Sanders, *Radiobiology and Radiation Hormesis*,
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4.1 Caloric Restriction

Life expectancy and health span have dramatically increased during the last two decades. The delay of aging is far more effective than preventing specific diseases, such as cancer. Among the most important factors associated with delay in aging are induction of apoptosis, antioxidants, and caloric restriction [7]. Caloric restriction (CR) is associated with enhanced intercellular antioxidants, induced apoptosis removing genetically damaged cells, and a wide variety of physiological responses very similar to those observed with low-dose ionizing radiation [8].

CR influences aging and disease by modulation of biological and pathological processes [9]. CR retards age-related functional deterioration and the onset or progression of age-related diseases, prolongs mean and maximum lifespans, and improves overall health (Table 4.1) [5]. Low-dose ionizing radiation also does all these things. Ewing in 1911 found that cancer was much more likely to occur in sedentary higher socioeconomic classes than in the "poor and overworked" [10]. The pioneering studies of Sivertsen and Dahlstrom in 1921 showed an inverse relationship between physical activity and cancer mortality in Minnesota residents [11]. Occupational or recreational exercise suppressed the development of cancer, particularly in the colon and prostate of males and the breast and reproductive organs of females. Szilard in 1959 proposed the hypothesis that the accumulation of DNA damage was a basic mechanism in the aging process and that cancer may result from faulty DNA repair [12]. McCay in the 1930s demonstrated a significant increase in lifespan in weanling rats on a severely restricted diet, an observation that was later extended to adult rodents on less restricted diets [13]. These benefits included decreased tumorigenesis, enhanced antioxidant enzyme defenses, and enhanced DNA repair and immune defenses.

Table 4.1 Significant physiological effects of food caloric restriction in rodents [5]

Parameter	Significant change
Lifespan	Increased by 50%
Carcinogenesis: skin mammary gland colon intestine pancreas liver	66% Decrease; 58% decrease; 47% decrease; 78% decrease; 62% decrease; 100% decrease
Oncogene expression	Decreased
DNA methylation of oncogenes	Increased
Growth and progression of preneoplastic lesions	Inhibited
Onset of degenerative diseases	Delayed
Antioxidant enzymes	Increased
Oxidative damage	Decreased
Free radical and H_2O_2 production	Decreased
Lipid peroxidation	Decreased
Cell proliferation	Decreased
Immune surveillance	Increased

The relationship of body weight and mortality, particularly with respect to optimal weight for longevity, is of great interest. Many studies have examined the relationship between weight loss and weight fluctuation with respect to mortality from all causes. The nature of this relationship between body weight and mortality may exhibit several associations: an inverse association, a **J**-shaped association or a **U**-shaped association. Weight loss and weight fluctuation were less related to death among healthy men who do not smoke. Reduced calorie intake to levels of 20–40% less than ad libitum intake extends the latency to onset and reduces the incidence of cancer and autoimmune diseases in rodents and prolongs lifespan in many mammalian species. Decreases, ranging from 30 to 100%, for common inflammatory, proliferative, and neoplastic diseases were found in rats on a restricted caloric diet as compared to an ad libitum diet. Maximum survival in male F344 rats increased from 950 days for rats fed ad libitum to 1350 days for rats fed a restricted diet. A study in Charles River male rats found a 50% increase in maximum survival (from 1000 days in ad libitum rats to 1500 days in restricted diet rats) following CR [5].

Enhanced DNA repair capacity is a hallmark of CR in animals [9]. CR is the most powerful and diversified strategy in the field of experimental gerontology. Dietary caloric intake plays an important role in the rate of DNA damage, including oncogene expression which is significantly reduced in rodents on restricted caloric diets. CR delays the progression of immune deficiency with aging and suppresses the rise in associated chronic diseases.

The antioxidant action of dietary restriction produces strong indications supporting the hypothesis that age-related oxidative damage to the subcellular membranes and the deterioration of cytoplasmic protective components are inhibited by dietary restriction. This strengthens the notion that dietary CR promotes an antiradical action, protecting DNA from oxidant injury. DNA repair shows a decline with increasing age. Stimulation of DNA repair by CR may be responsible for suppression of diseases associated with obesity and aging. CR in laboratory animals suppresses chemical carcinogen-induced tumorigenesis by altering xenobiotic metabolism. CR inhibited induced tumorigenesis from aflatoxin B_1, benzo(a) pyrene, 7,12-dimethylbenz(a)anthracene, and 3-methylcholanthrene [5].

Moderate exercise also has preventive therapy actions similar to those of CR [14]. About 60% of Americans can be classified as sedentary. Physical exercise increases aerobic capacity and inhibits the appearance and progression of many diseases and disabilities, including cancer. Possible mechanisms for exercise-related decrease in cancer are due to increased levels of several antioxidants in the blood. Exercise also influences xenobiotic metabolism and inhibits spontaneous and chemically induced tumors. A **U**-shaped mortality curve for cancer is seen with increased exercised [5]. Radiation hormesis, CR, and moderate exercise all benefit normal aging by increasing lifespan and suppressing a wide of diseases [5, 15]. ROS inducers lead to CR-like lifespan extension. CR delays or inhibits mortality associated with atherosclerosis, cancer, and neurodegenerative diseases [16]. Thus, CR can be justified as a hormesis-like agent or procedure with many similarities to radiation hormesis.

4.2 Radiation Deficiency

Radiophobia is an irrational fear of ionizing radiation inspired by radiation protection regulations based on the linear no-threshold (LNT) assumption. Rather than using just a straight positive line to represent health risk, such as cancer, the hormesis model utilizes all the data, particularly at radiation doses lower than natural background. According to the LNT assumption, all ionizing radiation is harmful. According to the hormesis model, too little radiation may actually increase risk, followed by a decrease in risk below that observed at natural environmental exposures, and followed at higher doses by a threshold where increased risk is observed into a linear zone (Fig. 4.1). Hormesis means that something that is harmful at high doses can be helpful at low doses. That something can be a wide variety of chemicals or ionizing radiation. The LNT assumption is wrongfully used to determine health risk for both. A "hockey stick" dose-response is often seen with the rounded blade of the stick dropping below the expected control level and the stick starting at a point above the control level.

Hormesis is the term for the circumstance where a substance has different effects in three different ranges—harm below a lower threshold with insufficient dose, benefit above that lower threshold and below a higher threshold, and harm again above the higher threshold—with a focus on the middle range where the organism responds to defend and protect itself and overdoes the defense/protection so that it is more resistant to subsequent impact from other harmful agents than it was before (Bill Sacks, S.A.R.I.).

Life on earth has been bathed in background radiation since the dawn of time. This ionizing radiation comes from cosmic rays, terrestrial radioactivity, and internally deposited naturally occurring radioactive material in the organism itself. We're all bathing in and surrounded by penetrating ionizing radiation. About 15,000 γ-rays and radioactive particles (α and β particles, neutrons, and cosmic particles) hit the

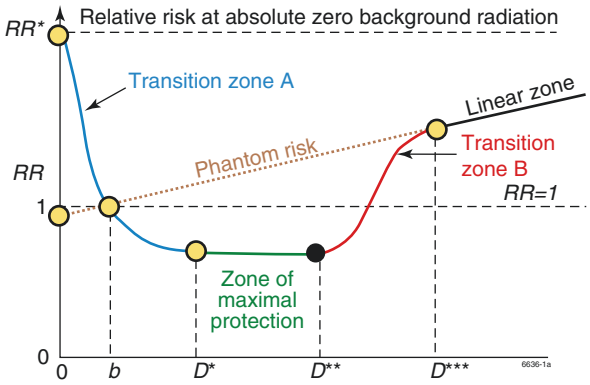

Fig. 4.1 Schematic representation of cancer relative risk (RR) showing the hormesis relative risk model. *D* is radiation dose or exposure level or exposure rate (for continuous lifetime exposure). The variable *b* is the natural background radiation level. RR = 1 at the natural background exposure level. RR* is the relative risk in the absence of any radiation exposure. The reference to phantom risk relates to use of the invalid linear no-threshold LNT hypothesis to extrapolate from high- to low-radiation doses (With kind permission of Bobby Scott [17])

average person in the world every second. In addition, each of us experiences ~300 million β-emissions (maximum energy 1.33 MeV) a day in our bodies from potassium-40. It's in the food we eat, the water we drink, the soil we tread, and even the air we breathe. It's background radiation that is everywhere and we can't get away from it. Low doses of ionizing radiation are beneficial for your health. However, receiving too little radiation or radiation deficiency provides suboptimal conditions for cell growth or health and is harmful to your health. Where you are living on the dose-response curve for radiation dose is critical to optimal health. Life has never existed without ionizing radiation and cannot exist without it.

ALARA and AHARS (As High As Reasonably Safe) are based upon the LNT assumption. The LNT assumption and ALARA are harmful: With ALARA, every time you reach a new low, you say we are going even lower; this then sounds reasonable. Actually going even lower becomes more and more a health hazard because of the harm from radiation deficiency (Fig. 4.2). Radiation deficiency caused by near total removal of radiation sources causes near 100% mortality in a variety of biological systems [15].

Proponents of the LNT do not like to mention natural background radiation exposures and dose but desire to give an unspoken impression that we humans are normally radiation-free.

Radiation research funded for radiation protection objectives support the LNT concept by suppressing contrary scientific data; this activity dating back to the 1950s. Potassium is an element that is essential to life. However, about 0.012% of natural potassium is a radioactive isotope, potassium-40. Potassium was processed to separate the potassium-40 from natural potassium at Oak Ridge National

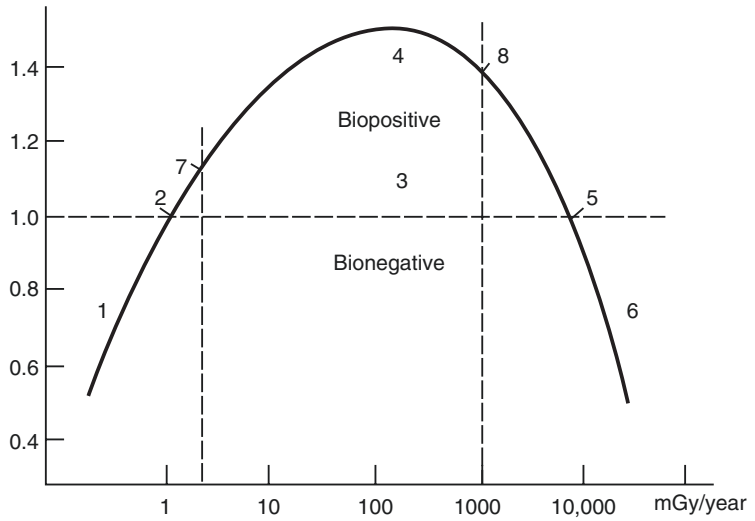

Fig. 4.2 Idealized dose-response curve for ionizing radiation. *1* deficient, *2* ambient, *3* hormetic, *4* optimum, *5* zero equivalent point, *6* harmful, *7* ALARA, *8* AHARS. Originally published by Luckey [18] (With kind permission of Jerry Cuttler (2014), Cuttler & Associates, Toronto)

Laboratory (ORNL) to conduct radiobiology experiments in the 1950s. The mice were stated to have "done poorly while on a potassium-40 deficient diet, but recovered when the extracted potassium-40 or natural potassium was added". The organisms placed in potassium-40-deficient diets were biologically deficient and suffered as a result. Scientists wanted to publish the results but were prevented from doing so by the AEC [19]. The US NRC's Charlie Willis in a March 1996 NRC transcript said: In 1958, at the lab (Oak Ridge), with K-40 removed from potassium, cells didn't function... The results weren't published, an effect of the LNT paradigm – No NRC inquiry! Despite requests. No NRC inquiry! The ORNL findings were consistent with several other studies with organisms that have been shielded from background radiation. For example, organisms grown on glass slides with a low thorium content were repeatedly found to grow differently.

Organisms shielded from background radiation fail to grow, reproduce, or otherwise function normally. Supplementing radiation causes them to return to normal functions. Suppressing natural background radiation always has detrimental biological effects. The Low Background Radiation Experiment is being carried out at the Waste Isolation Pilot Plant (WIPP) located 26 miles from Carlsbad, New Mexico. The facility is a half-mile below the desert floor in a salt formation. The site was constructed primarily as a geological depository for transuranic wastes. The WIPP underground is ideal for studying the effects of very low-dose rates on biological systems. The WIPP's underground is close to radiation-free. The effort is to test the linear no-threshold theory from the other side of background [20]. The research was led by Geoffrey Smith, New Mexico State University. The experiment at WIPP aims to better understand the effects of low-dose radiation by providing more insight into the role of background radiation in maintaining the fitness of living organisms. The adaptive response in human cells seems to have a threshold at 100 μGy. Surface background levels in New Mexico are about 0.4 μGy/h. It would take only about 10 days to accumulate the 100 μGy threshold dose for adaptive response from background exposure in New Mexico. The adaptive response in humans operates within upper- and lower-dose thresholds of about 1 and 100 mGy for a single low-dose-rate, low-LET exposure. A dose deficiency of <0.1 mGy is associated with an increased cancer relative risk [21].

The bacterium, *Desulforudis audaxviator*, lives 2.8 km underground in a gold mine of South Africa. It draws its energy from radioactivity emitted by uranium in the rocks [22].

One experiment at WIPP involved using two different types of bacteria, one of which is very sensitive to radiation and the other which is very resistant. The bacteria strains were grown in both simple and complex growth media. One-third of the experiment took place in the WIPP underground at the northern end of the repository. The idea is to let two strains of bacteria grow side by side in an environment where they are receiving virtually no background radiation. In fact, the bacteria

incubator has been placed in a pre-World War II steel chamber to eliminate even the slightest amount of background radiation. The bacteria underground will receive close to zero radiation dose for hundreds of generations.

> The amount of radioactivity in the environment from nuclear fallout is measured in pCi/l. In the laboratory you need to administer levels of radioactivity that is seven to nine orders of magnitude greater to induce serious biological changes, such as cancer.

The rest of the experiment took place inside a room near the waste handling bay at WIPP's aboveground facility. There, for comparison, the two strains of bacteria grow at natural background radiation levels. Another part of the experiment exposes both types of bacteria to significantly higher levels of radiation above normal background in the underground site. Researchers can then compare how well the bacteria does at zero, natural, and above natural levels of background radiation a half-mile underground and on the surface. WIPP indicates that bacteria and cells grown at far below normal background radiation dose levels experience less than normal growth and an increase in mutation frequency. Lung fibroblasts and bronchial epithelial cells demonstrated upregulation of stress proteins in response to growing at a very low-dose rate of 300 μGy/year [23].

Swiss experiments in a deep mine at a very low background radiation dose level carried out during the 1960s showed that plants and animals could not reproduce and grow if there was too little ionizing radiation. These early studies may have influenced the radon action level standard set for Switzerland, [23] which is considerably higher than for the US Studies at the Underground Gran Sasso National Laboratory (LNGS) in central Italy showed that cell cultures growing in a radiation-deficient environment exhibited elevated ROS levels and were more susceptible to harm from DNA-damaging agents; LNGS is 1400 m underground [20].

The Slanic Prahova ultralow background radiation laboratory is located 208 m underground in the biggest salt mine of Europe about 45 km NE of Ploiesti, Romania. Air radiation levels were 1.17 ± 0.14 nGy/h in the salt mine as compared to 87.0 ± 27.1 nGy/h on the surface outside the mine or almost 75 times higher outside than in the mine (Table 4.2). Uranium decay daughter products and K-40 were markedly lower in the mine than outside. Neutron background levels were below detection for commercial instruments within the mine [24].

Table 4.2 Levels (counts per 1000 s) of uranium decay daughter products and potassium-40 in the Slanic Prahova salt mine and on the surface outside the mine [24]

Radionuclide	Salt mine	Outside the mine
Ra-226	72.4 ± 3.9	2002 ± 398
Ac-228	3.7 ± 3.2	999 ± 793
Pb-212	273 ± 5.3	18,250 ± 630
Bi-214	194 ± 2.9	9590 ± 227
K-40	158 ± 2.5	59,390 ± 430

4.3 Radiation Hormesis-Threshold Model

Calabrese found approximately 5600 dose-response relationships satisfying evaluative criteria for hormesis following exposure to over approximately 900 agents from a broadly diversified spectrum of chemical classes and physical agents. The assessment revealed that hormetic dose-response relationships occur in males and females of numerous animal models in all principal age groups as well as across species displaying a broad range of differential susceptibilities to toxic agents. The biological models are extensive, including plants, viruses, bacteria, fungi, insects, fish, birds, rodents, primates, and humans [25]. Calabrese found that evidence of chemical and radiation hormesis was present in about one-third of relevant published papers. Hormetic responses showed average maximum stimulation of 30–60% compared to controls. Hormesis is a reproducible biological response in most dose-response relationships. Both bionegative and biopositive effects of LDR are observed in rodent models based upon the experimental design, genetics, radiation dose and dose rate, and statistical methodology [26]. Experimental designs that limit the range of doses will not detect hormesis. Most toxicological studies have been carried out at doses higher than the low-dose regions associated with hormesis [27]. While there is no doubt regarding the risks of acute exposure starting somewhere between 100 and 1000 mGy, scientific literature results clearly demonstrate the existence of a threshold and beneficial effects below this threshold.

> The zero-threshold policy for chemical carcinogens is not based on any scientifically established facts but is just a policy. There is, on the other hand, abundant scientific evidence that chemical carcinogens exhibit thresholds.

The region of hormesis or adaptive response occurs below the threshold dose level. Thresholds are ubiquitous among living biological systems. The zero-threshold concept says that no dose is so small that it will not cause cancer somewhere to someone. The reality is that chemical and radiation carcinogens have thresholds that exceed human occupational or natural environmental exposures. The existence of thresholds becomes inescapable. Preliminary data of the DOE low-dose million man lifespan study has shown no cancer increase associated with exposure to low-dose radiation but has shown a sparing effect.[1] Natural background radiation varies by geographic location up to three orders of magnitude (0.7–300 mGy/year). No increase in mortality or decrease in longevity has been observed in people living in high-dose regions. This fits many observations of increased longevity in animals receiving chronic or continuous whole-body X- or γ-irradiation.

[1] Department of Energy, DOE Low Dose Program, 2014.

Cancer is primarily a disease of old age, associated with a decline of defense mechanisms. The increasing incidence of cancer in the USA is because people are living longer. Eliminating all cancer as a cause of death would extend the average human lifespan by only a year.

Data from high-dose administration of toxic chemicals are routinely used to obtain and "predict" effects at low doses. The limitations of this methodology have been acknowledged by EPA in their 1986 Guidelines for Carcinogen Risk Assessment. The EPA risk model uses a linearized multistage model (initiation, promotion, progression) for carcinogen classification. Using a 100-mGy threshold would save a trillion dollars a year in the world. The EPA's regulations [6] for residential radon exposure cite the BEIR VII report as supporting LNT but fail to mention the corresponding French Academies report that does not support use of the LNT model for extrapolating cancer risk from high to low doses. In the concluding remarks, Pushkin states the following: "Nevertheless, unless compelling evidence for a practical threshold can be obtained, it must be acknowledged that there is likely to be a risk even at the lowest doses of ionizing radiation. Denials only fuel distrust. It is better to acknowledge that the science, so far, is consistent with a non-zero risk at low doses, even if direct verification is lacking. Please note that there is a nonzero cancer risk even in the absence of any above natural background radiation exposure. Please also note that this risk could go down (e.g., adaptive response) as a result of above natural background radiation exposure and still be above zero (i.e., a nonzero risk)".

A Google search on "radiation" and "adaptive response" produced about 12,600,000 hits.

The BEIR VII Committee and EPA recommended using the LNT approach. BEIR VII risk estimates were derived for low doses of gamma rays at energies of mostly 0.1–10 MeV. Like in the BEIR VII report, the authors cite some evidence that is not in support of the LNT hypothesis but then go on and ignore the evidence via stating that the results discussed in this article do not provide compelling evidence to abandon the LNT approach adapted for radiation protection. They imply that use of LNT should also be continued in low-dose radiation risk assessment. The authors could have stated that the results discussed in the paper do not provide compelling evidence for the use of the LNT model for low-dose radiation risk assessment. Low doses and dose rates of ionizing radiation have been defined by UNSCEAR and BEIR VII as those below 100–200 mGy and below 50–100 mGy/min, respectively. The NCRP defined the maximum permissible dose (MPD) in 1954 as: that radiation dose which should not be exceeded without careful consideration of the reasons for doing so [5]. Few experimental studies and essentially no human data can be said to prove or even provide direct support for the concept of

Table 4.3 Safe dose exposures proposed by radiation protection agencies

Cohort	Year	Safe dose (mGy)
Researchers (fogging photographic plate)	1902	100/day
Radiologists	1910–1920	60/month
Radiologists	1928	300/year
Public	1934	700/year
Public	1948	100/year
Public	1951	3/week
Public	1957	5/year
Public	1991	1/year
Nuclear workers	2013	50/year
Astronauts	2013	500/year
Residential radon	2013	8/year
Occupational emergency	2013	20/year
Tritium in drinking water	2013	0.04/year
Yucca Mountain limit	2013	0.1/year

the LNT.[2] It is important to note that the rates of cancer in most populations exposed to low-level radiation have not been found to be detectably increased, and in most cases the rates have appeared to be decreased.[3]

The first radiological protection standard was equivalent to the dose that would fog a photographic plate (Table 4.3). The skin erythema dose (SED) was used in the 1910s as a unit of acute X-ray exposure; it was about 2 Gy. Erythema is a reddening of the skin due to dilation of peripheral blood vessels. The American Roentgen Society in 1924 recommended a permissible dose rate of 0.2 R per day (2 mGy per day). The International Commission on Radiological Protection (ICRP) was established in 1928. In 1931 the ICRP considered a safe dose to be 70 R per year (700 mGy per year). This dose is 35 times greater than today's recommendation for occupational workers and 700 times greater than for the general public. The NCRP in 1934 used a standard of 0.1 R/day. The ICRP changed these early radiation standards in 1955 as a rejection of the tolerance dose model of the mid-1950s and to facilitate the application of Muller's LNT concept for a stochastic risk due to fatal cancer. The occupational and public dose limits were 50 mGy per year and 5 mGy per year in 1958, respectively, decreasing to 20 mGy per year and 1 mGy per year in 1990, respectively. The ICRP used to follow the lead of UNSCEAR until 2012 when the latter changed their position on the LNT. An UNSCEAR report in 2016 claimed that radiation doses of 1–10 Gy were unlikely to cause detrimental effects in animal or plant populations; this document did not endorse the LNT [28]. Since then, the ICRP continues to refuse to say that there is no radiation risk below a set radiation dose level and to deny the role of radiation hormesis while utilizing LNT assumption for making risk predictions [29].

[2] NCRP-121, 1995.

[3] NCRP-136, 2001.

British radiologists entering the profession prior to 1921 had a higher than normal cancer rate. Those that entered after 1921 had a lower than normal cancer rate (as well as lower rate for all causes of mortality) [30]. By 1957 the ICRP had recommended an occupational limit of 500 mGy/year. All-cause mortality and all-cancer mortality in UK radiologists who started work after 1954 were "remarkably" low in comparison to all other medical specialties. The occupational doses were beneficial to radiologists [31, 32]. US male radiologists were compared to psychiatrists (1979–2008); radiologists had lower death rates (RR = 0.94) [33].Today the ICRP is focusing on the effects on human health for whole-body doses <100 mGy, an issue that is being investigated and intensively debated [34]. Unfortunately, the LNT assumption for radiation carcinogenesis seems to be immune to scientific facts. We have Bernie Cohen's famous test of the LNT theory and 192 publications in Annex B of UNSCEAR 1994, plus hundreds more "ugly facts." Yet the LNT assumption survives in our regulatory regime.

Radiation exposure following the nuclear accident at Fukushima-Daiichi did not cause any immediate health effects. It is unlikely to be able to attribute any health effects in the future among the general public and the vast majority of workers. Tritium released from the Fukushima accident does not pose any health hazard. In fact tritium may cause an adaptive response [35]. The cumulative radiation dose for 1 year from Cs-137 in food is well below 0.01 mGy [36]. No health problems from the radiation exposure related to Fukushima should be expected unless the current exposure limits are exceeded by two orders of magnitude.

The French Academies of Medicine and Science in 2005 unanimously condemned the use of the LNT and collective dose at low-dose levels. These procedures (LNT) are without any scientific validity.[4] The authors of the French report concluded that epidemiological studies have been unable to detect a significant increase in cancer incidence in humans for doses below 100 mGy. This dose level is clearly above all common diagnostic, screening, and intervention associated radiation exposure. The French also addressed the question of the validity of the LNT model. The report points out that the studies used to justify the LNT model involved A-bomb survivors and individuals exposed to radiation in the workplace and that the levels of exposure were in the range of 125–500 mGy. The French report devotes considerable space to a discussion of potential mechanisms for the hormetic effect and its impact on low-dose risks [37]. In 2015, the Health Physics Society statement on radiation risk recommended an annual cumulative dose of less than 100 mSv. No mention was made of radiation hormesis. In contrast, many radiation scientists believe that the threshold level should be 0.7 Gy/year and the regulatory limit set at 0.3 Gy/year.

4.4 Mechanisms of Radiation Hormesis

Biological organisms have substantial adaptive protection systems that modify/repair damage caused by oxygen radicals or high-dose radiation. Low-dose radiation upregulates adaptive protection systems causing a net health benefit.

[4] French Academy of Medicine, 2001.

High-radiation doses impair these protective systems. DNA damage has emerged as a major culprit in cancer and many diseases related to aging. The stability of the genome is supported by an intricate machinery of repair, damage tolerance, and checkpoint pathways that counteract DNA damage. In addition, DNA damage and other stresses can trigger a highly conserved, anticancer, antiaging survival response that suppresses metabolism and growth and boosts defenses that maintain the integrity of the cell (Fig. 4.3). Induction of the survival response may allow interventions that improve health and extend the lifespan [39].

LDRprotects against chromosomal damage, mutation induction, neoplastic transformation, and high-dose chemical and radiation-induced cancer. LDR enhances immune system defenses, suppresses cancer induction by α-irradiation, suppresses metastases of existing cancer, extends tumor latency, and protects against a whole host of other diseases mostly associated with inflammation [40, 41]. Genotoxic stress, like low-dose radiation, stalls DNA replication and induces ligands found in natural killer (NK) cells and some T cells to attack and destroy tumor cells [42]. The expansion and cytotoxicity of NK cells were markedly augmented by low-dose ionizing radiation. These findings indicate that radiation induces a direct expansion and activation of NK cells which provides a potential mechanism for stimulation of NK cells by radiation [43].

The adaptive response operates primarily within a dose window of between 1 and 100 mGy for a single low-dose-rate exposure and substantially higher doses for chronic and continuous low-LET radiation exposures. The hormetic zone depends on the type of radiation (LET) and dose rate [21, 44]. Low-dose radiation

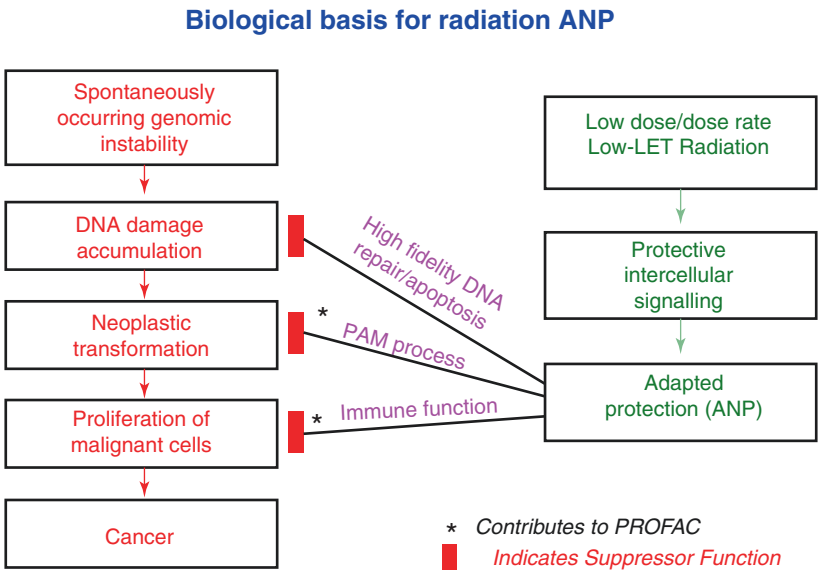

Fig. 4.3 With kind permission of Bobby Scott [38]

upregulates adaptive protection systems to deliver a net health benefit. High-dose radiation impairs protective systems resulting in a net harm. LDR upregulates adaptive protection systems in scores of genes, facilitating repair, replacement, and removal cancer cells [45].

Spontaneous damage to DNA is continuously caused by natural metabolism associated with living in an oxygen atmosphere (ROS). The degree of DNA damage from ROS is ten million-fold greater than caused by average background radiation [17]. Put another way, spontaneous DNA damage rate is more than six million times higher than 1 mGy/year DNA damage rate. About 0.1 DNA, double-strand breaks (DSBs) occur naturally in each cell of the body per day. An adult has 100 trillion cells. World, mean, background radiation (2.5 mGy/year) causes 1 DSB per 10,000 cells per day or 100,000 times less than seen spontaneously [46]. High-LET radiation (100–200 keV/μm), such as alpha particles from decay of unstable atomic nuclei, causes a higher frequency of DSBs and therefore is even more unlikely to result in a threshold for cancer formation. DNA damage in people living in high background radiation levels declines with age, in contrast to people living in low background levels [47].

Reactive oxygen species (ROS) play an important role in radioprotection. ROS are mostly generated by the oxygen atmosphere we live in, resulting in oxidative damage to cellular structures. Low-dose ionizing radiation induces an adaptive response to deal with ROS damage [6, 38].

The LNT is based on the concept that damage to genetic material (DNA) from ionizing radiation increases in direct proportion to the absorbed dose and that this DNA damage results in causing cancer in proportion to dose. The LNT hypothesis does not consider the complex nonlinear interactions before cancer formation is expressed. The dose-response relationship cannot be based on a simple mathematical equation of the first order. The LNT model should be rejected [48].

The number of double-strand DNA breaks (DSBs) from low-dose radiation is expected to be strictly proportional to dose; this is the primary basis for the LNT. Thus, according to the regulators, cancer must also be a linear function of dose requiring the use of the LNT to determine risk. Freely isolated DNA has nothing to do with intact cells. Multiple DNA double-strand breaks 1–2 μm apart in a cell can rapidly cluster to form repair centers following radiation exposure. This indicates doubt on the general assumption of the LNT that risks are proportional to dose [49].

Protective processes that suppress cancer can be stimulated by mild stress such as is associated with very low doses of low-LET radiation (e.g., X-rays, γ-rays, β-particles) [50]. The existence of genomic instability and bystander effects was observed as far back as 1915 [51]. Low-dose radiation effects are complex and sometimes not easily predicted (adaptive response, bystander, genomic instability,

and low-dose hypersensitivity) [52]. The adaptive response causes genomic instability-related outcomes, such as cell transformation and chromosomal aberration formation, to decrease below the normal background or to spontaneous levels following exposure to ultralow doses and dose rates. Cellular hormesis responses from natural and anthropogenic sources of radiation are similar [46]. However, dose rates from anthropogenic radiation sources are typically much higher than from natural sources [53].

The demonstration of a bystander effect in human tissues and in whole organisms has clear implication of the potential relevance of the nontargeted response to human health [54]. The radiation-induced bystander effect was first reported in 1992. It is the phenomenon in which unirradiated cells exhibit irradiation effects as a result of signals received from nearby irradiated cells [55]. There is evidence that targeted cytoplasmic irradiation results in mutation in the nucleus of the hit cells. Cells that are not directly hit by an alpha particle, but are in the vicinity of one that is hit, also contribute to the genotoxic response of the cell population [56, 57]. Similarly, when cells are irradiated, and the medium is transferred to unirradiated cells, these unirradiated cells show bystander responses when assayed for clonogenic survival and oncogenic transformation [58, 59]. This is also attributed to the bystander effect. Current evidence does not suggest that the bystander effect promotes carcinogenesis in humans at low doses [60].

DNA repair and apoptosis both are stimulated by very low harmless doses of low-LET radiation [50]. DNA damage in bystander cells can be induced by passage of ionizing radiation through neighboring cells, triggered by passage of a signal through intercellular gap junctions. Thus, it appears that the adaptive response and genomic instability can be induced by bystander cells [61]. Bystander signals from irradiated cells can also induce apoptosis in neighboring transformed cells [62], providing protection by deletion of aberrant cells. Thus, transformed cells are selectively deleted by signals from normal cells, and low-dose irradiation augments the efficacy of normal cells [62, 63].

The bystander effect may not be the same as the abscopal effect. The abscopal effect is a phenomenon where the response to radiation is seen in organs distant from the irradiated organ/area; the responding cells are not juxtaposed with the irradiated cells. T cells and neurons have been implicated to be part of the mechanism [64]. In suicide gene therapy, the bystander effect is the ability of the transfected cells to transfer death signals to neighboring tumor cells.

Low doses and dose rates of low-LET radiation activate a system of cooperative processes in the body [65, 66]. These include apoptosis that eliminates aberrant cells. Apoptosis involves the selective recognition and elimination (cell death) of aberrant precancerous and other damaged cells [63]. In cancer and in other diseases, elements of the apoptotic process become dysregulated. Cancer is characterized by the partial suppression of apoptosis, which in turn causes chemotherapy resistance. Various agents are known or suspected to have apoptosis-modulating properties in cancer, neurodegenerative diseases, and chronic inflammation/autoimmunity, including low-dose ionizing radiation [67].

There is no evidence that low doses of radiation (e.g., <100 mGy) can trigger a proliferative stimulus. What the evidence points to is stimulation of protective apoptosis in aberrant cells (possibly including mutant cells) which are selectively removed leaving the overall cell survival is essentially unchanged (e.g., one bad cell among a million good cells is selectively removed). Apoptosis increases up to maximum dose of 750 mGy.

Are there optimal photon energies that stimulate hormetic reactions? A few studies have examined the role of photon energy. Experimental evidence is limited. Lower-energy X-rays were more efficient in inducing genomic instability than γ-rays, while higher-energy γ-rays and 60-kvp X-rays were more efficient in activating the protective apoptosis-mediated (PAM) response than 28-kvp X-rays [68]. If you could chronically deliver the right gamma ray energy spectrum to critical cellular sites at the same time, then you might expect to see more significant positive biomedical effects, both in prevention and in therapy for inflammatory and proliferative diseases, at ultra-low-dose rates.

In some cases radioadaptive protection may last beyond a year. An adaptive response is seen in mammalian cells between a dose range of <1 mGy and <200 mGy for a single low-LET exposure [21]. An average of 1 electron track delivers about 6 keV per 1 ng mass (the average single cell mass) delivering about 1 mGy from exposure to 100-kvp X-rays. That means that each cell in the body receiving 1 track per year will experience a dose of 1 mGy per year [69]. Cellular lesions are eliminated by the disappearance of genetically damaged cells at doses <10 mGy, while repair systems are activated at >10 mGy.

Neoplastic transformation of HeLa x skin fibroblast human hybrid cells by doses of 1-GeV/nucleon iron ions in the range of 1 cGy–1 Gy to exposed cultures has been examined [70]. The data indicate a threshold-type dose-response curve with no increase in transformation frequency until doses above 20 cGy. At doses <10 cGy, not all exposed cells receive a direct traversal of an iron-ion track core, but all exposed cells receive up to several mGy of low-LET radiation associated with the δ-ray penumbra. It is proposed that the threshold-type response seen is a consequence of an adaptive response associated with the δ-ray exposure [44].

4.5 Thresholds for Animals

Duport examined about 800 data sets for cancer development in experimental animals exposed to low-dose radiation and found many examples of radiation hormesis [71]. The threshold for lifespan reduction in rats, mice, and guinea pigs chronically exposed to gamma rays was about 2 Gy/year. Mean survival increased by about 10% for animals given ~200 mGy/year. Chronic gamma and X-ray doses of <1 Gy in animals have been shown to increase mean survival time at dose rates of 1–50 mGy/day [72]. A 100-mGy threshold for radiation carcinogenesis has been seen in meta-analyses of experimental tumor data [73, 74]. The lung dose threshold for lung tumors in rats, dogs, and Mayak plutonium workers exposed to plutonium-239

dioxide aerosols ranged from 0.4 to 0.8 Gy [75–77]. A threshold of 1–2-Gy low-LET radiation for lung cancer was found in never smokers. Lung cancer risk among nuclear workers (smokers and non-smokers) was typically reduced by 40% following cumulative doses of <100 mGy. LDR protects not only against lung cancer in never smokers but also in cigarette smokers.

Evidence for large thresholds and radiation hormesis in rat, mice, and beagle dog studies was consistently ignored by DOE and radiation protection agencies long after the studies had been published. Only recently have some researchers felt "safe" to publish this evidence. They had been intimidated by the DOE's cancelation of excellent research programs that clearly demonstrated radiation hormesis in human populations, such as the radium dial painter program at Argonne National Laboratory and the nuclear shipyard workers program at Johns Hopkins University.

Low-dose gamma radiation at 250 times background levels or 22.6 μGy/h, giving an annual dose of 200 mGy, exhibited beneficial effects on natural populations of meadow voles exposed to Cs-137 γ-rays from a field irradiator [78].

There are about 75,000 beagle dogs used in biomedical research in the USA each year. Most dogs are either bred by the laboratories using them or bred by private companies that sell directly to the laboratories. Beagle dogs were used in research on radionuclide toxicity by several AEC/DOE laboratories. Photos of beagles in DOE-sponsored studies were rarely, if ever, shown in their publications.

Lifespan studies in beagle dogs have provided valuable, but expensive, information on biological toxicity of a wide variety of inhaled, ingested, and injected radionuclides. Well-funded radiobiological lifespan studies in beagles were carried out from 1960 to 1990 by the University of California at Davis (Sr-90, Ra-226), Pacific Northwest Laboratory (Pu-238, Pu-239) in Richland, WA, University of Utah (Ra-224, Ra-226, Ra-228, Th-228, Pu-239, Am-241, Cf-252) in Salt Lake City, UT, and the Inhalation Toxicology Research Laboratory (Cs-137, Ce-144, Sr-90, Y-90, Y-91, Pu-239) in Albuquerque, NM [79]. Nearly all the lifespan studies with radionuclides and dogs showed thresholds.

Radionuclide relative potencies for bone sarcoma formation from highest were Th-228, Pu-239, and Pu-238 to the lowest for Ra-226, followed by β-emitters. Bone surface-seeking α-emitting radionuclides, such as Th and Pu, were about an order of magnitude more potent inducers of bone tumors than bone volume-seeking α-emitting radionuclides like Ra, which is distributed in bone like calcium. Beta-emitting radionuclides exhibited thresholds for bone tumors that were about an order of magnitude greater than α-emitters.

Lung tumor incidence in unexposed beagle dogs at PNL was 18% (5/28) [1]. Lung tumors were also common in unexposed beagle dogs used for radionuclide research at Lovelace (ITRI) [80]. Control dogs had a higher frequency of bone tumors than dogs fed Sr-90 and receiving ≤10 Gy [81]. There were four bone

tumors found in 162 control dogs, and no bone tumors in the three lowest-dose groups of dogs fed Sr-90 [82]. Leukemia formation in dogs fed Sr-90 exhibited a threshold of 10 Gy. This was evidence of radiation hormesis with reduced bone tumors (from controls) as well as demonstrating an enhanced lifespan at low doses compared to control dogs.

The carcinogenicity of inhaled β,γ-emitters incorporated into submicron-sized fused clay (aluminosilicate) particles has been examined in lifespan studies with beagle dogs. No lifespan shortening was found at lung doses ≤20 Gy. Inhaled β,γ-emitters in fused clay particles exhibited a threshold for lung tumors of about 5–10 Gy with decreasing potency in lung carcinoma formation from Y-90 to Y-91 to Ce-144 and to Sr-90 [83]. Lung carcinoma formation from inhaled Pu-239 nitrate (soluble) exhibited a threshold of 0.5 Gy (10 Sv) [6]. At PNL, no lung tumors were found in 16 dogs with lung doses of 14.4 ± 7.6 cGy and only one lung tumor in ten dogs with 37.5 ± 10.9 cGy. Control dogs had significantly higher incidence of bone tumors than "low" dose dogs. The threshold for lung tumor development was estimated at ≥0.5–1.0 Gy (10–20 Sv).

The results of all studies in beagle dogs with β,γ-emitting fission products, uranium daughters (particularly radium), and transuranics (particularly Pu) were consistent and incontrovertible: Toxic radionuclides were not all that toxic in the skeleton or lung. Large thresholds for tumor formation of ≥5 Sv (most ≥10 Sv) were seen for skeletal and lung tumor development in beagle dogs [82, 83].

Ninety-two beagle dogs were kept during their entire life in an artificial high background of γ-radiation from Co-60 at a dose rate of 3 mGy/day or 1.1 Gy/year. The animals had a shorter lifespan only when the absorbed dose rate exceeded 3 mGy/day. A continuous exposure to 3 mGy/day causes every cell in the dog's body to be hit on average by 1 energy deposition event from an electron track every 2.4 h throughout life. No change in blood cell counts or tumor incidence was found. Dog lifespan was prolonged at doses of 10–500 mGy/year. At dose rates higher than 3 mGy/day, death was mainly due to hematopoietic failure [84].

4.6 Thresholds in Humans

Very small doses and dose rates of radiation often exhibit significant health hormetic effects based on observations in epidemiological and experimental studies [40]. Low doses and dose rates of ionizing radiation have been defined by UNSCEAR and BEIR VII as those below 100–200 mGy and below 50–100 mGy/min, respectively. An inverse dose rate effect has been observed with low-LET radiations for radioadaptive cellular and therapy mechanisms [85, 86]. Uniform, whole-body, continuous, low-LET radiation exposure was estimated to cause no excess risk of radiation-induced cancer at dose rates <150 mGy/year in humans [87]. For the system studied, the adaptive response operates within these doses and dose rate limits.

The average person in the world receives about 2.5 mGy per year from background radiation. Natural background radiation varies by geographic location up to three

orders of magnitude (0.7–700 mGy/year). The average annual effective dose per individual in the US population from all sources was 6.2 mGy in 2008, of which the ubiquitous background radiation contributed 3.1 mGy [2]. Research technical societies during the 1940s published research articles on biological effects that clearly demonstrated thresholds below cumulative doses of 500 mGy using low-dose rates.

According to the US Nuclear Regulatory Commission (NRC) in 2007, no US nuclear workers have been exposed to more than 50 mGy (5 rem) in a year since 1989. An Electric Power Research Institute (EPRI) analysis sought to determine whether the LNT approach is directly applicable to the nuclear power plant environment, where doses and dose rates are much lower than the high-dose atomic bomb studies on which the linear no-threshold model is based. The EPRI research team reviewed more than 200 studies where individual radiation doses were less than 10 rem in a single exposure. The studies were found to be too small to allow detection of any statistically significant excess cancers in the presence of naturally occurring cancers [88]. SMRs for all-cause mortality and all-cancer mortality for nuclear workers in 154 facilities in 15 countries clearly showed radiation hormesis. All-cause mortality was 38% less than expected and 26% less than expected for all-cause cancer [89]. A subsequent analysis 9 years later in over 300,000 nuclear workers in the USA, UK, and France showed no significant associations for solid cancers and non-CLL leukemia at doses of 100 mGy and 300 mGy, respectively [90] (Fig. 4.4]).

Follow-up of Japanese survivor cohorts (120,000) and their offspring (77,000) from 1947 to present day have shown no increase in mutations or frequency in abnormalities in offspring. A significantly elevated cancer risk (42% increase) and a decreased lifespan of only 1 year were observed in survivors that received >1000 mGy [92]. The lifespan of Japanese A-bomb survivors was increased, [93–95] and thresholds of up to 1000 mGy were found [40, 96, 97].

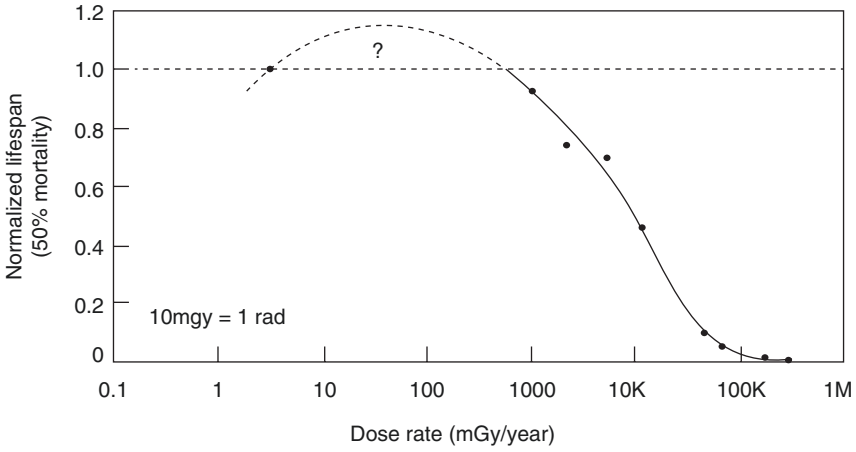

Fig. 4.4 Influence of radiation dose rate on lifespan [91] (With kind permission of Jerry Cuttler (2014), Cuttler & Associates, Toronto)

British radiologists who joined a radiologic society between 1897 and 1920 had a 75% greater cancer mortality than did controls. However, their death rate from all non-cancer causes was 14% less than controls. The overall longevity of this early group was not reduced despite high-radiation dose and cancer mortality. British radiologists who joined the society after 1920 had a 14% lower death rate from non-cancer and an 8% lower death rate from all causes than did controls. The healthiest British radiologists were those who joined from 1955 and 1979. Their death rate from cancer was 29% lower and from non-cancer was 36% lower (32% lower from all causes) than that of controls [31, 98]. Radiation doses received by these UK radiologist cohorts were substantially greater than would be allowed by today's radiation protection standards.

Several ^{60}Co orphan sources were inadvertently recycled into 20,000 tons of structural steel which was used to construct about 200 residential, industrial, and school buildings in 1982 housing 10,000 residents of Taiwan. The average cumulative dose for the exposed residential population was about 50 mGy; the average dose rate was estimated at 11 μGy/h [99]. Only seven fatal cancers were observed out of an expected 232 (SMR = 0.03) [100]. A latter paper showed an observed cancer incidence of 95 out of an expected 115 (SIR = 0.8) which was significantly less than expected; this paper used 10-year lagging (throwing away radiation dose) for solid cancers, resulting in a misrepresentation of the true dose and cancer risk and also did not provide any SMR values [101]. SIR values that are considerably higher than SMR values for cancer may represent, in part, a therapeutic effect of low-dose radiation on cancer progression.

Biopositive effects were estimated to occur at between 1 mGy and 1000 mGy/year [91, 102] Radiation is needed for life; 25–50 X worldwide, background average is optimal for health or a continuous dose rate of 7–12 μGy/h [77, 103]. Luckey believed that: We would have abundant health for any increased level up to the threshold, almost 3000 times the ambient level. This conclusion was based on review of about 3000 publications [104]. The use of the dose rate may be preferred to dose in predicting risk [105]. Radiation protocols showing evidence of radiation hormesis for γ-dose rates are found in the 1–50 μGy/h dose rate range. Luckey [91] estimated the optimal radiation level as 60 mGy/year or 6.9 μGy/h would reduce cancer mortality to near zero and that the elimination of cancer deaths would increase lifespan by about 10 years [106, 107]. We should have abundant health for any increased level up to a threshold of about 20 mGy/day [91]. Jerry Cuttler estimates a chronic threshold of 700 mGy/year; Wade Allison gives a threshold of 100 mGy/month. The threshold lies within the range of 50–300 mGy for acute single doses to adults or within the range of 100–700 mGy per year for continuous exposures [108, 109]. For uniform whole-body radiation exposure, the threshold dose for cancer is about 200 mGy/year (Table 4.4) [87]. The incidence of radiation-induced carcinogenesis increases in humans when single doses exceed 300 mGy [46]. Radiation doses (low LET) ≤ 2.0 Gy-protracted X- or γ-rays do not cause increase in lung cancer but often cause a reduction in natural incidence [110]. Many epidemiological studies have shown decreased cancer of all types following exposure to low-dose ionizing radiation often

Table 4.4 Approximate human threshold dose for low-LET, continuous radiation exposure [87]

Effect	Dose rate (mGy/year)	Cumulative dose (Gy)
Pancytopenia	400	20
Temporary sterility men	350	15
Sterility women	200	6
Cataracts	150	7.5
All cancer	200	–
Lung cancer	–	15
Breast cancer	–	3
Liver cancer	–	25
Bone cancer	–	10

delivered during employment [40]. For example, all-cause mortality (SMR 0.49) and all-cancer mortality (SMR 0.64) were significantly less among German aircrews than among the general German public [111].

Cataract formation has been classified as a deterministic effect of radiation exposure with a threshold from 0.5 to 2.0 Gy [112, 113]. The risk of secondary cancers after radiotherapy for a primary cancer depends on the dose at the site of the secondary cancer, which is itself a threshold of ~5 Gy following a typical 60-Gy therapeutic exposure to the primary tumor [114]. The secondary cancer risk is lower than expected at 20 Gy, which is even less than for zero dose [115].

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Plutonium Particle Toxicity Myth

5

Beware of false knowledge; it is more dangerous than ignorance (George Bernard Shaw).

5.1 Atmospheric Nuclear Weapons Tests

The official stance of the USA and the U.S.S.R. with respect to nuclear tests is that they represent the development and testing of nuclear weapon reliability. In fact, such tests also suggest a surrogate nuclear war among the superpowers, a war of intimidation by proxy. Henry Stimson of President Truman's cabinet called the first nuclear detonations in 1945 the second coming of wrath [1]. A "B.C." comic strip defined the word abomination as what a well-allocated nuclear arsenal should consist of. Perhaps the bomb, posing a historically new threat to life on the planet, was born in sin [2]. The total number of nuclear weapons tests for all purposes from 1945 to1984 was 1486, of which 762 have been by the USA, 535 by the U.S.S.R., 124 by France, 37 by England, and 27 by China [3]. The total announced yield of all weapons tests was about 500 MT. A total of about 10^{19} curies of fission products and 360,000 curies of Pu-239 that corresponds to a weight of 900,000 g have been released into the atmosphere as a result of nuclear weapons tests [4–6].[1] Atmospheric nuclear tests ended in 1963.

[1] Robert G Brooks, brother of Tony Brooks from S.A.R.I., participated in 'Desert Rock' as a military observer and 'guinea pig' during and after the detonation of an atomic bomb at the Nevada Test Site in 1951. He was placed in a 4-foot deep trench 3500 yards from ground zero. The detonation occurred atop a 200 foot tower. The yield of the bomb was ~15 ktn. Brooks said he saw a blinding flash of bright, white light that penetrated his eyes even though they were closed…A wave of heat engulfed me like the opening of a furnace door. This was followed by a giant explosion louder than a thousand claps of thunder. The ground shook as if an earthquake had hit causing the sand bags on the edge of the trench to topple in. Overhead, a blast of wind, laden with sand, stones, pieces of sage brush and metal loomed past as if carried by a hurricane. At the all clear the soldiers

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5.2 Hot Particle Problem

The fear of plutonium exposure has been greatly exaggerated by ignorant comments of the media and antinuclear activists who are not interested in truth and facts. Their agenda is to disavow, avoid, block, and deter nuclear power development. Helen Caldicott is a pediatrician and founding president of *Physicians for Social Responsibility*. She considered it her responsibility as an ardent antinuclear activist to make untrue statements about plutonium. In a 2013 article published in an Australian newspaper, Caldicott said that plutonium lasts for 240,000 years (actually it has a 24,110-year half-life), that plutonium is one of the most potent carcinogens known, and that plutonium readily crosses the placenta and causes birth deformities and heritable genetic effects [7]. None of these statements are true. The reality of science is quite different. The lethal dose (mass basis) for injected crystalline botulinum toxin is about a million times more potent than an injected dose of monomeric plutonium-239 [8]. Plutonium and its heavier transuranic neighbors are greatly feared by most people because of their association with nuclear weapons and from radiophobia-inducing inaccuracies from folks like Caldicott, whose ultimate agenda is to dismantle all nuclear power plants.

Glen T. Seaborg (1912–1999) first isolated and demonstrated the fissile behavior of Pu-239. He was lead investigator in rewriting the Periodic Table. Seaborg lived 87 years in spite of working intimately with transuranic elements.

A Columbia university study found that a single plutonium alpha particle induces mutations in mammalian cell culture [9]. This finding was used when plutonium was mentioned in news stories, often preceded by the adjective "deadly," "the most deadly element known," "a single speck of inhaled plutonium can kill a person," or similar outrageous, misleading statements. Ralph Nader claimed that a pound of plutonium could cause eight billion cancers. Another more recent claim is that the whole world would die if you could distribute 200 g of plutonium equally among them and that a single particle of plutonium (or even a single α-track) can cause cancer. A distinguished US senator in the 1970s had precisely said that.

Back in the 1970s, there was considerable interest in the possibility that one or a few "hot" particles of plutonium oxide could cause cancer. Tamplin and Cochran, antinuclear advocates, started the "hot particle" issue [10]. They believed that inhalation of a "hot" plutonium particle, presumably of plutonium-239 in insoluble dioxide form, by a human would lead to lung cancer. They failed to define what a "hot" particle is. They have clearly been debunked by decades of research

got out of the trenches and walked toward the tower. A huge ball of fire, turning from white to orange to bright red was raising itself toward the sky and a stem of dust was shooting up from the ground to meet it forming a giant mushroom, which zoomed to 50,000 feet. Robert Brooks died at the age of 89 of a heart attack.

publications. In fact, even American nuclear workers who have received the highest exposures to plutonium and other transuranic elements do not experience the cataclysmic destruction to their health that Caldicott, Tamplin, and Cochran had predicted. They actually live longer than the average folk [11]. This issue was scientifically examined [12]. The "hot" particle hypothesis was subsequently rejected by the US National Academy of Sciences (NAS), National Council on Radiation Protection and Measurements (NCRP), British Medical Research Council, UK National Radiological Protection Board, US AEC, and Nuclear Regulatory Commission (NRC). Bernard Cohen in 1977 published a paper in *Health Physics* that debunked this myth of plutonium toxicity [8].

5.3 Sources of Environmental Plutonium

Plutonium (Pu) is almost ubiquitous in the northern hemisphere from weapons testing. Miniscule amounts of plutonium are even naturally found within a few sandstone geological sites associated with highly enriched uranium deposits, such as in Gabon, Africa, and in an abandoned uranium mine in the Colorado Plateau. The world's first nuclear power plant was built in the city of Obninsk, U.S.S.R., in 1954. At present there are over 1000 nuclear reactors in the world on land and powering aircraft carriers and submarines and as research reactors (Fig. 5.1). Overall, nuclear power reactors provide about 10% of the world's electric power. The USA currently has the most generating power in the world and has plans for construction of new power reactors by the end of this decade. All these power plants "breed" plutonium, some intentionally to maximize the production of plutonium for construction of nuclear warheads. All isotopes of plutonium constitute about 1% of spent fuel mass. Literally tons of plutonium have been chemically isolated and stored from spent nuclear fuel in several countries of the world.

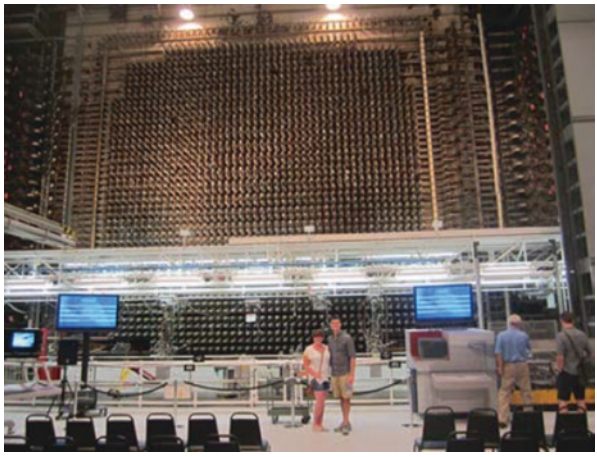

Fig. 5.1 Front face of the world's first plutonium production reactor (Hanford B-Reactor). The reactor went 'critical' in 1944 and continued to produce plutonium until 1968. (With kind permission of Gene Carbaugh, Richland, WA)

Millions of workers have been employed worldwide in the nuclear fuel cycle both for peaceful purposes and for the production of nuclear weapons. The world's nuclear power plants produce 10,000 kg of Pu-239 each year sufficient to construct 1000s of nuclear warheads per year. About 5 kg Pu-239 is required to fabricate a nuclear warhead [13] with a yield greater than the A-bomb dropped on Nagasaki, Japan, in 1945.

There have been many nuclear incidents and accidents from 1950 to 1990 [14, 15]. According to DeNike, over the 25 years of their existence, they (AEC) seem never to have been able to free themselves of their promotional bias when they found themselves in conflict with public health judgments which would seek to limit the free expansion of their technology…The AEC itself was reduced to a fanatically defensive protectionist clique of tenured bureaucrats who have been drawing job security and prestige from the miraculous achievement of the Manhattan Project…and whose best efforts since then have been divided between wildly inappropriate technological adventures and the justification of their past mistakes [16].

In 1957, President Eisenhower ordered the reassessment of steps that might be required to improve the Panama Canal. From this assessment came the idea of building a new canal using nuclear explosives as part of the *Plowshare* program. Plowshare program refers to the biblical phrase found in Isaiah 2:4: *They shall beat their swords into plowshares*. Plans were made to evacuate 40,000 native Indians in Panama as the new canal was being carved out with 315 MT in H-bombs. Interestingly, no plans were ever made to evacuate people around the Nevada Test Site. In fact, little effort was made to even warn them about potential dangers associated from fallout about more than 100 aboveground nuclear detonations carried out at the Nevada site. Underground nuclear explosions were used in project *Gasbuggy* in New Mexico (1967) and in project *Rulison* in Colorado (1969) to free natural gas from geological barriers. The idea never did work out and was abandoned.

Among the more interesting nuclear gadgets created by the AEC was project *Pluto*, a flying nuclear reactor buzz bomb similar to the German V-1 with a nuclear warhead up front; the project was scraped only after spending 1.5 billion dollars. Another 1.5 billion was spent for projects *Rover* and NERVA, for developing nuclear space rockets. The idea was to launch nuclear rockets from a NASA space shuttle. From 1959 to 1969, 31 nuclear rocket tests were carried out in Nevada before the projects were terminated. Among them was a test in 1965, dubbed Transient Nuclear Test (TNT) of the *Plowshare* series in which a nuclear reactor, named Kiwi, was intentionally allowed to explode, distributing small amounts of radioactive debris as far as 200 miles downwind.

The American handling of atomic weapons in peacetime has seen many mishaps. On several occasions, missile warheads have experienced accidental chemical explosive detonation and fires, which in one case caused burning plutonium to run along the airport runway. Two mishaps have involved the inadvertent launching of short-range US missiles carrying nuclear warheads. In 1980, a Titan liquid-fueled missile exploded in its silo in Arkansas, spewing its 9-MT warhead in the immediate countryside.

The US military has admitted to over 30 accidents involving nuclear weapons – which it terms *Broken Arrow*; the real number is undoubtedly much larger [17]. In early 1958, for example, a B-47 crashed into a fighter plane and jettisoned a nuclear weapon into the sea off Savannah Beach, Georgia. The bomb was never found. Later that year another B-47 accidentally dropped an atomic bomb while flying over Florence, South Carolina. When it hit the ground, an explosion with the power of several hundred pounds of TNT blasted out a crater 35 feet deep and spread a ring of plutonium around the area. In 1961 two more American atomic bombs were dropped over Goldsboro, North Carolina, by a crashing B-52. One deployed a parachute, which eased its fall to earth; the other broke apart on impact. Another B-52 with four hydrogen bombs aboard crashed into an ice floe near Thule, Greenland. The entire plane and its cargo apparently disintegrated, leaving a radioactive hole nearly half a mile long in its wake. With abundant apologies to the Danish government, which rules Greenland, the military was forced to ship 1.7 million gallons of contaminated ice and snow back to the USA for disposal. In January of 1966 yet another B-52 crashed into its refueling tanker and spewed three hydrogen bombs onto the fishing village of Palomares, Spain. A fourth bomb dropped into the Mediterranean. TNT exploded in two of the bombs and spread plutonium over a square mile, forcing the USA to destroy local crops and remove tons of radioactive topsoil back to South Carolina for burial.

Nuclear-powered, nuclear-armed submarines have sunk at sea. In 1986, a Soviet "Yankee" class submarine, with two nuclear reactors and 16 nuclear armed, SSN-6 ballistic missiles and a crew of 120, experienced a fire and explosion in one of its liquid-fueled missiles, blowing its warheads out the top into the sea. The sub sank into about 18,000 feet of water, 1060 nautical miles to the east of Cape Hatteras, North Carolina. Also in 1986, a ballistic missile launched from a Soviet submarine in the Barents Sea went 1400 miles off course, landing in China. Radiation killed sailors aboard a Soviet submarine in the Baltic Sea in 1961. Two Soviet submarines sank in 1968. In 1980 a fire killed nine crew members of another Soviet submarine. In 1983, another Soviet submarine sank in the North Pacific, killing 90. In 1985, a Soviet cruise missile went off course and landed in Finland. That same year, a Soviet nuclear-powered satellite crashed in the ocean; a similar satellite crashed in 1978 spewing radioactive material over a wide area of northern Canada.

Apollo spacecraft and a score of other satellites launched from June 1961 to March 1976 contained Pu-238-fueled nuclear power systems; Apollo spacecraft had a power source containing 44,500 Ci of Pu-238. Pu-239 has a half-life of 24,100 years, while Pu-238's half-life is 87.7 years. A total of about one million curies of Pu-238 had been placed on various space launches during this time. On April, 1964, satellite SNAP-9A was launched, containing a 17,000 Ci Pu-238 power source. It aborted on launch and burned up in the atmosphere on reentry, contaminating much of the northern hemisphere with about 100 g of Pu-238 fallout, equivalent in alpha particle activity to about 27,000 g Pu-239; Pu from the accident continued to fall out from the sky for several years.

On September 11, 1957, a spontaneous ignition of plutonium shavings occurred in a glove box at the Rocky Flats Plant located 15 miles northwest from Denver,

Colorado. The plant constructed Pu-239 warheads for nuclear weapons. The fire breached the roof and released an estimated 11–36 Ci Pu-239 (160–510 g) mostly as submicron Pu dioxide particles in the smoke of the fire. The released Pu-239 spread as a smoke plume to the northeast from Golden, Colorado [18]. Another Pu fire occurred in 1969 in a glove box at Rocky Flats; the Pu particle cloud was largely contained within the building by HEPA filters. Carl Johnson, health director for Jefferson County, claimed in 1981 to have found an increase in congenital birth defects and cancer rates for those living closest to the Rocky Flats Plant. A well-designed epidemiology study by Crump failed to find any health effects associated with the Pu fire or any other activities at Rocky Flats [19].

In 1970, Martell, a scientist from the National Center for Atmospheric Research, found out about the 1969 fire at Rocky Flats and collected soil samples downwind from the facility. He found plutonium concentrations that were up to 400 times the average background concentrations from global fallout. Martell claimed that submicron Pu particles released from Rocky Flats fire would cause radiation in the lung that was millions of times more intense than from an average naturally occurring radioactive dust particle of the same size. Only minute amounts in the lung are sufficient to cause cancer. Martell correctly predicted that alpha particles clump in pulmonary "hotspots" where their energy is concentrated at levels 100–1000 times their average lung concentrations, intensifying the potential for harm to surrounding cells.

5.4 Plutonium Particle Aggregation

Pu-239 emits alpha particles of 5.15-MeV energy which have a range in soft tissue of 45 μm or 180 μm in the deep alveolar region of the lung because of the presence of air. Nearly all environmental Pu aerosols are in the form of oxide, submicron-sized, insoluble particles. One nCi of Pu-239 weighs 2.5 ng. There are 3400–1.0 μm and 125,000–0.3 μm diameter Pu particles in 1 nCi of plutonium dioxide. The government mandated maximal permissible deposition of Pu-239 in the lung of a plutonium worker is 16 nCi or 2000,000, 0.3 μm diameter Pu particles dispersed in a 1000 g lung of standard man (2000 particles per gram).

A lifespan study with inhaled Pu-239 dioxide particles (count median diameter, 0.3 μm) was carried out in 3157 rats. Lung tumors were not seen at Pu particle concentrations <800,000 submicron diameter particles per g lung which corresponded to an observed threshold lung dose for lung tumor of 800 mGy (16,000 mSv) [20, 21]. Japanese researchers found a lung tumor, threshold lung dose of about 1 Gy from inhaled Pu-239 dioxide in rats [22]. Precancerous and epithelial tumors arose adjacent to Pu aggregates associated with microregions of very high radiation dose [23]. The conclusion from this study is that Pu particle aggregation explains the presence of a threshold. The radiation dose to focal areas of Pu particle aggregation is considerably higher than for the whole lung. There is no evidence in animal or epidemiological studies of any harm from inhaling thousands of submicron diameter Pu particles per gram lung.

Quantitative scanning electron microscopy shows a biphasic clearance pattern of inhaled Pu particles from the lung similar to that obtained by radiometric analyses (Fig. 5.2). Pu particle aggregation was seen in higher-dose animals by 90 days post-exposure. Aggregation was quantified by light and SEM autoradiography microscopy and by lung morphometry. Most of the radiation dose to the bronchiolar epithelium originated from Pu particles in nearby alveoli and clustering of particles in peribronchiolar and subpleural regions of the lung. Lung tumors arose from these Pu particle clusters, preceded by epithelial metaplasia (adenomatous and squamous cell). The threshold for lung tumor formation was >25 Pu particles/aggregates as seen on autoradiographs of paraffin lung sections (Fig. 5.3) [24–27].

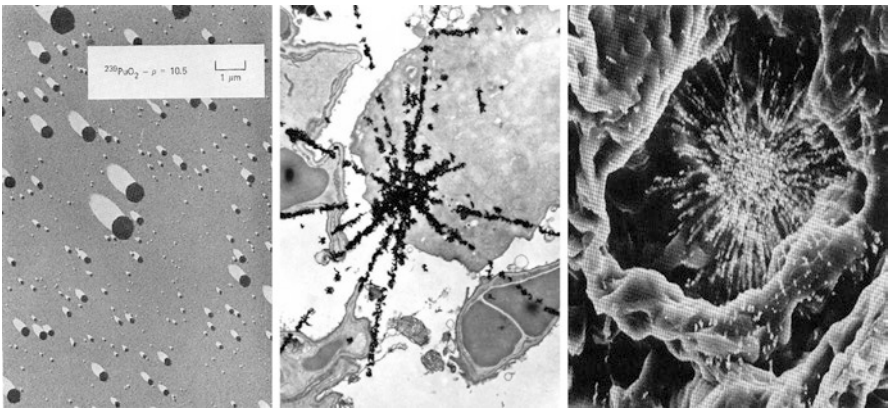

Fig. 5.2 Transmission electron micrograph of a typical plutonium dioxide aerosol (*left*) [20]. Transmission electron micrograph autoradiogram of a plutonium particle in an alveolar macrophage. Each *straight line* is comprised of reduced silver particles and represents one alpha particle (*center*) [28]. Scanning electron micrograph autoradiogram of a plutonium particle in an alveolar macrophage. The alveolar walls and intervening airspace are readily seen (*right*) [24, 26]

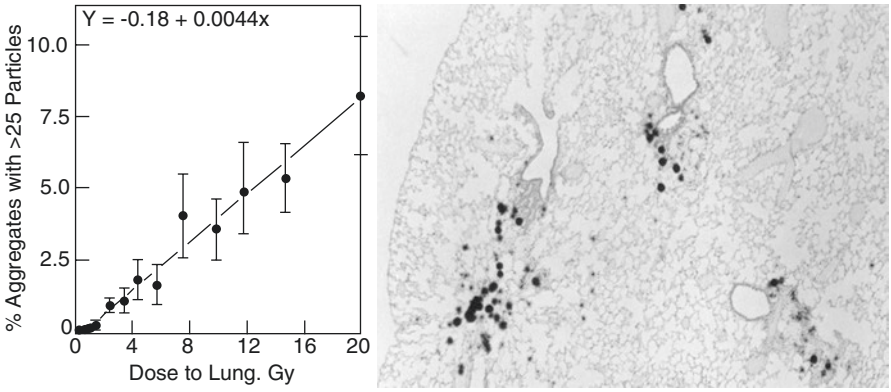

Fig. 5.3 Formation of large plutonium particle aggregates as a function of dose to the lung (*left*). Light micrograph autoradiogram of rat lung showing aggregation of inhaled Pu-239 dioxide particles at about 1 year after exposure [21, 25]

A study with Syrian hamsters was carried out in the 1970s at Los Alamos National Laboratory in New Mexico. The purpose of the study was to determine how radiation dose distribution influenced lung tumor formation. Animals were given an intravenous injection of two thousand to one million—10 μm diameter zirconium oxide ceramic microspheres that were loaded with varying amounts of plutonium-239 or plutonium-238. None of the 85 animals each receiving from 2000 to 11,000 microspheres, each microsphere containing from 9–60 pCi, exhibited evidence of precancer or cancer lesions. Lung tumors have not been observed to arise in small lung tissue volumes surrounding these large "hot particles" that give focal 100-Gy doses. The conclusion from these studies was that multiple large single particles containing plutonium are not carcinogenic in the lung [29]. About 1% of intraperitoneally injected $^{239}PuO_2$ particles found their way into the lung, representing up to several million 0.3-mm diameter Pu particles. Only one in 151 rats developed a primary lung tumor. Autoradiograms of the lung did not show Pu particle aggregations [30].

Pulmonary lymph nodes concentrate up to 4% of initial alveolar deposition of inhaled $^{239}PuO_2$ giving them a very high radiation dose. Lifespan studies of inhaled plutonium in rats and dogs have failed to find a single primary neoplasm originating from these lymph nodes [31, 32]. Primary tumors originating from pulmonary lymph nodes of plutonium workers or any other human population attributable to plutonium exposure have not been found.

5.5 Lung Cancer in Animals

Nonuniform irradiation of the lung from deposited radioactive particulates appears to be more carcinogenic than uniform exposure on a total lung dose basis. Alpha irradiation is more carcinogenic than beta irradiation by an order of magnitude [33]. Plutonium-239 emits a 37-KeV γ-ray along with a 5.1-MeV α-particle. Activated natural protection (ANP) by low-dose, low-LET irradiation acts to protect lung tumor formation from high-LET alpha irradiation as with inhaled Pu-239 in rat and dog models (Figs. 5.4 and 5.5; Table 5.1) and in humans. For example, 80% of α-radiation-induced lung cancer in rats was prevented by chronic low-dose-rate γ-radiation, activating a low-dose protective apoptosis-mediated (PAM) process and limiting potential cancer formation. PAM-related elimination of ROS, cigarette-induced or alpha irradiation-induced transformed pulmonary cells, decreases cancer risk [34]. Cuttler even suggested investigating the possibility of employing low-dose alpha radiation, such as from $^{239}PuO_2$ inhalation, as a prophylaxis against lung cancer [35].

Linus Pauling (1901–1994) received two Nobel prizes: the Nobel Prize in Chemistry in 1954 and the Nobel Peace Prize for his antinuclear peace activism in 1962. In his later years, Pauling promoted megavitamin therapy, especially the taking

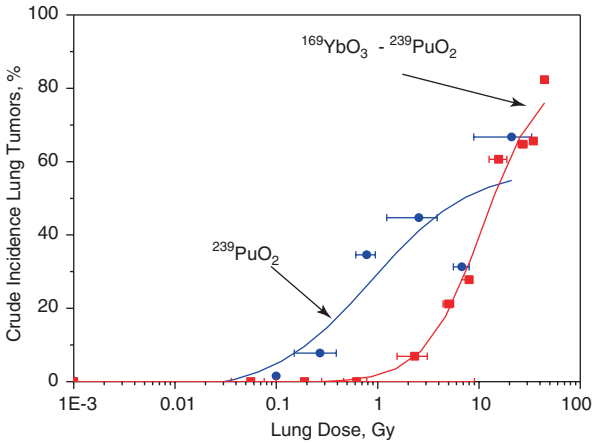

Fig. 5.4 Incidence of lung tumors as a function of lung dose at death. Comparison of identically designed studies of inhaled Pu-239 dioxide lifespan studies in rats, except for high temperature firing of plutonium aerosol with the gamma emitter Tb-169 to measure lung burden of inhaled Pu-239. Pu-239 only group (*blue*) [36] and Pu-239 + Yb-169 group (*red*) [21] (With kind permission by Springer, Charles L Sanders: Radiation Hormesis and the Linear-No-Threshold Assumption, © 2010)

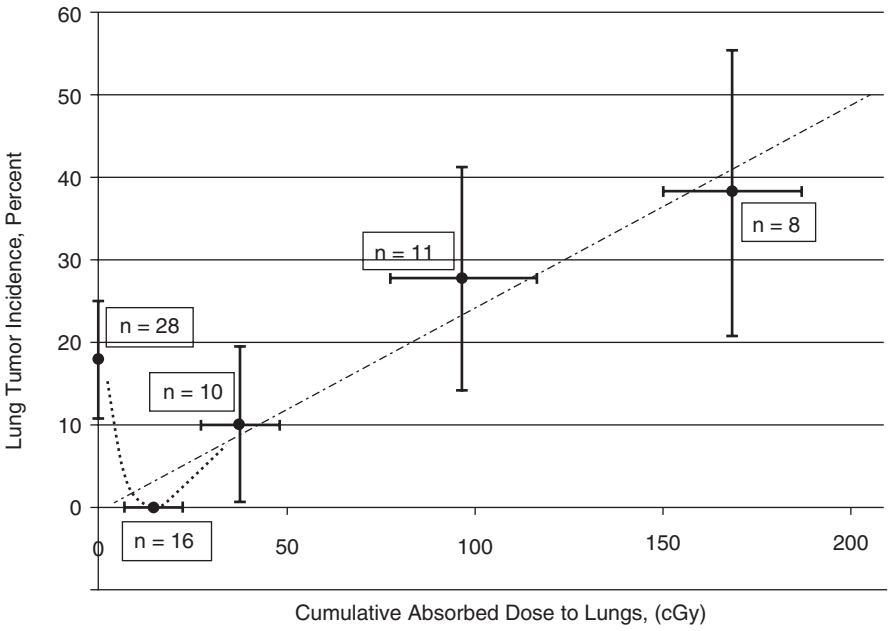

Fig. 5.5 Lung tumors in beagle dogs from inhaled $^{239}PuO_2$ as a function of lung dose (Adapted from Fisher DR and RE Weller. Carcinogenesis from inhaled $^{239}PuO_2$ in beagle dogs: Evidence for radiation homeostasis at low doses? Health Physics, © 2010 [39])

Table 5.1 Malignant lung tumors in lifespan rats following a single inhalation of high-fired, submicron diameter $^{239}PuO_2$ particles at 70 days of age

	Malignant lung tumors			
Number of rats	Lung dose (Gy)	Crude incidence (%)	Relative risk	Absolute risk[a]
1052	0.009	0.095	1.0	0
1389	0.056 ± 0.020	0	–	0
343	0.19 ± 0.09	0	–	0
145	0.62 ±0.16	0	–	0
58	2.32 ±0.77	6.9	73	290
38	5.03 ±0.60	21.2	220	420
18	7.99 ±0.67	27.8	290	350
33	15.7 ±3.1	60.6	640	390
17	27.1 ±2.7	64.7	680	260
32	34.5 ±2.7	65.6	690	190
17	44.4 ±3.1	82.3	870	185
15	55.1 ±3.7	46.7	490	85

Lung dose is mean ±standard deviation [21]

[a]Lung tumors per 10^4 rat-Gy. The threshold dose for lung tumor development was between 0.6 and 2.3 Gy

of large doses of vitamin C to control infectious diseases and cancer [37]. Pauling died at the age of 94 from prostate cancer, which may have been delayed by his habit of daily consumption of large doses of vitamin C. The continuous dosing with vitamin C in the drinking water of rats following the inhalation of Pu-239 dioxide particles was found to suppress the formation of squamous cell carcinomas in the lung [38].

5.6 Plutonium Carcinogenesis in Humans

KZ Morgan recounted an incident in 1945 by a colleague, Dr. Robert S. Stone, associate director of health of the Manhattan Project: Stone entered Morgan's office and said, "Karl, you remember that black truck driver who had multiple fractures in an accident and we rushed him to the (military) hospital?...Almost all of his bones were broken and we were surprised that he was still alive when he got to the hospital, we did not expect him to be alive the next morning so this was a good opportunity we've been waiting for. We gave him large doses by injection of plutonium-239. We were anticipating collecting not just urine and feces but a number of tissues, such as skeleton, liver, and other organs. This morning when the nurse went into his room, he was gone. We have no idea what happened, where he is, but we've lost valuable data we were expected to get. The driver's obituary appeared in a Knoxville paper many years later. Little effort was made to locate the missing "terminal" patient loaded with plutonium, which appeared not to have contributed to his death" [40]. A controversial study associated with the University of Rochester was carried out in 1951 that involved the IV injection of 95–400 nCi Pu-239 in 17 "terminally ill" patients. Eight of the 17 patients lived from 8 to 44 years after injection. None died from cancer or any other radiation-related disease [10].

There were tens of thousands of plutonium workers in the USA and U.S.S.R. who had inhaled large numbers of plutonium particles up to decades ago and have suffered no ill effects. One group of plutonium workers received a cumulative 2×10^{15} α-particle emission to the lungs without health problems. The radiological hazards of plutonium are the same types and magnitudes seen with naturally occurring elements such as α-particle emitting uranium, thorium, radium, and polonium which are present in the food we eat, in the water we drink, and in the air we inhale. All-cause mortality and lung cancer mortality was less than observed in non-plutonium workers or in the general public at US plutonium facilities [41]. The campaign to frighten the public about Pu toxicity appears political to the core [42].

Mayak (formerly Chelyabinsk-65 near Kyshtym) is a nuclear complex located in the Southern Urals. It included nuclear reactors, a radiochemical plant for plutonium separation, and a plutonium production plant. From 1948 to 1958, the Mayak region contained 200,000 inhabitants, including 100,000 nuclear workers. All the reactors were located near the SE shore of Lake Kyzyltash. They used open-cycle cooling with water from the lake being pumped directly through the reactor cores. About 120 million curies ^{137}Cs and ^{90}Sr, along with a host of other fission products from liquid radioactive waste, were dumped into the lake (compared to only 1.2 million curies released by the Chernobyl accident). Lake Kyshtym is ½ mile x ¼ mile and 8′ deep. The dose rate at the inlet and water surface was several Gy per hour. Plant 235 of the Mayak 2 facility was used since 1979 to store weapons-grade plutonium from Russia's dismantled nuclear weapons for later reuse. A vitrification plant for high-level liquid wastes has been operating at Mayak for over a decade.

Thousands of plutonium workers were employed by the Stalin regime in Mayak, situated among the Ural Mountains of the U.S.S.R. during the Cold War of the late 1940s and early 1950s, to feverishly construct their first nuclear weapons. They toiled under poor radiation protection procedures and in an environment contaminated with plutonium. Exposures and incorporations of plutonium were highest in the early years of operation. For the 10,655 workers hired before 1959 who had been monitored for external radiation, the mean cumulated external dose was 1.2 Gy, mostly from Co-60 γ-rays. About 1100 workers had estimated plutonium incorporations that exceeded 1.5 kBq (40 nCi) and extended up to 172 kBq (4662 nCi) (Table 5.2). The result was a worker cohort receiving not only a high α-radiation dose to the lung from Pu but also a high γ-exposure from Co-60. Even so, a significant increased lung cancer incidence due to radiation did not occur until a lung dose

Table 5.2 Body deposition of Pu-239 (kBq) and odds ratio of lung cancer in Mayak plutonium workers [43]

Pu-239 body burden, kBq	Odds ratio for lung cancer
0.010	1.0
0.34	0.56
1.18	0.59
4.20	0.83
16.5	2.48
54.2	59.3

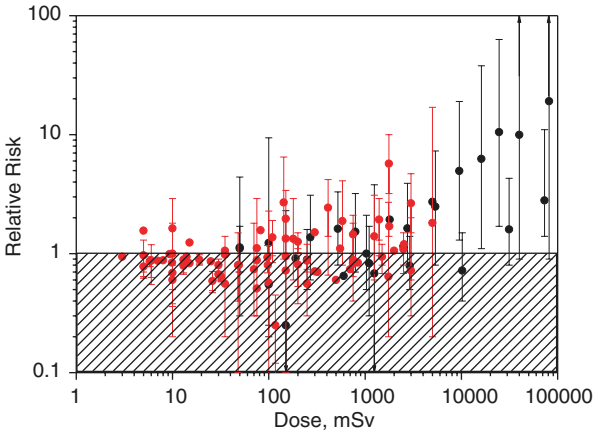

Fig. 5.6 Relationship between cumulative lung dose from exposure to low- and high-LET radiations and relative risk of lung cancer in nuclear workers; data points are means (±95% CI) from 46 epidemiological (non-radon) studies taken without apparent selection bias. High LET alpha particles (*black dot*); Low LET gamma rays (*red dot*) [11]. (With kind permission by Springer, Charles L Sanders: Radiation Hormesis and the Linear-No-Threshold Assumption, © 2010)

of 0.8 Gy (16 Sv) had been accumulated [25]. This constitutes the only group of humans that have experienced an increase in lung cancer from inhaled plutonium (Fig. 5.6).

A case-control study of 162 lung cancer cases and 338 controls was carried out at Mayak. The lung cancer incidence in Mayak nuclear workers exposed to ^{239}Pu showed a threshold of about 3.7 kBq (lung dose of 0.8 Gy) for incorporated ^{239}Pu that was described by linear-quadratic and quadratic models. Both squamous carcinoma and adenocarcinoma lung tumor incidences showed thresholds of about 1 Gy. The dose-response curve was linear at lung doses >5.2 Gy. The Pu workers also had a cumulative gamma radiation dose, mostly from cobalt-60, of about 1 Gy [43, 44]. The lung cancer data was corrected for cigarette smoking. The dose lung tumor response in Mayak workers was similar to what was observed in rats, both indicating a threshold of about 0.8 Gy (16 Sv) [21, 45].

The secret city of Ozyorsk was created in 1945 to house the nuclear workers involved with nuclear reactors and radiochemical and reprocessing plants in the Mayak nuclear facility. Many of the workers were exposed to plutonium, fission products, and external γ-irradiation. The all-cause mortality ratios compared to national U.S.S.R. mortality from 1953 to 2010 were 0.65 (35% less) for men and 0.56 (44% less) for women. Even when compared to nonnuclear working residents of Ozyorsk, the mortality ratios for nuclear workers were 16% less for men and 24% less for women [46].

A 42-year medical follow-up of 26 former Manhattan Project plutonium workers (1944–1945) who had been exposed to high levels of plutonium aerosols was carried out; the Pu workers had a relative risk (RR) of 0.41 for all-cause mortality [12]. Later reviews continued to show less than expected lung cancer [47, 48]. Several

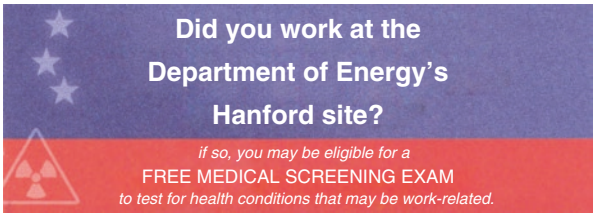

Fig. 5.7 The author worked at the Hanford site studying the pathobiology of plutonium and other transuranics from 1966 to 1993. He received this notice in October, 2016, that continues to perpetuate radio-phobia, in spite of overwhelming epidemiological evidence that there is no health risk but instead a health benefit to Hanford workers [49–53]

epidemiological studies of Hanford workers failed to demonstrate all-cause, all-cancer, or lung cancer risks [49–52]. Hanford workers with routine handling for plutonium exposure exhibited radiation hormesis with lower all-cause mortality rates and lower lung cancer rates than other Hanford workers (Fig. 5.7) [53]. A survey of mortality among plutonium workers showed an RR of 0.62 (38% protected) for all-cause mortality [54]. No study showed an increased risk of lung cancer. A cohort of 16,303 plutonium production workers employed at Rocky Flats Plant from 1952 to 1989 showed no associations between lung cancer mortality and radiation dose [55]. In fact, all-cause mortality in 350,000 nuclear workers at 154 nuclear facilities from 15 countries was 38% less than expected, resulting in a prolonged lifespan compared to nearby resident unexposed populations. Many other studies of nuclear workers showed a benefit in reduced all-cause mortality as a result of thresholds and radiation hormesis [11].

5.7 U.S.T.U.R.

The United States Transuranium and Uranium Registries (U.S.T.U.R.) and the associated National Human Radiobiology Tissue Repository are unique resources worldwide for the comprehensive study of the biokinetics and internal dosimetry of actinide elements in the human body. A finding was that the biological half-life in the deep lung for inhaled plutonium dioxide particles is greater than a human's lifespan.

The U.S.T.U.R. was established in 1968. The U.S.T.U.R. accepted volunteer donation of whole or partial body (organs) from individuals exposed to "high" levels of uranium or transuranic elements. Autopsy and tissue distribution studies of radionuclides were carried out at laboratories in the state of Washington. Tissues were examined by pathologists. An analysis of 319 U.S.T.U.R. deceased plutonium workers found no association between radiation dose from plutonium deposition and death due to cancer or any other disease [56]. In fact, death rates for U.S.T.U.R. registrants were significantly lower than expected using life tables for the US general public. Participants exceeded life table longevity expectation by an astounding average of 10.4 years [57].

Americium-241 is a man-made transuranic isotope formed following the emission of β-particles by Pu-241. Am-241 has a half-life of 433 years and decays with the emission of a 60 KeV gamma ray and a 5.5-MeV α-particle. In animals, Am-241 causes lung, liver, and bone tumors at high doses [58]. In 1983, a young man was accidentally exposed to significant amount of. Pu/Am; no decorporation measures were taken. Thirty years later his effective lung dose was estimated at 1 Sv. No health consequences of americium exposure were noted [59].

A most interesting and celebrated accident case associated with Am-241 occurred in 1976. The accident resulted in extreme contamination and physical injury to a nuclear chemical operator named Harold McCluskey (later named "The Atomic Man"). Numerous articles, including a special edition of the *Health Physics* Journal, Volume 45, Issue 4, published in October 1983, were devoted to this accident and the medical and decontamination treatment received by McCluskey. His medical and radiological status was followed until his death in 1987 from a preexisting cardiac condition totally unrelated to the accident.

A 64-year-old Hanford operator named Harold McCluskey (U.S.T.U.R. Case 246) [60] was injured by a chemical explosion in a glove box used for recovery of Am-241. As a result of the accident, the operator was heavily contaminated and sustained a substantial internal deposition of Am-241, through skin burned with nitric acid, cuts with flying debris, and by inhalation. He was administered intravenous calcium diethylenetriaminepentaacetic acid (CaDTPA) for several months which probably saved his life. DTPA has a high association constant for americium and plutonium in biological fluids causing chelated Am-DTPA to be rapidly excreted in the urine [23]. Based on previous biokinetic studies and autopsy tissue samples, the estimated cumulative bone surface dose to McCluskey was greater than 120 Gy. Very high cumulative doses to the lung, liver, and skeleton of 1.6, 8.0, and 18 Gy, respectively, were seen at death. The cumulative effective doses using an RBE of 10 were 16 Sv to the lung, 80 Sv to the liver, and 180 Sv to the skeleton [61]. Lung tissues obtained at autopsy showed hotspots of α- activity from Am-241 at 11 years after the accident.

Mr. McCluskey's chest radiographs, pulmonary function tests, and electrocardiograms were normal right after the accident. He had a previous history of acute myocardial infarction. He died at the age of 75, 11 years after the accident, of emphysema and congestive heart failure. There was no evidence of precancerous or cancer lesions at autopsy, but there were focal regions of Am-241 concentration (Fig. 5.8). The probability of observing a fatal cancer based on radiation protection risk factors with these absorbed doses was predicted to be 88% [21]. It is possible that Mr. McCluskey lived longer than expected because of the intense chelation therapy which could have been effective in treating his ongoing heart disease. The biological effects of intense α-irradiation of vital organs by Am-241 may have partially been negated by low energy γ-rays also coming from Am-241, as a result of the adaptive response. Overall, Am-241 seemed not to play a role in his longevity. In contrast, high-dose inhaled $^{241}AmO_2$ in rats does induce tumors in the lung, bone, and liver [58].

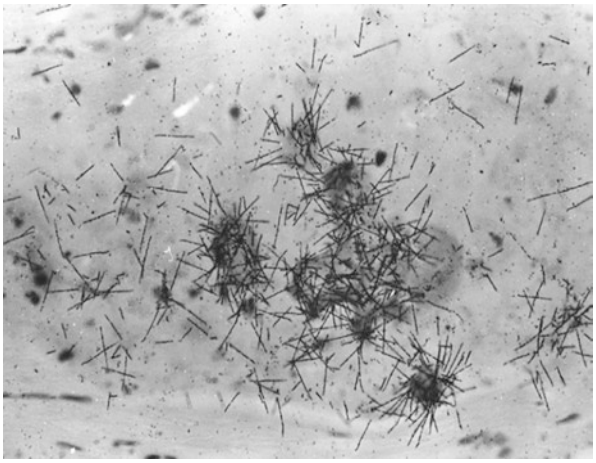

Fig. 5.8 Autoradiograph of small cartilaginous area in the lung taken at autopsy showing the distribution of Am-241

The U.S.T.U.R. in Richland, WA, convinced nuclear workers with "high" levels of plutonium and other transuranic elements in their bodies to give all or part of themselves upon their death for research study. They must have thought that they were at high risk for developing cancer and dying a premature death from the "ravages" of plutonium and radiation. Even Harold McCluskey with his enormous radiation doses to key organs failed to develop cancer or even exhibit a decrease in lifespan, in spite of his preexisting cardiac condition.

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Wonderful Radon

6

It is more prudent to worry about getting too little radon than too much.

6.1 Continental Surveys for Radon

In 2016 the American Lung Association (ALA) led a national work group to develop the *National Radon Action Plan: A Strategy for Saving Lives*. ALA was formed in the United States in 1904 in response to only one disease: tuberculosis (TB). At the time about 450 Americans died each day from TB, most between the ages of 15 and 44, very few recovered by rest, diet, and moderate outdoor exercise. In 1882 Robert Koch isolated the causative agent, *Mycobacterium tuberculosis*. Edward Trudeau (1848–1915) believed that rest, diet, exercise, and cool fresh air of the mountains could cure TB. Trudeau had much greater success in curing TB with his methods using mountain air. Hermann Brehmer was cured of TB while living in the Himalayan mountains and built the first TB sanatorium in the Adirondack Mountains of New York. Some springs of the Himalayas contain high radon levels [1]. Other American TB sanatoria were built in the mountains of Virginia and North Carolina and then in mountains of western states. A significant association of radon level and TB cures in sanatoria has not been made, although radon levels and background radiation tend to be higher in mountain regions; as such the association is an intriguing possibility (Fig. 6.1).

Is radon a poison or a cure? [2]

X-ray fluoroscopy examinations were given repeatedly in Canada and Massachusetts during the treatment of tuberculosis patients from the 1940s to 1960s. Cumulative doses to the lungs ranged up to 3 Gy. Cumulative doses of about 1 Gy

C.L. Sanders, *Radiobiology and Radiation Hormesis*,
DOI 10.1007/978-3-319-56372-5_6

Fig. 6.1 The western third of the USA is largely mountainous (US Geological Survey, http://ned.usgs.gov/images/nedus2.gif)

resulted in a benefit with risks of breast cancer and lung cancer decades later that were less than seen in unexposed control populations [3–6]. The sensitivity of the tubercular microorganism to X-rays was noted as early as 1896 (Chap. 7). X-rays were subsequently used to treat tuberculosis for the next few decades. Although not studied, it is possible that later tuberculosis patients receiving fractionated X-rays exposures benefited not just from visualization of treatment progress and radiation hormesis but also from direct effects of X-rays on mycobacterium.

The World Health Organization (WHO) has called radon the second leading cause of lung cancer, second only to tobacco. About 7% of Canadians live in homes above the American guideline of 4 pCi/L. The Canadian government takes a radiophobic position, estimating that 16% of all Canadian lung cancers are due to radon. The government claims that it has a way to clearly make a difference by waking up its population to the deep dark secret that is killing Canadians. For them, doing nothing about radon gas in Canada is unacceptable [7]. The Environmental Protection Agency (EPA) is projected to lead the plan, to address the radon problem in the USA. The aim of the plan is to annually save 3200 lives by the year 2020.

A number of homes in Lehigh County, Pennsylvania, were found in 2016 to have radon levels over 1000 pCi/L.[1] The Watras family of a husband and wife and three young children lived in Pennsylvania. The husband worked at a nearby nuclear plant. One day when being monitored before entering the facility he set off radiation alarms.

[1] Press release, 11/17/2016, Department of Environmental Protection, Commonwealth of Pennsylvania.

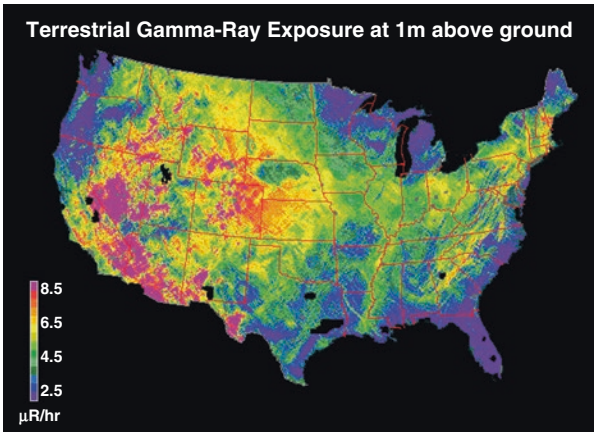

Fig. 6.2 US Geological Survey digital data series DDS-9, 1993, shows highest terrestrial gamma-ray exposures to be in the western U.S. [113]

The radioactivity was traced to his home where radon levels over a 100 times the EPA limit were found. The EPA predicted dire consequences as a result. That was in 1984. The EPA today continues indoor radon policy based on unsupported and biased opinion.[2] Today the Waltras' family is alive and healthy [9]. Not only will implementation of radon reduction be costly but it will not save lives. The actions of WHO, EPA, and ALA will paradoxically and markedly increase lung cancer mortality [10].

An inverse association between radon and cancer was also shown by Jagger comparing Rocky Mountain States and Gulf Coast States [11] and later by Hart who found a mean cancer mortality rate at low elevations in the U.S. to be 73.5±18.4 vs. 53.9±13.8 at high elevations; the difference was highly significant at $p<0.0001$ (Fig. 6.2) [12]. High altitude was also protective for heart disease [13]. Ecological epidemiological studies of US cities, using GIS software from Google Earth, have shown significantly decreased cancer rates with increased natural background radiation levels. The association was similar in both cities and counties [14]. Living at a low altitude is the second greatest cause of lung cancer (not radon) just below cigarette smoking [15]. Thus, land elevation is inversely related to cancer mortality [16]. The National Institutes of Health cancer map for 2006 showed that cancer mortality rates, particularly for lung cancer (Fig. 6.3), were lowest in the western mountainous states.[3]

The levels of natural background radiation increase with increasing elevation [17]. In 1971 a Federal Court found the Atomic Energy Commission (AEC) Environmental Impact Statement to be inadequate. The AEC then contracted for the *Argonne Radiological Impact Program* to improve the basis for assessing low-level radiation health effects with Dr. Norman Frigerio as the program director. Frigerio's results contradicted the LNT: There were consistently lower cancer rates in high

[2] Over the last 12 years the EPA has not provided any further analysis that demonstrate a statistical association of indoor radon levels that the EPA says are 'dangerous' with lung cancer risk.

[3] Cancer map of the U.S. for 2006. The National Cancer Institute. http://statecancerprofiles.cancer.gov. Accessed 31 Dec 2009.

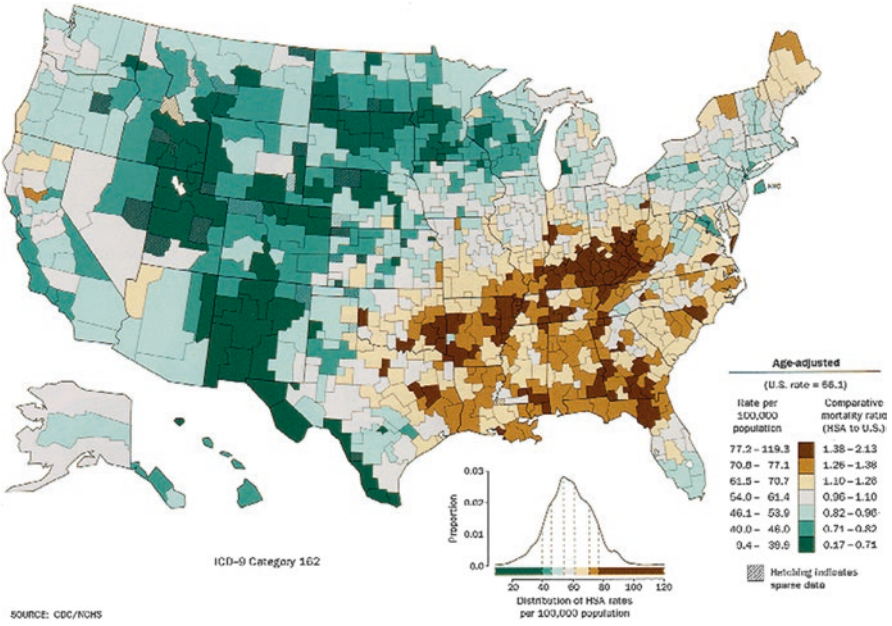

Fig. 6.3 Lung cancer mortality rates for white males in counties of the USA. Centers for Disease Control and Prevention and National Center for Health Statistics (CDC/NCHS). Last updated 2010 (https://www.cdc.gov/nchs/products/other/atlas/lcwm.htm)

background radiation states. This finding has since been consistently confirmed [18]. In 1973, the AEC terminated the study, and the results were not published. The study was presented at a 1976 conference on natural radioactivity, sponsored by the International Atomic Energy Agency (IAEA). However, Frigerio's results were suppressed in the 1977 Radiation Committee (BEIR III) in 1980, with no scientific inquiry. The results of the Argonne study were later confirmed in analysis of EPA radiation data of high vs. low background radiation states. Subsequent conferences on natural background radiation consistently reported the lack of health effects and the existence of beneficial effects, in high background exposed populations. The clear results of health benefits from radon have been ignored by the EPA, DOE, NCRP, ALA, WHO, IAEA, and ICRP.

6.2 Dosimetry

About 600 trillion tons of primordial radionuclides (U, Th, K) are in the earth's crust. Much larger amounts (60,000 trillion tons, including radioactive decay products), that are in the interior of the earth, heat the earth's core to a temperature of 11,000 °F. Uranium-238, thorium-232, and potassium-40 were present at the time of the earth's creation. Uranium and thorium undergo a series of decay events leading to emissions of α-, β-, and γ-radiations while predictably changing from one element to another (Fig. 6.4). Each decay occurs with its own precise half-life. Both

end their cascading decays with stable lead. The half-lives for radon emissions are 3.8 days for Rn-222 from uranium-238 and 56 s for Rn-220 from thorium-232; Rn-220 is also called thoron.

Over half of background radiation exposure in the world is due to radon and radon daughter exposures from radioactive decay of uranium and thorium (Fig. 6.5).

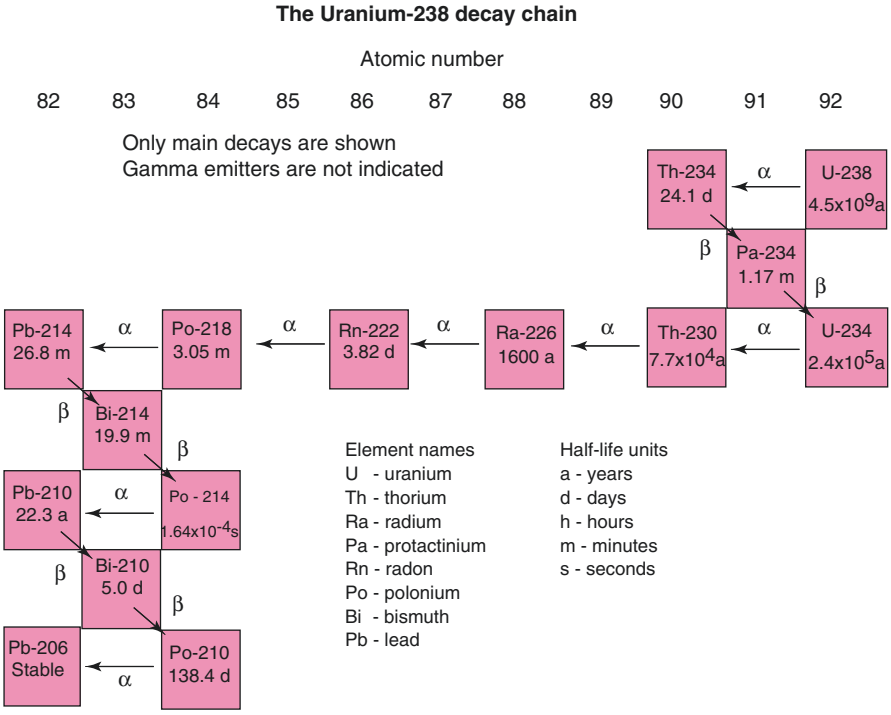

Fig. 6.4 https://pubs.usgs.gov/of/2004/1050/U-238-Decay-Chain.gif

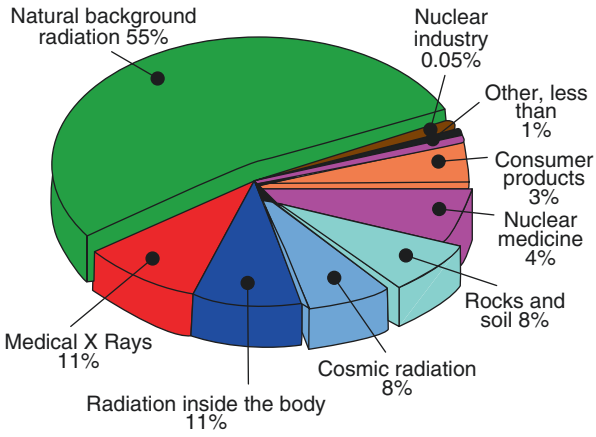

Fig. 6.5 Human sources of radiation dose (National Council on Radiation Protection and Measurements, NCRP Report 93)

Radon has an atomic number 86 and naturally occurs from the decay of radium. Radon is 7.6 times heavier than air and readily dissolves in water. Radon-222 emits 5.5 MeV alpha particles with a range in soft tissue of about 50 μm.

Radon and radon daughters are ubiquitous in our environment due to the dispersal of U-238 and Th-232 in soils and rocks at part per million concentrations. Uranium-238 decays through a series of 14 radionuclides with individual radioactive half-lives of fractions of a second to billions of years. Radon is an inert, colorless, odorless, heavy, radioactive gas that accumulates in the basement of residential homes. Surface air radon in the world averages about 1×10^{-10} μCi/cm^3 (100 pCi/m^3). High levels of radon in seeds of glass or gold and of radium in capsules and needles are used to treat cancer. The molecular, cellular, and pathogenic mechanisms from the effects of radon are different at low doses than at high doses [3].

A 70 kg adult, human body has 90 μg uranium isotopes, 30 μg thorium isotopes, 17 μg potassium-40, 31 pg radium isotopes, 22 ng carbon-14, 60 ng tritium, and 0.2 pg polonium isotopes.[4]

About 30% of the dose from radon and daughter products is low-LET (linear energy transfer) radiation, primarily β-particles and γ-ray emissions. The biological half-life for Rn-222 in the human body is about 45 min. About 80% of inhaled radon is expelled from the body during the first 2 h after the end of exposure. The 1993 report of UNSCEAR (the United Nations Scientific Committee on the Effects of Atomic Radiation), *Sources and Effects of Ionizing Radiation*, uses a radon conversion factor of 25 μGy/year per Bq/m^3 with an indoor occupancy factor of 0.8 or about 7000 h/year; a thoron conversion factor of 22 μGy/year per Bq/m^3 was inferred for the same occupancy conditions.

Because of the complex chain decay of uranium, radon radioactivity concentration is sometimes expressed in units of the working level (WL), particularly to measure lung dose for uranium miners. The working level is defined as the concentration of short-lived radon daughters that emit 1.3×10^5 MeV of alpha energy in 1 L of air; 1 WL = 100 pCi/L or 3700 Bq/m^3 for radon in equilibrium with its daughter products. Exposure to 1 WL for 170 h is equivalent to one working level month (WLM) [19]; 1 WLM delivers a dose to the bronchial epithelium of from 5 to 20 mGy. ICRP estimates the dose from inhaled radon to be 12 mGy per WLM for uranium workers and 9 mGy per WLM for residential radon exposure. A radon level of 300 Bq/m^3 in homes corresponds to an annual dose to the lung of ~10 mGy [20].

The EPA estimates the average indoor radon level in American homes to be 1.3 pCi/L. EPA residential action levels are 4 pCi/L for air exposure and

[4] Based on information from: http://physics.ise.edu/radinf/natural htm (courtesy of Bobby Scott).

4000 pCi/L for drinking water exposure. A 1000 WLM dose accumulation is equivalent to a dose of ~1 Gy to the lung. Dose to the lung from residential radon should be typically expressed in mGy.[5]

6.3 High Background Radiation Areas

The normal background radiation areas (NBRAs) of the world provide an average dose of about 2.5 mGy/year. However, there are many HBRAs (high background radiation areas) in the world [3]. One is comprised of thorium-enriched beach sand along the southern coast of India where the absorbed gamma dose rate is about ten times above other areas of India (Fig. 6.6) [21]. Other HBRA sites occur in Iran, China, and Brazil [22, 23]. Beneficial effects result from a prolonged exposure to high levels of natural radiation for inhabitants of HBRAs, which are inconsistent with LNT projections [24]. The cancer risk from low-dose radiation has been highly politicized. This has led to a frequently exaggerated perception of the potential health risks from radiation to the public which is not seen in HBRA areas of the world [25].

The world's highest dose HBRA is found in Ramsar, Iran. NORM (naturally occurring radiation material) refers to natural levels of radon and radium often

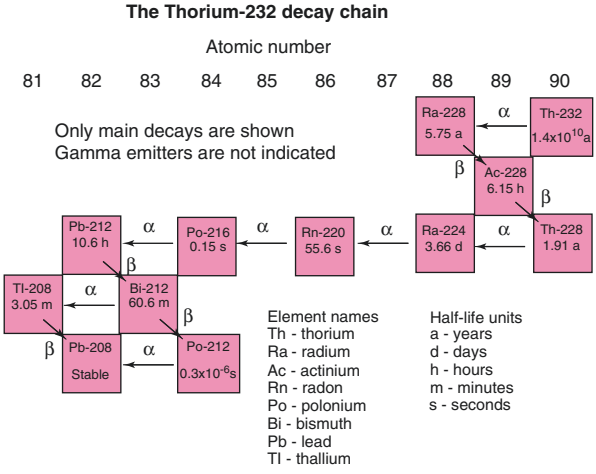

Fig. 6.6 https://pubs.usgs.gov/of/2004/1050/Th-232-Decay-Chain.gif

[5] The Sv unit is connected to man (dose-equivalent). The Gy represents absorbed dose. The Sv should not be used in biological experiments with animals and plants. Even so, a large number of published articles and opinions inappropriately use the Sv. The Sv (rem) units are concerned with 'deleterious effects on man' and are based upon the LNT assumption. The Gy is the unit of absorbed dose. Many believe that the Sv and Gy are interchangeable; they are not. The Sv is hypothetical and not uniquely defined and implicitly includes the LNT, additivity, collective dose and ALARA. Source: Health Physics website, www.hps.org fact sheets and Bobby Scott, S.A.R.I.

associated with natural gas wells and with Ramsar [26].[6] In Ramsar, natural radiation levels are 55–260 times greater than the average global dose rate; the annual radiation absorbed dose reaches as high as 260 mGy, which is 13 times higher than the current annual dose limit of 20 mGy suggested by the ICRP for radiation workers. The indoor radon concentration in one region of Ramsar, comprising 2000 individuals, was up to 31 kBq/m^3, a concentration that is over 200 times higher than the action level recommended by the EPA of 148 Bq/m^3 or 4 pCi/L [27, 28]. Many homes in Ramsar are constructed from limestone containing $RaCO_3$ giving in-home radon levels of 100 pCi/L or 3700 Bq/m^3; some residential radiation levels were >100 μGy/h. Some want to "protect" inhabitants of Ramsar by making it into *Ramsar Research Natural Radioactive Park*[7] and evacuating its citizens. Myron Pollycove addressed the question, "What is safe?". In visiting Ramsar, Iran—a city where part of the population has been living for many generations with very high natural background dose rates—he was impressed by the fact that public health and longevity is greater in the high radiation parts of the city. He pointed out that the DNA in our cells is constantly being destroyed and reconstituted, and it is becoming apparent that low doses stimulate the reconstitution process. Pollycove's conclusion: We don't have to worry about chronic radiation [29].

Up until 1991, over a 1000 students had attended Saeid Nafisi primary school in Ramsar. The background radiation dose was 28 μGy/h giving an annual dose of ~250 mGy/year. Students who are now a mean of 27 years old, who studied at the school for at least 5 years, were examined for health problems. No significant differences were noted between matched controls. In fact, there was a small positive beneficial difference in students from Saeid [30].

There are at least nine hot springs in Ramsar that are used by tourists and residents as spas. Some spa water sources contain up to 200 times higher levels of radioactivity than other low background levels in Ramsar. The people and their ancestors have been exposed to these high radiation levels over many generations. Yet, adverse health effects attributable to radiation have not been seen.

Short-term exposure to radon elicits an adaptive response in Balb/c mice [31]. Cytogenetical, immunological, and hematological studies on the residents of high background radiation areas of Ramsar demonstrate adaptive responses. Lymphocytes of Ramsar residents when subjected to 1.5 Gy of gamma rays showed fewer induced chromosome aberrations compared to residents in a nearby low background dose control area [32].

Ramsar is divided into eight health districts, and a health center provides primary health services in each health district. Indoor radon concentration levels were previously measured in each dwelling by the Iranian Nuclear Regulatory Authority experts. The overall cancer mortality, lung cancer mortality, and neonatal death rate of different districts were collected. The highest radon level residences were located

[6] Low level radioactive wastes placed in local landfills following oil and gas removal from Marcellus shale in Pennsylvania have radiation alarms set at 140 μrem/h.

[7] A 1997 video by Pollycove on the non-existence of the LNT is recommended. http://www.youtube.com/watch?v=pTOrRakmKjE

in Ramak. The highest lung cancer mortality rate was in Galesh Mahaleeh, where the radon levels were normal. On the other hand, the lowest lung cancer mortality rate was in Ramak, where the highest concentrations of radon in the dwellings were found [33]; overall, there was no increase in total cancer risk [34].

Thirty five individuals from a HBRA and 35 individuals from a normal background radiation area (NBRA) were randomly selected from districts of Ramsar. Among the eight biomarkers investigated, the means of PSA, CA15.3, CA125, CA19.9, and AFP concentrations between the HBRAs and NBRAs were not significantly different. However, Cyfra21, CEA, and Tag72 in HBRA group revealed statistically significant increases compared to those of NBRA group ($P<0.05$) [35]. Cancer mortality rates in Ramsar from 2007 to 2012 for GI, breast, leukemia, bone, gynecological, skin, and urinary tract cancers in the residents of HBRAs were much lower than those of the nearby normal background radiation areas (NBRAs) [36].

6.4 Uranium Mines

The Paracelsus paradigm, "the dose is everything," is ageless. The concept that small doses of poisons are stimulatory was verified experimentally by a Greifswald pharmacist, Dr. H. Schulz, in 1888 for mercury, chromium, arsenic, and iodine with studies using yeast cultures. This established the Arndt-Schultz law, which generally said that sufficiently diluted toxicants should have a beneficial effect on the organism.

Sixty miles from Prague, Czech Republic, are the sixteenth-century silver mines of Joachimsthaler. Silver coins from the mine were called "thalers" which became dollars in English. The mines produced a black, pitchy, heavy nodular mineral called pitchblende. Martin Klaproth (1743–1817) named the most prominent element in pitchblende, uranium. It was from pitchblende that Pierre and Marie Curie laboriously separated and named the first samples of new elements, radium and polonium [37]. In 1898 Marie and Pierre Curie also found a radioactive gas emanating from radium purified from pitchblende uranium ore [38]. Radon-222, a daughter product of radium, was described in 1900 by Dorn.

> The world's land-based uranium resources will suffice for the next 470,000 years at present usage rate according to the IAEA (2008). There are four billion tons uranium dissolved in seawater (three parts per billion) that is continuously replaced from 100 trillion tons of uranium in rocks on land. Polyethylene fibers coated with amidoxime (which binds with uranium) placed in seawater for 50 days yields 6 g U per kg fiber at a cost today that is only double current price [39].

Radon levels in the Joachimsthaler mine reached as high as 1,000,000 Bq/m^3. Paracelsus (1530) described a wasting disease in Czech miners, and Agricola recommended ventilation in mines to avoid this sickness. The sickness was identified as

pulmonary fibrosis and lung cancer in 1879. Up to 1926, as many as 75% of miners working in these mines had died from lung fibrosis and cancer. Miners at Joachimsthal and nearby mines at Schneeberg, Germany, also showed a remarkable increase in lung cancer mortality rates soon after cigarette smoking became popular. The first cigarette manufacturing facility was built in 1862 in Saxony. After this smoking and not radon became the greatest contributor to lung cancer in miners in men. Female lung cancer rates were inversely proportional to indoor radon levels [40].

The Czech miners worked under very difficult and generally unhealthy conditions and frequently suffering (and dying early) from lung diseases. However, they had less problems with arthritis and other inflammatory diseases than did non-miners. Miners with lower doses from the mine experienced these health benefits [41]. Their family members and town people drank water which originated in the mines and used pitchblende packages for the external treatment of inflammatory diseases. A "clinic" or spa was opened up in Joachimsthaler. The residents knew of the healing properties for painful inflammatory conditions, such as arthritis, from the mine air at its entrance for centuries before [42]. Bruschius wrote in 1548 in a description of the high radon Fichtelgebirge, Germany: Here people get very old, have few diseases, and recover quickly if they have any. Werner Schuttmann and Klaus Becker of Germany both showed that women in the very high radon uranium mining areas of Saxony, Germany, had significantly lower lung cancer rates than women in lower radon areas, irrespective of smoking habits. In spite of the evidence, the *Health Physics* journal denied publication of a Schuttmann and Becker article documenting these historical findings [19, 42].[8]

Po-210 is an alpha emitter and radionuclide formed by the decay of U-238 that accumulates on the tri-chromes found on the underside of the tobacco leaf. A two-pack-a-day smoker receives ~0.1 Sv (100 mGy) per year to bronchial bifurcations in the upper respiratory tract from Po-210.

Smoking is the greatest contributor to lung cancer in uranium miners and other nuclear workers [43, 44]. A study of 11 underground uranium miner cohorts showed a variable dose-response relationship between WLM and lung cancer based upon how well each study controlled for the confounding factor of cigarette smoking. Several studies showed a lung cancer threshold of >1000 mGy to the lung (Table 6.1). In US uranium mines, the radon levels averaged 1800–2900 pCi/L, with levels as high as 50,000 pCi/L measured in certain parts of the mines. The relative risk of lung cancer was 29 for miners with lung doses >1450 WLM compared to those exposed to <80 WLM. A threshold of about 500 WLM was seen for lung cancer formation in non-smoking uranium miners [3, 43]. For Chinese tin miners and German uranium miners, the threshold was 600–800 WLM. The German miner study emphasized the role of smoking status in its analysis. Smoking status was not

[8] Prof.dr.klaus.becker@t-online.de

Table 6.1 Threshold dose for lung cancer in underground miners [3]

Uranium mine location	Threshold (mSv)
Yunnan, China	1000
Colorado Plateau, US	3000
Newfoundland, Canada	2000
Malmberget, Sweden	250
Grants, New Mexico, US	1000
Eastern Germany	4000

carefully evaluated in US uranium miner epidemiological studies [43]. Where it was considered, as in the German study, the lung cancer threshold dose in smokers appeared similar to that in non-smoking US uranium miners.

Polycyclic aromatic hydrocarbons (PAH) can be powerful carcinogens. Low-dose radiation protects against PAH-induced carcinogenesis. Gamma radiation given as a single or fractionated doses to a total dose of 60–600 mGy decreased benzo(a)pyrene-induced lung tumor formation in mice [45]. Gamma radiation suppressed 20-methylanthrene-induced tumor formation in mice at a dose rate of 1 mGy/h [46]. Skin tumor formation in mice caused by methyl-nitro-nitrosoguanidine was suppressed by beta-irradiation [47]. Cigarette smoke contains polonium-210 and 60 chemicals that adduct to DNA. Using a revised hormetic relative risk model for cancer induction that accounts for both epigenetic activation (epiactivation) and episilencing of genes, Scott demonstrated that, on average, >80% of alpha-radiation-induced rat lung cancers were prevented by chronic, low-rate gamma-ray ANP [48].

A fascinating lifespan study in rats exposed to sequences of radon and tobacco smoke was carried out by French radiobiologists in the 1990s [49]. Heavy tobacco smoke given alone failed to induce any lung tumors. Heavy radon exposure given by itself induced an incidence of 22% lung tumors. When radon was given prior to exposure to tobacco smoke the lung tumor incidence soared to 78%. However, when the tobacco smoke was given before radon exposure the lung tumor incidence was only 16%. This corresponds to the idea that heavy smokers should get one or more of the older whole-body CT scans a year to prevent lung cancer formation [43]. An increase in pulmonary health issues, including lung cancer, has not been found in pets living in homes with high radon levels [50].

Dr. Geno Saccomanno (1915–1999) carried out research on the relationship of radon daughters and cigarette smoking in the development of lung cancer in uranium miners of the Colorado Plateau, starting in the 1950s. He found that few non-smoking uranium miners developed lung tumors even at high exposures of radon. The majority of lung tumors seen in uranium miners were of the oat cell or small-cell undifferentiated carcinoma type (57%) as compared to a much lower incidence distribution in non-mining smokers (18%) or in non-mining non-smokers (6%).

Dr. Saccomanno pioneered the use of sputum cytology for lung cancer screening. Exfoliative sputum cytology was used to document the progression of early metaplastic lesions to early carcinoma in situ and malignant invasive tumors in the

tracheobronchial tree. Abnormal cytology findings were up to ten times more frequent in smoking uranium miners than in non-smoking uranium miners. In addition he observed a clear threshold in radon mine exposure for lung cancer in uranium miners [51, 52]. In uranium miners with documented radon exposure levels, he found 35 lung cancer cases in smokers at <300 WLM and no lung cancer cases in non-smoking miners at <300 WLM [53]. He recommended a maximum allowable level of radon in homes at 20 pCi/L (0.10 WL) [51].

In a letter written on May 14, 1998, by Dr. Geno Saccomanno of St. Mary's Hospital, Grand Junction, Colorado, concerning the role of cigarette smoking and radon threshold in lung cancer, he wrote:

> Please note that the miner with the lowest exposure was diagnosed with lung cancer sustained 250 WLM. We have 44 miners who developed lung cancer and were non-smokers. Since none were found to have less than 250 WLM that would indicate that radon exposure is not linear and that all the talk about radon in the homes at 4 pCi is not justified. We agree that 20 pCi is a conservative level. All of the research by the EPA has not found any cases of lung cancer in homes of non-smokers, but they still insist on ventilation of homes with radon levels higher than 4 pCi. I hope that my testimony at the congressional hearings help stay the development of a law forcing the EPA recommendations.

6.5 Residential Radon

Annual worldwide cancer mortality is 7.6 million. There are about 1.5 million new cases of lung cancer diagnosed in the world every year accounting for 1.2 million deaths or 18% of global cancer deaths. Lung cancer is the most prevalent cause of cancer mortality in the USA accounting for nearly 30% of all cancer deaths. About 90% of worldwide and US lung cancer deaths are due to cigarette smoking. All cancer incidence and lung cancer incidence are not increased in populations living in proximity to uranium mines, mills, or processing operations [3].

In 1988 the maximum Canadian indoor radon level was set at 800 Bq/m^3 (21 pCi/L); the US guideline was set at 148 Bq/m^3 (4 pCi/L) [54]. The government in Ontario, Canada, is currently debating a bill, *Radon Awareness and Prevention Act*, that would regulate radon in homes to a level similar to the USA. This law will create unwarranted anxieties, stress, and radiophobia as well as influence the value and sale of homes. This has already happened in the USA due to overregulation by the EPA. It is not feasible to completely eliminate radon from indoor air. Radon mitigation systems are available to homeowners that currently cost between $1000 and $5000.

The linear extrapolation of lung cancer at high radon levels as found in underground uranium mines to very low levels of radon found in residences is well proven to be false in epidemiological and in animal studies [3]. The EPA radon gas action levels for lung cancer risk prediction in homes are taken mostly from data associated with lung cancer in high radon-containing uranium mines as applied by the National Academy of Sciences in 1999 [55]. The EPA has failed to find lung cancers

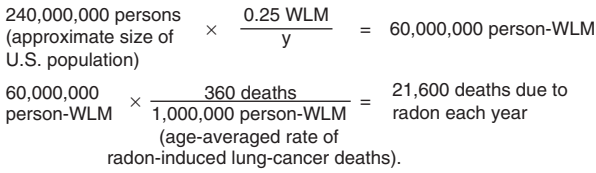

Fig. 6.7 Calculation of radon related lung cancer deaths from determination of collective dose

due to radon in non-smokers at radon levels <100 pCi/L. No lung cancers have been found in US non-smoking uranium miners at <60 pCi/L.[9]

The EPA has established radon exposure limits in homes and other dwellings in the USA based on the LNT assumption that there are 21,600 deaths from lung cancer each year from residential radon (Fig. 6.7); this is more than deaths due to falls in the home, drownings, and house fires combined [56]. The EPA estimate of indoor radon lung cancer deaths was obtained by the use of collective dose which has been disproven by radiation protection organizations.

There is a huge number of constituencies that would prefer the status quo of the LNT as they have financially benefited over the past 50 years by the fear of radon. This includes regulatory agencies and advisory bodies; universities; individual scientists, particularly epidemiologists, and their "research" dollars; journals and publishers; and manufacturers of radiation security and service products, such as used for radon abatement. These groups are very unlikely to sponsor seminars, symposia, or other scientific meetings to challenge their "advantageous" positions on the LNT. Remediation of radon costs money, scares away possible home buyers, and decreases the value of the home while increasing in most cases the risk of lung cancer. The cost to remediate in US homes for 1994 was estimated at 50 billion dollars. Follow the money for radon mitigation. The average cost per life "saved" using an action level of 4 pCi/L is $700,000; actually that is the cost to needlessly take another life that would have been saved by exposure to 4 pCi/L or higher radon levels. The high cost of radon remediation is a financial boondoggle with the human cost in lives being very high by removing low doses of radon.

EPA thinks all radiation can potentially kill you with cancer and recommends radon testing and remediation if radioactivity exceeds 4 pico-curies per liter of air. Note that humans naturally contain about 200,000 pico-curies of radioactivity. EPA's radon deaths are only based on an invalid theory called LNT. They are **not** observed, unlike the drunk driving deaths and others [57, 58].

Numerous epidemiological studies of environmental radon have clearly demonstrated the benefit of living in high radon regions of the world. There is no

[9] Letter from Dr. Geno Saccomanno, pathologist for U.S. uranium miners in the Colorado Plateau to HG Bosco, president, Hot Springs Lodge and Pool, Glenwood Springs.

relationship for early childhood deaths or cancers associated with living in HBRA areas.[10] A recent study found that children living in Switzerland are exposed to relatively high levels of indoor radon, giving an annual dose to the lung up to 20 mGy (the mean radon dose in the USA is ~1 mGy). A decreased risk of about 10% was observed for cancers common in Swiss children (Table 6.2) [59]. Cancer mortality in Poland is lower in higher radon level areas by 1.2%/mGy/year for all cancer deaths and by 0.82%/mGy/year for lung cancer deaths [60]. High radon exposure in Hungarian women lowered overall cancer risk in women younger than 61 years [61].

Colorado, where the author now lives, has one of the highest residential radon concentrations in the USA. The highest recorded levels of radon in buildings have been observed in several cities of Colorado built with and/or upon uranium mine tailings. Fifty of Colorado's 62 counties have indoor radon levels of >4 pCi/L. The

[10] Thomas M (2016) The radioactive remedy. Sentinelblog. https://sentinelblog.com/2016/01/09/the-radioactive-remedy/. Passages from Thomas (2016): "Soon after Lewis' grandfather, a mining engineer, opened the Free Enterprise Uranium Mine for commercial purposes, a woman visiting the mine noticed her bursitis—a condition in which the fluid-filled sacs that cushion bones, tendons, and muscles near joints become inflamed—rapidly improved. News spread fast. By 1952, there were more than a dozen health mines in the area, drawing more than 100,000 people in two years. Today, only three other health mines remain. Still, radiation exposure is a hard sell. Lewis says business at the Free Enterprise has dropped to a tenth of its peak in the late 1980s. Her break-even point is about 300 clients. She hopes for 200 this year. "As time goes by, drugs are better, but they're not perfect," she says. Most of the visitors at the Free Enterprise Health Mine in Boulder, Montana, are in severe pain. They drift about the waiting room clutching coffee cups, hands afflicted with the telltale signs of arthritis—the knobby knuckles, the gnarled and crooked fingers. It's mostly quiet, save for occasional talk of an ongoing elk hunt and the modest hum of the old Otis elevator, the gateway to the mine tunnel some 85 ft below…. A few hundred patrons visit the facility each year simply to sit here and breathe it in. They come from far corners of the country, desperately seeking relief from whatever ails them…Practitioners of radon therapy, like those at the Free Enterprise, believe low-dose radiation exposure has profound therapeutic benefits, including relief from chronic pain. The Environmental Protection Agency recommends that radon levels higher than four picocuries per liter of air (pCi/L) should be remediated. At the Free Enterprise, radon levels average about 1700 pCi/L, but fluctuate anywhere between 700 and 2200 pCi/L. "We are a last resort. I've heard it so many times: 'I cannot continue to live like this.'"…By the time clients walk through the door, Free Enterprise manager Patricia Lewis explains, some are experiencing the kind of pain that makes suicide look like an attractive option. "Like a bullet in my head—that kind of pain," she says. Her grandfather, Wade, founded the health mine in the early 1950s, the first in Montana. "We are a last resort. I've heard it so many times: 'I cannot continue to live like this.'" That health mines still draw hundreds of visitors each year is testament to their allure. There's virtually no other reason to visit Boulder….Some studies have found that a host of inflammatory rheumatic diseases may benefit from exposure to radon, including ankylosing spondylitis—a type of arthritis that can cause the vertebrae to fuse together—fibromyalgia, rheumatoid arthritis, and degenerative joint conditions like arthrosis. Mine visitors often claim that a few visits each year reduces their pain enough that they can rely less heavily on prescription medicine. Others turn to radon because they cannot stand the side effects of their medication, or because they have found that nothing else works for them….Lewis seems unfazed by her daily exposure to radon. "If I can't sit in my own stew…" she says, shrugging. As she trails off, an elderly woman limping on a cane hobbles into the Radon Room. Designed for those too claustrophobic to travel below ground to the original uranium mine, it pumps in radon gas."

Table 6.2 Mean radon levels in homes and radon action level in countries of Europe and the USA

Country	Mean radon in homes (pCi/L)	Radon action level (pCi/L)
USA	1.2	4.0
Czech Republic	3.7	5.3
Norway	1.5	5.3
UK	0.5	5.3
Germany	1.3	6.7
Sweden	2.9	10.7
Switzerland	1.9	26.7

mean radon level in the USA is 1.2 pCi/L; in Colorado it is 7.3 pCi/L. According to regulations promulgated by EPA, the entire state of Colorado needs to undergo remediation or evacuation to avoid a 1000 excess lung cancer deaths a year. Yet mortality from cancer of the lung in Colorado is 25% less than the national death rate. In 2014 the US death rate per 100,000 for all cancers was 192; in Colorado ski country it was 70. Six of the ten counties in the USA with the lowest cancer death rates are in the Colorado Rockies. Death rates for breast and colorectal cancers in Madison County, Mississippi, in 2014 were five times higher than in Summit County, Colorado [62].

The best remedy to prevent lung cancer is to STOP smoking.

The sad fact is that remediation of indoor radon at 4 pCi/L does not "save" 21,600 lives per year in the USA from lung cancer. Radon remediation at 2–10 pCi/L is much more likely to cause the needless, premature death of thousands of persons from lung cancer. That is because residential exposure to low levels of radon stimulates radiation hormesis which protects against lung cancer formation, 90% of which is caused by cigarette smoking. The best method for preventing lung cancer in smokers, other than to quit smoking, is to receive an annual older-type CT scan that delivers a whole-body dose of 10–20 mGy or sit in an uranium mine for a few hours a day for 10 days. This therapeutic strategy has the potential for significantly reducing lung cancer risk in smokers and non-smokers [43].

The notion that exposure to the radioactive emissions associated with radon and its decay products increases the risk of lung cancer is part of conventional wisdom during the last 25 years. EPA and BEIR IV and VI have misrepresented the data on the lung cancer risk of residential radon in the USA. Some call it the radon fraud [63]. In 1995 Bernard Cohen (1923–2013) found a highly significant negative correlation between radon exposure and lung cancer mortality in the USA, even after adjusting for smoking and other socioeconomic factors [64]. The study involved about 300,000 radon measurements in over 1600 counties, representing 90% of all counties in the USA. This result held up under extensive adjustment, with over 500 factors being examined for confounding. Cohen concluded that there was no evidence from this study that low-level radon caused lung cancer. What Cohen observed

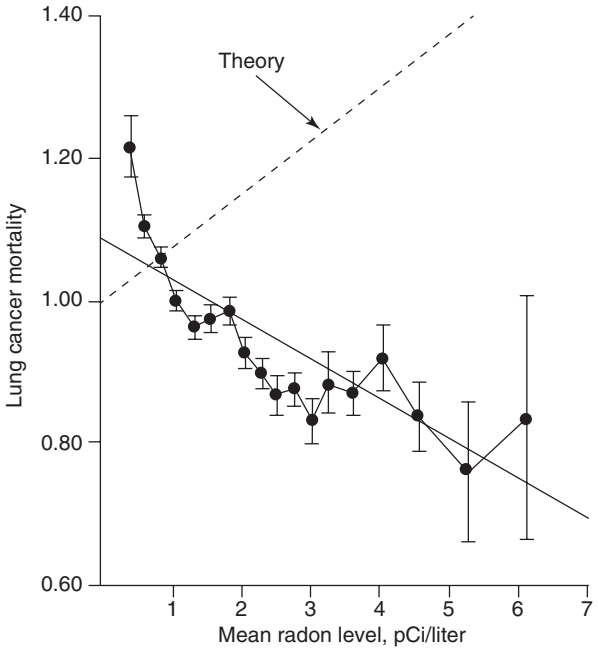

Fig. 6.8 Lung cancer mortality rates compared with mean home radon levels in US counties and comparison with linear model by BEIR IV adopted by the EPA [64] (with kind permission by Springer, Charles L Sanders: Radiation Hormesis and the Linear-No-Threshold Assumption, © 2010)

was a marked reduction in lung cancer. This was a conclusion that even Cohen had not expected when starting his study.

James Muckerheide published an excellent review of the work of Bernie Cohen and the unwarranted attacks on his work. Cohen's work was vindicated after the intellectual biased smoke had cleared. Cohen had overwhelmingly demonstrated the benefits of residential radon against all skeptics and continued to fight the radiation protection establishment for the rest of his life (Fig. 6.8). Mukerheide's words are given nearly verbatim below [65]:

> In the 1980s, Dr. Bernard Cohen, at the University of Pittsburgh, personally undertook natural background radiation studies similar to those terminated by the Atomic Energy Commission in 1973 (and by AEC's successors, ERDA and later DOE, and the NRC). He tested the LNT using the significant lung cancer data compared with variations in residential radon. Initially, he found that lung cancer incidence in the high-radon area of Cumberland County, Pennsylvania, was lower than the Pennsylvania average [66]. Many other studies found similar results.

> Because radon data did not exist at the county level, Dr. Cohen obtained at least 100 radon measurements in the 16 large counties with the lowest lung-cancer rates, and the 25 counties with the highest rates. He also found identical results in the various random counties in which 450 university physics professors at 101 universities supported his effort to obtain residential radon measurements.

Dr. Cohen then succeeded in a private effort to do, for radon and lung cancer, what the U.S. government had terminated with the Frigerio study—measuring radon in 272,000 homes in the most populated U.S. counties. These data also consistently found inverse results, in dozens of independent studies of, for example, "all-rural" counties, "all urban" counties, and so on [64]. Dr. Graham Colditz of Harvard University, a world renowned epidemiologist, contributed to an interim analysis of the data by counties. He confirmed the validity of the epidemiological analysis of these data [67].

Bernie Cohen did not believe his initial results. He sought the help of a statistician with the intention of finding the confounding influences that made his study appear to demonstrate a counterintuitive result. Together they examined over 500 combinations of confounders; the result showed the same trend that radon lowered lung cancer rates.

Dr. Cohen also acquired all EPA and state radon data that represented the experience of about 200 million Americans. These data showed an inverse relationship: the higher the radon levels, the lower the incidence of lung cancer. In the full data set, the inverse correlation exceeds 20 standard deviations, compared with the predictions of BEIR IV. The chance of error is equivalent to one in all the electrons in the universe! Any confounding factor must be: (1) much greater than smoking, (2) inversely correlated with radon, and (3) unrecognized. This is inconceivable—except for one postulate: Radon doses at the range of normal background levels stimulate lung tissue functions to protect against lung cancer.

Radiation-protection interests ignore the confirmed results of Cohen et al. by alleging simply that "they are ecological studies"; these critics provide no scientific basis to refute the data. In fact, there is no documented scientific criticism of Dr. Cohen's results, just general rationalizations of highly unlikely reasons why one study might not be valid. In fact, Dr. Cohen as produced dozens of separate studies that are consistent. Nevertheless, radiation protection interests use unfounded statements to misrepresent to the public that Dr. Cohen's data have been refuted.

Dr. Kenneth Bogen at Lawrence Livermore National Laboratory independently compared 1950-1954 lung cancer mortality for women of ages 40 to 80 and 60 to 80 (who had smoked little), in 2821 U.S. counties, with EPA county environmental (not residential) radon data. He also confirmed the inverse correlation between lung cancer and radon. Dr. Bogen's biological model applies cellular response data to show that the inverse relationship is consistent with known biological responses [68, 69].

LNT supporters erroneously claim that "case-control" studies are "better." However, the accuracy of such studies is completely dependent on the ability to know individual doses. This is true in most case-control studies where doses/exposures are measured and controlled. However, in most radon case-control studies, individual doses are poorly known… Therefore, "dose groups" are only statistical estimates, without knowing individual doses. Further, with the small numbers in the sample, combined with the uncertainty of the correlation, there are wide errors. Unlike large population studies, case-control cannot produce accurate or replicable dose-response results. In fact, in contrast, the nature of statistics provides statistical power in large ecological studies, because these apply rigorous statistics that more accurately represent mean doses compared with lung cancer rates.

> In addition, the uncertain doses in most radon case-control studies produce much greater bias in the higher-dose region. The high-dose group is likely to include persons who have low-doses, while it is unlikely that the low-dose group will have persons with high-doses. Therefore, the high-dose group will have a bias toward excess cancers that will seem to be shown to result from low radon exposures. In addition, case-control studies do not adequately address cases in the very low-radon regions, where the well-documented effects in Dr. Cohen's data (as well as those in other, more definitive population studies), demonstrate that increased lung cancer is expressed. However, despite all the problems with case-control studies, it has been shown that they do not contradict the results reported by Dr. Cohen and others.

Natural background radiation varies by geographic location up to three orders of magnitude (0.7–700 mGy/year). No increase in mortality or decrease in longevity has been observed in people living in high-dose regions [3]. Those that receive normal background radiation from all sources thrive. Human cells seem unable to tell the difference between weak β-particles from tritium and strong γ-rays from cobalt-60 [70]. A powerful protective effect against lung cancer was found at radon levels ≥2–6 pCi/L. However, lung cancer mortality increased up to 25% at radon levels ≤1 pCi/L [64]. This demonstrates the harmful effects of radiation deficiency. These observations indicate that we need our minimum daily requirement of ionizing radiation to achieve optimum health.

If you should be successful to decrease your indoor radon level to below 4 pCi/L, you can expect to experience not a decrease in lung cancer but as much as a 60% increased risk of lung cancer.

Interestingly, lifetime exposure to residential radon at the Environmental Protection Agency's action level of 4 pCi/L is associated with an average of >60% reduction in lung cancer cases from very low radon levels [64, 71]. The BEIR-IV (EPA) linear model (theory dashed line) shows an increasing risk of lung cancer with increasing radon level [64, 66, 67]. Age-adjusted lung cancer rates vs. residential ^{222}Rn level for counties in the USA show similar declines in lung cancer for both males and females.

Cohen's lung cancer mortality data, from his test of the LNT theory, do not extend to the no observed adverse effect level (NOAEL) above which inhaled radon decay products begin to induce excess lung cancer mortality. Since there is concern about the level of radon in homes, it is important to set the radon limit near the NOAEL to avoid the risk of losing a health benefit. The NOAEL for radon-induced lung tumors was estimated to be about 2100 Bq/m^3. The US Environmental Protection Agency should consider raising its radon action level from 150 to at least 1000 Bq/m^3. The annual mean absorbed dose to the lung from 300 Bq/m^3 is 7.1 mGy. The annual mean lung dose from 2100 Bq/m^3 is 50 mGy. The NOAEL from inhaled radon was estimated to be 2100 Bq/m^3 or 50 pCi/L (Fig. 6.9) [72].

Thus, residential radon does not cause lung cancer but rather protects, in an exposure-level-dependent manner, from cigarette-smoke-related carcinogens and

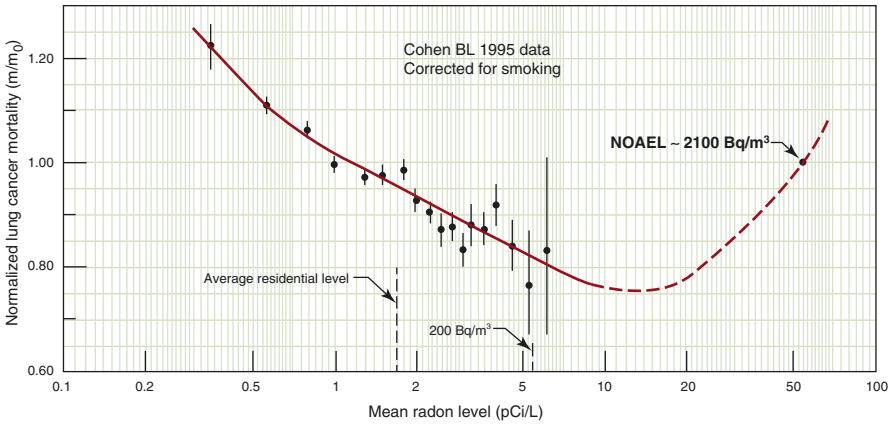

Fig. 6.9 The ratio of lung cancer mortality for residential radon levels was compared to that for US average residential level of 1.7 pCi/L. Residential radon prevents lung cancer at levels which the EPA says should be avoided. At radon levels <1 pCi/L that the EPA recommends remediating, there is a substantial increase in lung cancer (with kind permission of Jerry Cuttler) [72]

oxy-radicals. Radon exposure also gives a very strong negative correlation for smoking-induced cancers of the mouth, larynx, and esophagus, similar to the negative association seen with lung cancer [73].

There are many pitfalls to meta-analyses of lung cancer studies from indoor radon, such as the study published by Lubin and Boice [74]: These include data manipulation; inaccuracies; inadequate consideration of confounding factors, particularly dosimetry and smoking; and force fitting data to the LNT. There have been nearly 30 case-control, epidemiological, indoor radon studies carried out in the world. The pooled Bayesian analysis of 28 radon studies shows that there is no evidence for lung cancer risk increase in low-dose range [75]. Most were poorly controlled for smoking status and dosimetry [3, 43]. As with uranium miners, controlling for smoking status is critical since most lung cancers are due to smoking. The relationship between indoor radon exposure and relative risk of lung cancer from a meta-analysis of 20 case-control studies showed no correlation of increased risk of lung cancer with increasing radon level [3].

> Too little radon exposure is a disaster, markedly increasing lung cancer risk. This is followed by a region of radon-induced health effects reducing lung cancer risk substantially below that predicted by EPA. Only at higher radon exposures does one expect an increased risk of lung cancer [72, 76].

A radon concentration of 1000 Bq/m^3 gives a cumulative lung dose after 91 years of 2.3 Gy in humans, the apparent threshold for increased risk of lung cancer [77]. All of the existing radon studies can be easily analyzed together as one meta-study, leading to the conclusion that there is no evidence for excess lung cancer risk below

Table 6.3 Most case-control indoor radon studies were poorly controlled for smoking status and dosimetry

Radon (Bq/m^3)	RR	95% CI
<25	1.00	–
25–49	0.53*	0.24–1.13
50–74	0.31**	0.13–0.73
75–149	0.47*	0.20–1.10
150–249	0.22*	0.04–1.13
>249	2.50	0.47–13.46

This study was controlled for nine categories of smoking with extensive year-long dosimetry. The controls were individually matched to cases. The authors claim that this study is among the most careful ones in both data collection and analysis and that they were totally surprised by the results (*p <0.1 **P <0.05) [131]

800 Bq/m^3 [75]. Even when excluding studies that demonstrate benefit from inhaled radon from analysis, there is no evidence of increased risk [78].

The best indoor radon case-control study was performed by Thompson who initially was a proponent of EPA radon regulations and the LNT assumption [79]. His study was controlled for nine categories of smoking with extensive year-long radon dosimetry in homes. The first four radon exposure levels showed significant evidence of radiation hormesis (Table 6.3). Linear spline is a statistical continuous function formed by connecting linear segments along a dose-response curve. Radon exposure in Thompson's study was evaluated using linear spline terms to model for nonlinearity. Linear spline superimposed on smoothed data for lung cancer and radon concentration showed that radon levels >400 Bq/m^3 were associated with decreased lung cancer incidence [80]; this equates to a threshold for lung cancer formation of 600–800 WLM.

A recent study of indoor radon and lung cancer in residents of Guam showed a similar response as shown by Thompson [79]. Radon concentrations that exceeded levels of 3 pCi/L up to 18 pCi/L showed a negative correlation with lung cancer strongly suggesting a hormetic effect. Similar to the results of Cohen, radon levels <2 pCi/L on the dose-response curve were associated with a markedly increased incidence of lung cancer; the linear correlation was significant at P<0.005 level [81]. Other European studies have also shown no correlation or a negative correlation between lung cancer and low radon concentration [19, 82]. German indoor radon studies show a clear threshold for lung cancer risk which is over 20 pCi/L [3].

6.6 Radon Spas and Clinics

There are many ancient accounts of temples and gods/goddesses associated with healing and spas containing "healing waters" [83–85]. Asclepius was a student of Hippocrates and the god of healing for the Greeks and Romans. The most famous locations of asclepiad temples of healings were found in Ikaria, Trikala Gortys in Arcadia, Epidaurus in northeastern Peloponnese, and at Kos and Pergamon. Temple

ruins remain today at all sites. The Romans expanded the asclepiad temple in Arcadia into a lavish spa. Epidaurus contains today a mineral springs used for healing; its asclepiad ruins had 160 quest rooms for patients. Kos also has health spas today. The nearby island of Lesvos advertises a radon spa with low doses of Rn-222 (10–304 Bq/L); however, the annual dose to its fulltime employees approaches doses of 20 mGy. Other ancient spas found in northern Italy have radon levels in water between 2000 Bq/L (Merano) and 40,000 Bq/L (Lurisia) [86, 87].

Iannis Karimalis moved to Ikaria, Greece in 1970 after learning he would die in months from stomach cancer. In 2009 he found that he had outlived all his doctors.

A Greek island, Ikaria, has one of the most long-lived populations in the world. Its radon/radium hot spring has been used for therapy for 2500 years. Most of today's island residents regularly visit the ancient springs. The residents are known to have 20% less cancer, 50% less cardiovascular disease, and almost no dementias, with a long lifespan (30% live longer than 90 years of age). The curative properties of the island were known to Herodotus (484–410 B.C.); he recommended a 21-day stay at Ikaria for "cure" [88]. Today, conditions and diseases successfully treated in radon spas of Ikaria using the model of Herodotus include: neuralgia neuritis (including Parkinson's disease), acute and chronic arthropathy, skin diseases, respiratory diseases, gout, infertility, osteoporosis, post-traumatic and post-surgical conditions, and chronic fatigue syndrome [88].

J. J. Thompson, discoverer of the electron, in 1903 found radioactivity in well water, later determined to be radium. He discovered that every famous healing hot spring was radioactive.

People with health problems would come to the Asclepion to be healed of a wide variety of diseases. Those who were healed would give a thanksgiving offering to the gods that was representative of their illness or the body part that was healed. Hygieia, the daughter of Asclepius and goddess of health and hygiene, is found on coins discovered in Aelia Capitolina (Jerusalem was renamed Aelia Capitolina by the Roman emperor Hadrian); she is seated feeding a serpent. A serpent encircling Asclepius's rod is still a symbol of medicine and pharmacy today [89, 90].

The temple to Asclepius in Pergamon is mentioned in the Bible (Revelation 2:12–13). The mystic cist was a small box carried in the processions at the Greek festivals for the gods Demeter and Dionysus; the box contained the images of the deities. These images appeared on a series of large silver coins called cistophori that were minted by the kings of the Pergamene dynasty (200–48 BC). Some coins contained a relief snake and staff of a god who is administering medicine to a patient.

The modern equivalent is the American Medical Association (AMA) logo of a staff with a snake wound around it.

The asclepiad temple at Pergamon grew in fame and became the most famous therapeutic and healing center in the Roman Empire. The famous physician, Galen, was born and trained in Pergamon, working as a physician during the reign of the Roman emperor Marcus Aurelius. This was a place where Roman officials and wealthy citizens went for medical treatment. Here the physician priests gave advice and prescribed hot and cold baths in the sacred springs along with pools designated for mud baths. The asclepiad temples were viewed as places of healing for centuries.

6.7 Radium Therapy

Ernest Rutherford talked about radioactive emanations in 1900. J. J. Thompson found radioactivity in well water in 1903. Sieveking measured radon levels in 11 European spas in 1906 obtaining values up to 182,000 Bq/L. In 1903–1904, inhaled thoron was used to treat tuberculosis in Europe. Uranium ore and sands were placed in bathtubs for therapy in 1905. Two books were published in German in 1912–1913 on the use of radium therapy. The results for gout, rheumatism, and neuralgia were described as *extremely successful* in 1907. Meseritzky in 1911 found that radon therapy increased excretion of purines and uric acid in urine accounted for improvement in gout patients. An above ground radon inhalation facility was built in Austria in 1912 for treating gout patients.

Radium was discovered by the Curies; it took from 5 to 6 tons of pitchblende to extract one gram. Extracting radium from carnitine ore was even more an arduous task; only 1 g of radium was found in every 500–600 tons of carnitine ore from Colorado. When Madame Curie and her daughters went to Colorado, this is what they saw:

> In this uninhabited area of southwestern Colorado, and southwestern Utah, pockets of carnitine were discovered from a few pounds, to, in exceptional cases, 1,800 tons. Once the ore is mined, it is taken to a concentration mill nearby, where 500 tons is reduced to 125 tons. It is now in a powdered form, and shipped in 100 pound sacks, by wagon, and where possible, by motor trucks, the 65 miles to Placerville, Colorado. Here a narrow-gauge railroad takes it to the transcontinental railroad at Salida, Colorado. From Salida it travels the 2,300 miles to Canonsburg, Pa., just outside Pittsburgh. In Canonsburg, which Madame Curie had visited earlier in her trip, the pure radium salts were produced on a massive scale, using the exact procedure she and Pierre had devised 23 years earlier. Only here, the most modern technology of the day was at hand, and the quantities were much larger. The ore often had high levels of vanadium [37].[11]

In the early 1900s radium pendants, all natural radon water, uranium blankets, and thorium-laced "medicines" were used to treat rheumatism and enhance vigor and digestion. By the time radon-222 water reached the customer, nearly all the radon was gone. George H. Stover of Denver, Colorado, was the first American

[11] Bulletin of the Pan American Union 1921.

physician to obtain a supply of radium, purchasing some radium chloride in August 1903 from a Paris dealer. He was therefore one of the first Americans to conduct self-exposure experiments with radium [91]. In 1903, Hermann Strebel of Munich was the first person to propose the use of after-loading, which was then recognized for use in radium brachytherapy, including for cancer therapy [92].

The first radiation program in the US government was done by the National Bureau of Standards in 1913; it was devoted to measuring radium preparations for use in medicine. The journal *Radium* was also founded in 1913 to publish physician observations in patients treated with radium. In the first volume was a description of using naturally occurring emanation – room inhalation, augmenting by administering large quantities of natural radioactive water. Concern was given to patients receiving sufficient inhalation to be effective. This can be controlled by erecting a tent over the tub. The emanation was produced by 2–74 mg of radium, giving a room concentration from 0.003 to 0.8 μCi/L of air. Best healing results were obtained with 25 mg of radium [93]. Radium emanations were found effective in treating many diseases, including lupus erythematosus, tuberculosis adenitis, gout, rheumatism, polyarthritis, angioma, keloid and other scars, and chronic suppuration causing tinnitus and deafness [94–97]. Irradiating the kidneys was found most effective in lowering blood pressure. Vigorously passing 300-cc radium water (20 μCi/L) back and forth in the mouth was quite successful in treating alveolar pyorrhea [98]. A paper published in *Radium* in 1913 described the treatment of 657 cancer patients, 12% of which were cured; the greatest success was found for breast cancer [99]. By 1915 papers published in *Radium* talked about the relative value, efficiency, and limitations of radium therapy because of documented harmful side effects.

Painful inflammatory conditions were historically the first to be successfully treated with radon and radium. Hundreds of radon and radium gadgets for exposure to ionizing radium were marketed during the 1920s to 1940s to improve people's health, including the Revigator (a water cooler lined with carnotite ore). Surface radiation dose rates varied among the various radium devices: The radioendocrinator was 200 mR/h, radiothor was 3.5 μR/h, radium bromide was 4 μR/h, the National Radium Emanator was 5–8 mR/h, and the Thomas Cone was 30 μR/h. The radioendocrinator was a 2″ × 3″ case that contained paper impregnated with 250 μCi radium-226; the dose was sufficient to cause illumination on a fluorescent screen. By the 1920s radium was given in a variety of eatable and uneatable products as a cure for arteriosclerosis, arthritis, diabetes, epilepsy, heart disease, high blood pressure, infections, prostatitis, rheumatism, senility, and impotence. A 1929 pharmacy in Europe offered 80 radioactive products [100]. All these conditions and many more are potentially treatable by LDR today with a much better understanding of biological mechanisms and radiation dose.

A bottle of Radithor contained at least 1 μCi of Ra-226. The Revigator (1912) was constructed of clay containing uranium (radium) ore. The radon-solubilized in water was routinely drank. About 300,000 units were sold with no reports of harming anyone.

Radium was early seen as a way to treat disorders that were not affected enough by X-ray treatment because it could be applied in a multitude of ways and lower doses in which X-rays was not applied. External sources of radium exposures from impregnated pads and blankets were promoted, along with oral intake of water and "healthy foods." From 1910 to 1940, the healing powers of a wide variety of products, such as radium-impregnated bed blankets and radium-adulterated crackers, tea, coffee, and chocolate, were advertised. Different methods of applying radium had been tested, which fell into two categories: the use of radium emanation (now referred to as radon) and the use of radium salts. Inspired by this, bathwaters using preparations of radium salt were suggested as a way for patients to be treated at home, as the radioactivity in the bathwater was permanent. Radium baths were early used experimentally to treat arthritis, gout, and neuralgias [42] (see footnote 8).

Over 400,000 bottles of Radithor, a popular and expensive mixture of Ra-226 and Ra-228 in distilled water, were sold for $1 per bottle from 1925 to 1930. Each bottle contained 1–2 μCi Ra-226 [101]. Early attempts were made to treat arthritis with injections totaling 70–350 μCi Ra-226. A small group of patients were treated for hypertension in 1927 with radium water given by intravenous injection. Thousands of patients diagnosed with schizophrenia were treated with up to 300 μCi Ra-226 at Elgin State Hospital in Illinois in the 1930s. The study failed to demonstrate efficacy.

The manufacturer guarantee that Radithor is harmless in every respect, proved false. Radithor is one radioactive cure marketed in the first half of the twentieth century that can be unambiguously linked to someone's death, specifically to that of Eben Byers at age 51. He was a US amateur golf champion and industrialist who died from consumption of very large amounts of Radiothor believing that the more you took the healthier you would be. The massive amount of daily ingested radium was 2,000,000 times greater than the current EPA limit of 5 pCi/L. Byers did not die of cancer but of bone necrosis associated lesions, which required the surgical removal of his jaw. A belief that radiation is harmful at low doses was published in a 1936 report for the National Research Council (NRC); the NRC suppressed the well-known data at the time that low doses of radiation are beneficial. Prior to the unwise use of radium by Mr. Byers, the many radium products and applications proved effective in treating painful, inflammatory conditions for several decades. Paracelsus dictum that it is the dose that determines where radium is beneficial or harmful was ignored by politicians.

> Ward's Radium Ore Healing Pads was one of eleven products marketed by the company (Fig. 6.10). Another one was called a "radon pillow." The brochure for the pad says: A magic relief of constipation, gout, rheumatism, lumbago, sciatica, coughing at night, pains anywhere internally. The instructions included: Apply tightly to the flesh over the source of pain, soreness or swelling, 4-6 hours at a time...Helpful in any kind of chronic disease or pain. The price of the pad was $5.00.

The radium industry faltered and by 1950, Cold War propaganda had made such an industry unthinkable. Like for radon, radiation dangers were exaggerated to prevent the proliferation of the A-bomb.

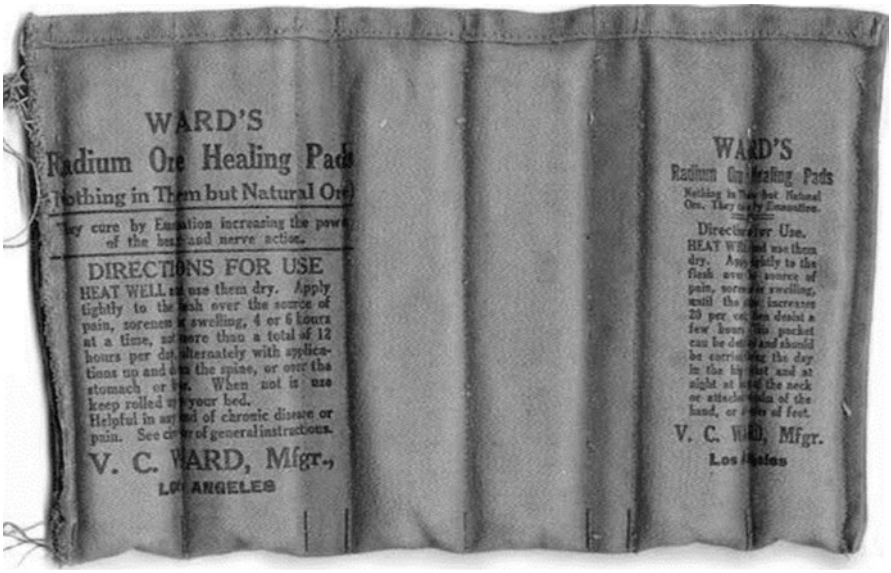

Fig. 6.10 Ward's Radium Ore Healing Pads (1916–1918) was one of 11 products marked by the company. Another one was called a "radon pillow." The brochure for the pad says: *A magic relief of constipation, gout, rheumatism, lumbago, sciatica, coughing at night, pains anywhere* internally. The instructions included: *Apply tightly to the flesh over the source of pain, soreness or swelling, 4–6 hours at a time...Helpful in any kind of chronic disease or pain.* The price of the pad was $5.00. The dose rate at 1 ft from the pad was 20 μR/h above background. The Oak Ridge Associated Universities calls all radium healing devices quack cures [123]

Several experimental studies in animals have been published that demonstrate the health benefits of radon. Mice which inhaled radon at a concentration of 2000 Bq/m^3 for 24 h significantly activated antioxidative functions in the liver and kidney, inhibiting induced hyperuricemia by activating antioxidative functions [103]. Radon inhibits inflammation [104]. Home radon prevents lung cancer [76]. Pain-related inflammatory conditions are commonly benefited by radon therapy. Nerve injury-induced inflammatory responses, mediated by TNF-a levels, norepinephrine levels and migration of inflammatory leukocytes, play important roles in neuropathic pain [105]. Both pretreatment and post-treatment with radon inhalation may have beneficial roles in controlling neuropathic pain [106]. Studies in rodents exposed to radon in air showed increased blood insulin levels, suppression of induced type 1 diabetes, and pain relief from formalin and carbon tetrachloride administration [107].

In the 1950s the American Medical Association (AMA) roundly denounced radon health mines as quackery and has not reconsidered its stance since. There is abundant and widespread medical evidence from patient's testimonials regarding the effectiveness of radon spa treatments for a variety of inflammatory illnesses [108]. Elsewhere, particularly in central Europe, Russia, and Japan, radon therapy for arthritis relief is an established alternative medicine. In Germany,

constructed radon tunnels are accessible by prescription only, as part of the country's national health system.

The Radium Palace in the Czech Republic was founded by Marie Curie in 1906. Today the facility treats 14,000 patients each year with a waiting list. Bad Schlema located in the mountains of Saxony was a mine five centuries ago. After 1946 the mine supplied 220,000 tons of uranium ore for the U.S.S.R. until German unification in 1989. Today it is a radon health spa. Today people come from all over the world to eight sanitariums in the town of Khmilnyk, Ukraine, which treat 50,000 patients annually for a variety of chronic inflammatory conditions. Patients receive radon pool therapy (25–35 nCi/L) in series, each for about 30 min [109].

Radon therapy is available in the form of baths, spas, steam rooms, and mines. Europe has a long history and tradition of radon therapy. Europeans often consider radon as a part of standard medical practice. Japan has the largest number of healing hot springs in the world. These springs are very popular. EURADON promotes the use of radon for autoimmune and respiratory diseases along with pain alleviation in European spas. Radon therapy carried out at Gastein, Austria, in a 2.5-km-long tunnel, has goals of reduction of pain and morbidity, particularly for inflammatory and degenerative conditions of the musculoskeletal system, respiratory tract, and skin. The cumulative radon dose is determined by the number, duration, and type of therapies. The mean radon concentration is 43 kBq/m^3. A classical cure at Gastein provides a dose of only 2.3 mGy/year. Locomotor disorders are treated with ten-2 mGy cycles. Up to 90% of patients visiting Gastein experience pain relief, improved quality of life, and often reduction in need for medication. Gastein attributes their healing responses to biological mechanisms of radiation hormesis [110].

In comparison to chemical pharmacological drugs used to treat proliferative and inflammatory diseases, no medical complications have been observed with radon therapy. Randomized double-blind studies demonstrated significant positive radon health benefits [42]. Radon therapy spas were visited by thousands of patients daily in the USA from the 1920s to 1950; the most popular spa was found in Saratoga Springs. Today an association of German Radon Spa Physicians (Radon Balneology) treats about 75,000 patients annually at 14 sites in Europe. There have been over a dozen books written on radon therapy since 1982. Typical annual effective dose to patients from one sequence of therapy is 2–3 mGy. Radon therapy personnel may receive more than 100 mGy/year without adverse effects [42].

> "Who would voluntarily breathe in radioactive gas? These days, there are people who do. They swear by the notorious noble gas radon, created by decay of uranium: They inhale it deeply. Most believers in the healing qualities of radiation are suffering from a chronic inflammatory disease…The gas, they argue, alleviates their problems for months. In Bad Kreuznach, in the German state of Rhineland-Palatinate, brave spa quests even trek into the tunnels of an abandoned mercury mine, attracted by the radon-filled air in the mountain…As has now become clear, these people are right: Radioactivity is good for them. These are the initial findings of an ongoing large-scale trial conducted by researchers from four German institutes. The leader is radiobiologist Claudia Fournier…Hundreds of patients in the spa resort of Bad Steven, in Upper Franconia, allowed themselves to be thoroughly examined for the study. The researchers found that after a series of radon baths, the blood of the test subjects had fewer signs of inflammation. Their immune

> defense,..also seemed to have calmed down. Accompanying experiments on arthritic mice delivered a further surprise…bone loss, which typically goes along with joint inflammation, was also reduced [111]."

Every year about 56,000 people in Germany die from septicemia, usually contacted within hospitals, associated with multiple organ failures. Dr. Luis Moita at the University of Lisbon has shown in a mouse model that low-dose radiation protects against septicemia. A study has been requested to offer terminally ill septicemia patient's radiation therapy [111], since enhancement of the immune system may cause a beneficial response in patients with septicemia [112].

"Gambanyoku" is Japanese for hot spring where one lies down on warm rock surfaces. The rocks may emanate radioactivity. The health effects of the Tamagawa Hot Springs have been well documented as a location to treat cancer, rheumatism, and diabetes. Japan has considerable empirical experience for several centuries with health spas later found to be associated with radon. The most famous is found at Misasa, where maximum radon levels of 8000 Bq/L are found. Clients and staff have a lung cancer incidence that is about 50% less than that found in low radon regions of the country; the mortality rate for all types of cancer is 37% less than expected [113, 114]. Patients bathe in a warm room with a radon concentration that is about 100 times background (2080 Bq/m^3). This therapeutic regimen has proven effective for osteoarthritis, ankylosing spondylitis, and bronchial asthma [115–117]. Radon baths have a therapeutic benefit on peripheral vessel diseases, decrease pain, and normalize the sleep cycle. Radon has a beneficial effect on lipolysis in adipose tissues, helping to reduce body weight.

> Once you convince the public that low-dose radiation can effectively and inexpensively treat painful inflammatory diseases without any side effects with an enjoyable therapeutic experience, they will demand it.

Pain is often the motivation for trying unconventional therapies. An older-age group comprises a large segment of people who seek radon therapy [118, 119]. A pattern of improved range of motion was found in those sitting in the mine even in those with advanced destructive joint and bone damage who were not expected to improve [120]. There is significantly reduced pain in rheumatoid arthritis patients bathing for 20 min in water with a radon concentration of 0.3–3 kBq/L or following a stay of 1 h in caves or rooms with natural radon levels of 30–160 kBq/m^3 [104]. The British Journal of Rheumatology recommends soaking in radon baths as a component of rehabilitative intervention.

According to the American Nuclear Association, there are about 5000 hospitals in Russia that use bathwater containing radon. Radioactivity in a Russian spa was first investigated in 1902. Radon therapy in Russia today uses portable radon-222 generation units (from radium-226) [121]. Radon hospitals in Russia treat 1000 individuals daily for asthma, arthritis, and rheumatism. About 75% of patients respond favorably to this treatment [42]. The best results obtained were for

rheumatic diseases, skin diseases, and hypertension. The greatest benefit for systolic hypertension was found in baths containing 40–120 nCi/L radon; the drop in blood pressure was followed with a decrease in heart rate [122]. Other conditions that respond to radon therapy include Meniere's disease, vertigo, imbalance, tinnitus, and genetic neuromuscular diseases.

There is a scarcity of pain control strategy in many locations of the USA. The fear of opioid addiction and the federal Drug Enforcement Administration's (DEA) war on doctors who abuse their prescribing privileges has made physicians, patients, and pharmacists collateral damage, making it difficult for patients to receive adequate medication to control pain. Legitimate patients with chronic pain have been left to find their own way. The result has been a victimization of chronic pain patients and not the installation of palliative care free of conflicts of interest and political manipulation. Health-care workers fear legal consequences for legitimate practice.[12] Low-dose radon therapy is an effective way to treat a variety of painful inflammatory diseases while avoiding the side effects of long-term use of anti-inflammatory drugs (steroids and NSAIDS). Radon therapy has been incorporated into traditional allopathic medicine [125]. The effectiveness of a radon therapy session, taking up to 2 weeks, typically lasts up to a year [42, 104].

Falkenbach described five trials of radon therapy for rheumatoid arthritis three of which were double-blind studies [104, 126]. Radon therapy as compared to interventions without radon inhalation showed significantly better pain reduction with significantly reduced NSAIDs use [127, 128]. Clinical and experimental radon exposure is associated with enhanced antioxidant enzyme activity [106]. In addition to arthritis and pain control, radon therapy was shown to be effective in treating hypertension, diabetes, skin diseases, lupus, scleroderma, ankylosing spondylitis, psoriasis, atopic asthma, bronchitis, cardiovascular disease, and dyslipidemia, chronic polyarthritis, fibromyalgia, scleroderma, rheumatoid arthritis, and degenerative and deforming joint infections [arthrosis, spondylosis, osteochondritis, neuralgia, ovarian cysts, endometriosis, and chronic pain such as one experienced as a result of a trauma, sinusitis, and allergic illnesses such as hay fever and neurodermatitis]. Successful radon treatments of complications involving the endocrine system, menopausal symptoms, impotence, and many other conditions have been documented [42, 104, 126, 129–132]. Radon therapy has been shown to increase blood estradiol levels in menopausal women and blood testosterone levels in men [133]. Radon may be a useful therapy for erectile dysfunction [134].

[12] Radiological emissions from coal-fired power plants are greater than from nuclear-fueled power plants under normal operating conditions. This is because coal contains 1–5 ppm uranium and thorium. The annual release of uranium and thorium out the stack of a coal-fired 1000 MW plant are 23 kg U and 46 kg T [123, 124]. The same LNT is often applied to chemical fossil fuel plant air emissions as for radiation, even though there are well known thresholds for toxic gases (sulfur dioxide, nitrous oxide, nitrogen dioxide, ozone), heavy metals (As, Cd, Pb), polycyclic aromatic hydrocarbons (benzepyrene), and particulates [124]. However, the annual workplace dose from radiation in coal mines is usually small (10^{-4} to 10^{-1} mGy/year). Overall, chemical rather than radiological toxicity is much greater in the fossil fuel cycle than in the nuclear fuel cycle.

Fig. 6.11 Free Enterprise Radon Health Mine near Boulder, Montana (with kind permission of Patricia Lewis)

6.8 Montana Radon Health Mines

There are only half a dozen radon health mines in the USA, and all six of them are located within 20-min drive of each other in western Montana. The Free Enterprise Mine is the oldest of the bunch, opening for business as Montana's first uranium mine in 1949, before transitioning from its uranium extraction focus to the more intangible resource of personal health just 3 years later (Figs. 6.11 and 6.12). The Merry Widow Mine and Free Enterprise Mines are located about 100 miles north of Yellowstone Park; the Merry Widow is located nine miles from the Free Enterprise in Boulder, Montana. National Geographic in 2004 did a piece on sufferers from arthritis, asthma, cataracts, and other chronic diseases gathering in the 1950s in the Merry Widow Mine in Basin, MT, to inhale radon gas that seeps naturally from this old silver and gold mine [135]. A 1952 *Life* Magazine piece shows Edna Kirsch entering the Free Enterprise Mine in a wheelchair and leaving walking, after her third day [136].

In 1952 the wife of a mining engineer visited the Boulder, Montana Free Enterprise Mine. Upon emerging she found her arm immobilized by bursitis could move without pain. Word spread fast and within a few months, 750 people had come to sit in the mine to relieve their suffering. Mine owners around this small region of Montana stopped mining and opened their mines to healing. "Experts" said radon gas could not help anybody. Nearly all of the more than 250,000 visiting the mine for the next several decades felt otherwise, claiming that there mine stay had done them good. During the 1950s, people would line up at the entrance

Fig. 6.12 Sitting in the Free Enterprise Mine (with kind permission of Patricia Lewis)

of the Merry Widow Mine in Basin, Colorado, and be admitted in groups of 50 for a 1-h stay [136]. Believers claim that 10 days in the mines, breathing in radioactive gas and drinking radioactive water, will cure a whole host of ailments. Hundreds of thousands of people have come from all over the world to sit in a radon mine for 1-h treatment three times a day. Miracles have happened here not just to believers in radon but to nonbelievers as well.

> Sue collects mud from the walls of the mine, swearing that it heals skin infections. Most visitors end up taking some of the mine away with them—even little pillows filled with radioactive gravel. Stories like Sue's brought Tanya Beck from Duluth, Georgia. Her four-year-old daughter, Allison, suffers from progressive rheumatoid arthritis; her doctors, having run out of solutions, predict she will spend her life in a wheelchair…When we got here to the mine and I saw what it was, it was kind of like a *Twilight Zone* thing…But Allison is running and playing now [135].

The radon health industry faltered because of Cold War propaganda making such an industry almost unthinkable. Radiation dangers were exaggerated to prevent the proliferation of nuclear weapons. No one wanted to even encounter radiation. A brief visit to a radon health mine changed many of their minds. Pat Lewis found from observations of thousands of people treated in the abandoned uranium mine, starting in the early 1950s, that their exposure regimen was effective in treating arthritis and a variety of other chronic inflammatory diseases [118]. The Free Enterprise Radon Health Mine is a place where people sit in comfortable chairs 85

feet below ground. Clients breathe a high concentration of radon gas and radon daughter products from decay of surrounding uranium-238 in the mine walls, ceiling, and floor [28]. The mine attracts many Canadians and Amish Americans who ignore the warnings of the EPA replacing them with common sense.

The Free Enterprise Mine exposes patients to an average radon concentration of 1600 pCi/L with a range of 770–2200 pCi/L. The radon levels in the mine are regularly determined by independent laboratories [137]. Background radiation levels outside the mine are >1000-fold less than in the mine. Mean dose rate in the mine is 170 μGy/h. Maximum levels in European mines may reach 4000 pCi/L. Treatment at Free Enterprise normally consists of several hours a day in the mine for 10 consecutive days.

Wade Lewis was one of the first to write about the beneficial health effects of internal radionuclide exposures [138] and wrote a book about radon and arthritis (Fig. 6.13) [118]. The mine is currently operated by his granddaughter, Pat Lewis, who started managing the mine in 1994. Mine exposures are external whole body and internal inhaled radon and daughter products. In addition to painful inflammatory conditions, Lewis has also seen positive responses in stage IV breast cancer and in neuropathy associated with diabetes. She says that neuropathy is slower to respond and requires longer exposures. She has also observed improved mobility associated with knee problems. Pat Lewis does not use the term "cure" to her clients, although many clients experience pain relief. Pat Lewis has been promoting the pro-radon therapy massage for over 20 years; for most of that time, she has been "drawn and quartered" by LNT-promoting critics.

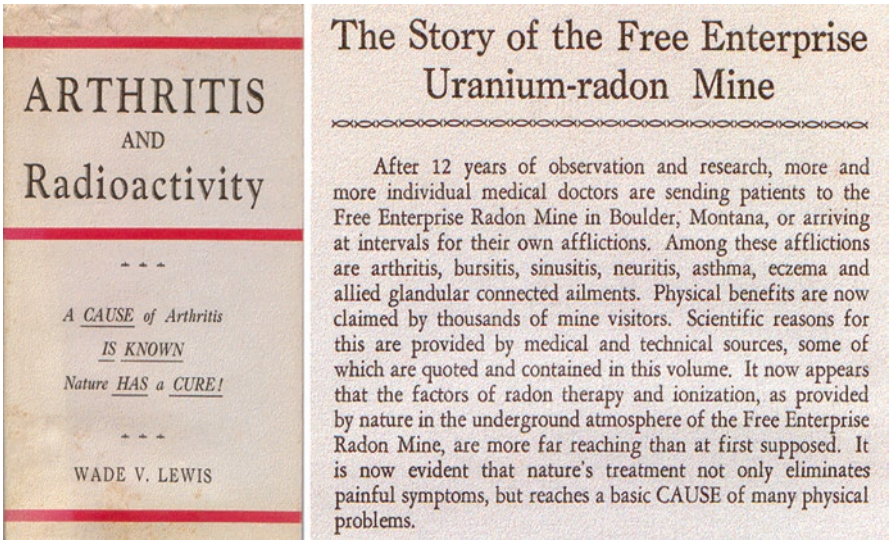

Fig. 6.13 Pamphlet on efficacy of radon for treating inflammatory diseases written by the grandfather of Patricia Lewis (with kind permission of Patricia Lewis)

The Free Enterprise Health Mine charges $8 for a 60-min visit; the mine has a pink-carpeted elevator furnished with a single red chair that takes you down into a wood-framed mine shaft, 87 ft beneath the surface. The walls are decorated with moss, graffiti, and rusted mining tools. Wall niches have padded benches and chairs sitting under heat lamps. Over the course of a typical treatment, clients spend between 30 and 60 h down in the Health Mine, spread out over a 10-day period [28, 139]. This corresponds to a cumulative dose of ~5–12 mGy. Pat Lewis has thousands of records of people who have visited the Free Enterprise Mine and experienced good to excellent results in their health status. Below are a few of them based on their physician-directed diagnosis.

Low dose radiotherapy is an effective therapy for acute and chronic inflammatory diseases and painful degenerative disorders (ankylosing spondylitis, arthritis, asthma, fibromyalgia, multiple sclerosis, psoriasis, scleroderma, ulcerative colitis, carpal tunnel) [140].

6.8.1 Ankylosing Spondylitis

At the age of 35 I had already suffered AS for 10 years. Prior to my discovery of Radon Therapy, my disease had advanced to such an extreme level that I was devastated to think that I would be forced to leave my physically demanding career as a farrier. Conventional drug therapies had failed and the specialists had no answers that didn't come at the high cost of drug side effects. I scoured the internet looking for alternative treatments, tried crazy diets and spent a bunch of money on stuff that did not work. My inflammation was high and my joints were starting to fuse. I found out about Radon Therapy on an internet AS forum. I did my homework. After tremendous amounts of investigation I felt comfortable enough to drive to Montana to give it a try in 2008. The results were amazing! My pain levels decreased almost immediately and within three months the symptoms were virtually gone. This has allowed me to keep my drug levels to a minimum and to continue life in my occupation. I highly encourage others to become familiar with this option to control their symptoms (Brad Erickson, Farrier, Bear Lake ID, www.braderickson.com)

I could no longer deal with the intense back pain and brain fog. I needed more answers: an internet search produced the Free Enterprise Mine. I was convinced that there would be benefits. Spring 2006 was my first stay with improvements at day 8. My second 10 day stay was October 2006. I'm now at home doing what I love to do instead of in a doctor's office thinking about my aches and pains (Pam Alvarez, Educator & Entrepreneur, Springville UT, alvarezps@hotmail.com).

My doctor knows I come here and he says that in my condition I am a walking miracle. He says that whatever I am doing, he wants me to continue doing it. It had been 20 years since I felt as good as I do since mine therapy. Mr. Wilcox died in 2016 at the age of 90 (Don Wilcox, Construction, Winnipeg Manitoba).

In 2005, at the age of 47, I visited the mine to see if it would help for my pain associated with AS - a condition I was diagnosed in 2003. Within a week I was able to stop my 3x/week Enbrel and have never resumed the injections. Two months later, a mammogram showed no sign of the calcifications that caused me concern for breast cancer - a condition I'd been tracking for about 2 years. My blood pressure diastolic dropped to normal. I made

no other changes in my stressful lifestyle and must attribute these results to radon therapy. I am lucky to live nearby to take advantage of the Free Enterprise Radon Health Mine (Anonymous, Certified Nurse Operating Room, MT).

That I was skeptical would be a huge understatement - but desperate times call for desperate measures. I took 20 1-hour sessions underground in 1993. Five weeks passed. I began to notice a feeling of strength - something foreign to me for the previous 25 years. Living close by allows me regular attendance. In my opinion, God has given us each the opportunity to make an informed choice for this alternative to drug therapy (the patient also had fibromyalgia) (Anita McCartney, Artist/Homemaker, 315 Morningside Dr., Hamilton MT 59840).

Actually, the doctor's wife no longer uses her wheelchair because she started visiting the Free Enterprise Health Mine. But seriously, the difference this place has made in my life is nothing short of miraculous. I have Ankylosing Spondylitis (which like most medical conditions comes w/an additional laundry list of U.C/fibro/IBS etc. Since my annual trek to the mine started 8 years ago, I am now pain free and rx free. Doctors can't explain it, but I can (Anonymous).

6.8.2 Rheumatoid Arthritis and Osteoarthritis

After about two days in the mine I became very ill - I was ready to leave. Everyone said that was a good sign and they were right. I was home about four weeks and my neck broke loose and I started getting relief from the pain. My doctor had told me to be prepared for a wheelchair - instead, I've put it in storage. I continue the mine therapy almost annually (Jim Gatschet, Diesel Mechanic, 509 Walker Road, Pleasant Hill MO 65080, (816) 540-3157).

The pain has gone away - no more pills. My family and friends can't believe what they see. It is just wonderful to sleep all night to see another pain-free day. I've been visiting since 1990. I'm ashamed to say I feel so good (Marie Klassen, 7230 Acorn Ave #1009, Burnaby BC Canada V5E 4N9).

Two auto accidents left me with chronic pain from neck and back injuries. Surgery, therapy and chiropractic had minimal success. I understood that there was a possibility that the mine therapy could give me some relief from pain. I started visiting in 2004. I can honestly say that I have less pain, that I am walking better and that I can sit more comfortably than before. Thank you for a wonderful facility. (Albert Wurst, Tool & Die, Kent WA, wuraldi@yahoo.com).

I was diagnosed with MS in 1998 and spent years battling pain. My option was to increase pain meds. What did I have to lose? First visiting in 2006, I noticed improvement within 4 days, then pain free before heading home. The disease is still there, but not the symptoms - I take no pain medication. I regret using this as a last resort and will return annually. (The patient also has multiple sclerosis and fibromyalgia.) (Bev Moulton, Wenatchee WA 98801, maisygrace@gmail.com).

6.8.3 Multiple Sclerosis

I was diagnosed with MS 22 years ago. I heard about radon therapy from a friend of my sister. This woman had been suffering from MS for 20+ years. She was in a wheelchair. She spent 10 days at the mine and never used her wheelchair again. Of course, I had to try it. I

went last year in September. I spent 10 days and nearly 100 hours in the mine. I have regained at least 10 years of my life. I can walk without a cane. I have no balance problems. In fact, I have none of the symptoms I had been experiencing for the past 2 decades. The only thing that reminds me I still have MS, is that I get fatigued once in a while. I no longer take any of the meds I was on for symptomatic relief. My Dr. was truly amazed. The biggest thing for me is that I do not have any pain!!! My heart breaks for those who won't even consider trying this alternative treatment for any chronic pain or illness. The price is considerably less than the hourly rate when you stay for 10 days. The facilities are exceptionally clean and comfy. The cost for me was just under $500.00, and that included my room and the use of the facility 24/7.I didn't mention that I went to the Free Enterprise Radon Health Mine and it is an annual trip for me (Anonymous).

6.8.4 Bronchitis

I have been going to the Free Enterprise Mine since 2002 with great success. The most important improvement is relief from bronchitis. I no longer suffer from weeks of an annual bronchitis cough. Additionally, years prior to my discovery of the mine, I broke my wrist. I would have to rest my wrist on a pillow while traveling. That wrist has been pain free for the last ten years (Grace Hartell, High River, Alberta, Canada).

6.8.5 Ulcerative Colitis

I've struggled with this disease for 17 years. Finally my surgeon wanted to remove my colon immediately. Instead I had heard about the Free Enterprise Mine and wanted to give it a try - I did so in October 2006. I felt improvement, which was confirmed by my doctor and via biopsy. I visited again in early 2003. Biopsies from latest colonoscopy show no dysplasia and no need for surgery. In my eyes, this is a miracle and an answer to prayers. I'll be back for more "mine-time" (Bill Stripling, Appraiser, Norcross GA 30092, billstripling@gmail.com).

6.8.6 Hepatitis C Infection

I have Hep C. I went to the mine in 2004 and while I didn't get my liver enzymes checked before I left for Montana, my joint and muscle pain went away while I was there. And my liver test was low when I returned home and got tested. I continue my annual visits to the mine (Ned Haskin (2010), Sound Engineer, Landover MD, feanor17@covad.net).

6.8.7 Scleroderma

I was diagnosed with scleroderma in 1995. This disease causes hardening of the skin and internal organs in addition to joint damage. I first visited the mine in 2001 after reading about it in our local paper. I have had unbelievable results. The skin on my face is much softer and my hands are more flexible and overall I find I am able to move around more easily. I truly believe that coming to the mine has kept my disease from progressing and has even reversed some of the damage. I will continue annual visits to maintain my health and to reduce my need for medication for inflammation (Ann Bumsted, Truck Driver/Finance, Box Elder SD, cookiemaker2222@msn.com).

6.8.8 Asthma, Behcet's Syndrome, and Psoriasis

I first visited in 2000. The psoriasis is gone. My asthma is almost gone and I've given up a long list of steroid medications. I love being back on my feet after so many years. Bob's arthritic knees no longer hurt him. We both look forward to each year's R&R (radon & rest). It really feels like home away from home. (Linda & Bob Cruz, PO Box 3434, Bay City OR 97107).

6.8.9 Migraine, Headache, Gout, and Fibromyalgia

Additionally the mine helps me with carpel tunnel and rheumatoid arthritis (Elaine Wilcox (2010), Banker, Winnipeg, MB, elaine_wilcox@hotmail.com).

6.8.10 Primary Pulmonary Hypertension

In 1997, my dad brought my mother, Mary, to the mine. He had pulmonary fibrosis. He visited once more but lived 4 years more than the doctors gave him. Then I brought my mother for a number of years. I have primary pulmonary hypertension (PPH): irreversible, progressive and fatal. My breathing always improves at the mine. I am better now than in 2002 when I was diagnosed. I am thankful for the mine and will continue to visit. (2008: My physician no longer detects evidence of PPH.) (Cheri Sweet Sundwall, Property Investments, Alpine UT, jcsundwall@yahoo.com).

6.8.11 Glomerulosclerosis

This disease causes scarring of the tiny blood vessels in the kidneys. My doctors state that I would soon need a kidney transplant. Since 2007, I have visited the mine 6 times. The disease has not progressed as predicted. Though my husband is ready to donate a kidney, we both would prefer to visit the mine instead (Bev Tuel (2010), Dental Hygienist, Clark Fork ID, mbtuel@yahoo.com)

6.8.12 Carpal Tunnel

My mom, a mine visitor since 1989, suggested that the mine might help my severe carpal tunnel in both hands. The doctor was ready to do surgery. Within a month after visiting the mine I was painting the front porch - it has worked wonders. Now my once doubtful husband joins me for help with his arthritis. An annual trip to Montana keeps me from surgery - and keeps us working (Teri & Michael Kenowski, 1222 S Cuyler Avenue, Berwyn IL 60402, mtkenowski@ameritech.net).

Here are some more unedited testimonials from the Free Enterprise Mine:

You would never believe my testimonial if I told you…Alright, if you insist I must tell you. I have no pain in my back or anywhere else for that matter (Marisol Ojeda, 2012). I will never be able to thank you enough for giving my my life back and taking away the pain, No pain at all (Kathy Franum, 2012). I spend ten days a year in the mine. It's definitely made

me more functional. It's allowed me to live without pain (B Blackburn, 2012). We like lots of people were very skeptical at first about radon therapy. After a 10-day stay, I will never question the treatments again. It works (Avis Czerniewski, 2011). Our arthritis in shoulders and hands goes away after mine therapy (Eunice Boeve, 2011). My wife's arms are still pain free after 20-years of pain (Joe Zehr, 2011). Marked improvement in arthritis for me, my husband and our dog (Donna Lutz, 2010). I have had a disc problem since 1995 causing pain in my arms. Radon made me feel like I did before 1995 (Melissa Baldwin, 2009). I had ankylosing spondylitis at the age of 37. I greatly improved after a stay at the radon mine that lasted for over ten months (Brad Erickson, 2009). I had carpal tunnel in my wrists and could not wring out a dish rag or open a pop can or open and close my hand. Now I can do all easily (Teri Kerowski, 2001).

Today there is a growing recognition in the USA and Europe that health care is driven to a significant extent by an emphasis on consumer choice and demand. As consumers, people regularly choose their own solution for health promotion and maintenance, solutions which may or may not be sanctioned by mainstream medicine [141]. Among these alternatives is radon therapy. Thousands of people annually chose to sit in abandoned uranium mines or upscale radon spas exposing themselves to radon for therapeutic purposes. No evidence of increased cancer has been shown in 100,000s of patients that are annually treated by radon in former uranium mines or spas.

Low-dose radiation or radon therapies are ignored, scorned, and arrogantly dismissed by many US physicians. The American system of health care and governmental institutions (AMA, EPA) ridicule people sitting in an abandoned radon mine. Chronically ill people usually take expensive medications with serious side effects. Most of these people are elderly. Pharmacokinetics is different in the aged, medications are typically multiple, and drug side effects are more serious in the aged. Also drug dose often needs to be increased more in the aged to achieve its initial effectiveness. Follow the money. American doctors and pharmaceutical companies may "avoid" radon therapy or any effective natural therapy irrespective of benefits because of the very limited profit potential.

6.9 Radium Dial Painters

The Radium Chemical Company produced a watch dial paint containing radium and zinc sulfide along with rare earths; radiation from radium caused fluorescence so that the watch dial could be seen at night. Radium dial painters were mostly women who tipped the end of a camel's hair paint brush with their tongue ingesting varying amounts of radium into their gastrointestinal tract, from where it was absorbed and deposited into the bone. Women were paid $18 for a 40-h workweek. After 1925 when harmful effects of this practice were observed, the tipping was stopped.

Argonne National Laboratory (ANL) in Argonne, IL, carried out the largest epidemiological study of humans exposed to internally deposited radionuclides [142]. A total of 2403 former radium dial painters were studied by ANL with respect to radium distribution in the body, radiation dose determinations, and cancer

development, particularly in the skeleton and nasal cavity. The probability of developing a bone tumor (mostly sarcoma) was up to 50% if up to 5000 μCi Ra-226 had been ingested over a few months to years. This threshold level for bone tumors or other diseases corresponded to a dose of about 10 Gy to the skeleton. This threshold for bone tumors is more than 125,000 times the annual limits for radium in drinking water which is 5 pCi/L. There was no lifespan shortening at bones doses <10 Gy; the last report of the radium dial cohort actually showed the painters living longer than unexposed controls. The conclusion to the over 30-year study was that radium-induced malignancies in humans were not seen below a dose of 10 Gy [142]. Josephine Lamb, a radium dial painter, was still alive in 2006 at an age of 100. Bureaucrats in Washington did not want to see research promoting the benefits of ionizing radiation particularly at these high doses. This exceptionally well-done study had received rave reviews by DOE but was still terminated by DOE in 1990 even though about 1000 radiation dial subjects were still alive.

Robley Evans made the first measurements of exhaled radon and radium excretion from a former dial painter in 1933. At the Massachusetts Institute of Technology, he gathered dependable body measurements from 27 dial painters. This information was used in 1941 by the National Bureau of Standards to establish the tolerance level for radium of 0.1 μCi (3.7 kBq). Evans showed in 1972 that BEIR had misrepresented data on bone tumors seen in radium dial painters in order to "force" a LNT assumption response. In 1981, the now retired Evans showed that there were no bone sarcomas or nasal carcinomas in dial painters with cumulative bone doses of <10 Gy. DOE then initiated a beginning termination of the dial painter study in 1983. In contrast, the Radiation Effects Research Foundation (RERF) which has studied the Japanese A-bomb survivors for "life" and produced consistent biased and false data that "fit" the LNT assumption was allowed to continue. Robert Thomas, radiobiologist at Los Alamos National Laboratory and Argonne National Laboratory with a stint in between as program manager at DOE, proposed a threshold for dial painters and bone sarcomas of at least 4 Gy. Robert Rowland, then director of the dial painter study at ANL said:

> All 64 bone sarcoma cases occurred in the 264 cases with more than 10 Gy while no sarcomas appeared in the 2,119 radium cases with less than 10 Gy [142, 143].

An analysis by Pacific Northwest Laboratory in 2012 of cumulative incidence of bone tumors in radium dial workers a linear line occurring after having achieved a threshold dose of 11.6 Gy to the skeleton.

Charles Mays and Raymond Lloyd from the University of Utah clearly misrepresented the dial painter data and "manufactured" a linear result for BEIR IV. EPA then took the same data and forced it into a linear response to establish widely unrealistic radium limits in water. Simply put, science is irrelevant in the campaign to mislead the public about the hazards of radium and radiation in general. The thousands of people who had used radium supplements (e.g., Radiothor) in moderate amounts had not experienced any adverse effects. This information was intentionally ignored by EPA, BEIR, and all other radiation protection agencies.

Otto Raabe, Radiobiologist UC Davis, and former President Health Physics Society said:

> By grouping the Evans data into six non-uniform dose groups selected so that only one dose group included no bone cancer cases (one with average skeletal alpha doses from zero to about 500 rad or 10,000 rem) and so that the next highest dose group included a few cases of bone cancer (cases were only observed for average skeletal alpha radiation doses that exceeded 1,000 rad or 20,000 rem), Chuck Mays and Ray Lloyd created the appealing, but misleading, linear plot shown on page 198 of BEIR IV. In their plot the "threshold" region, which is below 1,000 rad, is obscured near the origin since the abscissa is extended to 16,000 rad and only one dose group was assigned to this region. Their plot proves nothing about linearity. Evans's analysis shows that no linear model fits these data.[13]

Don Wiles was employed at Eldorado Mining and Refining as a radium chemist in 1944. He used fractional crystallization of barium-radium bromide mixture to refine radium much as Marie Curie had done 40 years earlier. He collected 75 curies Ra which was used to irradiate a bag of diamonds because the owner felt that radiation made them more brilliant. Robley Evans in 1950 measured his radon exhalation while at MIT as 25 times the legal limit [144]. There were no radiation detectors in the room. He wore a film badge down below a 3-in. lead shield (shielding from chest to crotch). The badges were usually black every day (and changed every day). This dose was interpreted at the time “as three daily doses.” Gamma-ray peaks suggestive of Ra-226 were clearly evident in his early 80s. Wiles is still alive and healthy and has three children. He is 88 years old and expects to live to 100 [144]. High amounts of selenium and radium-226 are also found in Brazil nuts (8–58 pCi per nut).

Thresholds for induction of skeletal tumors in beagles were seen at skeletal doses of 0.9–1.4 Gy for α-emitters and 28–70 Gy for β-emitters. The lowest doses at which malignant bone tumors were observed in animals injected with Ra-226 or Ra-228 were about 1 Gy. Similar results were seen for monomeric Pu-239, Am-241, and Th-228. For the β-emitter, Sr-90, the lowest dose where bone tumors were found, was 18 Gy [145].

About 2000 German patients between 1944 and 1951 received fractionated injections of Ra-224 for treatment of tuberculosis and ankylosing spondylitis. Bone tumors were found at a threshold skeletal dose of 1 Gy in children. The higher injected dose (rather than much smaller daily doses from tipped brushes) and shorter physical half-life of Ra-224 (than Ra-226) resulted in bone tumors at lower doses (than radium dial painters) in the German patients [145–147]. Radium chloride has been more recently used to treat 308 ankylosing spondylitis patients with radiological evidence of spinal involvement in Germany. Most of these patients received the full cycle of ten injections (a total of 10 MBq radium-224). Patients showed significant improvement in pain control at 6-months post-treatment [148]. Protracted Ra-223 injections offer a clear increased survival benefit and improved quality of life in men with bone metastases from prostate cancer that no longer responded to hormone therapy [149].

[13] Otto Raabe e-mail to S.A.R.I. (2016).

Nasal radium irradiation (NRI) treatment, an accepted medical treatment from the 1920s until the 1960s, was used to treat aerotitis media in submariners and aviators in the military and to about 2.5 million children to treat hearing loss, chronic otitis, and other conditions. Radiation dose estimates were 2000 rad to local tissue, 24 rad to the pituitary gland, 5 rad to the brain, and 2 rad to the thyroid. These NRI treatments did not cause cancer or any other harm [150, 151].

Radium emanation was quite effective in 1915, increasing agricultural yields of many vegetables by mixing 2–3 mg of radium per ton of soil; yields increased from 35 to 70% for lima beans, carrots and sweet corn [152].

6.10 Thorium

Thorium is a naturally occurring radioactive element that was discovered in 1928 by a Norwegian mineralogist and a Swedish chemist. Thorium is used in many applications from lantern mantles to radiological imaging in medicine. Prior to the appearance of electric lights, illumination was principally achieved by gas or kerosene flame causing incandescence in a mantle manufactured in part with thorium. During World War II, the largest single stored supply of thorium was transferred from a company in France to Germany. A potential nuclear fuel cycle based on the conversion of thorium to U-233 could theoretically be used to make A-bombs in Nazi Germany. Fortunately, the thorium supply from France was not destined for bombs but for toothpaste [153].

Thorium is an abundant heavy metal. Factory-manufactured liquid fluoride thorium reactors (LFTRs) can produce energy 40% cheaper than coal and 80% cheaper than wind or solar energy [154]. Economics alone can drive worldwide adoption of this clean energy source, without contentious, unworkable carbon taxes. Thorium-based power reactors can provide cheap and an inexhaustible energy. China and India are both interested in developing LFTR technology [155].

Thorium is transmuted into uranium-233 for fission; the resultant fission products are different than seen for fission of uranium-235. In fact, thorium could fuel the atomic energy needs of the future. The thorium reactor would produce heat and steam which would drive a turbine just like a uranium reactor. One gram (g) thorium would be equivalent to over 7000 gallons of gasoline in energy; 8 g would power a car for a century. A thorium fuel car was designed in 1957 as the Ford Nucleon concept and again in 2009 as the Cadillac World Thorium Fuel concept. Although small, a thorium reactor would produce a series of radioactive daughter products similar to those of uranium.

Thorium-232 has a half-life of 1.4×10^{10} years and like U-238 (half-life of 4.5×10^{9} years) is ubiquitous throughout the earth present in nearly all locations at ppm or less amounts in rocks and soils. Th-232 decays through a series of ten radionuclide daughters before finally reaching stable lead. One of the decay products is Rn-220 (Thoron) which has a half-life of 56 s and emits a 6.3 MeV alpha particle.

Table 6.4 Concentration of Th-232 (Bq/kg) in sand samples of beaches in the world [156]

Location	Th-232 concentration
Preta beach, Brazil	128–349
Dois Rios beach, Brazil	12–87
Visakhapatnam, India	300–600
Northeast coast, Spain	5–44
Ullal, India	1841
Valencia, Spain	1–11
Kalpakkam, India	352–3872

On the Atlantic coast of Brazil and the southern coast of India are beaches with sand high in thorium-rich monazite and zirconite (Table 6.4). India has about 30% of the world's thorium reserves including monazite-bearing beach sands. Monazite contains 2–7% thorium by weight. The mean thorium-related radioactivity level of monazite bearing soil of Chavara, Kerala, was 56 times greater than the national average for India; the indoor Rn-220 levels were up to 26 times greater than normal levels for India [157, 158]. Residents living in houses built on thorium-rich black sands of Kerala, India, experience a mean annual dose of 17 mGy.

Thoriated gas mantles are widely used in India for lighting both outdoors and indoors resulting in an average, annual dose of 2–8 mGy, respectively [157]. Thorium workers involved with lantern mantle production from 1920s to 1973 experienced radiation levels in 1952 of 5–50 μGy/h at locations within the plant. No increased risk of cancer was observed in workers [159]. People in parts of Iran use the ash from burned thorium-containing mantles for healing of skin wounds. Radioactive lantern mantle ash has been shown experimentally to enhance healing of excision wounds in the skin of rats [160].

A recent review of high-level radiation background areas of India failed to show any increased risk of cancer [161]. The population living in Kerala, India (~200,000), presents a unique opportunity for studies on the health effects of chronic exposure to high environmental radiation dose levels. The frequency of DNA double-strand breaks in peripheral blood mononuclear cells for residents of Kerala coast was less than in low radiation areas of India (0.078 ± 0.004 at 11 mGy/year compared to 0.095 ± 0.009 at 1.3 mGy/year) [162]. Cancer risk, adjusted for smoking and other confounding factors, was decreased from expected levels compared to low-dose regions of India, for residents of Kerala [23]. A negative correlation of lung cancer with increasing Rn-220 concentration was found in an epidemiological study in the Haryana State of India. A negative correlation was also found for all cancer incidence and mortality with increasing external natural background dose rate in cities of India [163].

A facility comprising 19 wooden warehouses and two hangers in the Sverdlovsk region of Russia had been used since 1960 as a storage site for 82,000 tons of monazite sand stored in 50-kg bags. The mean ambient gamma radiation dose rates for the facility were 90 μGy/h inside the buildings and 44 μGy/h just outside the walls. The mean Rn-222 levels in the buildings were 220 Bq/m^3 compared to 19 Bq/m^3 outside. A total of 438 temporary and regular workers have been employed at the facility for up to 50 years. The maximum cumulative external dose received by a

worker was 330 mGy, and the maximum internal + external dose was 1300 mGy. An epidemiological study including 4679 non-exposed local controls showed no significant impact on health for the facility employees [164].

One thorium compound that has shown significant risk of cancer formation at a high radiation dose is Thorotrast, a colloidal contrast material comprised of highly insoluble, tiny Th-232 dioxide particles that was used for angiography in thousands of European patients from 1930 to 1950. Just prior to World War II, Thorotrast was removed from the approved drug list in the USA. A published paper in 1940 said:

> Thorotrast should never be introduced into the human body because of the danger of inducing tumor formation.

Intravenous injected Thorotrast, typically given as a single 25 mL injection, concentrates and is tenaciously retained in reticuloendothelial (RES) tissues of the bone marrow, spleen, lymph nodes, and liver, causing significant radiation doses from α-particle emissions.

Radiation-induced cancers were not seen at organ/tissue doses <1 Gy. Excess cancer was seen in Thorotrast patients at a threshold dose of 3–7 Gy for the liver, 3 Gy for the bone and bone marrow, and 1 Gy for the lung [153, 165]. Lung tumors were caused by exhaled thoron gas. Ten cases of carcinoma of the paranasal sinuses and mastoid air cells have been recorded in humans who received antral injections of Thorotrast [3]. The use of Thorotrast in human patients has also been implicated in occasional mesothelioma formation at very high doses of surrounding thorium particle concentration [147, 166].

Inhaled thoron has been used to treat human health conditions. Seventy-six subjects (mean age, 62) inhaled thoron (~4900 Bq/m^3) for 2 weeks. The α-atrial natriuretic peptide level of a rheumatoid arthritis group was increased and the blood pressure was decreased. These beneficial effects were associated with an increase in SOD activity, an enhanced concanavalin A-induced mitogen response and an increased level of CD4-positive cells and decreased level of CD8-positive cells. The results indicated that low-level inhaled thoron therapy may prevent and treat age-related chronic diseases such as diabetes and rheumatoid arthritis [167].

A group of four patients with advanced cancer and two patients with severe rheumatoid arthritis and dermatomyositis were exposed to radon and γ-rays from monazite sand for 1 h, three times weekly, for a period of 3–36 consecutive months. Radon-222 (200 pCi/L) was delivered at a dose to the lung of 25 μGy/h, while monazite delivered 40 μGy/h from γ-rays. The weekly dose was ~200 μGy and the monthly dose was ~1 mGy. All patients had failed orthodox therapy. In each case biopositive changes were noted, including a decrease in tumor marker antigens, improved tumor control, and improved appetite, muscle strength, and exercise ability [168]. Patients with advanced cancer are currently being treated using thin silicon plates (50 × 50 cm) containing concentrated monazite which give about 2000 μGy/h from beta and gamma radiations [169]. No harmful side effects were found in any patient during the clinical course. Biopositive effects could be observed regardless of malignant or benign background [170]. Jerry Cuttler told me (2015) of a visit in Japan in 2007 to a medical clinic. The facility had several small rooms with

wooden walls. The rooms were warm and humid with sources of radioactivity in the walls. Water with dissolved radon was delivered to patients.

Tumor reduction has been observed in a female patient with advanced gastric cancer and a male patient with pancreatic cancer using monazite and radon gas emanation. The therapy room provides 2 mGy/h at a distance of 10 cm from the walls and a radon gas concentration of 100,000 Bq/m^3. Patients were also treated with radioactive silicon sheets [168, 170]. One patient at Takatori's clinic was a 61-year-old male who had undergone surgery in 2010 for advanced rectal carcinoma with multiple metastases in the lung, liver, and sacrum. The patient had received two cycles of chemotherapy. In addition he received low-dose radiation therapy at home using a radon gas aspirator for 15 min, three times daily—17,000 Bq/m^3 radon-222 in a vinyl bag. The patient exhibited a decrease in tumor markers and dramatic sacral pain relief; no significant change in tumor size or location was seen [169]. Radon and radium were also used to treat many benign conditions, including hemangiomas prior to 1960 [171].

6.11 Natural Nuclear Reactor on the Colorado Plateau: Radiological Characterization

Fourteen natural nuclear reactors have been found in Oklo, Gabon, Africa. Regions within the reactors contained concentrations of up to 70% uranium oxide in meter(s) thick uranium ore seams in sandstone [172]. This natural, thermal neutron reactor was moderated by groundwater which slowed down the neutrons to make them easier to cause fission as well as absorbing neutrons for breeding of plutonium and other transuranics. The Oklo natural reactor was predicted by Kuroda many years before its discovery in 1972 [173, 174].

Uranium contains only one naturally occurring isotope, ^{235}U, which can sustain a nuclear chain reaction using water to moderate and reflect neutrons at a concentration of ~3%. The Oklo reactor consumed an estimated 5–6 metric tons of ^{235}U and produced an equal mass of fission products and trace amounts of plutonium. Uranium deposits found at this site had a ^{235}U abundance as low as 0.44% (0.72% is normal). Overall, the isotopic composition of the Gabon uranium ore resembled aged spent nuclear fuel [172, 175]. Found at this site was a high concentration of the fission product, Ru-99, along with the fission-product gas, xenon, trapped in geologic remnants, and transuranic radionuclides such as plutonium.

It also seems likely that other natural reactors were operational in the past. Other parts of the world have large, high assay deposits of uranium mineralization in sedimentary strata, so the circumstances which led to the formation of the Gabon reactor may not have been unique. It seems safe to assume that this process may have taken place throughout the history of the earth. Indeed, there is evidence that a natural reactor was operational in the Colorado Plateau and elsewhere in the USA [176].

Isotope fractionation between ^{235}U and ^{238}U is not normally considered significant given the small difference of <1% in mass. The $^{238}U/^{235}U$ ratio has generally been considered invariant in nature with a value of 137.8. Two modal values of the isotopic ratio exist. Their relative difference, 0.03%, is statistically significant. The lower mode is found in ores from the Colorado Plateau. This difference was recognized in 1963 by the US Atomic Energy Commission, but the substantiating data have not been published. Insufficient data presently exists to attribute this difference either to chemical differentiation of the uranium isotopes in the sandstone deposits of the Colorado Plateau or to dilution with ore deposits depleted in ^{235}U by nuclear reactions [177].

Uranium chemistry is about as complex as any of the natural elements—one aspect is that uranium, while soluble in oxygen-saturated water, is insoluble in waters that lack oxygen. Uraniferous mineralization consists primarily of the oxides, uraninite, and pitchblende [178]. Uranium deposits form when oxidized groundwater that had leached uranium from surface rocks flowed down into aquifers, where it is reduced to precipitate uraninite, the primary ore mineral of uranium. Diffusion is a probable process for isotope fractionation. Both diffusion in solids and diffusion in liquids may occur, the latter being more important [179]. Sequential leaching experiments of U-rich minerals indicate that mineral weathering is a possible mechanism by which ^{235}U can be fractionated from ^{238}U in groundwaters [180]. A low temperature change in the redox state of uranium ($U^{6+} \leftrightarrow U^{4+}$) is the primary mechanism for separation of the ^{238}U from ^{235}U ratio [178]. Depleted ^{235}U from sandstone due to uranium ore precipitation from groundwaters reflect a temperature-dependent separation of ^{235}U and subsequent concentration within nearby geological layers [181]. Sufficient separation and concentration of ^{235}U to ~3% level required to sustain a nuclear reaction appeared to have occurred in the uranium rocks from the Utah mine.

Uranium, fission products, and small amounts of transuranics are held together in carbonaceous sandstone deposits of uraninite from Oklo [182]. Pitchblende is a brown to black mineral that contains 50–80% U along with Ra, Pb, and rare-earth elements. The origin of pitchblende is difficult to determine based on its mechanism of crystallization, its phase transformation and composition, and morphology, since natural pitchblende is an aggregate of several mineral phases [183]. Uranium is precipitated out of solution near petroleum deposits in nuclear reaction zones. Organic matter of asphaltic type combined to form pitchblende in high uranium sandstone deposits, such as found in reactor zones in Oklo that were rich in partly graphitized bitumen, kerogen, and liquid oil inclusions [182].[14]

An antinuclear scientist was giving a lecture in a Salzburg, Austrian school while demonstrating the use of a Geiger counter. He scanned a collection of rocks in the classroom and the counter jump 200× normal from a rock obtained from a uranium mine. The entire school was immediately evacuated. The rock was estimated to deliver a dose of about 200 mGy/year. A search of 336 other regional schools found 11 with radioactive rocks [184].

[14] Wikipedia.org/wiki/natural_nuclear_fission_reactor (2010).

Plutonium-239 is created by the absorption of a neutron by ^{238}U leading to emission of a β-particle forming ^{239}Np which emits a β-particle forming ^{239}Pu. Plutonium-239 was found in pitchblende and uraninite ores from Canada and Belgium Congo [185, 186] ; an upper limit was set at one part ^{239}Pu in 4×10^{15} parts ore to 0.7 parts ^{239}Pu in 10^{12} parts ore concentrate, respectively [186, 187]. Much lower levels of ^{238}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, and ^{244}Pu than ^{239}Pu were also found in Congo ore concentrate [187]. Minute amounts of americium and curium have also been found in pitchblende [188]. Laser-induced spectroscopic sensitivity for Am(III) in 0.1 M $HClO_4$ is 1×10^{-8} M [189]. The americium content in the UT rock as determined by laser fluorescent spectroscopy appears to be much greater than has previously been determined in high-grade uranium ore.

Uranium mine tailings are usually not considered significantly radioactive [190]. However, there are exceptions. Sandstones from an abandoned uranium mine, emitting γ-rays at 5–10 μGy/h from their surfaces, were used to build a Navaho Hogan in Monument Valley, UT [191]. The γ-dose rate from tailings of the Radium Hill Mine in Australia was 12 μGy/h at the rock surface [192]. The γ-dose rate in a uranium mine in Tanzania showed hotspots of 30–100 μGy/h [193]. One uranium mine rock in France kept at the home of a worker had a surface γ-dose rate of 1000 μSv/h and a dose rate of 18 μGy/h a meter from its surface [194]. A few rocks from the Free Enterprise Mine near Boulder, Montana, have γ-dose rates of up to 46 μGy/h. These relatively high-dose rates indicate natural nuclear reactors as source of excessive radiation.

In 1955 there were 800 mines on the Colorado Plateau producing uranium ore. Uranium ore is included in sandstone-type (roll front) deposits which are abundant in the sedimentary rocks of the Colorado Plateau. This type of uranium deposit is easier and cheaper to mine than the other types because the uranium is found near the surface. In some deposits, like those found in Colorado and Utah, reduction took place along curved zones which represent the transition from oxidized to reduced conditions in the aquifer [195, 196]. This very rich uranium vein may have undergone hydrodynamic separation of uranium-235 from uranium-238, concentrating the uranium-235 to at least 3% within interstices of porous limestone rock resulting in an in situ geological nuclear reactor [179, 180, 195]. The process of uranium isotope separation and concentration and nuclear fission needed water for neutron moderation. Irradiation also alters the valence state of uranium [197].

Initially uranium ore only contains the uranium isotopes ^{238}U and ^{235}U. Within a few days, ^{231}Th (U-235 series), and within a few months, ^{234}Th and ^{234m}Pa (U-238 series) grow in. The activity then remains stable for more than 10,000 years. After this time, ^{230}Th and all other decay products of the U-238 series and ^{231}Pa and all other decay products of the U-235 series grow in. Beta-particles (ranging from 0.2 to 0.9 MeV) in the U-238 decay series include ^{234m}Pa, ^{214}Pb, ^{214}Bi, and ^{210}Bi. Gamma emissions from the U-238 decay series come mostly from ^{214}Pb (0.2 MeV) and ^{214}Bi (0.9 MeV) [198]. For uranium ore, about 50% of γ-dose comes from energies <30 KeV, 29% from energies of 30–250 KeV, and 21% from energies >250 KeV [199].

The γ + β dose rate from pitchblende is 310 μGy/h of which 90 μGy/h is from γ-rays. The neutron dose rate from pitchblende ore is ~0.07% of the α, β, γ dose rate

or too small to be included in dose calculations. The high level of ^{226}Ra in pitchblende is a significant source of γ-radiation [185]. The α, β, γ decay of ^{238}U daughter products alone is insufficient to account for the high Utah mine rock radioactivity.

The contribution from actinides and their daughter products to beta decay in CANDU (*CAN*adian *D*euterium *U*ranium) reactor spent fuel becomes significant after 200 years and is dominant at times greater than 300 years, at which time the radiation dose is predominantly from beta decay [200]. Like ore from the Oklo mine, rocks from Utah show radiation profiles similar to spent nuclear fuel [172, 175] (see footnote 14).

Radioactive limestone rocks were obtained from an abandoned uranium mine near Monticello in San Juan County, UT. Ore from this region contained high levels of U and V [201]. The mine near where the rocks were obtained had the highest-grade uranium ore found in the continental USA. A large amount of very high-grade uraninite (up to 87% U_3O_8) was found in the mine. The ore was contained within a matrix of calcareous sandstones (filling interstices in the sandstone) and conglomerates colored dark gray to black [202].

Examination of the Utah rocks by gamma ray and laser-induced breakdown fluorescence spectroscopy indicated trace amounts of plutonium and other transuranics and fission products in addition to expected ^{238}U daughter decay products (Figs. 6.14, 6.15 and 6.16). The Utah mine rocks exhibited radiation profiles similar to aged spent uranium nuclear fuel with a surface dose distribution of 93% due to β-particles and 7% due to γ-rays. The β, γ-ray surface dose-rates for mud packs ranged from 10 to 450 μGy/h (20–2000 times background in Loveland, Colorado).[15] The γ-ray surface dose-rates for mud packs ranged from ~1 to 30 μGy/h. The half-value distance for γ-rays in air was about 1.5 cm with 10% of surface dose rate found at about 9 cm from the rock surface.

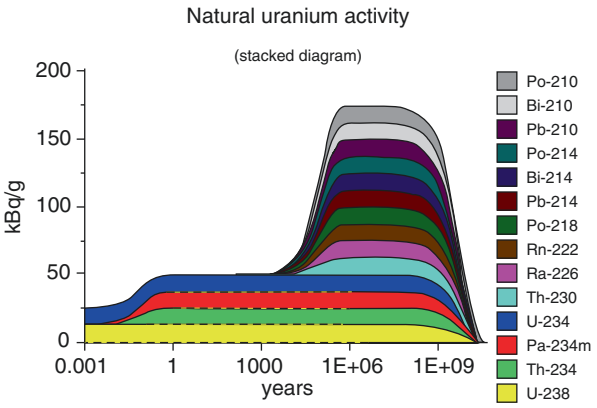

Fig. 6.14 Buildup of daughter products in the U-238 and U-235 decay series up to over a billion years (with kind permission of Wise-Uranium, Arnsdorf, Germany) [190]

[15] The gamma ray surface dose rate was measured over a photon energy range of 30 keV to 1.2 keV.

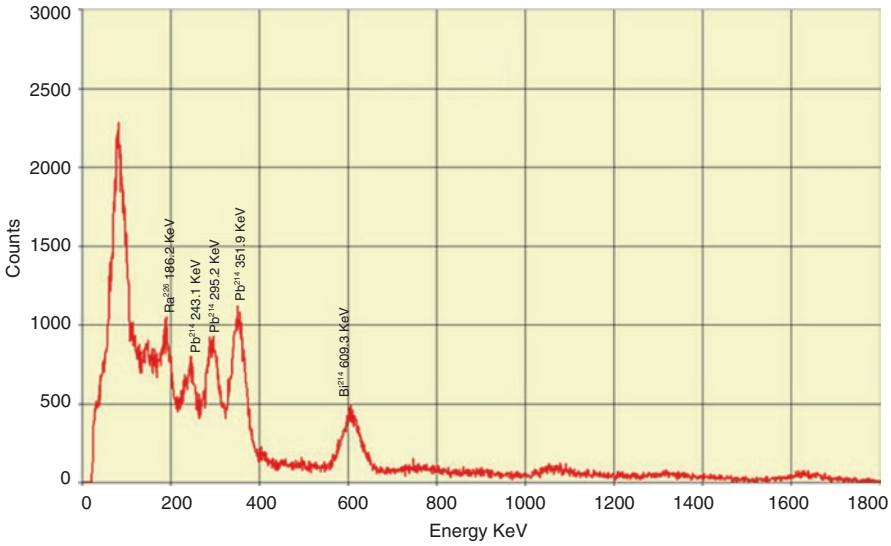

Fig. 6.15 Gamma ray spectroscopy of typical oxidized uranium ore sample; Ra-226, Bi-214, and Pb-214 are well defined (with kind permission of Stratamodel Professional Geologic Services) [198]

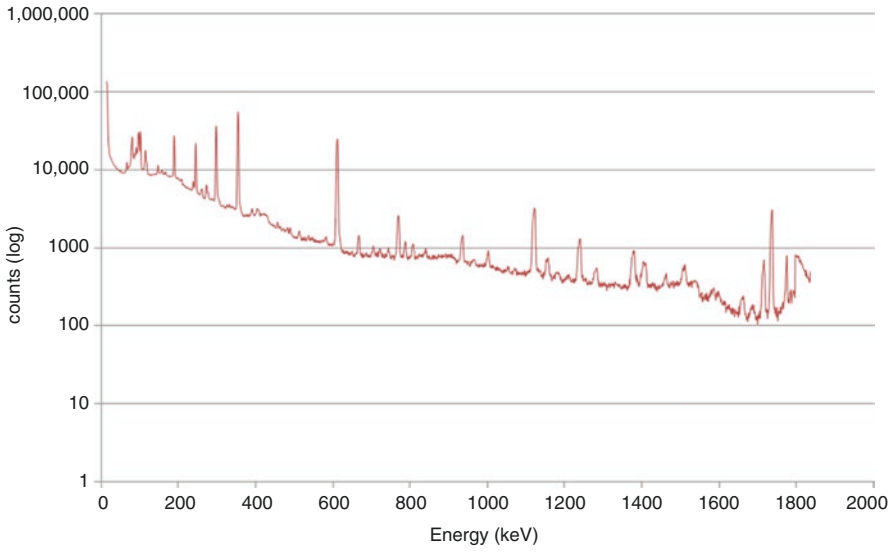

Fig. 6.16 Surface γ-ray spectroscopy of a small flat rock from an abandoned uranium mine in Utah; the surface γ-dose rates were 11 and 140 μGy/h for β, γ

Laser-induced breakdown fluorescence spectroscopy was used for elemental analysis of eight regions on a small flat rock that had a dose rate of 9.8 μGy/h. The entire rock had a high vanadium content. Only in one region was there found a high uranium content which was associated with a small but detectible amount of americium.

The maximum range of β-particles, with energies >0.8 MeV, in soft tissue is about ½ their energy in MeV given as range in cm. Thus, a 2.3 MeV β-particle has a range of 1.1 cm and a 1.1 MeV β-particle has a range of 0.5 cm in soft tissue. The vast majority of β-energy is absorbed by the first cm of skin. Gamma photons are much more penetrating in tissues. The mixed-type dose distribution pattern was similar to that seen with aged spent nuclear fuel.

Individual rocks from the Utah mine and the Free Enterprise Montana Mine had surface γ-dose rates up to 45 μGy/h. β,γ dose rates from the mud pack surface ranged from 30 to 450 μGy/h. Indigenous radioactive rocks were obtained near an abandoned mine in Utah that produced the highest-grade uranium ore found in the USA and exhibited radiological characteristics of a natural nuclear reactor. The "mud" packs made from the Utah mine were comprised of finely pulverized rock dust (obtained with use of a diamond saw) enclosed in heavy plastic bags (Figs. 6.17 and 6.18). This removed dose inhomogeneity of rocks, provides a large range of dose rates making dose rate estimates at the pad surface quite easy to measure, and allows them to be formed around anatomical regions you wish to irradiate.

Gamma-ray spectroscopy was performed on the surface area of a small flat rock that had a surface γ-dose rate of 11 μGy/h. The spectrum was quite different from that seen with typical uranium ore samples. Gamma-ray spectroscopy of typical oxidized uranium ore shows well defined gamma-ray peaks for ^{226}Ra, ^{214}Bi and

Fig. 6.17 Mud pack comprised of uranium ore dust from the Utah mine was produced by a diamond saw and enclosed in a sealed plastic envelope may deliver from 2 to 300 μGy/h. Radioactivity from surface (not including alpha) is 93% beta and 7% gamma

Fig. 6.18 Rock obtained from a uranium mine in Utah. *Red* circles show area of analyses at KAIST by laser-induced spectroscopy. The rock had a dose rate of 10 μGy/h, γ-rays. *Red* circle 1 had a high level of uranium and a significant amount of americium. The entire rock also had a high level of vanadium

^{214}Pb, and other ^{238}U daughters. Presumptive radionuclides detected in the Utah rock included ^{214}Bi, ^{214}Pb, ^{125}Xe, ^{226}Ra, ^{133}Ba, ^{196}Au, ^{111m}Cd, ^{114}In, ^{237}Pu, and ^{242}Am (Fig. 6.16). These radionuclides were associated with ^{238}U daughters and fission products and transuranics associated with a nuclear pile-like reaction.

The γ-ray dose rate in air was determined at intervals up to 27.5 cm from the rock surface for six rocks. A similar absorption pattern in air was seen for all six rocks. The half-value distance for γ-rays from the surface in air was about 1.5 cm with 10% of the surface dose rate found at 9 cm from the rock surface and 2.5–3.0% of surface dose rate found at about 25 cm from the rock surface.

Cumulative doses of up to several 100 mGy from pulverized Utah rocks as mud packs have been used to successfully treat a variety of inflammatory, fibrotic, and proliferative conditions in humans (Chap. 7) [203].

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Benefits in Disease Prevention, Control, and Cure

7

Don't take life so seriously. It's not like you're going to get out alive (Kermit the Frog)

7.1 Lifespan

The *Bulletin of the Atomic Scientists* was founded in 1945 by Manhattan Project scientists. The bulletin has a doomsday clock that expresses a perceived threat of nuclear war. In 1945 it was set at 3 min to midnight. The longest to midnight was 17 min during the Cold War; today it is set at two and half minutes. Henry Kendall (Kendall Oil) used part of his fortune to start and run the *Union of Concerned Scientists*. Paradoxically both the bulletin and the union promote nuclear power over fossil fuel power to counteract the "dangers" of climate change while at the same time promoting all the constraints of the LNT-based radiation health risk projections. The two organizations see benefits for climate and health risk from low-dose radiation. The not so subtle outcome has been the marginalization of nuclear power by climate change actions.

> Of my many colleagues in this field the world over, I do not know of any who have died of what might in any way be ascribed to their exposure to radiation which, in several cases has amounted to hundreds of rad over several years (Lauriston Taylor) [1].

Wooden cabinets, first built by Karrer in 1924, had a radiation source in the bottom which used 50 kv X-rays to visualize the bones of the feet in about 10,000 shoe stores during the 1930s–1950s. The author remembers having used the shoe fluoroscope with a child in California during the 1940s. There were no reported injuries to shoe store customers. A few shoe salespersons exposed to the X-ray beam many

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times a day experienced skin lesions on their hands [2]. However, there was no relationship from exposure to X-rays from shoe fluoroscopes and cancer in shoe customers or in much more highly exposed shoe salespersons [3]. Millions of children and adults did benefit from better fitting shoes, improved posture, and fewer falls.

The current mean life expectancy in the USA is about 81 years for females and 76 years for males [4]. Our individual gene pool is an important factor in determining our lifespan. Buettner, who traveled around the world for *National Geographic* to find "blue zones" where inhabitants lived significantly longer than expected according to their genes than those living nearby, listed nine factors that he believed significantly influenced lifespan; these were diet, moderate exercise, alcohol and food intake, outlook, lifestyle, love, and faith. Buettner believed that most people can add an extra 12 years to their life applying these factors, but not from a pill or surgery [5]. He found one of the longest living populations in the world on the island of Ikaria, located 30 miles from the coast of Turkey. The island has ten times as many siblings over the age of 90 years compared to any other place in Europe. The islanders live and bath in an environment high in radon and radium (Chap. 6).

According to the World Health Organization (WHO), the death rate in Afghanistan for 2012 was 14.6 deaths per 1000 persons per year; the death rate in the USA was 6.2. The life expectancy at birth in Afghanistan was less than 50 years.[1] Many countries in Africa also have life expectancies at birth for both sexes of <50 years. Benefits from low-dose radiation exposures might expect to be greater in countries with low life expectancy than for countries where its population lives much longer. Worldwide, about 50% of all deaths are due to nine diseases (Table 7.1). Most groupings of disease categories have significant inflammatory and proliferative components in their pathogenesis, making them amenable to prevention and treatment with low-dose ionizing radiation.

Table 7.1 Nine most leading causes of death in the world for 2002 (World Health Organization) [6]

Cause	Percent (%)
Ischemic heart disease	12.6
Cerebrovascular disease	9.7
Respiratory infections	6.8
HIV/AIDS	4.9
COPD	4.8
Diarrheal diseases	3.2
Tuberculosis	2.7
Lung cancer	2.2
Malaria	2.2

[1] UNICEF. Malawi death rate for 2013.

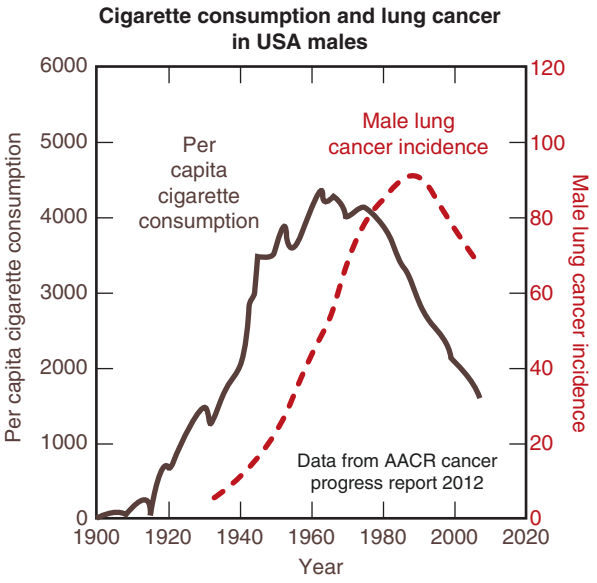

Fig. 7.1 With kind permission of Mohan Doss [10]

There were 2,470,000 deaths in the USA during 2010; total death from major disease categories was 1,690,000. There are 1.6 million new cases of cancer in the USA and 600,000 deaths from cancer per year. The major avoidable causes of cancer in the USA are tobacco use, excessive alcohol consumption, and obesity [7]. According to the American Cancer Society, cancer was the cause of 13% of deaths worldwide or 7.6 million deaths in 2008. Today, worldwide cancer death rates average 21,000 per day. Annual worldwide cancer deaths are expected to increase to 13.2 million by 2030.

Cancer mortality increases markedly after the age of 20 in both males and females. There was a markedly decreasing mortality rate for heart disease and stroke, but not for cancer from 1960 to 2005 [8]. The cancer mortality rate is partially skewed due to an increasing life expectancy during this time. A major cause of lung cancer in both sexes is cigarette smoking; decreasing lung cancer rates from 1960 to 2016 is due to cessation of smoking (Fig. 7.1).

7.2 Radiation Hormesis in Epidemiology

It is difficult for people to accept the benefits of low-dose ionizing radiation (LDR) when confronted with intentional promotion of radiophobia by so-called experts in epidemiology, authoritarian radiation protection agencies, and political correctness of governments. There has been a conscious and premeditated denial of radiation hormesis by members of radiation protection agencies and national and international committees. Adjectives used for various dose levels include high, moderate, low, and very low. LDR is usually defined as <0.5 Gy low linear energy transfer

Table 7.2 Application of adjectives for range of radiation dose bands

Dose band	Range of low-LET dose	Examples
High	>1 Gy	Severe accidents, radiotherapy
Moderate	100 mGy–1 Gy	Chernobyl recovery workers
Low	10–100 mGy	Whole-body CT scan, high radiation background regions in world
Very low	<10 mGy	Conventional radiology, larger geographical, high radiation background areas

Radiation hormesis occurs in dose bands from moderate to very low [9]

(LET), typically X, γ radiation, cumulative annual dose, and a dose rate <100 μGy/h. There are inconsistent messages when dose limits are set at values of <1 mGy or much less, or when the presence of radioactivity (contamination) is interpreted as dangerous [9].

No US nuclear workers have been exposed to more than 50 mGy (5 rad) in a year since 1989.[2] An EPRI analysis sought to determine whether the LNT approach is directly applicable to the nuclear power plant environment, where doses are much lower, and dose rates are several times lower than the high-dose atomic bomb studies on which the linear no-threshold model is based. The EPRI research team reviewed more than 200 studies where individual radiation doses were less than 10 rem in a single exposure. The results were found to be too small to allow detection of any statistically significant excess cancers in the presence of naturally occurring cancers and preponderance of cancers caused by lifestyle, such as smoking [11].

The National Research Council evaluated cancer risk associated with living around 104 operating nuclear reactors at 65 sites in 31 states. In this comprehensive review by dozens of well-known scientists in its 424 pages, there was no mention of the word hormesis (they did mention "hormetic" one time but only in the Appendix) and only referred to the "adaptive response" again in the Appendix (Table 7.2). This NRC-NAS study ignored the overwhelming and clear evidence for radiation hormesis and the radioadaptive response [12].

The LNT model was developed based only on extremely high, acute exposures to radiation from atomic bombs. The effects of these extreme radiation doses were plotted on a graph, and then a straight line back to zero was drawn without any validation and/or additional research on how human cells react to low levels of radiation exposure. As it turns out, newer research shows cells actually heal themselves after exposure to low levels of radiation. For example, there is no evidence of higher cancer rates in nuclear power plant workers, who are routinely exposed to significantly higher levels of radiation, levels still considered to be low, than in the general public.

No hereditary disorders nor increased leukemia or solid cancer risk were seen in Japanese A-bomb survivors at doses less than 500 mGy [13–19]. Fliedner pointed

[2] U.S. Nuclear Regulatory Commission (2007).

out that bone marrow stem cells, which produce the blood cell components, are very sensitive to radiation, yet they are remarkably resistant to chronic low-dose exposure regarding function and maintenance of blood supply [20]. He found that no increased leukemia deaths occurred at doses below 700 mGy/year despite the fact that the latency for leukemia is much shorter than for other radiation-induced cancers. This clear evidence of radiation hormesis—a failure of cancer risk at low-dose radiation—adds to many other data of this kind and should cause UNSCEAR, the NAS, and all the radiation protection organizations to revoke the generalized link they created in 1958 between low radiation and a risk of cancer, which is the basis for all of the fear of ionizing radiation we see today.

Children have benefited from radiotherapy despite receiving relatively high radiation doses at a young age. Back in the 1920s it was believed by the medical community that thymus gland hypertrophy (enlargement) was the cause of sudden death in infants and young children. As a result the enlarged thymus gland of tens of thousands of children was routinely irradiated with X-rays or radium γ-rays from 1924 to 1946. The policy of the Massachusetts Eye and Ear Infirmary in Boston was to apply prophylactic X-irradiation in every case in which an enlarged thymus gland was diagnosed in infancy. Boston children with a mean age of 5 years old received four doses of 100 R for a total fractionated dose of 400 R [21]. One physician with 20 years' experience from 1926 to 1946 in treating thymus enlargement by irradiation said there is absolutely no danger in children from roentgen treatment.

Evaluation of 31 published studies indicated an overall ambiguous relationship of thyroid dose with thyroid cancer with evidence of benefit and harm distributed over a thyroid dose range of 1–1000 mGy [22]. The incidence of cancer for children irradiated for thymus enlargement from 1926 to 1952 at the University of Rochester, New York, was less than anticipated [23]. A threshold for thyroid cancer in these children ranged from 200 to 400 mGy [24, 25]. A thyroid cancer threshold dose of 200 mGy was also seen in children exposed to radioiodine. Japanese A-bomb survivors aged >20 years old at exposure had a relative risk for thyroid cancer of 0.3 or less (70+% protected).

The war on cancer during the last 50 years has failed to substantially prevent or reduce cancer mortality in spite of high investments in research. It can be assumed that 10–30% reduction in cancer mortality rate can be achieved by the use of LDR in humans (Fig. 7.2). Background cancer rate in the USA is ~35%. Thus, using the estimate of 577,190 annual cancer deaths in the USA [26], over 1.2 million cancer deaths may have been prevented in a 20-year period by the application of radiation hormesis. The worldwide numbers would be ~13 times higher, or ~8 million lives saved (Mohan Doss). Increasing the mean annual, natural background dose of 2.5 mGy to 20 mGy by adding anthropogenic sources or even moving to higher background locations might decrease cancer and other major disease categories, saving six million lives a year. Of course, logistics and stubborn resistance of national and international radiation protection agencies would make this an impossible task today.

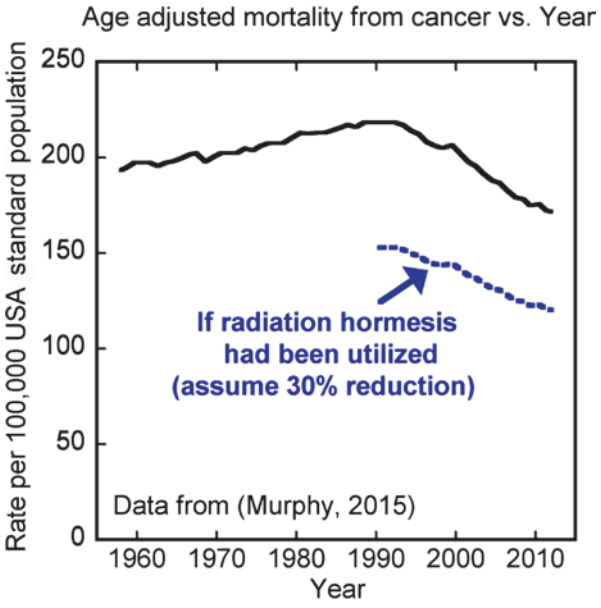

Fig. 7.2 With kind permission of Mohan Doss [10]

7.3 Reverse Aging

Health insurance coverage often excludes naturopathic, homeopathic, and other alternative therapies. Pharmaceutical companies want to promote money-making drugs (with serious side effects) and not inexpensive alternatives, no matter how effective. Modern medicine has often not been particularly effective in treating many chronic illnesses while not offering a definitive cure. Alternative therapies are labeled under a broad category and have gained more interest in medicine. About 50% of the US population use some form of alternative care (as opposed to allopathic therapies) [27]. Hormesis does play an important role in human aging and health [28–30].

Aging is inevitable as the body tissues wear out and organ function diminishes. However, the process can be reversed for a time and slowed down; these include thinning of hair, wrinkling of skin, brittle nails, aching joints, reduced circulation, waning eyesight, reduced memory and cognition, lack of energy, slow and unconfident gait, and decreased bone density. A dysfunctional immune system and decreased stem cell availability are the two hallmarks of aging.

Very common pre-malignant lesions are found as a person ages. These include carcinoma in situ prostate cancer, breast ductal carcinoma in situ, Barrett's esophagus, actinic keratoses, a variety of premalignant metaplasias, oncogene and tumor suppressor mutations, error-prone DNA replication, and background mutations [31]. It is a surprise that we can live 90 years with a malignant cancer risk of only one in three [31, 32].

Nonsteroidal anti-inflammatory drugs (NSAIDs) are the most widely used drugs in the USA. The annual incidence of upper gastrointestinal (GI) complications such as bleeding with regular NSAID use is approximately 1.0–1.5%, whereas the annual rate of upper GI ulcers is approximately 2.5–4.5% [33]. A variety of recalcitrant chronic inflammatory conditions (eczema, ankylosing spondylitis, ulcerative colitis, rheumatoid arthritis, osteoarthritis, lupus, Crohn's disease, psoriasis) which are no longer controlled by NSAIDs may be treated with several expensive drug groupings. These include: interleukin antagonists, kinase inhibitors, CTLA-4 agonists, NSAID-histamine 2 antagonists, NSAID-proton pump inhibitor combinations, monoclonal antibodies, adrenocorticotropic hormones, CD20 antibodies, and TRPV1 agonists. These drugs are administered by self-injection, infusion, or tablets. The cost of NSAIDs per month ranges from $10 to 100. The cost of drugs in the other groupings ranges from $1000 to >$30,000 per treatment period that may range from a month to several months. The drug, Humira, costs $3500 for treatment period. The side effects can be serious since many of these drugs depress the immune system, making the patient susceptible to infections and cancer formation as well as exacerbating preexisting infections, such as hepatitis, tuberculosis, and HIV. About 15 million patients are annually prescribed NSAID drugs, leading to about 2500 annual deaths in the USA from their side effects. Why is this NSAID-related death rate tolerated while the phantom radiation-related death rate not tolerated? This is particularly egregious since LDR is effective in treating these inflammatory diseases at low cost with no side effects.

The health effects of LDR are well established. The expenditure of billions of dollars each year to reduce what are hypothetical, nonexistence risks for cancer formation from LDR is incredibly wasteful. These funds are not available to address more important real issues in our daily lives [34, 35], when the health effects of LDR have been well established [36]. LDR may be administered in a continuous fashion or at regular intervals for a long time. It may be administered simply by moving to a higher radiation background region. LDR radiation protocols lack standard dose quantization, dose fractionation, and duration of a treatment course for specific diseases and for individual patients. Mathematical models, computer simulations, and clinical trials are warranted to exploit the potential of low-dose radiation therapy to control and cure chronic and complicated diseases. The target groups for LDR education are those in the medical and radiation protection communities who live and die by the LNT assumption as well as laypersons who can be convinced to demand from their physicians to receive LDR therapy for their personal health [37].

Nuclear studies rarely result in catastrophic failure with loss of life. An exception was a small 3 MW thermal, experimental, nuclear power reactor that underwent an explosion and meltdown in 1961 at the Idaho National Laboratory (INL), located 40 miles west of Idaho Falls. Three operators were killed, one impaled in the ceiling by a fuel rod. A total of 790 INL workers were exposed to radiation from the accident; 22 of them received whole-body doses of from 30 to 270 mGy. No harmful radiation health effects were found. Extensive epidemiological studies have been performed on INL workers over a time frame covering the SL-1 accident rescue and

cleanup workers that remove the healthy worker effect (HWE) as a possible explanation for hormesis effects of LDR. SMRs were compared for badged male workers at INEEL with zero dose or with positive dose. They all received the same medical care. SMR for all-cause mortality and all cancer mortality were 10–20% less in workers that received positive radiation dose [38]. Similar evidences of hormesis for all-cause mortality and all cancer mortality were observed in 12 US DOE labs and in nuclear shipyard workers (Chap. 3) [39].

LDR increases longevity and is a cure for radiophobia.

Henry, a scientist from Oak Ridge National Laboratory in Tennessee, proposed in 1961 that a dose rate of 10 mGy/day increased longevity. The preponderance of data better supports the hypothesis that low chronic exposures result in an increased longevity, a well-recognized phenomenon [23]. The LNT assumption is not supported at dose rates up to 200 mGy/year [40]. That means a dose rate that is 100–1000 times background is not a health hazard but may enhance health and longevity. In fact, the first benefits were seen in 1896, 1 year after the discovery of X-rays by Roentgen, when X-rays were shown to prevent and cure many diseases associated with inflammation and infection. Radiobiological data shows that biological functions are stimulated at low doses of ionizing radiation, while high doses result in detrimental effects. This results in improved health and successful treatment of medical conditions by low to moderate doses, as shown in numerous studies, in both animal experiments and human epidemiological studies [41]. The results of improved health and successful treatment of medical conditions at low to moderate radiation doses has been shown by Luckey in numerous animal and human studies [42].

Health benefits from low-dose radiation exposure have been documented in about 4000 publications. Included in them is clear evidence for effects of radiation deficiency and a predicted optimum dose of 60 mGy/year. Luckey recommended construction of meeting rooms next to nuclear power plants having a dose rate of 1 mGy/day and the use of monazite for radon rooms used for therapy and prevention [42]. The most ideal dose rate for prevention of inflammatory-related diseases was continuous 25 μGy/h or about 100 times the normal worldwide background rate [43].

Ian Soutar played in the Ranwick Uranium Mine near Sault Ste. Marie, Canada, as a kid collecting radioactive samples using a friend's Geiger counter. He slept with radioactive rocks under his pillow and on the night table up until 1960. In 2011 he called all his childhood friends who had played in the Ranwick Uranium Mine. They had all been told to expect problems later in life from their radiation exposure. Ian found them all healthy; none had had cancer. Soutar uses pure thorite crystals from Thailand, Czech glass beads, and a pendant and mudpack from Night Hawk Minerals that emit between 3 and 85 μGy/h. The Czech beads, made with 2% natural uranium, were first manufactured in 1840 [44]. The first day of self-irradiation

an allergy that had developed to his cat completely disappeared, never to return. The mudpack was effective in removing arthritic and plantar wart pain [45]. Leslie Corrice, a member of S.A.R.I., has worn a uranium stone necklace from Night Hawk Minerals for the last 5 years; Corrice claims to not have had any colds or upper respiratory tract infections since. He said: "I firmly accept that if everyone wore one of these, we would have a significantly healthier society".

Low doses of low-LET radiation can also stimulate immunity to cancer and biological defenses against DNA damage [46, 47] and eliminate existing cancer cells as has been pointed out by Sakai and colleagues in Japan and by S.-Z. Liu and colleagues in China [48]. This points to the potential usage of low-dose radiation (alone or in combination with other agents [e.g., agents that shut down cancer cell survival signaling pathways]) in cancer therapy as some of you are now pursuing (or planning to pursue) [49].

The widely held paradigm that all radiation exposure is harmful is incorrect. There is overwhelming evidence to show that relatively low doses of ionizing increase longevity and produce other beneficial effects. Observations of life lengthening were made as far back as the early days of the Manhattan Project in World War II by Lorenz. He observed that mice exposed to 1.1 mGy/day outlived unexposed mice. This observation has been repeated many times in rodents. This beneficial effect was termed radiation hormesis by Luckey in 1980. The beneficial effects of ionizing radiation are well known and well accepted by botanists and entomologists using ionizing radiation in their studies. Low-dose-rate, gamma rays in a rapid aging animal model (caused by mutation of the klotho gene) significantly slowed the rate of aging [50].

Meadow voles benefit from continuous exposure to low-dose gamma radiation at 50–200 times their normal background levels [51]. Lifespan of microbes, plants, seeds, fungi, insects (flour beetle, housefly, codling moth, cricket, and mosquito), invertebrates, vertebrates, mammals, and humans are all increased by exposure to LDR [52]. It seems that about anything living will benefit from a small dose of ionizing radiation.

My research career in radiobiology began when I obtained a position as research assistant to a Korean postdoc in the Radiobiology Laboratory of Texas A&M University in College Station, TX. The laboratory was run by two wonderful professors, Dr. Sidney O. Brown and Dr. George M. Krise. As an M.S. graduate student, I participated in a large reproduction study with rats who continuously received γ-ray exposure from a ^{60}Co source at dose rates of 0, 10, 20, 50, and 100 mGy per 23-h day. I remember the perplexing discussions over the results. Successive generations of reproducing rats exposed continuously at 10 mGy/day [3.5 Gy/year] had significantly longer lifespan, more robust reproduction, and fewer tumors than unexposed controls [53]. In 1962, they had no explanations that made sense to them. Being in the midst of Cold War radiation hysteria, the last possible explanation would be that these "high"-dose rates were of benefit. Many of the earlier studies on rodent lifespan had not yet been declassified and published. A much later study found the same thing; 1-month-old C57BL/6 mice receiving lifespan, continuous exposure to

gamma irradiation at very low-dose rates 50 times background had an increased lifespan by 23% [54]. Meta-analyses of experimental animal data (85,000 exposed animals and 45,000 controls) showed significant evidence of both reduced tumor incidence and increased lifespan [55].

About 40 papers per year were published on hormesis during the 1960s and 1970s. In 1963 the AEC (Atomic Energy Commission) confirmed lower mortality in irradiated rodents. Cows exposed to 1-2 Gy from the Trinity A-bomb test in 1946 were quietly euthanized because of their extreme old age [56]. A research study during the Manhattan Project, with mice raised in an atmosphere of uranium dust, showed that they lived longer than did the controls; the radiation levels were ten times an arbitrary maximum permissible dose of radiation for that time [56].

Yamamoto carried out studies of cancer in mice given chronic exposures to tritium water. The risk of cancer was significantly less than controls at a dose rate of 3 mGy/day from tritium [57]. Multiple doses of 100 mGy had no effect on tumorigenesis in mice [58].

Those that work on nuclear powered ships have a lower mortality than nonnuclear workers. Investigators matched 29,000 nuclear workers (many received more than 50 mGy of radiation) with 33,000 nonnuclear workers [59]. Co-60 contaminated steel was used in the construction of 1360 housing units in Taipei in 1982–1984. Over the next 20 years, gamma rays from the Co-60 provided unintentional low-level, whole-body irradiation to about 10,000 working class Taiwanese. The exposures were an average of 5 mGy/y for all people, 10 mGy/y for 50% of the people, and >50 mGy/year for 10% of the people; the maximum exposure was 640 mGy/y. The average background exposure in the USA is 1.3 mGy/year. After 17 years, the cancer mortality rate of the exposed population was only 3% that of the Taipei population background level [60, 61].

Confounding factors in radiation pulmonary carcinogenesis are passive and active cigarette smoke exposures and radiation hormesis. Significantly increased lung cancer risk from ionizing radiation at lung doses <1–2 Gy is not observed in never smokers exposed to ionizing radiations. Residential radon is not a cause of lung cancer in never smokers but protects against lung cancer in smokers. The risk of lung cancer found in many epidemiological studies was less than the expected risk for nuclear weapons and power plant workers, shipyard workers, fluoroscopy patients, and inhabitants of high-dose background radiation. The protective effect was noted for low and mixed high and low linear energy transfer (LET) radiations in both genders. Many studies showed a protection factor (PROFAC) >0.50 (50% avoided) against the occurrence of cancer and inflammatory diseases (Table 7.3). Low-dose radiation may stimulate DNA repair/apoptosis and immunity to suppress and eliminate cigarette-smoke-induced transformed cells in the lung, reducing lung cancer occurrence in smokers [63].

The mortality of thousands of nuclear workers under the UK Atomic Energy Authority was followed for 33 years and compared to the general population; all-cause mortality was consistently about 20% less than in the general population (Fig. 7.3) [64]. A 10-year, $10-million study of 39,004 nuclear workers was carefully matched with 33,352 nonnuclear workers (controls) who all received the same

Table 7.3 Relative risk (RR) for 53,698 nuclear power workers employed at 15 utility sites in the USA [62]

Cause of death	RR	95% CI
All cause	0.41	0.38–0.43
All noncancer	0.34	0.32–0.36
Circulatory system disease	0.42	0.38–0.47
All respiratory system disease	0.29	0.20–0.40
All GI disease	0.21	0.15–0.30
All solid cancer	0.65	0.59–0.72
Lung cancer	0.59	0.49–0.71

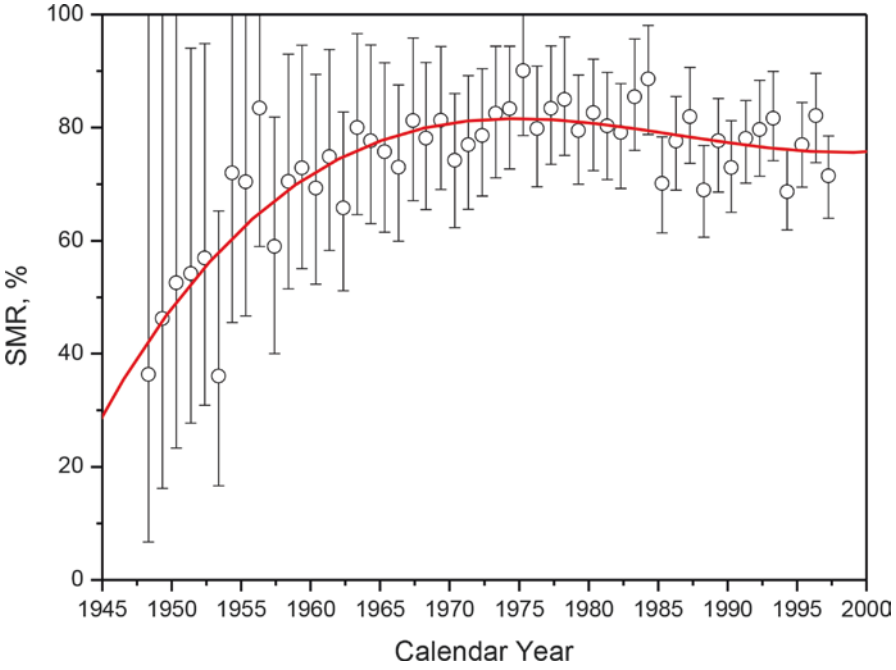

Fig. 7.3 All-cause mortality of the UK Atomic Energy Authority compared to the general population of England and Wales. Radiation dose during the early years of nuclear weapons development was substantially higher than later years. From 1946 to 1979, the mean cumulative dose was 43 mGy, while from 1980 to 1997, it was 11 mGy [64]. The lifespan benefits from those earlier high exposures are clearly evident (with kind permission by Springer, Charles L. Sanders: Radiation Hormesis and the Linear-No-Threshold Assumption, © 2010)

medical care. The study was completed in 1987. The DOE chose not to allow publication of the study, even though it had the reputation among epidemiologists as one of the best studies ever carried out. Dr. Genevieve Matanoski, principal investigator for the shipyard worker study, retired as Head of Epidemiology at Johns Hopkins University. The rate of cancer mortality, as well as overall mortality rate,

among the nuclear workers was substantially lower than in the nonnuclear population [65]. It is the only study of radiation workers where the control group was basically identical to the cohort. This reduces the "healthy worker" effect. The all cancer death rate of nuclear workers was 15% lower than the controls ($p<0.01$); the all-cause mortality rate of nuclear workers was 24% less than of nonnuclear workers (Table 7.4). The DOE summary did not want to report all cancer mortality, which was highly significantly lower in nuclear workers than in nonnuclear workers at the same site. In the nuclear shipyard worker original publication, the lowest exposed group (0–5 mGy) was excluded in Table 7.6 of the publication. That group had a far lower leukemia mortality than found in nonnuclear workers. Instead the author used the 5–10 mGy group as control (instead of the 0–5 mGy group). This inflated the risk estimate causing the dose response to go from hormetic to the LNT. This was a blatant example of post hoc data manipulation.

The radiation workers in the study were exposed to external cobalt-60. They had good radiation dosimetry and records in the Nuclear Navy program controlled by Admiral Hyman Rickover. These data were kept out of BEIR V, even though the technical advisory panel chairman for the nuclear shipyard workers study and the chairman of BEIR V were the same person, Dr. Arthur Upton. BEIR V chose to instead use non-published sources [66]. The summary report of the nuclear shipyard workers study did not include "all cancer mortality," which is the most common factor and of most interest in any such study. Dr. Myron Pollycove, of the Nuclear Regulatory Commission, found that the "all cancer mortality" in the detailed tables was statistically significantly lower among nuclear workers than among the nonnuclear workers.

Until 2005 and the published study of Sponsler and Cameron [65], there was no report to congress, radiation protection agencies, or to the public about the shipyard workers. Further, this most definitive nuclear workers study was not included in a study of "all" US, UK, and Canadian nuclear workers, contracted by DOE and with the International Association for Research on Cancer (IARC) [67]. The principle author of the 1995 study of nuclear workers, Dr. Elizabeth Cardis, failed to include the shipyard results in her data; Dr. Cardis also failed to do so in later nuclear worker studies [68, 69].The "raw" data for the 15-country study by Cardis that was published in the same volume of Radiation Research by different authors clearly

Table 7.4 Adjusted standardized mortality ratios for nuclear shipyard workers chronically exposed to γ-rays [65]

Cause of death	SMR	*p* value	PROFAC
Allergic, endocrine, metabolic	0.69 ± 0.12	4.3×10^{-3}	0.31
All respiratory disease	0.62 ± 0.08	1.4×10^{-6}	0.38
Pneumonia	0.68 ± 0.04	2.4×10^{-14}	0.32
Emphysema	0.63 ± 0.10	7.2×10^{-2}	0.37
Asthma	0.30 ± 0.43	5.1×10^{-2}	0.70
All infectious and parasitic	0.86 ± 0.72	4.2×10^{-1}	0.14
All mortality	0.78 ± 0.04	1.1×10^{-7}	0.22

demonstrated the beneficial effects of low-dose radiation in all nuclear workers; the SMR for all-cause mortality was 0.62 and for all cancer mortality, 0.74 [70].

In a more recent study, a total of 4606 nuclear workers (1956–2001) from the nuclear center at Swierk, Poland, who had received an average cumulative radiation dose of 34 mGy, had an odds ratio (OR) for all cancers of 0.90, an insignificant decrease from expected. No cancer cases were found in 52 workers who had received the highest cumulative doses (up to 653 mGy) [71].

Study of second cancers following high-dose radiation therapy where adjacent but distant normal tissues receive doses <200 mGy shows a protective effect with less than expected (from spontaneous) cancers [72]. Between 1992 and 2010, 440,000 men in the USA were diagnosed with prostate cancer. Large clinical trials had been performed to show more benefit than harm using the PSA test. The FDA approved the PSA test on a small sample in a clinical study run by the company who applied for approval to sell the lab test. Subsequent studies have found no significant improvement in the longevity of men with prostate cancer using the PSA test. Most positive PSA tests led to unwarranted fear and worry among men and their families, unneeded therapy with side effects such as impotence and incontinence. Many cases uncovered occult prostate cancer that would never have become clinically manifested during the person's lifetime. Men receiving a high-dose radiotherapy for prostate cancer had a 70% increased risk of rectal cancer and a 40% increased risk of bladder cancer. However, the risk of developing other cancers outside the high-dose radiation zone was less than expected than for men without prostate cancer (SEER) [73].

7.4 Inflammation

Jim Muckerheide carried out a review of early participants in health and medical benefits from exposure to roentgen and radium rays [74]. Caffrey and Wilson in 1897 described a series of case reports involving the treatment of various inflammatory conditions with Roentgen rays [75]:

> "One patient was suffering from rheumatism to such an extent that a grain of morphine each night was necessary to enable him to sleep, and for five nights he had not had his clothes off. We exposed the affected hand for one half hour to the rays and that night he slept splendidly, the pain having almost entirely ceased. The next night we again treated him for 30 minutes and the following day he went to work. In a few days the swelling ceased entirely, and since then he has had no return of the rheumatism. The next case was a lady about 50 years old, who had lost the use of the fingers on her left hand, due to rheumatism, the disease being of five months standing. We treated her in precisely the same manner and she immediately recovered the use of her fingers".

> A little girl brought … to have a hand amputated. A sore had developed on the back of her hand … continually giving off pus. We made a radiograph of the hand and discovered three pieces of glass lying next to the joint. Owing to the cramped condition of the fingers we were obliged to make a second negative, using a film in the place of a glass plate.

> Immediately after this treatment she sat upon her father's knee and fell asleep in his arms, not having been able to sleep before for several days. At the end of two weeks her father returned and brought a piece of bone which had sloughed out and reported that the inflammation had entirely disappeared and that the sore had healed over. From the time of the making of the radiograph to the present time she has had no pain [75].

> The next case was one of bronchitis of 30 years standing. We are still treating this gentleman, and the results so far have been remarkable. For 25 years he had not slept the entire night without waking up almost choked. But after the second treatment he was enabled to sleep all night, and now the pain has ceased entirely, the cough has been reduced over one half, the expectoration is not nearly what it was, and it is quite apparent that the treatment has killed the germs of fermentation, as the expectorated matter has no taste or odor. He can now use his voice immediately upon arising where, heretofore, it was several hours before he could speak above a whisper. His entire demeanor has changed … [75].

X-rays were traditionally used in the clinical settings as early as 1898, when Sokoloff first reported on pain relief in patients with arthritis [76]. External beam X-rays were used in 1899 for successful treatment of superficial tumors (Fig. 7.4) [77]. In 1911 Pusey described cell stimulation and the successful treatment of some chronic inflammatory conditions [78]. The use of LDR for active therapy of inflammatory and proliferative diseases is undergoing a renaissance as a reinvention of common medical practice from 1920 to 1945. During the 1930s a wide variety of inflammatory and infectious diseases were successfully treated by X-rays and radium γ-rays in the dose range of 0.5–2.0 Gy [43]. Simple calculations will show little or no morbidity and an annual saving of millions of lives in the world using LDR therapy for preventing and treating inflammatory diseases at a small fraction of current costs.

> Healthy people get cancer proportionally more and more as they age. You have to be healthy for most people to live long enough to get cancer. Unhealthy people die earlier of non-cancer diseases (Carol Marcus, S.A.R.I.).

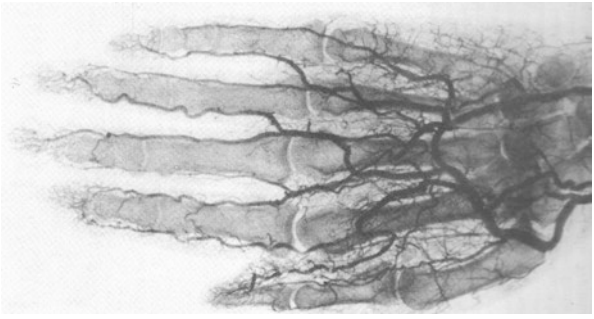

Fig. 7.4 Arteriograms were taken as early as 1899. Radiology and radiotherapy departments were found in many hospitals by 1905. Photo shows arteriogram of the human hand taken in Australia during 1904 [77]

Chronic inflammation is an important component in infectious diseases and in noninfectious diseases such as cancer, Alzheimer's disease, peripheral vascular disease and heart disease, and type 2 diabetes that are associated with aging, affecting today more than 100 million Americans. Although inflammation is often a common starting component in the pathogenesis of these diseases, the mechanisms causing chronic inflammation for each may be quite different. Chronic inflammation markedly represses p53 functions, one of which is acting as a suppressor of inflammation, helping to keep it within safe limits [79].

Many treatment strategies may hamper or inhibit the immune system, counteracting natural healing processes that are stimulated by LDR. In traditional radiotherapy for cancer, a very large radiation dose is delivered to both the cancer and immediately surrounding normal, healthy cells. LDR applied only to healthy cells will initiate the adaptive response which will protect (precondition) normal cells from the large therapeutic dose. LDR is effective in treating most inflammatory conditions without any side effects at small cost.

> It may be prudent to heed to … adaption after low dose exposures and activation of immune system by low doses of radiation along with the upregulation of antioxidant defense in the evaluation of harm to low dose radiation exposures. It appears reasonable to consider the existence of a threshold dose, below which organisms utilize low dose exposures for beneficial cellular and organ functions … (Mishra) [80].

LDR accelerates wound healing and infection control, cancer cure, and treatment of a variety of painful inflammatory conditions [81, 82]. The LDR strategy targets inflammation associated with major disease categories with a broad-based enhancement of the immune system and a variety of anti-inflammatory actions. A small dose of low-LET ionizing radiation in a continuous or chronic delivery for a prolonged time may be used in the prevention, control of progression, and cure of chronic and complicated diseases exhibiting a significant inflammatory component. LDR has been shown to be an effective therapy for acute and chronic inflammatory diseases and painful degenerative disorders (ankylosing spondylitis, arthritis, asthma, fibromyalgia, multiple sclerosis, psoriasis, scleroderma, ulcerative colitis, carpal tunnel) [83]. Asthma was effectively treated in 1926 by ionizing radiation [84]. We expect the relief of pain, stopping or suppressing the progress of the disease and recovery from the diseases by low-dose applications of ionizing radiation, especially for the case of patients with obstinate diseases [85]. Hattori's list of diseases helped by LDR includes: arthritis, rheumatoid arthritis, neuralgia, spondylitis, bursitis, amyotrophia, tenosynovitis, osteoporosis, asthma, diabetes, hypertension, hepatitis, Parkinson's disease, Alzheimer's disease, and allergic and atopic eczema. According to S.A.R.I. members who received radiation or as physicians treated patients, radiation therapy was found effective in the treatment of postoperative large unsightly keloids, pterygium (a web that grows across the pupil of the eye

obstructing vision), plantar wart, hidradenitis scalp dissecting cellulitis, and acne conglobate. No cancers were known to be induced by these local exposures.

The interrelationship between ionizing radiation and the immune system is complex, multifactorial, and depends on the radiation dose/quality and immune cell types investigated. In general, X-irradiation with higher doses (e.g., single doses ≥2 Gy) exerts pro-inflammatory effects and results in inflammatory processes as common toxicity of radiation therapy [86]. On the contrary, low-dose radiation therapy (LD-RT) (single doses <1 Gy) modulates a variety of inflammatory processes and clearly reveals anti-inflammatory properties [87]. Although LD-RT is clinically used for decades for the treatment of noncancerous inflammatory and degenerative diseases [88, 89], underlying molecular mechanisms are far from being fully explored, in part because of their prominent discontinuous dose dependency and putative non-DNA targeted properties.

Radiation therapy for pain management grows more acceptable and important as a substitute for opioid narcotic addiction and their side effects (constipation, confusion, drowsiness, and nausea); these pain relievers often need to be taken every few hours. High radiation doses have been used to control bone pain from cancer (8 Gy) and nerve pain from tic douloureux or trigeminal neuralgia (75 Gy), among many other examples (Table 7.5). Treatment schedules and doses in clinical applications were established empirically in the 1930s of the last century with recommended single doses of 0.3–1.0 Gy in 4–5 fractions for acute and 1–3 fractions for chronic diseases per week to total doses of 3–5 Gy and 12 Gy, respectively [99]. LD-RT is considered unfashionable in some countries because of bone marrow diseases at high doses [100, 101]. The turn away from LD-RT was further encouraged by the availability of effective nonsteroidal and steroidal drugs. These therapies also display numerous side effects, and a considerable number of patients do not respond properly, if at all.

Table 7.5 Treatment of mostly painful inflammatory and fibrotic conditions by moderate-dose radiation therapy in Germany

Inflammatory disease	Number of patients	References
Plantar fasciitis	7947	[90]
Gonarthrosis	5046	[91, 92]
Heel spur syndrome	130	[93]
Periarthritis of the shoulder	141	[94]
Dupuytren's contracture	135	[95]
Plantar fibromatosis	24	[96]
Calcifying tendonitis of the shoulder joint	102	[97]

Typical dose schedules gave 0.5–1.0 Gy in 1–5 fractions for a total dose of 3–5 Gy over a week or more. Most common responses to patients were pain relief and improved mobility. Data taken from Rodel [98]

Table 7.6 Ratio of radiation dose from a chest X-ray to dose contributions from other cardiac imaging techniques [167, 168]

Imaging technique	Ratio
Chest X-ray	1
Cardiac catheterization	350
Cardiac ventriculography	390
Myocardial perfusion	700
Percutaneous coronary intervention	750
Helical coronary CTA	1250

7.5 Arthritis

Low-dose radiation has been shown to be highly effective in the treatment and control of arthritis [102]. Radiotherapy in humans with fractions of 0.3–1.0 Gy and a total dose of 3–12 Gy exerted anti-inflammatory and analgesic effects for painful degenerative disorders. Relatively low-dose radiotherapy for joint inflammation was an effective and less toxic alternative to steroids and low-dose chemotherapy drugs in treating arthritis and a variety of other chronic painful conditions [83, 88, 89, 99, 103–111].

A series of animal studies on the effects of low-dose ionizing irradiation on osteoarthritis was performed by von Pannewitz in the early 1930s of the last century. He reported an improvement of the clinical symptoms, joint swelling, and pain in arthritis animal models receiving X-rays or γ-rays. Pannewitz could not detect any effect on degenerative changes or structural integrity [103]. Acute arthritis was induced in rabbit knees using an intra-articular injection of inactivated mycobacterium tuberculosis or papain. In these models, five weekly fractions of 1.5 or 1.0 Gy reduced the inflammatory proliferation of the synovial cover cells and swelling of the joints [112–114].

Low-dose-rate γ-irradiation suppresses collagen-induced arthritis by reducing pro-inflammatory cytokines and autoantibody production and upregulating T cells [115, 116]. Frey used a transgenic mouse model to examine the effects of LD-RT on rheumatoid arthritis. In this model, transgenic mice express the human cytokine TNF-α and develop a chronic polyarthritis at an age of 4–6 weeks which was characterized by synovial inflammation, cartilage damage, and bone erosion. He observed a significant temporal improvement of the clinical progression of disease in terms of grip strength and joint swelling when mice were irradiated at the beginning of the disease with 0.5 Gy in five fractions within 1 week [117].

In 2004 a patterns-of-care study performed in Germany was published with 37,410 patients treated for degenerative or hyper-proliferative disorders like impingement of the shoulder joint (rotator cuff syndrome), tennis/golfer's elbow, plantar fasciitis (painful heel spur), osteoarthritis, and Dupuytren's disease. Concerning the most important clinical end point of pain relief, complete response and longtime analgesic effects, LDR resulted in a 33–100%, a 47–100%, and a 12–89% efficacy, respectively [104, 105, 118–120]. A patterns-of-care study in

2010 with 4500 patients with osteoarthritis of the knee received LDR demonstrating an increased acceptance of this treatment (95% referral for radiotherapy) [121].

Retinitis pigmentosa is an inherited degenerative eye disease that can lead to blindness due to damage to retinal pigment epithelium. Currently there is no cure. A dose of 650 mGy was found to be beneficial in an animal model of retinitis pigmentosa [122].

7.6 Infections

Over 115 years ago, physicians recognized the value of X-rays to treat infections associated with gas gangrene, pneumonia, bronchitis, tuberculosis, staphylococcus infections, diphtheria, ulcerative dermatitis, otitis media, and mastoiditis [123], and more recently the possibility of treating HIV/AIDS and other viral diseases. In 1896, Professor William Shrader of Missouri State University tested the effect of the roentgen rays on diphtheria bacilli in guinea pigs. One injected animal was exposed to the rays for 4 h in a wooden box and was alive after 8 weeks with no trace of disease. Another animal, not exposed to the rays, died within 28 h after the injection. The postmortem examination showed that his death was due to the diphtheria germs [124]. Freund injected cholera, tuberculosis, diphtheria or typhus microorganisms in 5 cc saline under the skin of both ears of rabbits. One ear was exposed to "uranium" rays; no inflammation occurred in the irradiated ears [125]. Lortet of Lyon, France, showed the attenuation of tuberculosis infections by roentgen rays in guinea pigs. Every day the inoculated area of animals was exposed to X-rays. The unexposed animals displayed ulcerous sores at the point of inoculation and loss of weight. The exposed animals had no ulceration and had gain of weight [126]. Irradiated guinea pigs inoculated with tuberculosis lived longer than controls [127].

Prior to World War II, X-rays were used successfully to treat a variety of infections [128, 129]. There was a 66% decrease in the death rate from infection and parasitic disease in exposed workers at the Savannah River Plant when compared with unexposed controls within the same area [130]. It was 14% less for shipyard workers [65, 131].

There are over 2.2 million cases of otitis media in the US per year. Otitis media is a persistent infection of the inner ear with tympanic membrane perforation. Traditional treatment is by antibiotics and drainage of the inner ear. Mastoiditis occurs when otitis media with eardrum perforation causes infection of the mastoid bone. Treatment is by antibiotics and/or mastoidectomy. Intracranial complications can occur if left untreated. This is a serious problem in developing countries.

Cervical adenitis is characterized by massively enlarged lymph nodes in the neck that is associated with tonsillitis, dental infections, otitis media, mastoiditis, mumps, influenza, and other childhood diseases. The first case of cervical adenitis was treated with X-rays in 1902. Clinical success was found in 75–90% of patients without surgical intervention. Relief was marked and rapid [132, 133]. Historical estimated doses to treat inflammatory conditions were 10–20% of the skin erythema

dose (SED). X-ray therapy caused resolution of mastoiditis without bone destruction. Decreased temperature, pain, pus discharge, and insomnia were seen within 24 h. LDR prevented the progression of mastoiditis to osteomyelitis (20–25 rad). Medical support for therapy continued until the mid-1940s. Cumulative doses for these three conditions ranged from 75 to 200 rad most often given as a single exposure to X-rays. Treatment was effective in 85% otitis media cases. Patients with mastoiditis usually required multiple (fractionated) exposures [134].

X-rays were used to treat impaired hearing loss related to throat inflammation and lymphoid tissue growth in the nasopharynx. X-rays readily reduced the lymphoid mass within 1–2 days. About 25,000 airplane pilots were treated by nasopharyngeal γ-rays from radium for hearing loss during World War II; submariners were also similarly treated to qualify them for service. Thousands of children also received similar radiation therapy [135]. Epidemiological studies decades later failed to find a significant increase in malignancies of the head and neck.

Gas gangrene is caused by *Clostridium perfringens* exotoxin-producing gas as a result of tissue necrosis. The infection spreads most often from the limbs throughout the body. Treatment today is by antibiotics and hyperbaric oxygen (helpful since the pathogen is anaerobic). Prior to World War II, the infection was successfully treated with X-ray doses of 100–200 rad [136–138].

X-ray therapy was used successfully to treat bacterial (lobar and bronchopneumonia) pneumonia during the first half of the twentieth century. Of 15 studies, 863 pneumonia patients were given about 50 r X-rays, of which 717 survived (83%) [139]. The mechanism by which the X-ray treatment acts upon pneumonia involves the induction of an anti-inflammatory phenotype that leads to a rapid reversal of clinical symptoms, facilitating disease resolution. The capacity of low doses of X-rays to suppress inflammatory responses is a significant new concept with widespread biomedical and therapeutic applications.

From 1923 to 1948, low-dose X-rays were used to reduce inflammation and increase tissue repair in sinus infections with a cure rate up to 80%; the effective dose was between 30 and 70 rad [140]. In 1916 Osmond found that pain in the forehead was released by radiograms used to diagnose frontal sinusitis. In 1923 he showed that symptoms of sinusitis were absent after 1–3 weeks following two to three X-ray treatments [141]. In the 1990s, German physicians were successfully treating between 40,000 and 50,000 people with X-rays for sinus infections [142]. Periodontal disease, caused mostly by inflammation and ulceration of gingiva tissues from anaerobic bacteria, was successfully treated by LDR (recommend 10 cGy per day) [143].

Serious *Staphylococcus* infections associated with the skin are often the cause of furuncles and carbuncles. Furuncle is a boil or infection that starts in a hair follicle. A carbuncle is an abscessed skin lesion with multiple openings and draining pus. Untreated they can lead to sepsis with a mortality rate of 10–20% (pre-antibiotic age). Treatment from 1920 to 1940 was often by X-rays at a 10–20% of the erythema skin dose (0.1–0.2 SED). This was equivalent to ~75–200 R. X-rays killed lymphocytes within the lesions within 30 min. Exposure was associated with a rapid decrease in pain from reduction of inflammatory components [144].

There have occurred an increase of mutated drug-resistant pathogens in a battle between antibiotic efficacy and disease control. Strains of TB and MRSA (methicillin-resistant *Staphylococcus aureus*) and other "resistant" infections may be effectively treated by LDR based upon historical experience prior to 1945. The enhancement of immune responses by LDR would not be of interest to pharmaceutical companies because it cannot be patented. In addition, these companies do not spend a proportionately large amount of time or money on antibiotic development because they are usually not large profit makers. However, someone ought to prepare a benefit-risk assessment for clinical use of LDR for the treatment of life-threatening drug-resistant pathogens.

The control of viral infections by LDR also been demonstrated in many animal models. Exposure of prion-infected mice to 4 × 500 mGy fractions of ^{60}Co γ-rays administered every other day at a dose rate of 0.5 mGy/min at 50 days post-infection significantly prolonged symptom-free survival [145]. Mice exposed to 1.5 mGy at 5 and 12 days following infection with Friend virus, a type of murine AIDS, recovered, while all of the controls died within 40 days [146]. LDR is also effective in controlling ulcerative dermatitis and ulcerative colitis in mice [147]. Radiation-induced adaptation in immune cells protects mice with the Friend leukemia virus, a member of the retrovirus family that includes HIV-1 [148]. Limited human studies suggest that low-dose TBI may be beneficial in treating AIDS due to radiation-induced immune defense mechanisms [145, 149, 150]. There is every indication that low-dose radiation could be successfully used to treat HIV/AIDS. Because AIDS is an immune deficiency disease, and because strong and enhanced immune response has succeeded in preventing full-blown AIDS in persons with HIV, it can be expected that the stimulating effect of low-dose radiation will suppress the development of AIDS in persons whose immune systems are degrading. Del Regato initiated human trials which indicated that whole-body radiation may be beneficial in treating AIDS [151].

Low-dose radiation accelerates wound healing by up to 50% based on X-ray therapy for wound healing carried out in the USA from 1900 to 1960 [152]. It is well known that LDR stimulates the immune system which can destroy precancerous cells, cancer cells, and tumor metastases [153–155]. Infections are associated with increased neutrophils and mononuclear cells related to inflammation. These cells can help "capture" and isolate circulating tumor cells.

7.7 Cardiovascular-Related Chronic Diseases

Low-dose cumulative radiation (<500 mGy) does not appear to be involved with inflammation and chronic diseases, such as in kidney, cardiovascular system, and associated with abnormal lipid profiles and diabetes. There was no statistically significant associations of cardiovascular disease in humans at cumulative doses <500 mGy and at dose rates <10 mGy/day) [156–158]. Low-dose-rate γ-irradiation suppresses development of type 2 diabetes in mice by maintaining insulin secretion and normal lipid levels and preventing the development of nephropathy; the result

is an enhanced lifespan [159–162]. Diabetic mice given total body 50 mGy every other day for 4 weeks or 25, 50, or 75 mGy for 4 or 8 weeks significantly attenuated inflammation, insulin resistance, and lipid profiles as well as preventing nephropathy [159, 162, 163]. Whole-body LDR at 12.5 mGy every other day for 8 weeks appeared the optimal schedule and dose for protecting the kidney from the effects of diabetes [164]. Mice with chemically induced type 1 diabetes, who received 25 or 50 mGy whole-body irradiation, failed to develop diabetic cardiomyopathy and had improved cardiac function and less cardiomyocyte hypertrophy than did unirradiated diabetic controls [165].

Cardiology accounts for 40% of patient radiology exposure. Typical patient exposure is similar to 50 chest X-rays per person per year (Table 7.6). Most dose is from CT, percutaneous coronary intervention, cardiac electrophysiology, and nuclear cardiology (they deliver the equivalent of 750 chest X-rays). Coronary angiography and percutaneous transluminal coronary angioplasty give mean skin doses to the patient of ~10 cGy and maximum doses of >70 cGy. Doses to the lung are typically 25 mGy. No unexpected risk of cancer was associated in staff working in cardiac catheterization laboratories who had received a median cumulative radiation dose of 46 mGy [166]. Cancer risk compared to the general population was reduced in post-coronary artery bypass graft patients aged 55–75 who had received coronary CT angiography [167].

A good way to reduce heart damage to high-dose radiation is the well-known adaptive response (i.e., give a low conditioning dose of 150 mGy a day before the high dose of breast cancer treatment (2 Gy)). The treatment has been recommended by Sakamoto (LDI and HDI). Low radiation doses upregulate adaptive protection systems that benefit the normal, healthy heart tissues but do not benefit the abnormal cancer cells in the breast. This would be a significant improvement in therapy [81]. Cardiologists (at least mine does) have a saying "everyone knows that cardiologists do not get cancer."

> The preponderance of data supports the hypothesis that low chronic exposures result in an increased longevity … increased vitality at low exposures is a well-recognized phenomenon (researcher at ORNL) [23].

7.8 Neurodegenerative Disease

The last new Alzheimer's disease (AD) therapy won approval in 2003. It failed as did the last 77 clinical trials for AD to slow progression or reduce the mortality rate. Current drugs only help with symptoms and do not prevent, slow, or reverse brain damage [169]. Most AD patients have CT scans that are used to diagnose and examine progression of AD (brain atrophy and changes in brain structure) [170]. However, the CT scans might be beneficial in prevention of early AD, slowing AD progression, or even in reversing symptoms.

The free radical theory is one of the major hypotheses on aging mechanisms. It states that reactive oxygen species (ROS) induce stochastic occurrence and accumulation of macromolecular damage, particularly to DNA that lead to a progressive decrease in maintenance of normal health [156]. Mitochondrial dysfunction is strongly associated with the onset of numerous age-related diseases, such as neurodegenerative diseases [90]. Human lifespan is influenced by excess ROS damage and by the LDR-related adaptive response. Ideally lifespan can be increased to 140 years with optimal adaptive response that counteracts ROS damage [171]. Derivatives of ROS create oscillations in antioxidant systems as well as in cell signaling associated with inflammation and immune response.

> We expect the relief of pain, stopping or suppressing the progress of disease, and recovery from disease by low-dose application of ionizing radiation – especially for the case of patients with obstinate diseases [85].

The healthy adult human brain contains about 100 billion neurons and 100 trillion synapses. Restorative neurogenesis in the brain sustains a normal active life and recognition function of learning and memory, which progressively decreases in adult aging, remarkably so in neurodegenerative disorders such as Alzheimer's disease [94, 97]. In neurodegenerative diseases, information transfer begins to fail, and neurons die due to inflammation as a first direct cause and/or as a result of pathogenic conditions that appear in the midst of disease progression. Alzheimer's disease (AD), Parkinson's disease (PD), Huntington's disease HD), multiple sclerosis, and AIDS-related dementia all have early inflammatory pathological mechanisms associated with accumulating DNA damage, some due to mitochondrial DNA damage [95, 172]. There is presently no proven method for curing, preventing, or even slowing down AD, PD, and HD. LDR may be effective by controlling inflammation and stimulating restorative/regenerative neurogenesis [173, 174].

> The epicenter of AD in the USA is Florida where 0.5 million AD patients reside. AD is the most expensive disease in America using 20% of Medicare dollars today; by 2050 total AD cost will reach one trillion dollars. Typical good institutional AD care costs 4–6 thousand dollars per month.

AD was first recognized in 1906 by Dr. Alois Alzheimer who demonstrated the association of progressive cognitive impairment with pathological plaques and tangles in the cortex of the brain [175]. AD affects 5.5 million Americans today, making it the fifth or sixth leading cause of death and the most prevalent neurodegenerative disease. Common diseases, such as stroke, heart disease, prostate cancer, and HIV-related deaths, have experienced a 8–29% decline in mortality from 2000 to 2008. In contrast, AD has shown a 66% increased mortality during this same period (Fig. 7.5) [43]. AD rates greatly increase after the age of 75 and are predicted to greatly increase as the US population disproportionately ages and lifespan increases.

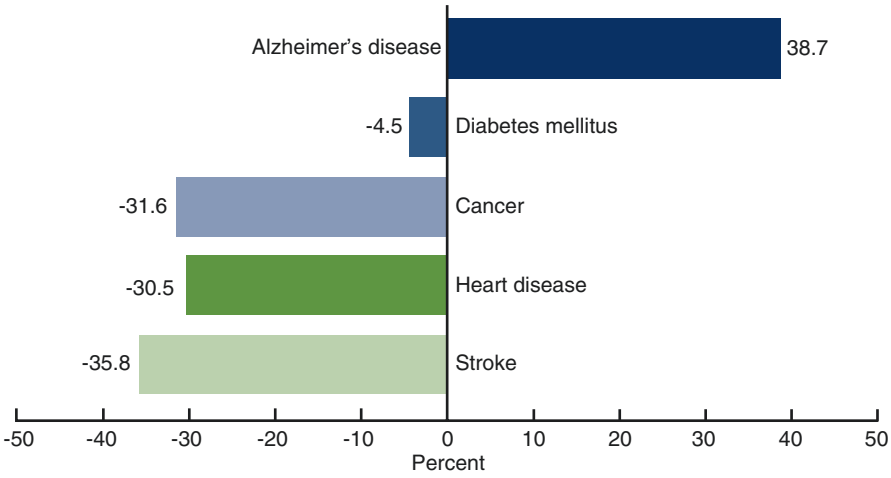

Fig. 7.5 Percent change in age-adjusted death rates for selected causes of death in the USA from 2000 to 2010. The age-adjusted death rate for AD increased by 39% from 2000 to 2010 in the USA (National Vital Statistics System, Mortality) [178]

AD is the cause of over half the dementias in the USA; 5.2 million Americans >65 had AD in 2012. Mean survival after diagnosis of AD is 8–10 years. The mortality rate per 100,000 for AD in the USA is markedly age dependent: at 40–45 it is 0.3, at 55–64 it is 2.1, at 65–74 it is 19.8, and at >74 it is 987 [176].

Gradual increasing forgetfulness, emotional disturbances, and loss of bodily functions are signs of AD. Many neurons are lost during the late stages due to the accumulation of extracellular β-amyloid and intracellular tau protein. The precise relationship between amyloid plaque formation and neuronal dysfunction is not known. Interestingly, small physiological levels of β-amyloid protein may actually protect neurons [177].

Parkinson's disease is a degenerative disorder characterized by slow movement, uncontrolled tremors or shaking, rigid muscles, and poor balance due to a loss of dopaminergic neurons in the substantia nigra of the brain. Cognitive symptoms and dementia are seen in advanced cases. Most cases of PD occur >50 years of age. Prevalence of PD in the USA at any given time is about 0.3%, increasing to 1% for those over the age of 60.

Focused ultrasound has been used to thermally ablate small areas of the brain associated with PD symptoms. FDA-approved medications for PD all currently involve manipulation of levels of dopamine, a significant neurotransmitter in the brain (directly increase dopamine, mimic dopamine, prevent breakdown of dopamine). The involvement of inflammatory processes in nigral degeneration contributes to the loss of dopaminergic cells. NSAIDs have shown some promise in reducing the risk of AD and PD. In a similar vein, the apparent protective effect of cigarette smoking on Parkinson's disease (PD) is one of the few consistent results in

epidemiology; cigarette smoking could have a similar effect on Alzheimer's dementia [90]. The widely used herbal medicine, *Ginkgo biloba* extract, and low-dose γ-irradiation have protective effects against Parkinson's disease in a rat model possibly by replenishment of glutathione levels [91].

Huntington's disease is an inherited neurodegenerative disease associated with the loss of specialized neurons that are critical for motor control. Today, Huntington's disease affects 30,000 people in the USA. The disease causes involuntary movements, coordination problems, and mental deterioration. There is currently no treatment to slow or alter the progression of Huntington's disease. Research is being carried out to regenerate neurons lost in Huntington's disease based on studies in mice [92]. Creutzfeldt-Jakob's disease (mad cow disease) is an encephalopathy characterized by the presence of amyloid plaques in the brain. Prion protein molecules polymerize into sheets of amyloid fibrils during this disease, producing a pathogenesis similar to AD.

In recent years epigenetic mechanisms have emerged as key players in regulation of life expectancy. Epigenetic refers to something that is in addition to genetics or genetic expression modifier that is independent of the DNA sequence of a gene. Examples include methylation of DNA or acetylation of histones which alter gene expression. Arthritis, cardiovascular disease, cancer, and AD have all been associated with harmful epigenetic changes. Exposure to ionizing radiation may elicit positive or negative epigenetic modifications depending on the dose of radiation [179].

The amyloid hypothesis for AD proposes the deposition of β-amyloid in the brain as the critical pathological event [180]. The progression of AD may be driven by a vicious cycle in which epigenetic factors contribute to accumulation of Aβ, which then in turn induces further changes in global DNA methylation. These resulting changes in DNA methylation correlate with progression of AD pathology from early to final stages of the disease in 5XFAD mice, including neuronal loss, gliosis, and cognition and behavioral. Pallas and Sanfeliu hope that their findings will provide insight and help to assess future therapeutic interventions developed to target the epigenome in cases where Aβ deposition (and thus disease onset) has already begun [181, 182]. Tau protein is also neurotoxic due to its hyperphosphorylation. The level of tau accumulation can predict the age of onset, cognitive decline, and disease duration in AD [183, 184]. Drugs developed for AD have provided only short-term symptomatic benefits without significantly influencing disease progression [185]. Aβ immunization can inhibit amyloidosis and lead to cognitive improvements in an AD mouse model [186].

Morris water-maze swimming test for rat learning was evaluated at 7, 14, and 28 days after irradiation; 300 mGy caused a significant improvement in learning [187].

Fractionated whole-brain irradiation is given to over 100,000 patients in the USA each year, mostly for the treatment of primary brain tumors and metastatic disease to the brain. Typical cumulative doses range from 20 to 60 Gy. Significant cognitive impairment is common at the highest doses, while late demyelization and white matter necrosis have been largely eliminated by modern radiotherapy techniques. Total doses of 30–60 Gy given in 2 Gy fractions can impair cognition [188]. Wilson proposed the use of a total brain dose of 10 Gy in 2 Gy fractions given daily for prophylactic use in small-cell lung cancer and pediatric leukemia [183].

Administration of 1–2 Gy cranial irradiation to children receiving scalp irradiation for ringworm infestation caused a decline in cognitive ability which was thought to be associated with a reduction in neurogenesis [93]. Brain irradiation of mice with Fe-56 ions at doses of 1 and 10 Sv (RBE = 10) resulted in early signs of cognitive impairment and Aβ plaque formation [96]. Significant depletion of neuron stem cells has been seen in rodents given a single, low-LET, acute dose of 2–6 Gy [39]. There is, however, no clinical or epidemiological evidence linking LDR in humans to development of AD or PD [189]. A single or fractionated (5 × 2 Gy) X-ray dose has been used successfully to treat extracranial amyloidosis with benefits lasting for 5 years [190].

Moderate-dose radiotherapy has successfully been used to treat amyloidosis in humans [34]; therapy protocols were based on previous studies in mice. Doses from 160 kVp X-rays at 0.7 Gy/min of 5 × 2 Gy were delivered to the brain of transgenic mice genetically susceptible to AD development. This regimen decreased brain plaque formation by about half and reduced histochemical evidence of tau protein in brain tissue [191, 192]. Whether loss of plaque was associated with improved cognitive function was not been determined in this study. Rodents experiencing contusions of the optic nerve or spinal cord exhibited a significant increase in neuron survival and more rapid recovery from injuries after receiving a radiation dose of 3.5 Gy up to 3 days post-injury [193].

Radiation hormesis is expected to have a significant positive effect on AD and PD [28]. This view is, however, more based on studies peripheral to AD and PD and on animal studies, than directly demonstrating benefits of LDR in AD and PD in human patients. Hattori believes that LDR can stop the progression of AD [51]. There is abundant experimental work in animals that demonstrated the stimulation of neurogenesis in the brain associated with restoration and regeneration of neurons by low-dose ionizing radiation [173, 187, 194].

MDs are very reluctant to treat AD patients with imaging CT scans even though this is a non-risk treatment for 80-year-old patients.

LDR may be beneficial in treating a wide variety of inflammatory neurodegenerative diseases for which there may be few therapeutic options [195]. LDR-induced free radicals can activate signaling pathways that increase the resistance of neurons to high radiation doses [196]. Injected stem cells may induce neural cell

regeneration and functional recovery for stroke, Parkinson's disease, Alzheimer's disease, and Huntington's disease [197–199]. The brain is capable of regenerating mature neurons [197]. Radiation hormesis is also a promising method to protect neurons from damage from toxic agents as well as enhancing neurogenesis [198].

> Radiation therapy as a treatment approach for AD could be implemented quickly and inexpensively, given the prevalence of radiotherapy centers across the USA. Additionally, the use of radiation therapy for AD is suitable to all patients with mild or severe AD symptoms [183].

Neurodegenerative diseases such as Alzheimer's disease, Parkinson's disease, amyotrophic lateral sclerosis, and frontotemporal lobar dementia are significant issues with aging populations. Maintaining an optimal milieu for neuronal function rests with supportive glial cells and the blood-brain barrier. Neurodegeneration occurs in part because the environment is affected during disease in a cascade of processes collectively termed neuro-inflammation. These observations indicate that therapies targeting glial cells might provide benefit for those afflicted by neurodegenerative disorders [200].

Glial cell activation in AD brains promotes Aβ clearance, providing neuroprotection in AD patients. Whole-brain LDR could involve the recruitment of protective glial cells that would be beneficial in AD patients [183, 201]. Whole-body fractionated LDR protected against development of Parkinson's disease that appeared to be associated with the replenishment of GSH levels [91]. LDR improved learning in a mouse AD model, indicating that radiation has the potential for preventing or suppressing disease progression. Wei found that an X-ray dose of 300 mGy enhanced neurogenesis in hippocampus in mice and increased cell survival and reduced apoptotic of neuronal stem cells that resulted in improved learning [187].

Some researchers suggest that radiation at any dose accelerates aging, thus increasing the risk of AD. There is no epidemiological or molecular data that unequivocally demonstrates an association of ionizing radiation to the brain and risk of developing AD [202]. LDR is not carcinogenic in the brain, but often hormetic, at doses that may control neurodegenerative diseases. This paves the way for considering LDR for treating AD and PD in clinical trials [203]. No clinical trials have been carried out using LDR to treat these diseases. Higher radiation doses may be required to treat neurodegenerative diseases than for inflammatory conditions associated with many other conditions. A single acute dose >500 mGy may kill neuron stem cells, while chronic or fractionated total doses of <500 mGy may stimulate neuron stem cell proliferation by the adaptive response of radiation hormesis.

> Exceptional patients who had been diagnosed with incurable cancer by medical report and subsequently became disease-free or survived for long time periods had the characteristic of personal activism as a common feature. They took charge and got involved in their diagnosis and treatment. They also tended to be altruistic (carried about others more than themselves) and responsible for their own life, did things that they loved, and had a mission (goal) in life [204].

Cuttler gave a presentation of a case report on treatment of Alzheimer's disease with CT scans at the International Dose-Response Conference in 2016 [206]. There was discussion following the presentation on how to move this concept forward. An 81-year-old AD patient was completely nonresponsive on May 21, 2015, when she received her first CT scan. She had been diagnosed with AD nearly 10 years before receiving CT scans while in hospice care. Four months after receiving the first of five 40 mGy scans, she was alert, happy, eating reasonably well, mobile, and partially responsive to verbal communication [206, 207]. The patient's neuropsychologist, William MacInnes, PhD, A.B.N., in a letter written on April 16, 2016, gave a presumptive diagnosis of senile dementia-probable Alzheimer's disease. MacInnes described the improvement in Mrs. Moore since last time he saw her in October, 2015 [205]. She continues to receive a brain CT scan every 6–7 weeks; her improved condition has stabilized. Jerry Cuttler has written a short update on the AD patient that was treated with CT scans. She has been receiving periodic "booster" CT scans over the past year and is maintaining (improving on?) her partial recovery. This Letter to the Editor will be published very soon. Her husband has been similarly treated for Parkinson disease since mid-October 2015. A scan every 4 weeks appears to be optimal for him. A second AD patient, living in Amherst, MA, has received two CT scans during April–June, 2016. His wife has reported significant improvement in playing a musical instrument after his first scan (Fig. 7.6) [205].

Fig. 7.6 Dr. Eugene Moore and Barbara Moore. Photo taken while Jerry Cuttler (*left*) was visiting on December 4, 2015 (with kind permission of Jerry Cuttler) [205]

A patent application, titled *Radiation therapy for treating Alzheimer's disease*, recommends total doses to the brain from different radiation sources of 3000–18,000 mGy administered at 500–3000 mGy per day [208]. Bistolfi suggests a weekly long-term dose of 500–1000 mGy to treat AD [192]. Based only on his experience with one patient, Cuttler recommends a much lower total dose of 160–200 mGy given in fractions over several months [206].

Cuttler had many conversations with Dr. Eugene Moore (husband of the first AD patient who was treated) who took considerable initiative to make this happen in spite of many obstacles. Moore is an engineer, has been fascinated by radiation hormesis for many years, and is interested in S.A.R.I. (Fig. 7.6). Moore also has Parkinson's disease; his doctor prescribed a monthly CT brain scan; the first scan alleviated his night tremors and markedly reduced his need for medication. His condition has stabilized with no evidence of progression. Pat Lewis has managed the Free Enterprise Mine radon inhalation facility near Boulder, Montana, for over 20 years. She has seen AD patients experience a degree of "awakening" after visiting the mine [209]. Her husband was diagnosed with Parkinson's disease when he was 35. He is now 64. He started working in the mine when he was 44. His neurologist considers his lack of PD progression remarkable and better than his other Parkinson's patients. During the last year he has slept with a bag of rock fragments on his pillow that give about 40 μGy/h γ-radiation [209].

Developing a drug for treatment of AD offers a potential huge profit for commercialization. The price of a typical CT scan is $1200. The cost would be much less if not using radiological imaging interpretation and since the facilities already exist.

In a PD rat model, LDR reduced disease symptoms and increased stem cell proliferation and neuro-regeneration in the brain [91]. Animals receiving 100 mGy X-rays showed enhanced production of antioxidants, protection of dopamergic neurons, and stabilization or prevention of Parkinson's disease development [203]. Parkinson's disease is seen in the author's family line. He had early signs and started using a radioactive pad within a cap on his head. The symptoms disappeared after a month and have not returned for over a year. A good friend of the author began experiencing short-term memory loss; after using the pad for a few months, the symptoms disappeared.

The idea that low-dose radiation may be useful to reduce Alzheimer's disease was proposed in 1999 by Kojima. The main reason low-dose radiation has not been tested in clinical trials so far is the fear of even the lowest levels of radiation based on the linear no-threshold (LNT) model which is presently accepted and used worldwide. If we had tested low-dose radiation for treating/preventing AD soon after it was proposed in 1999, we would have likely observed its effectiveness in controlling AD, and its use would have become widespread by now, reducing the toll of the disease. The main culprit dissuading such use of

low-dose radiation is the LNT model. It is thus important to eliminate the use of the LNT model so that low-dose radiation can be studied and used without any concerns for the prevention and treatment of diseases such as AD [210].

7.9 Historical Radiation Therapy

Radiotherapy is 120 years old and its birth can be set in the year 1896. That year, three novel concepts came together in the French city of Lyon. The first was the discovery of X-rays. At the same time, the bacterial theory of disease was taking hold. Victor Despeignes performed in July 1896 the first documented anticancer radiation treatment on his neighbor who probably suffered from a gastric lymphoma. He gave the very first description of tumor regression following radiation [211].

In 1920, Murphy gave repeated small or single large doses that destroyed lymphoid tissue, while a single small exposure stimulated lymphocytes. Mice receiving a dose of X-rays were inoculated along with unexposed controls with a transplantable cancer a week later. Transplants grew in 28% of irradiated mice and in 75% of controls [212]. By 1934, Coutard had developed a protracted, fractionated process that remains the basis for current radiation therapy [213]. Coutard's dosage and fractionation were designed to create a severe but recoverable acute mucosal reaction. Unlike previous physicians, who believed that cancerous cells were more affected by radiation, Coutard assumed that the population of cancerous cells had the same sensitivity for regeneration as normal cells. He reported a 23% cure rate in the treatment of head and neck cancer. In 1935, hospitals everywhere began following his treatment plan. The Japanese pioneered the use of low-dose radiation in medicine [40]. The historical effectiveness of 1–2 Gy fractions delivered at dose rates of about 50 Gy/h in near daily fractions to a total dose of about 60 Gy to the tumor volume gained favor because this therapeutic strategy was more sparing of contiguous normal tissues while more potent in producing tumor regression than was a single or few higher-dose fractions. The use of five daily consecutive fractions per week has emerged as the standard regimen for treating solid cancers. Many reports now indicate even lower doses and lower dose rates over an extended period are effective in preferentially sensitizing neoplastic cells to a subsequent high-dose-rate exposure.

7.10 Neoplastic Transformation

Adaptive responses involve communication between cell types and multiple cytokine releases stimulated by low γ-ray doses. Although modeling of anti-inflammatory responses following low-dose irradiation has not yet been performed, modeling of discontinuous dose responses for other biological end points such as apoptosis [214, 215], in vitro neoplastic transformation [216, 217], and lung cancer [218, 219] have already been successfully established. Different groups of researchers have shown

that single low doses of low linear energy transfer (LET) exposures delivered at low-dose rates can significantly reduce the risk of neoplastic transformation below the spontaneous level [220–224].

Neoplastic transformation of HeLa x skin fibroblast hybrid cells at a very low-dose rate (VLDR) of ~2 mGy/day (30 keV photons) for an accumulated dose of 194 mGy was significantly reduced [224].

Neoplastic transformation of HeLa × skin fibroblast human hybrid cells by doses of 1 GeV/nucleon iron ions in the range 1 cGy–1 Gy to exposed cultures has been examined. The data indicate a threshold-type dose-response curve with no increase in transformation frequency until doses above 20 cGy. At doses <10 cGy, not all exposed cells receive a direct traversal of an iron-ion track core, but all exposed cells receive up to several mGy of low-LET radiation associated with the δ-ray penumbra. It is proposed that the threshold-type response seen is a consequence of an adaptive response associated with the δ-ray exposure.

7.11 Immune Therapy

Basic immunotherapies were employed in the eighteenth and nineteenth centuries to treat cancer. Some of these therapies (e.g., Coley's toxins) may have been as effective as current therapies for treating cancer of the ovary, kidney, breast, and soft tissue sarcomas [225, 226]. MRL-*lpr/lpr* mice carry a deletion in the apoptosis-regulating *Fas* gene that markedly shortens life due to multiple severe diseases. Irradiation of mice at 0.35 or 1.2 mGy/h for 5 weeks markedly prolonged lifespan, accompanied by immunological activation. Irradiation for the entire life further improved survival; the 50% survival time for untreated mice was 134 days which increased to 502 days by 1.2 mGy/h lifelong irradiation. Drastic ameliorations of multiple severe diseases, such as total-body lymphadenopathy, splenomegaly and serious autoimmune diseases including proteinuria, encephalomyelitis, and other brain-central nervous system syndromes, were found in parallel with immunological activation [227, 228]. Stimulation of antineoplastic immune surveillance is mediated by NK lymphocytes and activated macrophages. Low-LET radiation inhibits the development of spontaneous and artificial metastases in humans and laboratory animals [229]. This suggests that γ-irradiation may be used to treat and cure cancer and prevent cancer metastases [230, 231]. Radionuclide therapy has shown hormetic effects with radionuclides such as yttrium-90 attached to monoclonal antibodies, prolonging the lives of "terminal" cancer patients [232]. Rhenium-188 attached to Listeria-binding antibodies resulted in a dramatic decrease in metastases in a highly metastatic pancreatic mouse tumor model [233].

There are several new drugs using immunotherapy as an adjuvant in the treatment of advanced cancers such as non-small-cell lung cancer and melanoma. Clinical trials may involve using doses up to five times the dose recommended for

patients. Advertisements for drugs like Optivo fail to mention that life extension may be only 3–12 months, that the drugs do not cure, that some patients do not respond, that grade 3–4 toxicity is present in over 50% of patients receiving the drug, and that in some cases the therapy will cause catastrophic organ failures. The drugs by weight are about a thousand times more expensive than gold with a typical therapy cycle costing $250,000. Such immunotherapies are unsustainable, prices are astronomical, and life extension is marginal with side effects making added life in many miserable.

7.12 Abscopal (Bystander) Effect

RH Mole in 1953 observed cases where irradiation of one part of the body affected distant regions of the body outside the area of radiotherapy. He defined the abscopal effect as an action at a distance from the irradiated volume but within the same individual [234]. The abscopal effect is also called the bystander effect; both are part of the adaptive response to LDR. All three effects involve ROS and are mediated in part by stimulation of the immune system [235]. The activated immune system is partially responsible for tumor growth inhibition and tumoricidal actions [236].

Douglas R Boreham, McMaste University, demonstrated for the first time the bystander effect, the role of apoptosis in the radioadaptive effect, and radiation protection during embryogenesis [237–239].

Low-dose radiation (alone or in combination) with high-dose radiotherapy or chemotherapy may enhance the latter's effectiveness in treating cancer and reduce toxic side effects of anticancer therapy. High-dose chemotherapy and radiotherapy are associated by themselves with increased cancer risk. LDR has the potential to reduce the adverse effects of traditional anticancer therapies [240]. Low-dose radiation fractionation potentiates the effects of taxanes and cisplatin in tumor cell lines in vitro. Hyper-fractionation using doses from 0.1 to 0.6 Gy enhances the effects of chemotherapy in tumor control and cure. These include abscopal bystander effects, activation of the immune system, endothelial cell death, and the effect of hypoxia. Positive effects of LD-RT were observed in advanced peritoneal and ovarian tumors, glioblastoma multiforme in the brain, and small-cell carcinoma in the lung. Trials consistently showed benefit at low-dose fractionation, potentiating the effects of chemotherapy [241]. Robust abscopal effects are seen in distant tumor or metastatic lesions that are outside the clinical high-dose zone [242].

Among patients with stage IV metastatic melanoma, in which the cancer has spread to other organs, 1-year survival rates range from just 33–62%. This year in the US, about 76,000 patients will be diagnosed with melanoma, and about 10,000 people are expected to die of the disease (American Cancer Society). A key observation that supports the role of the immune system in melanoma is the abscopal

effect. This rare phenomenon occurs when a localized treatment such as radiation not only shrinks the targeted tumor but also stimulates the immune system to mount a systemic attack on cancer cells throughout the body. A physician saw the abscopal effect firsthand when he gave radiation treatment to a patient who had melanoma that had spread to his liver and bones. The palliative radiation was intended to control pain in the patient's thigh bone and reduce the risk of fracture. Three months later, a CT scan found no trace of cancer anywhere; the patient was free from tumor 12 years later [243]. Another case also involved a young man with widespread melanoma, who completely recovered following palliative radiotherapy of the hip for tumor-related bone pain [244]. A patient underwent palliative radiotherapy for skeletal metastases which was followed with complete regression of the primary tumor hepatocellular carcinoma of the liver [245]. This indicates that LDR-TBI may be effective in treating advanced melanoma and other metastatic cancers.

7.13 Low-Dose Radiation Therapy

Calabrese has documented tens of thousands of patients who were treated by low radiation doses of up to 1500 mGy during the 1930s–1940s in the USA [246, 247]. If the hormetic effect observed in the atomic bomb survivors, and many other irradiated population groups, would be confirmed in human studies and applied to the general population, it could result in a considerable reduction in cancer mortality. Traditional approaches to combat cancers have had limited success [248, 249], and there has been only about 10% reduction in age-adjusted cancer mortality rate in the past 45 years. Despite many advances in cancer therapy, over 40% of patients will eventually die from local recurrence, metastatic disease, or a combination of both. The rapid expansion of older persons in the US will lead to a substantial increase in cancer. Low doses of radiation may be useful in preventing cancers in older high-risk populations, such as in heavy cigarette smokers, as well as in curing early-stage cancers [250]. Based on an evaluation of many studies, Pollycove and Feinendegen suggested that LDR-TBI would be useful in treating cancer patients [251–254]. Cuttler suggested that old men should be given periodic LDR-TBI to prevent and control cancers, such as prostate cancer [255].

In 1998, Jerry Cuttler and Doug Boreham tried to persuade a young radiation oncologist at the University of Ottawa Hospital to try HB LDI treatments for cancer patients. The oncologist wouldn't even consider it. Boreham was finally able to start a clinical study (on recurrent prostate cancer) at the Juravinski Regional Cancer Centre in August 2016, after he received a research grant. This is based on the "old research" that Dr. Sakamoto carried out in the 1990s (Cuttler, S.A.R.I., 2016).

In contrast to high doses of chemotherapy drugs and radiation, LDR upregulates the immune system rather than suppression. Conservatively, the LNT is responsible for millions of unnecessary cancer deaths each year over the world. Peter Fong predicted in 1996 that about 1,000,000 cancer deaths would be prevented by low-dose radiation [28]. The deaths are due to radiation deficiency and avoidance of optimal radiation dose rate exposures of 5–10 μSv/h that is about 25–50× the world mean background dose rate. Excess deaths from radiophobia are also due to avoidance of medical radiological examinations, avoidance of moderate therapeutic doses for a variety of inflammatory conditions, and avoidance of in-home radon and radon therapy in health spas and mines. The estimate of cancer sparing is based on the assumption that those receiving optimal dose rates will live 10% longer and that LDR is effective in preventing, treating, and curing a wide variety of proliferative diseases such as cancer [256].

LDR (10–500 mGy X, γ-rays) stimulates the proliferation of normal cells and stem cells and activates antioxidants, DNA repair, and immune defense systems. These adaptive effects are not observed in most cancer cell types [240, 257]. Very low and ultralow-dose and low-dose-rate radiation may induce radioresistance in normal cells. Very low-dose rate (VLDR) is considered to be 0.01–0.1 Gy/h, while ultralow-dose rate (ULDR) is <0.01 Gy/h [258]. For purposes of this chapter, low-dose radiotherapy (LDR) will include both VLDR and ULDR. Maximum adaptive protection occurs after single doses of 100–200 mGy, given repetitively or continuously to initiate maximum protection [259]. The adaptive response operates within an estimated dose window of between 1 and 500 mGy for a single low-dose-rate exposure. These thresholds vary with dose rate [260].

Moderate doses of radiation from 2 to 8 Gy have been used to successfully treat regional sites of refractory aggressive lymphoma without toxicity low doses of total-body irradiation (TBI) significantly delayed tumor growth [261], decreased metastatic growth [262, 263] while upregulating immune cells. Acute X-irradiation induced thymic lymphoma formation in mice was suppressed by continuous low-dose-rate X-irradiation [264–266].

Low-dose X-rays decreased the growth of spontaneous tumors in mice that was associated with an overproduction of lymphocytes [267]. LDR alone increases the latency of spontaneous lymphoma and spinal osteosarcoma in cancer-prone mice [268]. A small pre-dose of 100 mGy of 6 MV X-rays given 24 h before start of radiotherapy with 48 Gy in 16 × 3 Gy fractions to dogs with oral cancer caused a cytoprotective effect to surrounding normal tissues [269]. Continuous ultralow-dose radiation increased the effect of high-dose radiation treatments in experimental malignant glioma. This increased effect could be clinically applied to the therapy of human malignant brain tumors [270]. Both single and fractionated total doses of 100 mGy activate macrophages as anticancer cytotoxic effectors [271]. Immunosuppressive networks operating at later stages of carcinogenesis show how LDR exposures might reverse immunosuppression and enhance anticancer responses (Marek Janiak, S.A.R.I.). On the other hand, LDR can also suppress immune factor function to treat autoimmune diseases [228].

In Sri Lanka, India, Pakistan, and Bangladesh, oral cancer outnumbers all other cancers. In parts of India, oral cancer accounts for over half of all cancer. Gutka, a combination of areca nut, slaked lime, paraffin, and catechu along with tobacco, is virtually a poison. Promoted as a mouth freshener, this mixture is a combination of 4000 chemicals of which at least 40 are carcinogenic compounds. Around 26% of Indian adults use chewing tobacco [272]. A negative cancer rate mortality is seen in India with increasing environmental radiation [273]. A negative oral cancer mortality rate is seen in American men and women with increasing environmental radon exposure. Reductions in oral cancer mortality were large, from 33 to 81% in five epidemiological studies of radiological technologists and nuclear workers [39]. Regular CT scans of the head and neck would be expected to prevent a large fraction of potential oropharyngeal cancers seen in users of tobacco products due to elimination by apoptosis of tobacco-induced transformed epithelial cells [272, 274].

The effectiveness of conventional high-dose radiotherapy for treatment of cancer is limited by the resistance of tumors and surrounding normal tissue radiosensitivity. The addition of LDR improves local tumor control with decreased normal tissue damage by stimulating antioxidants, repair of DNA damage, apoptosis, and immune responses. The use of LDR radiotherapy strategies either alone or as an adjuvant improves overall anticancer treatment [275]. Precision in radiation oncology matches radiation dose strategy that is unique for each patient. The genomic-adjusted radiation dose (GARD) provides individualization of radiotherapy based on initial tumor radiosensitivity to a small priming dose [276]. Radiation oncology could be significant improved by first using a small "priming" dose to kill hypersensitive tumor cells prior to giving high-dose radiotherapy. A dose of only 100 mGy blocks malignant transformation, such as KRAS-induced transformation in human cells [277]. A study of tumor spheroids irradiated with Co-60 γ-rays demonstrated substantial hypersensitivity using a priming dose of 80–500 mGy [278].

Low-dose priming therapy is being examined when given in combination with high-dose conventional radiotherapy. In the study by Joiner [279], hypersensitivity in cells disappeared when the cells were exposed to 200 mGy (priming dose) 6 h before the experimental irradiation with doses up to 1 Gy. When the priming dose of 200 mGy was given immediately before the experimental doses, there was no change in hypersensitivity, i.e., there was no protection against hypersensitivity. Hypersensitivity was induced in micrometastases at threshold doses of 100–300 mGy. In fact, a very low dose of total-body irradiation may prevent the development of micrometastases [280]. The mechanism of the priming dose appears to involve radiation hormesis associated largely with induced apoptosis. Apoptosis is seen in human gastric cells at a dose of 150 mGy. Three consecutive daily doses of 150 mGy produce hyper-radiosensitivity and chermopotentiation of docetaxel, cisplatin, and 5′-fluorouracil in gastric cancer cells [281].

> There's little doubt in my mind that the no-threshold assertion for genetic mutation and cancer initiation was at least partly a business-driven decision to create a fear-producing myth out of an assertion by credentialed scientists [282].

Generally minute doses of drugs have been prescribed in biotherapies, homeopathy, immunization, and vaccinations for centuries. Now the use of low doses of drugs is on the rise to combat advanced cancers and many chronic, complicated diseases. A small dose of the prescribed drug is administered in a continuous fashion, at regular intervals, either as a standard treatment or as a maintenance therapy. Metronomic therapy and radiation hormesis have similar mechanisms and both occur in low-dose ranges [283].

> If LDR treatment is given to accelerate the healing of a wound or to stop an infection (gas gangrene, boils, sinus, inner ear, pneumonia, etc.) or to reduce an inflammation, the beneficial effect on the patient will be observed rather soon, within hours/days … If the treatment is being given to destroy residual cancer metastases after surgery, then blood samples can be taken before and at appropriate times after low-dose radiation exposures to measure radiation-induced changes in key immune system variables and other relevant variables. I would expect the amount of stimulation to be different in each person. The whole field of stimulating the protection systems with low doses of radiation has to be studied properly, scientifically. The radiation exposures to the patient need to be measured accurately. The human responses need to be measured accurately. Optimum exposures need to be determined. I don't believe there is any cancer risk from these low doses; however, the health benefits could be very significant (Jerry Cuttler, S.A.R.I.).

Nude mice with ovarian cancer xenografts showed radiosensitivity from 500 mGy X-rays [284]. Low-dose radiation (~3 cGy) delivered to the ovaries during high-dose radiotherapy of rectosigmoid cancer and breast cancer reduced the risk of ovarian cancer by 24 and 44%, respectively. In addition, there was a significant inverse relationship between ovarian cancer in white women and radon background radiation ($p = 0.002$) and total background radiation ($p = 0.002$). The data analysis suggests that low-dose pelvic irradiation might be a good choice to reduce the risk of ovarian cancer [285].

Cuttler published a paper in 2000 in which he summarized the use of low-dose radiation therapy up to that year [286]. The beneficial health effects from low doses of ionizing radiation have been observed for more than a century. Hatori's studies stimulated a large research program in Japan [287]. Japanese scientists published many scientific studies, which lent support to the beneficial health effects following low doses (Fig. 7.7). Publications by Calabrese and Baldwin [246] and Pollycove [288] gave additional confidence in the existence of this phenomenon.

Dr. Kiyohiko Sakamoto has treated ~200 cancer patients, mostly non-Hodgkin's patients, using repeated TBI or HBI treatments of 10–15 cGy (rad)—30 cGy per week for 5 weeks—a total dose of 150 cGy, achieving beneficial results including long-term cures with no symptomatic side effects (Fig. 7.8). One patient with advanced ovarian cancer received 15 TBI irradiations of 10 cGy each. All tumor and

Fig. 7.7 From left S. Hattori, Don Luckey and Jerry Cuttler (With kind permission of Jerry Cuttler)

Fig. 7.8 Dr. Kiyohiko Sakamoto, MD, PhD is director, Tohoku Radiological Science Center, Japan. In 2012 Sakamoto at the age of 66 was unsuccessfully treated for colon cancer. In 1997, he applied the TBI protocol to himself, repeating it again in 1998. He recovered and is in excellent health (with kind permission from Jerry Cuttler) [205]

metastatic disease disappeared [289]. It would appear that many cancer patients could benefit greatly from this therapy, at little (if any) risk. Unfortunately, low-dose X-ray therapy of metastatic malignancy remains virtually unavailable in the USA, Canada, and Europe. Sakamoto, at age 66, is himself a survivor of advanced colon cancer. Following three surgeries to remove colon tumors in three places, he was in

very poor health. After applying his TBI protocol to himself in July 1997 and repeating it in February 1998 as a booster, he completely recovered [290]. HBI has also been recommended for treatment of advanced resected exocrine pancreatic cancer [291]. However, caution should be considered when designing therapeutic strategies using LDR to induce beneficial effects in humans with preexisting genetic disease, such as ataxia telangiectasia [292].

Multiple myeloma has been successfully treated with LDR-TBI [293]. E. J. Bauser was a retired US Navy captain, who, at age 81, was diagnosed in 1998 with Waldenstrom's macroglobulinemia (WM), a rare cancer of the bone marrow. WM is characterized by an overproduction of a normal protein, IgM, increasing blood viscosity. Bauser was treated with oral chlorambucil and prednisone for 6 months, at which time the therapy was stopped because of hematopoietic failure. Bauser's colleague from the Rickover nuclear submarine propulsion program, Dr. Ted Rockwell, informed Bauser about low-dose, total-body irradiation (TBI) therapy which had been developed in Japan. Bauser was told by "experts" that his bone marrow would be completely destroyed by such a treatment. He was later seen by Dr. James S. Welsh at the Johns Hopkins Medical Center in Baltimore, who began TBI therapy at Johns Hopkins on September 1999 and completed it on October, 1999. The dose schedule consisted of 15 cGy, twice a week, for 5 weeks (ten exposures totaling 150 cGy). Bauser experienced no discomfort from this procedure. Serum protein levels decreased to levels achieved by chemotherapy, and the spleen decreased 30% to normal size following completion of TBI. Several months later, Dr. Welsh administered a booster series of the same low doses limited only to the spleen, achieving similar beneficial results as with TBI [294].

The ease of application, short duration, and lack of any significant, adverse side effects suggests this therapy is advantageous for treating cancer, by stimulating the body's natural defenses. Yet many oncologists seem to be very reluctant to employ low-dose irradiation therapy. Widespread use of this therapy for cancer and study of its applications for treating other diseases would help resolve the controversy over the beneficial effects of low doses of ionizing radiation and lead to greater public acceptance of all nuclear technologies [286].

Studies in Japan and the USA have shown that 10–15 cGy total-body (TBI) or half-body (HBI) irradiation delivered in 1–2 min, several days apart, stimulate the body's defense mechanisms causing a substantially longer lifespan than patients given high-dose radiotherapy and chemotherapy alone. Extensive evidence that low-dose radiation stimulates immune responses has not been considered by radiological organizations as a component of successful treatment of cancer used both alone and in combination with traditional high-dose radiation and chemical cancer therapy. Positive experimental and clinical results from TBI and HBI have been found in treating cancer by Yu [295], Sakamoto [289, 296–298], Miyamoto [299], Chaffey [300], Hattori [301, 302], and Takai [303, 304]. Solid tumors exist in a state of active inflammation; low-dose radiation can reduce inflammation inducing beneficial antitumor effects [305].

Successful cancer therapy with low-dose total-body irradiation (TBI) therapy to patients with non-Hodgkin's lymphoma, receiving standard chemotherapy

and localized high-dose radiation of tumors, was reported from Harvard University by Chaffey [300]; by Choi [306]; by Sakamoto [296] Tohoku University, Japan; by Richaud [307] of the Institut Bergonie; and by Mishra [308]. The Harvard studies [300, 306] reported that low-dose TBI increased the 4-year survival to 70 and 74% of those treated, significantly greater than that of the controls, and 40 and 52% of those treated, respectively, with COP and subsequent CHOP chemotherapy and local high-dose radiation. Similar TBI, or equally effective upper half-body irradiation (HBI), therapy at Tohoku University increased 4-year survival to 84% of those treated, which is greater than the survival of the controls, and 65% of those treated, who received CHOP and local high-dose radiation therapy [296]. Subsequently, all Japanese patients receiving TBI or HBI survived 5 additional years, while the survival of the controls at 9 years was 50% of those treated. Sakamoto stated that 12-year survival of these 20 patients continues to be 84% [290]. The Institut Bergonie study reported that low-dose TBI was very well tolerated, gave a high response rate (83%), and extended recurrence-free survival [307]. The use of TBI for cancer therapy was summarized by Safwat [309].

Dr. Sakamoto has said that he has never seen cancer cells being stimulated by a low dose of radiation. Radiation stimulates only normal healthy cells. Tumor cells do not seem to have protection systems that are upregulated by low-dose radiation. High-dose radiotherapy to region of the tumor combined with TBI results in removal of metastases (TBI given twice weekly on Monday and Thursday, 6–10 h before high fractionated dose) [310]. The benefits of this treatment are prevented from being used in the USA and elsewhere in order to protect the myth that radiation is dangerous at any dose.

Dr. Sakamoto treated the wife of Jerry Cuttler in 2011 with HB LDI as a prophylaxis against cancer recurrence [311].

> My wife discovered she had uterine cancer (grade 3, stage 1) several years ago. After surgery, she received a course of half-body, low-dose irradiation (150 mGy x twice a week x 5 weeks for a total dose of 1500 mGy) that was prescribed by Dr. Sakamoto. Blood tests during this treatment revealed a significant up-regulation of her immune system. We are confident there will be no recurrence of cancer, after this prophylaxis treatment [205].

Studies in Japan and in the USA have shown that 10–15 cGy total-body or half-body irradiation delivered in 1–2 min, several days apart, stimulate the body's defense mechanisms [256]. Specific immune responses were sufficiently definitive in animal studies to justify clinical trials for cancer suppression in human beings, by Dr. Sakamoto and associates. The patients were generally far-advanced cases and therefore not ideal candidates for immune function stimulation. However, individual cases were successful, and a long-term clinical trial on non-Hodgkin's lymphoma patients has confirmed that the group that received low-dose radiation substantially outlived the control group at 5 years and 10 years [25]. The three clinical studies in non-Hodgkin's lymphoma patients using TBI/HBI low-dose radiotherapy have all shown the same results.

Low-dose total-body irradiation and half-body irradiation has successfully treated and prevented some cancers, as documented in Japan and elsewhere. That breast cancer and other cancers have been prevented or treated should be data to be

investigated, not suppressed. It is costing the public hundreds of billions of dollars in environmental cleanup alone, to control radioactivity sources that are far below natural background radioactivity. But this "radiation protection" policy may have even greater costs to women with breast cancer and to millions of others with cancers and other diseases that may be readily preventable or treatable at low cost, with inconsequential "side effects," by low-dose radiation treatment. There is also substantial reason to believe that low-dose radiation treatments will be effective against HIV/AIDS. As noted by Hattori, funding for this research is constrained by radiation-protection interests that prevent such government support of medical research [302]. Private investment in research is constrained by the lack of potential profits in medical applications that would potentially provide health care, and even cancer cures, by low-cost low-dose radiation treatments vs. pharmaceuticals.

All treatments for disease have less than 100% success (i.e., they are stochastic). Pharmacological agents may offer only minor improvements in outcome but with high cost and a long list of serious side effects. Not everyone will benefit from LDR, although a large majority will. The financial cost of LDR should be small and harmful side effects essentially nonexistent.

New initiatives are under way to establish the role of radiation in health, rather than to maintain the constraints of committees and research committed solely to radiation protection. More is needed. However, existing voluminous radiobiology and epidemiology data provide sufficient bases to refute the LNT, to find that low-dose radiation does not constitute a public health hazard, and to determine that it is beneficial. Directed research is necessary to better understand the precise mechanisms, to quantify the various levels and conditions at which these benefits exist, and to more precisely establish the levels and conditions at which human exposure can be considered safe. But these dose levels are many multiples above average natural background radiation.

Survival of stage III, IV non-Hodgkin's lymphoma patients receiving standard treatment with high-dose radiotherapy or chemotherapy were compared with patients also receiving TBI or HBI. Ten-year survival with only chemotherapy was 50%. Six-year survival with only high-dose radiotherapy was 36%. Survival of patients receiving TBI or HBI at 12 years was 84% [256, 296, 312].

7.14 Therapeutic Use of Radiation from Radioactive Pads

Various methods of exposure to LDR may be in radon spas, high background radiation areas, abandoned uranium mines, Th/U pads, or by building low-dose radiation therapy centers using spent nuclear fuel. Spent nuclear fuel is obtained from nuclear power plants and contains a variety of fission products and transuranics. Ninety-six percent of the mass in spent nuclear fuel is the original U-238. Most of the original enriched U-235 (initially enriched from the natural level of 0.7–3.0%) has undergone nuclear fission during a typical nuclear power plant fuel cycle. Spent nuclear

fuel removed from the reactor is typically stored underwater, for up to 20 years at some sites. Radioactive decay of β,γ fission products removes about tenfold of radioactivity after 1–10 years of storage and another tenfold reduction in radioactivity after 10–100 years of storage. The US has produced about 64,000 metric tons of used fuel rods from its power reactors. Nearly all of the nuclear power plants have run out of underwater storage space. Dry storage is scheduled for Yucca Mountain in Nevada and at WIPP (Waste Isolation Pilot Plant in New Mexico) [294].

Nuclear waste was called the most deadly material in the world in a January 2017 presentation on PBS called *Uranium Drive-In*. This is patently not true. Spent fuel rods could be pulverized and mixed with concrete to construct efficient low-dose radiation therapy facilities. The cost of LDR therapy would be low once the facility was constructed. Construction could be simple with each facility able to hold many patients. The facility could be constructed with several rooms, each providing a selected dose rate [42]. Professor Y. C. Luan from Sindian City, Taiwan, proposed using nuclear waste from nuclear power plants that is currently stored on Orchid Island, Taiwan, as a source of LDR to treat patients [313].

Discernment is the ability to make sound judgments by determining what may not be obvious to many people. Alexander Fleming (1881–1955) observed on September 3, 1928, a mold growing on a petri dish containing colonies of *Staphylococcus*. The area immediately around the mold (later identified as *Penicillium notatum*) was clear. From this "anecdotal" observation came a "wonder drug" antibiotic with broad-ranging capabilities to control many bacterial infections.

Anecdotal may refer to a personal narrative that describes something witnessed or experienced. It can be difficult to interpret because of possible subjectivity from a personal testimony. The witness objectivity may be enhanced by education as a trained observer and by research study and publications. Anecdotal witness testimonies of the benefits of LDR may add up to thousands over a wide variety of inflammatory diseases. A stage I clinical trial, where everyone receiving an investigative drug respond positively with few or no side effects, would cause the researchers to unblind the study so that all groups would receive the beneficial drug. Untold numbers of individuals have testified as to the beneficial effects of low-dose ionizing radiation. Their beneficial medical responses are what one might expect from reading the thousands of publications demonstrating radiation hormesis.

Controlled double-blind, clinical trials are not the only way to gain valid knowledge. Try using common sense.

The author had proposed using ultralow doses of ionizing radiation such as those emitted by the rocks and pads to treat a large variety of inflammatory diseases [43]; the abstract reads:

> "Ultra-low doses and dose- rates of ionizing radiation are effective in preventing disease which suggests that they also may be effective in treating disease. Limited experimental and anecdotal evidence indicates that low radiation doses from radon in mines and spas,

thorium-bearing monazite sands and enhanced radioactive uranium ore obtained from a natural geological reactor may be useful in treating many inflammatory conditions and proliferative disorders, including cancer. Optimal therapeutic applications were identified via a literature survey as dose-rates ranging from 7 to 11μGy/hr or 28 to 44 times world average background rates. Rocks from an abandoned uranium mine in Utah were considered for therapeutic application and were examined by γ-ray and laser-induced breakdown fluorescence spectroscopy. The rocks showed the presence of transuranics and fission products with a γ-ray energy profile similar to aged spent uranium nuclear fuel (93% dose due to β particles and 7% due to γ rays). Mud packs of pulverized uranium ore rock dust in sealed plastic bags delivering bag surface β,γ dose-rates of 10–450 μGy/h were used with apparent success to treat several inflammatory and proliferative conditions in humans".

Jay Gutierrez, founder of Night Hawk Minerals [314], visited Dr. Don Luckey in 2013 (Fig. 7.9). Jay told the author about several amazing cases of people exposed to radiation from his rocks and pads (The origin and radiological description are found in Chap. 6). An old diabetic cowboy became blind with wet retinopathy associated with diabetes. Exposure of his eyes for several months restored his sight so that he could drive again. Another diabetic was scheduled for amputation of his feet; several months' exposure to his feet and lower legs restored circulation to his feet and he recovered. Other successfully treated cases (with estimated total dose) mentioned by Jay were for Dupuytren's contracture of the hand (15–18 mGy), Meniere's disease (19 mGy) using an ear stone, and arthritis of the hand (130 mGy) allowing a concert pianist to return playing [315].

Fig. 7.9 Jay Gutierrez visited Don Luckey in his home in 2013. Jay and Don both agreed about the potential for LDR to treat many common inflammatory diseases (with kind permission of Jay Gutierrez and Night Hawk Minerals) [314]

I met a 50-year-old lady with breast cancer on a visit Jay's radon clinic in Pritchard, Colorado. She had refused surgery, radiation therapy, and chemotherapy when she came to the clinic. She was rapidly losing weight and had difficulty in breathing. She had a large tumor in her breast and metastases in her lung. I helped design a jacket lined with packs and she was exposed 24/7 while awake and in bed. By week 6 her appetite had recovered and her breathing returned to normal. By week 8 an X-ray showed her lung metastases had disappeared. Her cumulative dose of gamma irradiation to the surface of the skin was <50 mGy and less than 700 mGy cumulative β,γ-irradiation. She was under the care of a M.D. from Aurora, Colorado, who was associated with the clinic. Later the primary tumor became necrotic and was surgically removed. She also later received irradiation of her head for metastatic tumors and low-dose chemotherapy. She is alive today 4 years later with no evidence of cancer. One of the more unusual observations was made by Jay and his M.D. associate. They both had independently used a small radioactive rock placed at the back of the skull to rapidly stop brain seizures.

The author has used radioactive pads and rocks described in Chap. 6 to treat a variety of inflammatory/proliferative conditions in himself and his family for over 5 years. He found that exposure to beta and gamma radiation emanating from the rocks and pads was effective in treating warts and senile keratosis (they never returned even after 5 years), Dupuytren's contracture, early presumptive Parkinson's disease, sore throat, back and neck aches, sinus infection, earache, and presumptive precancerous skin lesions. An abnormal liver enzyme pattern due to fatty liver had been documented in a family member for 5 years up to 2014; she was diagnosed by a CT scan. Her liver enzymes for the last 2 years have been normal after periodic use of a large pad over her abdomen. She has had "suspect" cysts seen on her mammograms for nearly 10 years that often required aspiration. The last 2 years after using the pads on her chest, her mammograms have been clear.

In 2010 on returning from Korea, the author's cardiologist in Colorado diagnosed him with heart block and sick sinus syndrome due to malfunction of the neural node that controls heartbeat, along with cardiovascular disease (partial block in a femoral artery) and systolic hypertension. He wanted to do invasive cardiac electrical studies to prepare for a pacemaker. The author refused all invasive procedures. Following exposures of the chest for several hours a day for about 2 years (estimated total chest dose of ~200 mGy γ-rays), his blood pressure had normalized. In 2014 his cardiologist reluctantly said that the author might be better. An EKG in May 2015 failed to find evidence of sick sinus syndrome. He continued to use the pads almost every day. At the last visit to his cardiologist in October, 2015, he told the author that he could find nothing wrong with him. He said, "You can take credit for it." He knew how the author had been treating himself. Blood pressure control by radium rays was recommended in 1915 in an article published in Radium.

Benefits of low-dose radiation are not only for cancer prevention but for prevention and treatment of a wide variety of other diseases that have pathological inflammatory components. The number of lives that could be saved, improved, and prolonged by low-dose radiation is enormous.

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Heuristic View on Quantum Bio-Photon Cellular Communication

8

Jesus said to the people: I am the light of the world. If you follow me, you won't be stumbling through the darkness, because you will have the light that leads to life [1].

8.1 Quantum Biology

A number of experimental groups around the world are investigating the outlandish but not utterly inconceivable hunch that the boundaries of quantum theory have to do with the complexity of a system or even with life itself [2]. China is developing quantum communication technology with the launch of the satellite, dubbed *Quantum Science Satellite*, designed as a hack-proof communications system for transmitting undecipherable encryption keys from space to the ground that are immune to cyberattacks. The satellite will teleport entangled photons from the satellite to relay stations separated by about 1200 km [3, 4]. The Internet of Everything (IoE) is a global network that intends to connect everything by transportation, teleportation, and telepresence, where trillions of connections create unprecedented opportunities as well as risks [5, 6]. The IoE is scheduled to be operational by 2020 when nearly 100% of earth's inhabitants will have access to the Internet. The IoE for the earth has similar quantum correlations with communication in and among human cells of the body.

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Quantum biology is where physics meets biology. Both classical physics and quantum mechanics may be operational in cell communication. Each living cell "talks"

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with other cells with incredible precision and accuracy to maintain synchrony, unity of purpose, and health. Each cell may be envisioned as communicating intelligence. The vehicle for cell signaling and passing information is either chemical reaction, electromagnetic wave or by quantum transfer, or all of the above. Data communication of unbelievable complexity occurs within each cell millions of times a second and among nearby cells and cells at a distance. The speed of communication may be of light for bio-photons or faster or even instantaneous for quantum transfer.

> In medicine, we have known for a long time, at least since the days of the medieval Paracelsus, that something that is bad and unhealthy sometimes can actually become its own cure if it is used in a different way…this means that quantum mechanics itself is called upon to come to the rescue [7].

The cell is the irreducible, minimal unit of life [8]. Most of each of the 300 trillion cells of over 100 cell types in the adult human undergo an incredible number of chemical reactions per second. The brain has 100 billion neurons with many trillions of synapses. Cell metabolism is total energy released and consumed by the cell (all chemical reactions happening in the cell and in all cells of the body). Just look at energy production alone. ATP energy used by the human body requires the hydrolysis of 200–300 moles ATP daily. One molecule of ATP synthase produces 600 ATP/s [9]. Each ATP molecule is recycled 2000–3000 times a day. A single cell uses about 15 million ATP molecules per second, recycling all ATP molecules every 20–30 s [10]. Interestingly ATP also serves as a signaling molecule. Another example of cell complexity comprises catalytic proteins, the largest component of total cell dry mass, which are used to build molecular constituents of a functioning cell. Superoxide dismutase and carbonic anhydrase alone may carry out 10^6–10^7 reactions per second in one human cell. Enzymes may increase rates by an astonishing ten orders of magnitude [11]. For an enzyme to be functional, it must fold in a precise three-dimensional pattern. A small chain of 150 amino acids making up an enzyme must be tested within the cell for 10^{12} different possible configurations per second, taking 10^{26} years to find the right one. This suggests quantum effects at work even at comparatively large distances within the cell spanned by a protein molecule [12, 13]. These two examples comprise a very, very, very small degree of the chemical complexity of a human cell.

Quantum biology refers to applications of quantum mechanics and theoretical chemistry to biological objects and problems. Quantum biology uses computations to model biological interactions in light of quantum mechanical effects [14]. The human body is in a constant flux of chemical/biological interactions and processes connecting atoms, molecules, cells, organs, and fluids, throughout the body and nervous system. Up until recently it was thought that all these interactions operated in a linear sequence, passing on information much like a runner passing the baton to the next runner. However, findings in quantum biology have shown that there is a tremendous degree of coherence involving cell communication with electromagnetic waves within all living systems [15].

Each human cell may comprise an incredibly complex quantum system (quantum communication, teleportation, entanglement of quantum mechanics) as source

of data transfer both within each cell and among other cells. Each human cell has about 30,000 genes dispersed among chromosomes of the cell nucleus. The cellular chemical environment activates or silences genes. Very fast signaling would be required to pass information from DNA that controls all metabolic components in a single cell as well as to all other cells in the body. Current molecular "lock and key" models are slow, inflexible, and mechanical. Random collisions of molecules within a cell cannot explain the order and processes. Chemical signaling takes milliseconds to seconds. Ultra-weak light photons may communicate intracellular and extracellular data at the speed of light or greater. It only takes $3–4 \times 10^{-14}$ s for light to travel the diameter of a typical cell.

What is the command and control center for all this amazing complexity? It must be ultra-stable, interactive, and fast. Fundamental biological processes that involve the conversion of energy in forms that are useable within the cell, such as light, are quantum mechanical in nature. Quantum effects are counterintuitive but solve the issue of fast communication within a cell and to all cells in the body. How can cells communicate with each other at a fast enough speed to explain the biological observations? Can cells talk to each other giving precise information to carry out specific functions? Does the DNA within a cell become its command and control center? Is this signaling system like a language that could be learned to redirect cancer cells to stop growing or stimulate wound healing? The questions could be almost endless. There is abundant experimental evidence showing electromagnetic cell-to-cell communication [7, 16–21].

8.2 Quantum Mechanics

Quantum theory and facts are undisputed but interpreting what it all means is controversial. Bell's theorem experiments established the existence of entanglement (Einstein's "spooky action"). In recent years, physicists, philosophers, computer engineers, and biologists have all explored the significance of quantum phenomena [22].

A debate was carried out during the seventeenth century as to what was light. Isaac Newton (1643–1727) believed light consisted of a stream of particles, while Newton's colleague, Christian Huygens (1629–1695), argued that light is a wave. Albert Einstein (1879–1955), Louis de Broglie (1892–1987), and many others postulated and confirmed that photons of light consist of both particles and waves. This is known as the wave-particle duality. Physicists have argued about the correct way of expressing the duality for about a century. In the 1920s Niels Bohr (1885–1962) held that all atomic particles exist in all states until they are observed in specific positions. In the second half of the eighteenth century, the deterministic character of Newton's equations encouraged many people to see the physical world in strictly mechanical terms, as if the universe is a gigantic piece of cosmic clockwork. Twentieth-century physics saw the death of this merely mechanical picture through the discovery of intrinsic unpredictabilities found in quantum theory. Quantum mechanics provides a concrete model of nature that is comparable in its essence to Newton's laws of motion, Maxwell's theory of electricity and magnetism, and Einstein's theory of relativity [23].

In 1905 Einstein (1879–1955) proposed a new quantum theory based on the photoelectric effect that was first earlier introduced by Planck. In 1909 Einstein said: "A fundamental change of our concepts of the essence and constitution of light is indispensable." Einstein imagined energy quanta (today light quanta or photons) that move without being split and which can be generated and absorbed only as a whole. This new concept was used to understand photoluminescence, photoelectric effect, and ionization of gases with UV light. Einstein believed that an energy quantum of the light generated can obtain its energy from several generating quanta. Einstein's views were intuitive and paradoxical and understandable and inconceivable. Light photons appear to have a split personality, being neither a wave nor a particle since quantum mechanics accomplishes a formal synthesis. These are difficult to understand in the case of light, because of "crazy things" that occur in the world of atoms, which also occur on a macroscopic scale.

Light quanta were called photons by Gilbert Lewis in 1926. Max Planck had earlier argued about the role of little packets of energy. This would explain jumps of quanta for orbital electrons, for the photoelectric effect, and eventually for radioactivity. Bohr's correspondence principle stated that quantum theory of the atom ought to match seamlessly with classical analyses of atomic behavior, since both quantum and classical behaviors tend to have the same outcome. Many state only things that could be mathematically proven. Quantum theory needs imagination since it is difficult to describe in familiar language.

Erwin Schrodinger (1887–1961) and Werner Heisenberg (1901–1976) birthed quantum mechanics by examining the wave/particle paradox or dualism of light. A quantum field exhibits both discrete quantized properties (particle-like behavior) and spread-out properties (wavelike properties). To Heisenberg this is what the atom looked like, a fuzz of energy, concentrated in the center, where precise location and momentum could not be both known at the same time. Heisenberg's uncertainty principle states that quantum particles do not occupy a fixed, measurable position (Fig. 8.1). Measurement is everything in quantum mechanics.

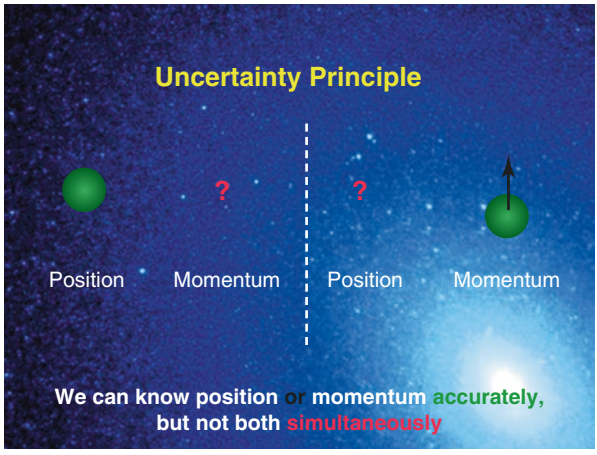

Fig. 8.1 The uncertainty principle. Adapted from an image taken from www.zmescience.com, 2015

Heisenberg believed that if you knew at one moment the precise location in time and space of every particle in the universe, you could predict the future (you would be omniscient; you would be God) [24]. This is, of course, a divine prerogative and, according to Einstein, none of our business. However, for God there is no uncertainty. The solution for Bohr was to accept the different and mutually exclusive results of light waves and particles as equally valid and stand them side by side to build up a composite picture of the atom. These exclusive abstractions complemented each other but could not be resolved or merged. Bohr attempted to close the gap between life existence and quantum existence. He felt that biological laws must be consistent with physical and chemical laws [25].

Quantum theory implies a counterintuitive "togetherness-in-separation" by which two quantum entities that had interacted with each other retained a degree of instantaneous mutual influence; however far, they had subsequently separated. Quantum particles travel through space in waves that spread out and that can be in many places at the same time. Two quantum particles or waves can interact at a distance in a way that may seem telepathic.

Quantum theory is supposed to describe the behavior of elementary particles, atoms, molecules, and every other form of matter in the universe. Quantum theory attempts to explain the intrinsic reality of atoms in statistical terms, using analogies and metaphors. It does not follow classical rules in physics. Every part of quantum mechanics seems to violate some cherished notion that we cling to. Quantum mechanics changes the rules. What are the kinds of relationships between waves and particles? You have always got waves and you have always got particles. Advances in quantum mechanics which are linked to nuclear processes have revealed strong and mysterious forces and effects (Fig. 8.2).

Schrodinger envisioned a cat placed in a box and potentially killed by poison that is simultaneously dead and alive until someone opens the box and peaks inside. Such also is found in quantum mechanics, where an atom can be in two states at the same time. It is very hard to see how one might make sense of any of these

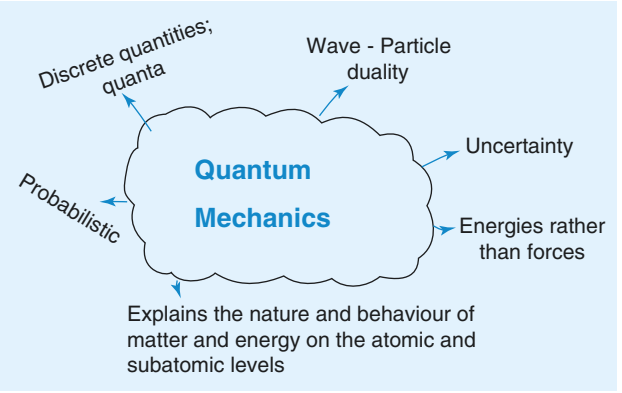

Fig. 8.2 Basic principles of quantum mechanics (Adapted from an image posted on theteeneconomists. blogspot.com)

disciplines, let alone see a unifying picture that underlies them all and explains their deep interrelations and mutual dependence. The reality problem is not solvable within quantum theory as it stands. And so, along with the variables that describe potentialities and possibilities, we need to supplement our quantum equations with quantities that correspond directly to real events or things—real "stuff" in the world. Bohr said: "Everything we call real is made of things that cannot be regarded as real."

For example, spontaneous disintegrations of α- and β-particles and γ-rays and conversion electrons from radioactive atoms occur at a predictable rate (statistical probability). Radioactive decay is stochastic (random) and isotropic (all directions without bias) at the level of a single atom. According to quantum theory, it is impossible to predict when a particular atom will decay, regardless of how long the atom has existed. For a population of like atoms, the decay rate and physical half-life can be calculated without any special hypothesis. Each radioactive atom in a population of like atoms appears "programmed" within it a statistical probability for disintegration [26].

In addition to the mathematical quantities given to us by quantum theory, we also have equations defining a definite path through space and time for each elementary particle in nature. Quantum mechanics great achievement was to show that we can find a mathematically consistent description of reality alongside quantum theory. Theoretical physicists are happy to exploit the opportunities provided by the fact of deep and beautiful intelligibility, but simply as physicists, they are unable to explain why this is the case. A religious perspective on the physical world, understanding it to be a divine creation, can offer the insight that deep cosmic rationality is an indication that the mind of the Creator lies behind its wonderful order, and our access to it reflects the fact that we are creatures made "in the image of our Creator."

8.3 Properties of Light

Photons are conceived as localized energy packets. A light beam can be viewed as a stream of photons. Radiation originates from individually independent processes, during which a single photon (energy packet of magnitude hv, where h is Planck's constant and v is photon frequency) is emitted. It is possible to speak of an individual photon only when a single atom is its "generator." Propagation processes can be described only with the aid of wave theory. A photon has energetic indivisibility; its energy cannot be arbitrarily "diluted," either we find a photon or we do not. Light particles also have no rest mass and thus can travel at the speed of light or perhaps even faster.

The momentum of the photon is experienced by the medium in which it is absorbed or reflected. One cannot observe in the same experiment both atomic recoil (particle nature of light) and interference (wave nature of light). The photon possesses angular momentum—known as left-handed or right-handed spin—that is closely circular polarization of light. The spin of a photon is transferred to the absorbing medium. Light waves can be generated in an optical resonator that

confines and stores light of certain resonate frequencies. Light can be repeatedly reflected in a helical system and used for bio-sensing [27].

In optical physics, two wave sources are perfectly coherent if they have a constant phase difference and the same frequency [28] Coherence describes all properties of the correlation between physical quantities of a single wave and a wave packet. Coherence in physics and quantum physics is an ideal property of waves that gives the wave very stable intensity and the potential to very accurately transmit information. Squeezed light exhibits a coherent state. Processes associated with nonlinear optics in biological systems are best suited for the generation of squeezed light.

Squeezed coherent light (photon) has a close connection to Heisenberg's uncertainty principle. The amplitude of squeezed light has a narrower photon number distribution than one of a coherent state of the same amplitude, resulting in a minimum quantum noise and improvement of the signal to noise ratio. Squeezed coherent states may use multiple wave mixing. The squeezed state is used for quantum information processing for continuous variable systems, such as for quantum communication, quantum teleportation, and one-way quantum computing [27, 29]. Squeezed light finds application in teleportation (teleport from one beam of light to another). Parametric in optical physics is any process in which an interaction occurs between light and matter that does not change the state of the material, such as components of a human cell. Another example is found with photons using the Mach-Zehnder interferometer, which shows both wavelike interference and particle-like detection.

Light photons, entangled in energy and time, are not limited to the microscopic (atomic, molecular) dimensions but can extend over macroscopic distances. Quantum entanglement is a physical phenomenon that occurs when pairs of coherent light photons (particles) are generated or interact in ways such that the quantum state of each particle cannot be described independently of the others, even when the particles are separated by a large distance. Instead, a quantum state must be described for the system as a whole. It appears that one particle of an entangled pair "knows" what measurement has been performed on the other, and with what outcome, even though there is no known means for such information to be communicated between the particles, which at the time of measurement may be separated by arbitrarily large distances [30, 31]. Einstein called this phenomenon "spooky." Space and time may result from the quantum entanglement of qubits, which provide an underlying informational code for the universe [32].

The counterintuitive predictions of quantum mechanics have been verified experimentally. This has been shown to occur even when the measurements are performed more quickly than light could travel between the sites of measurement. Recent experiments have measured entangled particles within less than one hundredth of a percent of the travel time of light between them. According to the formalism of quantum theory, the effect of measurement happens instantaneously. Quantum entanglement is an area of extremely active research by the physics community, and its effects have been demonstrated experimentally with photons, neutrinos, and electrons. Research is also focused on the utilization of entanglement effects in quantum communication and computation [33, 34].

8.4 Teleportation

Information transfer has a significant role in quantum physics, and that role seems to go beyond classical physics. The quantum state that is being teleported is nothing other than information. Space and time in Einstein's relativity are unified as space-time, in particular, quantum nonlocality/teleportation within the framework of concepts introduced by Einstein, Podolsky, and Rosen [35]. The notion of information and reality may also be unified in quantum communication [7]. Quantum teleportation—the transmission and reconstruction over arbitrary distances of the state of a quantum system—is demonstrated experimentally. During teleportation, an initial photon which carries the polarization that is to be transferred and one of a pair of entangled photons are subjected to a measurement such that the second photon of the entangled pair acquires the polarization of the initial photon. This latter photon can be arbitrarily far away from the initial one. Quantum teleportation will be a critical ingredient for quantum computation networks [35].

The qubit is a computing quantum bit or a unit of smallest possible amount of quantum information. In quantum mechanics, the qubit is a superimposition of vertical and horizontal polarization of a single photon at the same time. Superposition of two states at the same time is fundamental to quantum computing. Quantum information processing with single photons or photo pairs as qubits is all intimately related to quantum entanglement [36]. The qubit is a way of compressing states emitted by a quantum source of information. Multiple qubits can exhibit quantum entanglement that processes information more efficiently than on a classical computer where bits have only one value at a time. The technology can be used to produce a holographic "memory qubit" for quantum data storage [37, 38]. Quantum entanglement and teleportation are unique to quantum computing.

Teleportation means transportation of things from one place to another. Relativity theory teaches us that the velocity of light is the upper limit for motion of an object. According to quantum theory, the quantum mechanical wave function represents the maximum information known about the object. Teleported photons disappear and reappear almost instantaneously at its destination. Quantum mechanics offers "magical tricks"—the transmission of the wave function that needs to be successful requires that two systems must be entangled. The vehicle of teleportation is the entangled pair. Quantum teleportation is feasible in the case of continuous variables, identifying both position and momentum [22, 36–40].

Teleportation can be achieved between photons, atoms, and molecules and between different states of atoms (ions). Quantum states can have a long life. Teleportation is the perfect way to transfer quantum information from the output of one place to the input of another. One-way quantum computers are also possible. Coherent light from lasers produces a special kind of light, in the form of peculiar pairs of photons that are quantum entangled (intimately connected) with each other. When one is measured, the state of the other one is instantly influenced, no matter how far apart they are separated [7, 41]. Two particles of light that collide with each other are still intimately connected. Quantum entanglement has philosophical and theological implications [42, 43]. Quantum entanglement works across a distance in

terms of traveling signals that are faster than the speed of light. Entanglement can be used to circumvent the limitations imposed by Heisenberg's uncertainty principle without violating it and open a way to teleportation [41]. Thus, the human cell may transmit information among all other cells in the human body using quantum teleportation.

Numerous studies have been published during the past 95 years showing evidence of electromagnetic cell-to-cell communication [17, 44]. A shift in focus to biochemistry after World War II greatly slowed down further research interest in cellular communication. An interest in earlier "dish-to-dish" studies of physically disconnected cell cultures returned during the 1970s and continues with increasing awareness today.

Alexander Gavrilovich Gurwitsch (1874–1954), a famous Russian embryologist, physician, and professor of histology in the 1920s, discovered ultra-weak UV photon emissions from living tissue. He named these photon emissions "mitogenetic rays" because they stimulated an increase in cell division (mitosis), even from nearby unexposed cells. Gurwitsch devised what he called the basic experiment. Normal window glass blocks UV rays, while quartz glass is transparent for UV light at 260 nm. Two onion roots were arranged at right angles to one another with the horizontal root pointed toward the vertical stem with a space for either normal window glass or quartz glass plate. The subject of observation was cell mitoses rate on the stem where the root tip was pointed. When window glass was placed in the space between the root and the stem, no cell division changes were noted, whereas when quartz glass was placed in the space, cell division increased significantly by 30%. Gurwitsch concluded that ultra-weak UV photon emissions in the horizontal root were stimulating increased cell division in the vertical stem. The data suggested that photons might regulate cell growth and differentiation [45, 46]. Natural gamma radiation may serve in part as a substitute for sunlight by stimulation of photosynthesis in algae-denied natural sunlight [47]. UV photon emissions are also associated with exposure of cells to low-LET radiation [48]. In the ensuing age of biochemistry, molecular biology, and hormones, Gurwitsch's studies were largely forgotten.

Dr. Vlail Kaznacheyev was director of the Institute for Clinical and Experimental Medicine in Novosibirsk, U.S.S.R. Guided by Gurwitsch's work, he carried out 1000 of experiments over a 20-year period in the U.S.S.R. which were published in a book in 1981 [49]. They indicated that cellular information can be transmitted electromagnetically in target cells absorbing photon radiation from damaged cells. Kaznacheyev had demonstrated optical coupling between two sealed quartz cell cultures.

In the basic experiment, two sealed quartz containers containing the same cell culture were separated by a thin optical quartz window. One sample was equally divided and placed in each of the two halves of the apparatus. Thus, the two containers were completely and environmentally shielded except for optical coupling. The cells in one sample were subjected to ionizing radiation. This usually led to death of cells in the exposed culture. Kaznacheyev's observations were unexpected and counterintuitive. If the window was made of ordinary window glass, the untreated cells on the other side of the window were undamaged and remained healthy. This was as expected from Gurwitsch's studies. However, if the window was made of quartz,

then cell death appeared after about 12 h in the unirradiated sample. From 70 to 80% of the tests demonstrated this "optical coupling." Cells in the irradiated culture were thought to give off photons in the near-ultraviolet region when they died. The quartz window was transparent to the UV "death photons" which were absorbed in the unirradiated culture on the other side of the window. The same type of responses was also observed for cells treated with microbiological and chemical agents.

The detection of ultra-weak light photons within and between cells is difficult because of possible "light noise" from many potential sources, such as reactive oxygen species (ROS), enzyme catalysis, and phosphorescence [50]. The Japanese manufacturer of optical devices, Hamamatsu Photonics, developed a photomultiplier tube which was able to accurately measure and count single ultra-weak photons [51]. The typical observed photon density in biological tissues in the visible and ultraviolet regions was approximately 1–1000 photons/cm^2/second using this system. This light intensity was detectable above the background of thermal radiation emitted by tissues at their normal temperature.

Fritz-Albert Popp, a German biophysicist and cancer radiotherapist, discovered a wider spectrum of ultra-weak photon emissions from 200 to 800 nm common from living cells. He coined the term "bio-photon" for these photons of very weak light [52]. According to Popp, a bio-photon (from the Greek βίος meaning "life" and φῶς meaning "light") is a photon of nonthermal origin in the visible and ultraviolet spectrum emitted from a biological system. The typical observed radiant emittance of bio-photons in biological tissues in the visible and ultraviolet frequencies ranges from 10^{-19} to 10^{-16} W/cm^2. This light intensity is much weaker than that seen in the perceptually visible and well-researched phenomenon of normal bioluminescence but is detectable above the background of thermal radiation emitted by tissues at their normal temperature.

Lower-energy photons (longer wavelengths) not detected by the human eye can be detected by special detectors. Low-energy thermal photons abound in the cell. These energies are so tiny compared to room temperature thermal energy that it is very difficult to separate them as quantized entities (Table 8.1). Their presence literally swamps the cell with background energies. The thermal energy of a molecule at

Table 8.1 Quantum energy of the electromagnetic spectrum in electron volts (eV)

Source	Minimum	Maximum
AM radio band	2×10^{-9}	6×10^{-9}
Short wave	0.66×10^{-8}	0.22×10^{-6}
TV and FM radio band	0.22×10^{-6}	0.66×10^{-5}
Microwave, radar	0.66×10^{-5}	0.12×10^{-3}
Millimeter wave, telemetry	0.12×10^{-3}	0.12×10^{-2}
Infrared	0.12×10^{-2}	1.65
Visible light	1.65	3.10
Ultraviolet	3.10	124
X-rays	>124	Over 10^6
Gamma rays	>124	Over 10^6

room temperature is about 0.04 eV. Mammalian cells have a metabolic rate of about 30×10^{-12} W/cell. The combined heat of 33,000 normal cells is detectible if instrument sensitivity is at least 1 μW. A comprehensive review of the field of bio-photons is provided by Ted Nissen [53].

Bio-photons represent a more subtly complex cell-to-cell communication that relies upon speed of light transmission for communication. Popp found that bio-photons were coherent and may regulate all life processes of an organism [54–56]. This is a very small number and is why bio-photon research is so controversial. Mammalian tumor cells emit photons at rates as high as 1400/cm^2/min compared to healthy tissues that averaged rates of less than 40 [57]. Bio-photons may even signal malignancy in tissue before more conventional imaging [58].

Bio-photon energies appear to spread from infrared to ultraviolet. Albrecht-Buehler spent 30 years researching possible data processing of infrared signals. 3T3 cells were found to extend their pseudopodia toward single or paired infrared sources, particularly in the 800–900 nm wavelengths at 30–60 pulses/min. Temperature changes were negligible, and chemotaxis was both ruled out as being involved. Cells seem to see objects suggesting that cytoplasm has a certain capacity of data processing and integration. In other words, cells seemed to exhibit intelligence [59, 60].

8.5 DNA

A quantum dot (QD) is a single-atom-like light emitter which can be used in quantum light sources. The properties of QD can vary depending on temperature and external electromagnetic fields. A QD is a nanostructure containing highly tunable properties that may have applications in quantum computers. Its unique photophysical properties may allow for optical encoding. Spectral tuning can be modified by curvature of a 1-micron diameter microfiber when coupled with a single quantum dot. Placing a right resonant frequency quantum dot at the right place is required for an on-demand reconfigurable photonic crystal resonator (RPCR). The RPCR is applicable to a quantum dot single-photon source. A photonic crystal is a nanostructure that affects the motion of photons. A resonator is used to generate electromagnetic waves of specific frequencies. By employing the contact of a curved microfiber (1-micron diameter), it is possible to achieve spatial relocation and spectral tuning of the resonator as well as photon collection efficiency [61, 62]. DNA-programmable methods are used to prepare 3-D photonic crystals, as precursors of assembling nanostructures into a very complex structure [63]. It is not known if the QD can encode by directly tuning, nor is it known if all these discovers in the discipline of physics will be applicable to biology. Is it possible to exploit quantum nonlocality to transmit usable signals than can travel faster than light? Quantum entanglement can be injected into optical fibers and "mysteriously" interact at a distance. Quantum teleportation is the most surprising application [64]. Communication (abscopal, bystander, bio-photon) between cultures and animals could be viewed as quantum teleportation, and DNA could be the command and control center for cells.

DNA is a liquid-crystal, lattice-type structure that may store and emit bio-photons. DNA may operate as a quantum field. About 95% of human DNA not involved in protein building is not "junk" DNA but is active within a quantum state in transfer of information. Signals can "be read out" by DNA without any essential loss of the information [20]. DNA is a complicated electronic biological chip that communicates within each cell and with other cells of the body. The DNA code is used for hyper-communication, which is a data exchange at the DNA level using genetic code. The Watson Crick Chargaff rules, A-T and G-C, for coding DNA is correct but only uses about 5% of DNA. Coherent bio-photons generated in DNA may be a key element in this information transmission system. Another aspect is an electromagnetically mediated "language" for communication between DNA and the cells. Codons may actually form words and sentences just like our ordinary human language follows grammar rules. Since the DNA was found to have a syntax and semantics akin to our human languages, it indicated that our currently restricted understanding of DNA serving only for the coding of the reproduction of proteins for the chemical makeup of an organism is only part of the story.

Ultra-weak bio-photons may represent a complex cell-to-cell communication system that relies upon speed of light or greater transmission based on data in DNA [65–67]. The physics of light seems to fit the biological observations. Light is the most efficient and fastest mediator of information in the world. The coherent property of bio-photons has a profound effect on their ability to influence information transfer. Frequency coding gives light a capability of encoding information from DNA in bio-photons. An optical resonator is required to store light within a very small confined space. The ability to trap photons and influence the propagation of light plays a significant role in quantum optics [68]. Photon signaling among cells and animals indicates that cells can talk to each other. Bio-photonic signaling is used in the reception, transmission, and processing of electromagnetic data perhaps with some of the same transmission features of fiber optics [69].

Popp spent nearly 20 years studying bio-photon emission [70]. Popp found that DNA is the main supplier of bio-photons. He discovered that DNA is a harmonic oscillator—an oscillating system with its own particular resonating frequency. Bio-photons probably represent a wide variety of frequencies which seem to originate from DNA and be concentrated in DNA of the cell nucleus [71]. According to Popp light can be stored in tissues and gradually released over minutes to hours. Popp concluded that bio-photons appear to communicate instantaneously with all the cells of the body in a synchronous wave of informational energy. Popp put forward the hypothesis that bio-photons, analogous to a laser, are emitted from a coherent electrodynamic field within the living system [72]. Popp believed that bio-photons may represent a wide variety of frequencies which seem to originate from DNA and be concentrated in DNA of the cell nucleus; accordingly light can be stored in DNA and released over time [71]. He concluded that bio-photons appear to communicate with all the cells of the body instantaneously in a synchronous wave of informational energy [54, 56]. Overall, there is a relatively large amount of literature about DNA and its ability to create photons in a coherent state [73].

Light can, as a bunch of photons, be manipulated in many different ways. Beam twisting using eight beams of light causes the beam to exhibit DNA-like helical shape that is propagated in free space. Multiparty clusters of photon entanglement of up to eight spatially separated photons have been demonstrated [74–76]. With twisted beams of light, it is possible to send up to 2.6 terabits per second. Light beam twisting can form a propagated helical shape that possibly could scan and encode parts of DNA and transmit an enormous amount of data [77, 78]. When DNA in test tubes is exposed to coherent light, the light spirals along the DNA helix as if it was guided by the structure of the DNA molecule [19, 79].

In truth, DNA is not just a blueprint for constructing the body, but it is also a storage medium for optical information as well as an organ for communication [19].

When an atom absorbs a short burst of energy, it splits into two versions of itself, one excited and the other not. A following burst of coherent X-ray light scatters both versions which then combine to form an X-ray hologram [80]. Liquid crystal phases of the chromosome apparatus (the laser mirror analogues) can be considered as a fractal, holographic environment to store localized photons, so as to create a coherent continuum of quantum nonlocally distributed polarized wave genomic information. The fundamental notion is that the photon-laser-radio wave features of liquid crystals and DNA are stored for definite but varying times by means of laser mirrors as "memory." Memory is an aspect of the genome's nonlocality.

The Russian biophysicist and molecular biologist, Pjotr Garjajev, a member of the Russian Academy of Sciences as well as of the Academy of Sciences in New York, discovered that the DNA, which is not used for protein synthesis, is instead used for communication—more exactly for hyper-communication. Garjajev's research shows how DNA operates through resonance and vibratory frequencies. DNA is a living, fluid, and dynamic quantum informational field that is responsive to coherent light waves. DNA functions also a medium for the storage, receiving, and communication of information. Garjajev's findings go far beyond those of Popp. According to Garjajev, DNA is not only the transmitter and receiver of electromagnetic radiation (in the form of energy), but it also absorbs information contained in the radiation and interprets it further. Thus, DNA is an extremely complex interactive optical biochip.

Intracellular and extracellular cell-to-cell communication serves as the basis for coordination of information transfer both within each individual cell and between a myriad of different cell types found in the human body [81]. Cell data transfer appears nondiffusible and non-neuronal over extended tissue regions for physically disconnected cells [82]. Chemical signaling in tissues is restricted by molecular diffusion which can only "slowly" transfer signals for small distances. The source of cell communication is nonchemical, nondiffusible, and noncontact [44]. *Paramecium caudatum* populations separated by quartz seemed to use two or more photon

frequencies for cellular information transfer. Photon cellular communication was different from a triggered, inducible receptor-based system [83].

Bio-photons emitted from growing fish and frog eggs can encourage the growth of other "distant" eggs of a similar age. Bio-photons from mature eggs can also hinder and disrupt the growth of younger eggs at a different stage of development. In some cases, bio-photons from older eggs seem to stop the growth of immature eggs entirely [84]. Thus, bio-photon emissions from distant sources result in synchronization of egg development [85]. A photon communication algorithm developed from experimental studies in fish and frog eggs appears similar to the communication of binary encoded data in a computer net via optical channels [86].

Do cells speak using light signals? Signal pulsation is possibly important for social behavior, cell sorting, cell position in tissues, and cell differentiation (embryogenesis). The ability of cells to emit and detect infrared signals is due to "long" distant communication. Using infrared photon pulses, he was able to demonstrate that cells are intelligent and that cytoplasm has a certain capacity of data processing and integration. In other words, cells seemed to exhibit intelligence. Restoration property is well known in biology (grafting of plants, regeneration of a lizard's tail, regeneration of a whole organism from the oocyte).

Nature is just as strange as quantum physics of the atom. Quantum communication within a cell or outside a cell to other cells in the human body can be much faster than the speed of light [7].

There are examples of hyper-communication at work in nature. For example, the organization of ant colonies appears to make use of bio-photon communication. When a queen ant is separated from her colony, the worker ants continue to build and construct the colony as if following some form of blueprint. Yet if the queen ant is killed, then all work in the colony ceases, as if the blueprint had suddenly been taken offline. This suggests that the queen ant need not be in physical contact to continue to transmit the blueprint, yet upon her death the group consciousness ceases to operate within a communicative informational field. Other natural examples are bee workers swarming around the queen bee, 1000 of fish in the ocean swimming in synchronous unity, and migration of the monarch butterfly and birds. [87] Environmental ionizing radiation is required for health and normal growth of organisms (Chap. 4). Natural radioactivity stimulates photosynthesis in algae-denied natural light and also serves as a substitute for sunlight for deep sea and subsurface organisms [47].

The term cell intelligence was coined by Nels Quevli in the year 1916 [88]. The basic tenet of the book is that the actions and properties of cells are too amazing to be explained by anything but their intelligence, which comes as a result of intelligent design. Albrecht-Buehler automatically discarded intelligent design because of his theological prejudices. A book from the 1930s written by a Catholic monk with a PhD in Botany demonstrated the statistically significant, positive impact of prayer on plants. A Presbyterian pastor showed in 1959 that praying for plants increases growth, flowering, and yield [89]. Several double-blind studies of patients in coronary care units showed that prayer at a distance (medical staff and patients did not know they were being prayed for) gave statistically significant better outcomes than

those not receiving prayer [90, 91]. An MD cardiologist friend of mine did his intern work caring for a group of ~10 terminal cancer patients. Another MD had a similar number of terminal cancer patients in the same facility. John prayed daily for his patients and the other MD did not. All of the other intern's patients died before any of Johns'. The ramifications of these observations are enormous to the understanding of life processes and healing.

8.6 Brain

John von Neumann (1903–1957) calculated that during an average lifetime of 70 years, we accumulate some 280 trillion bits of information. He developed the operator theory of quantum mechanics as might occur in cell-to-cell interactions by biophysical means (such as photons) [66, 92].

Creation of biocomputers, based on new principles of DNA-wave biocomputation which uses quantum teleportation, can be compared to the human brain regarding methods of data processing and functional capabilities [21, 93]. Genes appear to have holographic memory, which is also true for memory of the cerebral cortex [94]. The intercellular diffusion of signal substances in the nervous system is far too inertial for this purpose. Even if it is conceded that intercellular transmissions take place electromagnetically at the speed of light, this would still be insufficient to explain how highly evolved, highly complex neural biosystems work in real time [95]. How do 100 billion neurons and 100 trillion synapses in the brain function and communicate in a synchronous manner? How does the brain store and retain memory? Is data transferred by UV, visible, infrared, radio wave, or even gamma rays? Clarke notes that neuronal function may involve quantum coherence; if so this might open the door for large-scale quantum effects. However, coherence is thought to be rare in biology, or exceedingly brief, because molecular noise in living cells tends to destroy the coherence… a few examples of quantum effects in the nervous system have been reported, and this new field is gaining momentum, but some of the data are controversial [96]. However, quantum entangled coherent, squeezed, biophotons of light may facilitate neuron-to-neuron communication and brain function.

> There are about 100 billion neurons in the human brain and about 100 billion galaxies in the universe. Maybe it is just a coincidence.

Neurons can be optically activated by a laser beam during fear conditioning following manipulating of memory [97]. A research project at the University of Rochester in the brain and cognitive sciences involving 129 individuals fitted with an eye tracker, showing that 50% could "see" the movement of their own hand in the absence of all light. The researchers concluded that sight is as much a function of their own brains as our eyes [98]. Bio-photon production by the hand and highly

sensitive detection by the eyes of such ultra-weak photons could also explain the observations. Light is used for therapy associated with molecular changes in the cell [99, 100]. Low-energy light photons promote tissue regeneration, reduce inflammation, and relieve pain [101]. Significant improvement in neurological severity score was seen in experimental mice given low-level laser therapy [18].

8.7 Radiation Adaptive Response

Today many physicists believe that all must proceed from quantum mechanics. In so complex subject as radiobiology and the radiation adaptive response, this may appear impossible and impossible to comprehend, that is, impossible to comprehend but possible in principle based on statistics and thermodynamics. While physicists would like to think that all is physics, so quantum mechanics should also apply to radiobiology, at least in the physical or material sense. The complexity of biology is immense. As such a "reductionist-physical" phenomenological modeling may apply with grouping of assumptions to bring new knowledge [102].

The response of the cell to low-dose-rate ionizing radiation can result in the adaptive response spreading out to surrounding cells to elicit the bystander effect and the rescue effect, minimizing damage and prepping cells for further radiation exposure and damage. The overall effect may be to reduce cell damage in nonirradiated cells causing cancer and other proliferative and inflammatory disease to decrease below natural or spontaneous levels. Bystander effects, which are part of the adaptive response, [103] follow exposure to both low- and high-LET radiations (Chaps. 4 and 7). The bystander effect involving ROS [104] is a biological response in cells that do not receive any energy deposition from ionizing radiation but respond to signals produced by cells that do [105]. Low-dose hypersensitivity for cell killing appears to be a protective effect related to the elimination of genetically altered unstable cells (apoptosis) by bystander signaling [106, 107].

> The term "photon hormesis" should not be confused with bio-photon communication and the adaptive response. Photon hormesis refers to diminishing of biological effects from high-LET radiation (α-particles) by low-LET radiation (γ-rays). Low-LET radiation may induce bystander signals to neighboring naïve cells or organisms [108].

In vivo bystander injury was shown in clonal descendants of hematopoietic stem cells following irradiation of bone marrow in mice [109]. An intriguing and fascinating series of publications has appeared in Dose-Response published by Dr. Carmel Mothersill and colleagues at McMasters University in Hamilton, Ontario, Canada [110–113]. She has found in vitro and in vivo evidence for bystander "information" transmission from irradiated to unirradiated cells/tissues/ animals. Information transfer occurred both from cell to cell and also from animal to animal [114].

She exposed the right hemisphere of the brain in rats to a very high radiation dose (35 Gy or 350 Gy) from a synchrotron microbeam and then placed an unirradiated (cage mate) rat in the same cage for 48 h. Clonogenic reporter survival (plating efficiency for colony formation of immortalized human epithelial reporter cells cultured in harvested media) was determined in irradiated rats and their unirradiated cage mates. Explanted tissues from the brain and urinary bladder were placed in growth medium and cell-free medium harvested after 48 h. The unirradiated cage mates had a similar or even more severe suppression of cell proliferation than did irradiated rates. Signals were transmitted to the unirradiated cage mate causing similar or even greater effects in the cage mates than in the irradiated rats [110]. In similar studies, adverse effects were found in unirradiated cage mate animals placed with mates who had received ≥4 Gy; effects included immune suppression, chromosome damage, and leukopenia [115, 116]. Out-of-field abscopal effects were found where immunocompromised mice produce signals which alter the response of unirradiated mice cells [117] and where two esophageal adenocarcinoma cell lines produce bystander signals in human keratinocyte reporter cells [118]. Mothersill suggested that signals may have a physical component such as UV photons [111].

Dr. Carmel Mothersill is a researcher in radiobiology at McMasters University in Hamilton, Canada. She has found abundant evidence of "bystander" information transfer both from cell to cell but also from animal to animal.

In 2015 I became aware of a review paper by Scholkmann et al. published in 2013 [44] that ploughs much of the same scientific literature as my paper published in *Dose-Response* in 2014 [17]. Weak electromagnetic radiation in the ultraviolet, visible, and near infrared may be the medium for radiation adaptation and bystander effects and cell-to-cell communication. Radiation-induced bystander responses have been demonstrated for a variety of deleterious end points, such as induction of SCEs, chromosome instability, mutations, and apoptosis [119].

A new cellular signaling effect in cells was found in 2011, called the rescue effect that complicates the signaling dynamics among cells. Mammalian cells respond to ionizing radiation by sending out extracellular signals that influence non-irradiated neighboring cells (bystander effect). The rescue effect refers to bystander cells that rescue irradiated cells by intercellular signal feedback. The rescue effect has been observed in normal and cancerous human cells. Co-culturing irradiated cells with nonirradiated bystander cells decreases micronucleus formation and DNA double-strand breaks in irradiated cells, mitigating the cytotoxicity and genotoxicity of radiation [120]. The rescue effect may potentially compromise the effectiveness of radiotherapy and radio-immunotherapy because nonirradiated normal bystander cells can rescue irradiated cancer cells [121]. The rescue effect has also been observed between irradiated and bystander zebra fish embryos [122].

Living organisms experience the laws of quantum mechanics, where adaptation formation is unlike genetic information [123]; the responses are temporary and not inherited and not mediated by changes in DNA. There are, however, greater than 150 genes involved in defense of cells against toxic agents, including ionizing radiation [124]. Ethionine is a highly toxic analogue of methionine that when added to mammalian cell cultures produces an adaptive response for drug resistance that was shared in unexposed, physically separated cultures, behaving as though they were in an entangled quantum system [125]. Adaptive signals traveling from exposed to unexposed cultures appeared to result in increased resistance to ethionine in the unexposed cultures. They could not find a molecular explanation for formation of these adaptive mutants.

Geneticist and biophysicist, Mae-Wan Ho (1941–2016), described how the living organism, such as the human body, is coordinated throughout and is coherent beyond our wildest dreams. Ho believed that the cell is in a quantum coherent state where quantum optics, DNA, and liquid crystals operate to convey information [95]. It appears that every part of our body is in communication with every other part through a dynamic, tuneable, responsive, liquid crystalline medium that pervades the whole body, from organs and tissues to the interior of every cell. Dr. Ho is also an advocate of homeopathy, precursor to radiation hormesis [126].

The results of Popp and Garjajev provide a remarkable connection: Light represents an important factor in the power supply for DNA. Light provides healthy functioning of all procedures in our cells. A large variety of biological systems have shown significant bio-photon emissions in optical and UV range [84, 127, 128]. Bio-photon emissions are associated with cellular damage and slow cell death during apoptosis [84, 128]. A form of quantum coherence operates within living biological systems through what is known as biological excitations and bio-photon emissions in the range from 200 to 300 nm. What this means is that each living cell is giving off a bio-photon field of coherent energy. Bio-photons are the entities through which the living system communicates; there is near-instantaneous intercommunication throughout. And this, claims Popp, is the basis for coherent biological organization—referred to as quantum coherence. Quantum communication can happen nearly instantaneously. Biological observations of Gurwitsch, Kaznacheyev, Popp, Albrecht-Buehler, Garjajev, Mothersill, and many others clearly demonstrate a form of intracellular and cell-to-cell and organism-to-organism communication that may utilize bio-photon and/or quantum teleportation [129].

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