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."

C.L. Sanders, *Radiobiology and Radiation Hormesis*,
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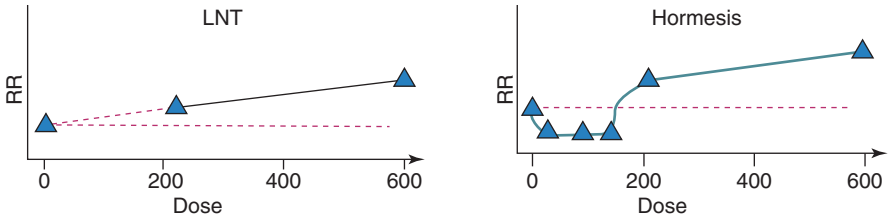

Fig. 1.1 Models of relative risk (RR) for biomedical effects following exposure to ionizing radiation: linear no-threshold (LNT) and radiation hormesis (With kind permission of Dr. Bobby Scott [42])

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

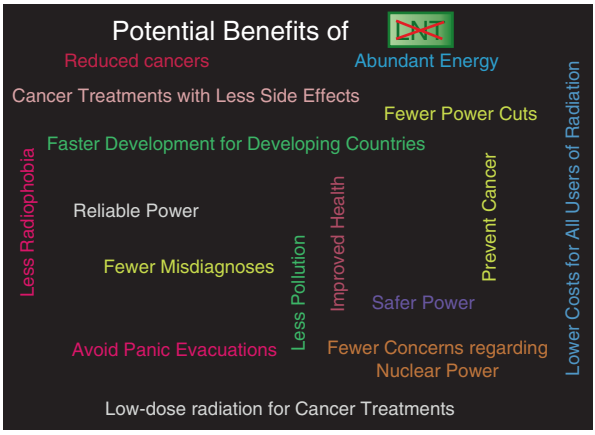

Fig. 1.3 Blog that does not support the LNT model pointing out why it should not be relied upon [32] (With kind permission of XLNT Foundation of which the author is a member)

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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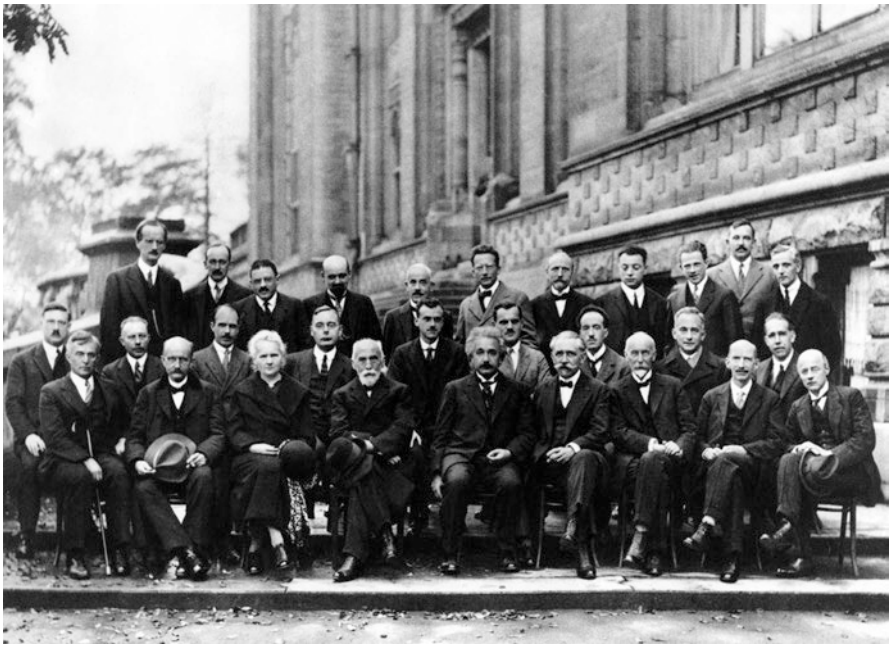

Fig. 2.1 The Fifth Solvay Conference was also held in Brussels in 1927. The subject of the conference was *Electrons and Photons*. Seventeen of the 29 participants were or later became Nobel Prize winners. Marie Curie remained as the only woman and also the only person to be awarded the Nobel Prize in 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