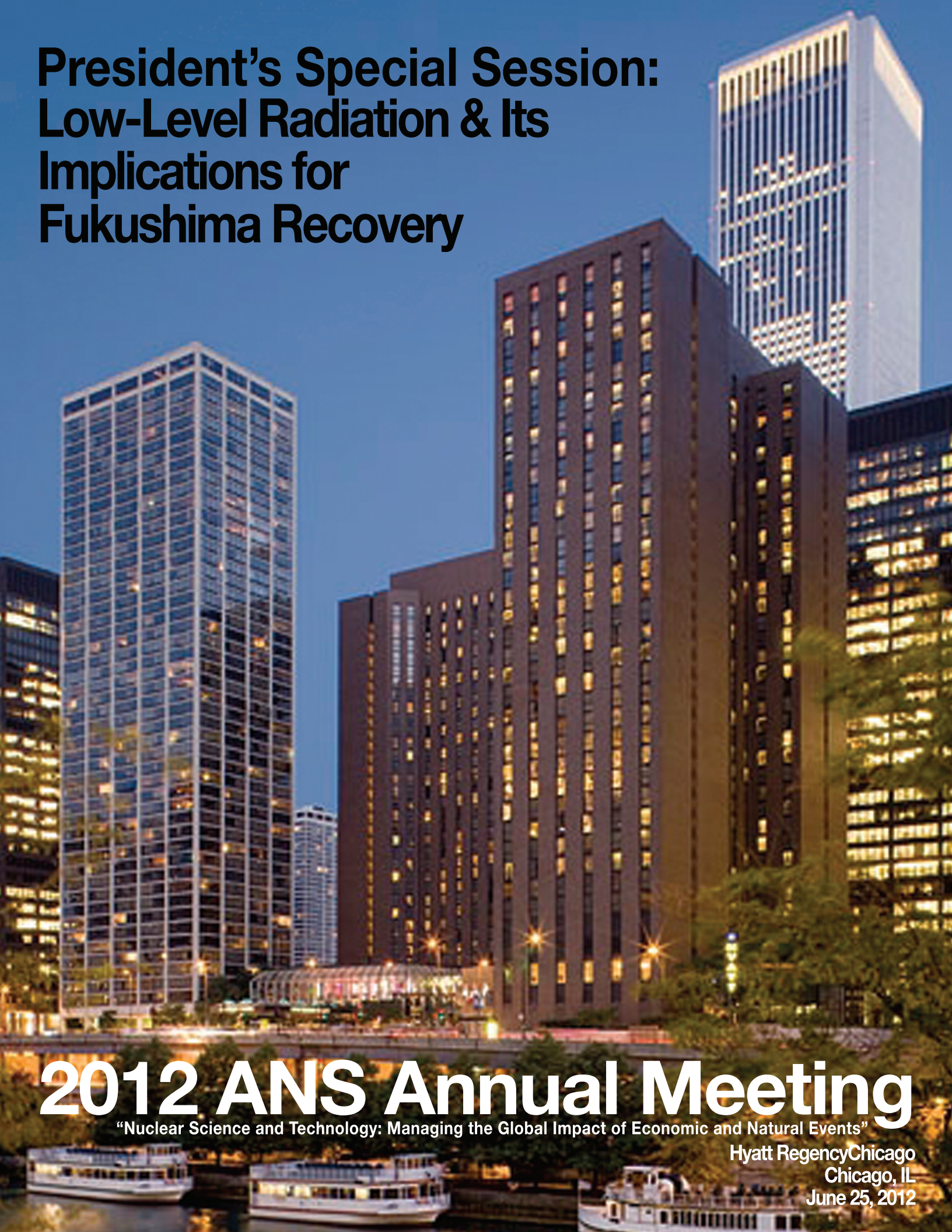
President's Special Session: Low-Level Radiation & Its Implications for Fukushima Recovery



2012 ANS Annual Meeting

"Nuclear Science and Technology: Managing the Global Impact of Economic and Natural Events"

Hyatt RegencyChicago
Chicago, IL
June 25, 2012

President's Special Session
Low-Level Radiation and Its Implications For Fukushima Recovery

2012 American Nuclear Society Annual Meeting
Chicago, June 24-28, 2012

FOREWORD

Meeting attendees, welcome to Chicago, the host city for this year's ANS Annual Meeting with the theme, " Nuclear Science and Technology: Managing the Global Impact of Economic and Natural Events."

This is ANS's 114th national meeting since our founding in 1954. This Annual Meeting's General Chair is Amir Shahkarami (CEO, Exelon Nuclear Partners; Senior VP, Exelon Generation) and the Technical Program Chair is Ray Klann (Argonne National Laboratory). Thank you both for your leadership.

We do well at identifying, quantifying, and mitigating most hazards. For example, we did not stop using fire when the first caveman burned his fingers — we learned how to be careful around hot objects. In addition, we did not stop the industrial expansion after the first boiler explosion. Instead, we developed mechanical standards and operating procedures. In more recent times, we did not stop biking, skiing, and swimming for recreation even though these activities result in injury and death. Instead, we found ways to make these activities safer. And, we did not stop the development of nuclear science and technology after the first death attributed to cumulative X-ray overexposure in 1904. Once again, we learned from the experience and improved how we manage the risk.

We did, however, in the early 1950s, overreact to the hypothetical risks of low-level radiation with the adoption of the Linear No Threshold (LNT) model to account for potential effects of overexposure to nuclear radiation.

This report from the ANS President's Special Session at the 2012 Annual Meeting focuses on the LNT model and questions the validity of assumptions and discusses the science and policies that created the model. This report presents the information collected and discussed, and invites your review of the LNT model; it also suggests a more realistic approach to address the health effects, mitigate the hazards, and set appropriate limits to sensibly and realistically avoid the potentially adverse consequences of radiation exposure.

The pessimism that now makes much noise in the global public about nuclear radiation can, in our time, be shown to be wrong. The information collected and discussed in this Special Session has, we are hopeful, opened the door to a change in our attitudes with the foundation of scientific evidence about radiation. It is dedicated to the residents surrounding the Fukushima site who are still unable to return to their homes due to the overreaction toward low-level radiation.

Eric P. Loewen, Ph.D.
ANS President
June 25, 2012

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Introduction

Ever since Hiroshima and the Manhattan Atomic Bomb Project – more than two human generations ago – the radiation protection field has been dominated by persons whose stated goal is to minimize the radiation exposure of those under their control. They believe that depicting radiation in dreadful terms justifies imposing ever-tightening quality control measures, and thus greater safety, and not incidentally, justifies greater prestige and power to the inner circle of practitioners. This situation has been maintained with increasing ruthlessness through the decades – controlling membership on BEIR committees that determine regulatory criteria, deciding which reports to ignore, etc.

Fukushima has shown that **obsession with reducing harmless radiation doses has not led to greater safety, but has in fact led to an unprecedented amount of avoidable human suffering.** And by repeatedly tightening the controls, the impression is given that we keep discovering that we've not been safe enough. What else could one reasonably conclude? The first part of this ANS Report documents the impact this situation has had on research on radiation and on radiation's impact on health. This second section cites some of the relevant policy statements and political commentary produced largely by people and organizations outside the radiation regulation field. We live in a world where medical and dental diagnosis and therapy, flying, skiing, radon health spas, radon-filled houses, stone-clad houses, granite counters and bananas, give a total of radiation exposures far exceeding the radiation exposure that is regulated. When forced to face the questionable value of strictly regulating only a small and decreasing fraction of the radiation exposure everyone gets, the latest proposal from the radiation regulators is to boldly go into the world at large, and attempt to implant their controls on the natural radiation found throughout the entire planet.

In the rest of this section, we look briefly at a wide variety of situations where radiation protection policy and procedures do more harm than good, generally by focusing on reducing harmless radiation doses still further, fostering fear and uncertainty with no compensating benefit.

Theodore Rockwell June 2012

The radiation pioneer Alan Waltar, author of several books on radiation, suggests that if people were aware of the pervasive role of radiation in their lives, and the many useful functions it performs, perhaps the irrational radiophobia would start to fade away. He explores this idea in a brief booklet:
http://dl.dropbox.com/u/71478013/a-day-w-atom081030.pdf

Respected radiation authority Wade Allison, author of *Radiation and Reason,* has proposed that the 1 mSv/year chronic exposure limit be raised 1000-fold, which he says is still well below the hazard level, based on clinical data. He discusses his views on radiation protection and the situation at Fukushima in the following paper:
http://www.world-nuclear.org/uploadedFiles/org/WNA_Personal_Perspectives/Public_Trust_in_Nuclear_Energy.pdf

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The key nuclear organizations have taken a strong, public position on the need to reform radiation protection policy. **At the international level,** Ambassador John Ritch, Director-General of the World Nuclear Association, bluntly described it in letters to the IAEA, ICRP and others involved in implementing radiation protection policy. His message is that by continually requiring further reduction of harmless radiation doses, radiation regulators make it increasingly difficult for nuclear energy to compete with fossil fuel energy. This is detrimental to world health, with no compensating benefits.

Addressing the Director-General of the International Atomic Energy Agency (IAEA), in a letter dated 1 May 2010, following up on previous correspondence on the same topic, he summarizes the issue as follows: http://www.world-nuclear.org/uploadedFiles/org/John_Ritch_speeches/WNA%20Letters%20to%20IAEA%20-%201%20May,%2019%20April,%2028%20Oct_3.pdf

"It thus bears emphasis that, compared to exposure from all other main sources, public exposure from nuclear power is smaller by several orders of magnitude, yet nuclear exposure is the most strictly controlled. Such controls are neither balanced nor commensurate with actual risk. Simple numbers tell the story. Together, natural background radiation and medical use contribute over 99% of overall public exposure (2.8 mSv/y). Of natural background radiation (85% of overall exposure), only half of exposure is covered by requirements for radon. For medical sources (14% of overall exposure), there is no numerical dose criterion. This includes diagnostic x-rays in common use worldwide. At the opposite extreme is the tiny exposure from nuclear energy. Though less than 0.01% of overall exposure (0.0002 mSv/y), this source is subject to a highly stringent, needlessly complicated three-level control mechanism in which more than 100 requirements apply."

"Any objective observer must ask why a rational system of public protection should be so myopically focused on a minuscule source of risk. In comparison, public exposure from the naturally occurring radioactive material (NORM) generated by many non-nuclear industries can often be higher than those from nuclear power. Yet so too are the dosage allowances, which range from 1 to 20 mSv/y. Equally telling is the exemption for radioactive material with a dose criterion of 0.01 mSv/y – a level 50 times higher than nuclear exposure. (There is even an option allowing 1 mSv/y for a low probability event.) If such

standards are reasonable, then current BSS [Basic Safety Standards] restrictions on nuclear power are not."

Amb. Ritch explores the wider implications of this position at the beginning http://www.world-nuclear.org/John_Ritch/Leadershipforanuclearcentury2011.html and at the end http://www.worldnuclear.org/John_Ritch/AResponsibilityofLeadershipBuildingPublicUnderstandingoftheGlobalImperativeofNuclearPower.htmlof the Seventh Annual Summer Institute of the World Nuclear University, 11 July 2011 and 19 August 2011, respectively, in lectures on the obligations involved in responsible nuclear leadership. The news and publications arms of WNA support these efforts with a detailed technical report on Nuclear Radiation Health Effects http://www.world-nuclear.org/info/inf05.html and a news report on potential risks from a nuclear accident http://www.world-nuclear-news.org/RS-Low_risk_from_major_accident_consequences-0202127.html .

The **ANS has also taken a carefully considered and publicly stated stand** on this issue. ANS Position Statement 41, "Health Effects of Low-Level Radiation (June 2001)" http://www.new.ans.org/pi/ps/docs/ps41.pdf opens with the words:

It is the position of the American Nuclear Society that there is insufficient scientific evidence to support the use of the Linear No Threshold Hypothesis (LNTH) in the projection of the health effects of low-level radiation.

This Position Statement is supported by a Background Report http://www.new.ans.org/pi/ps/docs/ps41-bi.pdf and a Technical Brief http://www.new.ans.org/pi/ps/docs/ps41-tb.pdf , citing a large number of scientific papers and policy statements on which the Position Statement is based. A similar Position Statement was published by the Health Physics Society http://hps.org/documents/risk_ps010-2.pdf , the professional organization of the radiation protection community. Regulators owe considerable deference to such strong public statements of professional opinion.

The **French Academy of Sciences**, and later the **French Academy of Medicine**, took the unusual step on interjecting themselves into this American regulatory dispute with a unanimous statement of opinion on the subject:

http://lowrad.wonuc.org/lowrad/lowrad-bulletin.htm

It contained such blunt phrases as:

"The hypothesis of the risks of cancer induced by low doses and dose-rates is founded on the extrapolation of data of highly-exposed human groups, applying the risk as being constantly proportional to the received dose without being limited by a threshold, the linear no-threshold (LNT) assumption. This hypothesis conflicts with itself and has many scientific objections; and it is contradicted by experimental data and epidemiology."

That issue, the inapplicability of applying the LNT premise to predicting or attributing radiation damage to doses of less than 5 or 10 Rad (0.05 or 0.1 gray) was only part of the larger issue of Realism that the ANS took on under the presidency of Dr. Larry Foulke. That effort resulted in a **Realism Report** http://dl.dropbox.com/u/71478013/ANS-WhitePaper-fin.doc and a Position Statement 51 http://www.ans.org/pi/ps/docs/ps51.pdf and its backup document http://www.ans.org/pi/ps/docs/ps51-bi.pdf . And Position Statement 65 http://www.ans.org/pi/ps/docs/ps65.pdf . Despite the good work that went into the Realism Report, it has been largely dismissed and ignored by the LNT-oriented radiation protection community.

In 1994, James B. Muckerheide, then Massachusetts State Nuclear Engineer and co-director of the Center for Nuclear Technology and Society at Worcester Polytechnic Institute (WPI), created an international public interest group called **Radiation, Science & Health, Inc**. It had a distinguished board of directors including Nobel Laureate Rosalyn Yalow. It closed down when WPI shut down its reactor and its nuclear engineering department. The RSH website was transferred to MPR Associates, which maintains it in the public interest as http://www.radscihealth.org/rsh/ RSH described itself as "Independent individuals knowledgeable in radiation science and public policy, committed to change radiation science policy in the public interest. Its stated purpose was:

To document the scientific data that contradict "the linear model";
To advocate for revision of radiation science policies;
Responding to world-wide criticism;
Apply the data and cost/benefits in radiation protection;
Advocate for research.

Its public brochure on the organization is at: http://www.radscihealth.org/rsh/About/brochure.html

An interesting paper posted on the RSH site describes and refutes the extreme stories of death and pollution attributed to Chernobyl: http://www.radscihealth.org/RSH/Docs/UN-Chernobyl/WPROSTChernBluff/wprost_chernobyl_bluff.htm

Muckerheide and Rockwell testified on the need to rationalize radiation protection policy before the U.S. Advisory Committee on Nuclear Waste. This was reported in the May 1999 *Nuclear News* as: The Quixotic Quest for Zero Radiation Dose
http://dl.dropbox.com/u/71478013/May99NN%20Perspective%20Reprint.pdf

In 2005, RSH submitted comments on a proposal by the International Committee on Radiological Protection (ICRP) to completely overhaul and greatly tighten the regulations and practices of radiation protection. That proposal, and the RSH comments are at: http://www.icrp.org/consultation_viewitem.asp?guid=%7B7CF99B0F-17E9-4144-8ED2-F8C95F6DFB5F%7D
When the comment period opened on the accompanying backup report, RSH commented in more detail. The comment was broken into five parts, because of ICRP rules limited the length of each comment. This report is available at:
http://dl.dropbox.com/u/71478013/RSH%20on%20ICRP-2005.pdf

RSH sponsored a number of seminars and workshops, including a score of sessions in many of the annual ANS Conferences. These are summarized at:
http://dl.dropbox.com/u/71478013/ANS%20Sessions%20on%20RadProt.pdf

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Phobic Thinking About Nuclear Power

Nothing in this life is to be feared
it is only to be understood.
Now is the time to understand more,
so that we may fear less.

Marie Curie, radiation pioneer

Right from the start, this new idea of atomic weapons
was linked with a more impressive idea: the end of the world.
This was an entirely new idea: that it might be technically possible
for someone to destroy the world deliberately.
Yet the idea slipped into the public mind with suspicious ease…
The imagery of bombs and reactors did not spread by itself;
it was promoted by particular people for their own purposes
[and] came to represent what everyone "knows" – or feels – about nuclear devices.

Spencer Weart, historian of physics

We nuclear people have made a Faustian bargain with society…
the price we demand of society for this magical source
is both a vigilance from and longevity of our social institutions
that we are quite unaccustomed to.

Alvin M Weinberg, nuclear pioneer

In 1980, The Media Institute published a 29-page, red-covered booklet titled "Nuclear Phobia: Phobic Thinking About Nuclear Power" now out of print. The first 24 pages contain a discussion between the Media representative and Robert L. DuPont, M.D., an expert on phobias. This is followed by an Appendix with excerpts from Mental Health Aspects of the Peaceful Uses of Atomic Energy *(WHO Tech Report 151, Geneva (1957).*

Dr. DuPont was shown an aggregate of 13 hours of videotaped news broadcasts on nuclear power, from which he concluded that ***"the major TV networks have injected, intentionally or otherwise, further fear – irrational, phobic fear – into an already fear-inspiring subject: nuclear energy."***

What follows below are excerpts from that discussion, that explain and discuss what he means by saying that public fear is phobic, rather than rational thinking. Although that discussion took place not long after Three Mile Island, subsequent events, including Chernobyl and Fukushima, have kept the fear alive. All the words below are from that discussion, so I will not use quotation marks.

Fear was the motif of the entire series of nuclear stories…voices of reassurance are constantly being undermined by the fear process itself…What this implies is that almost anybody who knows anything about nuclear energy has an investment in it, and therefore cannot be believed, unless, of course, he is one of that minority that says that nuclear power is as bad as you think, or worse. Only then is the expert credible. It is

amazing…The debate is hinged on fear of a particular kind. I would call it nuclear phobia, or more precisely, phobic thinking about nuclear power. A phobia is fear based on an exaggerated, unrealistic danger…phobic people are generally mentally healthy people who have been sensitized to particular experiences or situations which trigger terror or panic reactions…

A phobia is a malignant disease of *what ifs…*Phobic thinking always travels down the worst possible branchings of *what ifs*, until the person is absolutely overwhelmed with the potentials for disaster…Consider for a moment the *China Syndrome,* a Hollywood film…The actual feared thing itself did not happen, yet the frightened person will come back and say "But it almost did." That is characteristic of phobic thinking…**Phobic fear, at root, is fear of fear.** Fear of the panicky feeling.

The presumption on the tapes is, you either will not have cancer if you do not have radiation exposure, or you will get it if you do. This is incorrect…Finally, **the tapes suggest that nuclear power is a primary source of radiation exposure.** This also is incorrect.

There are two parts to the transmission process. You see people in various roles on camera who are afraid. Then you are told by some experts who are critical of nuclear power, authority figures, that *they* are afraid…And that is the key. You see authority figures who say I fear it…**This authority figure says the right way to behave is to be afraid…That is not common in journalism.** You just do not see a lot of stories of planes that might have crashed…Why is this news? The answer is: **Fear is news** because fear is interesting…The adrenalin gets flowing, our minds become more alert. It is like taking amphetamines. Fear is an upper…The longest lines at amusement parks are always for the scariest rides…there is no question but that one gets attention with fear; there is nothing to parallel it.

If you reassure people and say there is no problem, that's like saying, "There is no news. I have nothing to say"…nobody wants to be in the position of having said the danger is exaggerated only to have disaster strike…the pessimist is never disappointed. "After all," **he can always say," disaster almost did happen**…"

It is magical thinking. "They," by their expertise, have become alien from you and me…it is almost as if anybody who understands the issue of nuclear power cannot be like you and me. He cannot be credible right from the beginning…On the other hand, there is the person who says, "There is a cover-up"…That person has instant credibility…

Even the logos that the networks used for nuclear stories were often negative…the sign of the danger of radioactivity…and the hexagonal sign with an atom symbolized inside. While it lacks two sides of being the common octagonal "stop sign," it is so close in form that it is highly suggestive of the real thing. It implies that what we should do about nuclear energy now is to "STOP" it. **Using that logo is like doing a show about medicine and constantly using the skull and cross bones as a logo**…

I believe there is a lot more fearlessness out there than the media…leads a viewer to believe. The people who covered the news during the crisis at Three Mile Island often seemed surprised by that…I remember one woman who said, in effect, "I'm not

going to leave my home when they still have people on the Island. They have workers on that island; they're letting them go there. Then why am I going to leave my home a few miles away? It doesn't make sense."

My own expectation of how the nuclear phobia will play out is that we will, as a nation, reach a point of boredom. Most phobic people get over their phobia by becoming bored stiff…**We really do not solve these issues of risk; we just get bored with them…I think we will, one day, get bored with nuclear fear too.**

As one might expect, this viewpoint created quite a storm. The Washington Post *ran an editorial saying that no one can get away with calling everyone who disagrees with his political stance insane. And of course, he had not done so, though that was the published charge. The next phase in this struggle against nuclear phobia was a report by a consulting firm:*

The LuntzGlobal Plan
for Validating Phobic Terror

LuntzGlobal (LG), a company selling advice on public relations, issued a report on September 13, 2011, advising nuclear advocates to respond to public concerns about the dangers of nuclear radiation by *validating that concern* and telling people that we're really concerned about it too. That it's such a serious problem that we worry about it every hour of the day. And as we discover new information, we keep tightening the rules (saying that we keep discovering that we haven't been safe enough). By validating their unwarranted concern, people will trust us more. Wouldn't that be nice?

There are so many things wrong with that advice, that it's hard to know where to start. First, it is simply untrue that radiation from nuclear plants poses a serious health problem. LG is pushing the old pre-NEI argument: that we should feel so ashamed of the "TMI catastrophe" that we fully deserve our loss of credibility. After TMI, the media kept saying that anyone who tries to minimize the unprecedented extent of this disaster is lying, and we didn't want to be in that category. And now that argument is "supported by the nuclear disasters" of Chernobyl and Fukushima. So we celebrate the anniversaries of these "world's worst industrial disasters" while ignoring the countless thousands that died in the Banqiao Dam failure, the Bhopal pesticide plant failure, and the damage from the BP gulf oil spill. Not to mention ordinary, boring coal-mine deaths.

The fact is that the International Atomic Energy Agency has stated officially that:

> **"To date no health effects have been reported in any person**
>
> **as a result of radiation exposure from the nuclear accident"**

But LG's advice for hiding the truth goes even further. **We are not to cite the radiation from bananas, or in fact any other source of radiation** we are all exposed to; that would sound as if we were trying to trivialize this terrible problem. And if people really knew how much radiation they are already getting from non-nuclear sources—well, LG doesn't even want to consider that possibility.

In words uncomfortably reminiscent of George Orwell's famous books on worlds run by deceit, **LG tells us what facts we should *not* use, and even what words we should not use,** capitalizing and underscoring them. This leads to two harmful results: In straining to avoid forbidden words, we can no longer speak naturally. We come across like caricatures of communist (or corporate) puppets, speaking from a script, rather than from our heart or from our personal beliefs and experience.

Second, **by focusing on what we want to avoid, we *increase, rather than decrease* the probability of doing just that.** (E.g., One might expect that golfers have a less-than-average chance of putting the ball onto a particular part of the fairway if a sand-trap is there, since that is their intent. But in fact, by concentrating on what they want to avoid, non-expert golfers actually do just the opposite: sand-traps seem to attract their golf balls.)

Illustrating this problem (unintentionally), LG gives us a "Best Speech on Radiation" in which they inadvertently do just that: they use the specifically forbidden word "aggressively" when, by their rules, they should have said "expertly."

Trying to put all this in perspective, the nuclear medicine pioneer, **Rosalyn Yalow, Nobel Laureate** in Medicine, asserted:

No reproducible evidence exists of harmful effects from increases in background radiation three to ten times the usual levels. There is no increase in leukemia or other cancers among American participants in nuclear testing, no increase in leukemia or thyroid cancer among medical patients receiving I-131 for diagnosis or treatment of hyperthyroidism, and no increase in lung cancer among non-smokers exposed to increased radon in the home. The association of radiation with the atomic bomb and with excessive regulatory and health physics ALARA practices has created a climate of fear about the dangers of radiation at any level. However there is no evidence that radiation exposures at the levels equivalent to medical usage are harmful. The unjustified excessive concern with radiation at any level, however, precludes beneficial uses of radiation and radioactivity in medicine, science and industry. (*Mayo Clinic Proc 69:436-440, 1994*)

Hugh F. Henry at Oak Ridge summarized the low dose data in the *Journal of the American Medical Association:*

A significant and growing amount of experimental information indicates that the overall effects of chronic exposure (at low levels) are not harmful…The preponderance of data better supports the hypothesis that low chronic exposures result in an increased longevity… Increased vitality at low exposures to materials that are markedly toxic at high exposures is a well-recognized phenomenon. (*JAMA176, 27 May 1961)*

Lauriston S. Taylor, chair of the first radiation protection societies, stated:

"Today, we know about all we need to know to adequately protect ourselves from ionizing radiation... 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 [about 35-fold higher radiation level than the present recommendations]. Let us stop arguing about the people who are being injured by exposures to radiation at the levels far below those where any effects can be found. The fact is, the effects are not found despite over [75] years of trying to find them. The theories about people being injured have still not led

to the demonstration of injury and, if considered as facts by some, must only be looked upon as figments of the imagination." Taylor, L.S. "Some Non-Scientific Influences on Radiation Protection Standards and Practice," *Health Physics,* 39 851-874 (1980)

Senator Caught Telling the Truth!

Things have come to a sad state when speaking the truth in Washington is news. ***The Hill*** is a widely respected congressional newspaper that publishes daily when Congress is in session. One of its favorite tools is the Truth-o-Meter, by which it tests political statements to see how far they have distorted the truth. If the statement is found to be only a little misleading, it is awarded only one Pinocchio, after the famous puppet whose nose grew longer with each lie. With more serious distortion, a second, third or even a fourth Pinocchio will appear. Very seldom does a statement escape one or more Pinocchios

One day I got an email from ANS Outreach Director, Laura Scheele, reading as follows:

In March, Senator Lamar Alexander and Ted Rockwell co-wrote an op-ed piece that appeared in *The Hill* and is currently online via Senator Alexander's website here: http://bit.ly/cxGyMO. The link to the op-ed was distributed via ANS Headlines when it appeared.

Following the op-ed piece, PolitiFact.com's 'Truth-O-Meter' specifically examined the op-ed's statement that "No member of the American public has ever been killed by commercial nuclear power -- a record unmatched by other fuels." The link to this Truth-O-Meter article is here:

http://www.politifact.com/truth-o-meter/statements/2010/apr/22/lamar-alexander/facts-risks-nuclear-power-plants/

Alexander's staff told us the senator got his facts from the American Nuclear Society Web site, which states in a "Myths and Facts" section that "No member of the public has ever been injured or killed in the entire 50-year history of commercial nuclear power in the U.S."

The statement was found to be true by the Truth-o-Meter (of course!). [Instead of the usual Pinocchios, the article show a truth-o-meter pegged at 100%] The article was published in March. I happened to come across it today and thought it was a good example of how the resources that ANS makes available can be used by our members and other nuclear proponents.

The Strange Story of Radon

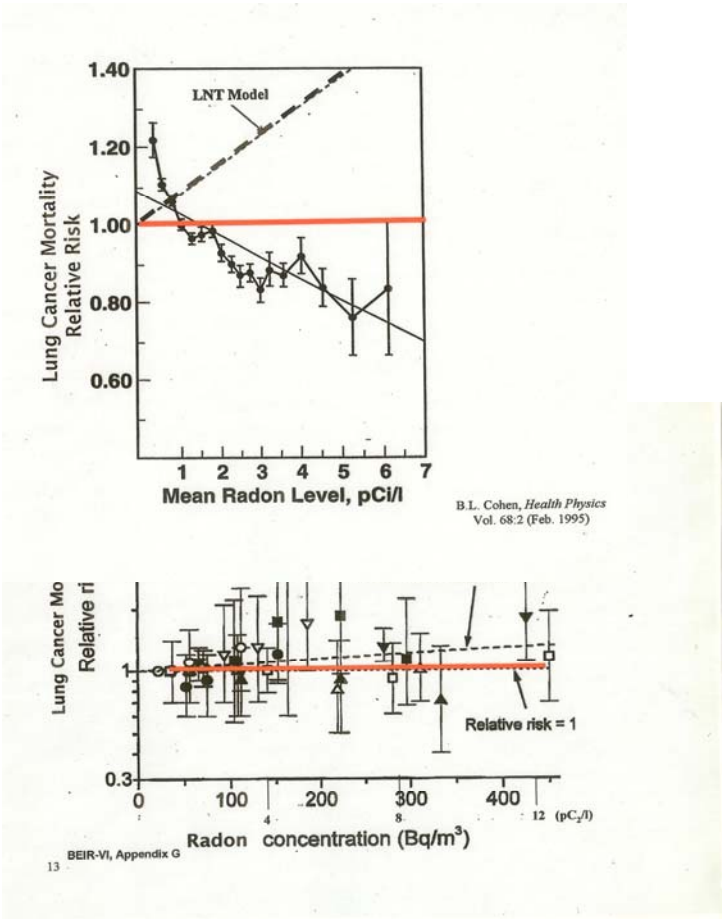
In the environmental movement of the early 1970s, the Environmental Protection Agency was formed to stop technological Man from bulldozing the Garden of Eden. As the 1980s dawned, some scientists began to point out that in its zeal to eliminate all traces of radioactivity, EPA was now requiring nuclear power plants, nuclear medical facilities and industries using radiation, to monitor, control, and reduce radiation levels below the natural background radiation people were exposed to in their own homes from radon, a natural decay product of uranium. EPA managed to ignore this inconsistency for over a decade, but when forced to face it, it performed a remarkable turnabout: Instead of admitting that its radiation

protection standards were unrealistic, it announced it would regulate Nature. The environment, so poignantly portrayed as the innocent victim, was now to be seen as a merciless, silent killer.

The first impact of this change in strategy was to extend EPA's empire from control over a handful of corporations to the entire world. Thousands of radon detectors were issued to school-children, who were told to measure the extent of the threat and to pressure their parents to do something about it. EPA contracted the National Research Council to set up a committee. On February 19,1998, the committee announced in report BEIR-VI that radon in homes causes 15,400 to 21,800 deaths each year in America. Scientists with impressive credentials spoke convincingly of their confidence in this conclusion, despite the fact that no evidence has ever directly demonstrated that radon in homes is harmful. The report noted that about 90% of the deaths attributed to radon occurred in smokers, and "most of the radon-related deaths among smokers would not have occurred if the victims had not smoked."

In the mid 1980s EPA began issuing pamphlets warning against the "colorless, odorless killer" and running TV ads showing a typical American family sitting happily in their living-room while a dire warning is intoned against funereal background music. The skit ends as the parents, then the children, and finally the dog turn to skeletons. The predicted annual death rate from radon was said to equal the death rate from automobile accidents.

There is a great deal of good data on radium and radon in homes. The most extensive and the most thoroughly analyzed is a series of measurements and calculations by the late Dr. Bernard L. Cohen, Professor Emeritus of Physics, University of Pittsburgh. Prof. Cohen supervised the measurement of radon levels in about 350,000 American homes and compared the radon levels, county by county, with the lung cancer mortality in each county (since lung cancer is the only potential health effect that radon might cause). Cohen surveyed nearly 2000 counties housing more than 90% of the U.S. population and therefore has excellent statistical precision. He found exactly the opposite of what he and the EPA expected. He found that the counties with the highest radon levels had the *lowest* lung cancer mortality and those with the lowest radon had the *highest* lung cancer. He then turned off his radon-removal system.



Since he was dealing with *average* radon levels and *average* cancer mortality figures, rather than with individuals, Cohen was well aware that other confounding factors might be causing this relationship. "It's legitimate to raise generic questions about ecological studies. But when those question have been answered for this particular set of data, then it is no longer legitimate to keep dismissing this evidence solely on the basis of the generic questions. You can always question how precisely we can correct for various factors, but the discrepancy between these data and the LNT is so large that I cannot imagine how one could explain it away."

But the final word on this subject is given in the report that EPA commissioned from the National Research Council, BEIR-VI. The body of the one-inch-thick report contains virtually no discussion of Cohen's and others' work with people living above ground in the kinds of situations to which EPA's regulations apply. Appendix G, the last in the book, dismisses the matter as follows:

"Because of the inability to control for confounding...the Committee believes that ecological studies of indoor radon exposure and lung cancer are essentially non-informative and shed little light on the association of indoor radon-progeny exposure and lung cancer…There was a strong negative association between 1970-1979 lung-cancer mortality and the county-average radon concentrations; this association could not be explained by confounding. In interpreting this finding, Cohen proposes that the negative association implies failure of the linear non-threshold theory for carcinogenesis from inhaled radon products."

And with this portentous sentence, the report closes the discussion and gives no further consideration of Cohen's conclusion, or of this vast body of data and ten years of analysis.

Cohen's work has been replicated by others. For example, Dr. Gary Sandquist and others (1997) took EPA's radon data and cancer data from the American Cancer Society and showed the same relationship that Cohen's work shows. They found that average radon doses vary from state to state by an order of magnitude, and that the cancer rate in the lowest radon states was nearly four times that "predicted" by the LNT model, whereas the cancer rate in the high-radon states was only one-seventh of the LNT prediction.

An interesting contrast to the hypothetical speculations of the EPA and its contractors is given by the data on radioactive health spas that people have visited since ancient times. Radium and radon levels in the air and in the "healing waters" are monitored and proudly advertised by many of these facilities. At some healing spas in central Europe people drink and bathe in water with radon concentrations *one million times higher than EPA's recommended upper limit.* Visitors spend hours a day on repeated visits under the care of in-house physicians, and workers at the facilities are exposed to it for years. Austrian and German government health insurance recognizes these spas as legitimate health treatment, and pay 90% of all costs incurred by patients visiting such spas. Austrian spas cannot officially qualify as healthfully radioactive waters unless they maintain at least 30 times the EPA limit. EPA claims its radon limit poses one chance in 10,000 of getting lung cancer, which means that the Hungarian spa poses a 100% risk of lung cancer (one million divided by ten thousand). Many of these facilities keep detailed records of the names and health conditions of each person using the springs, along with radium and radon concentrations. A doctoral thesis (in Ref 1, below) has evaluated some of this data base.

References

1 Some sources of data on health benefits from radon exposure:
www.radscihealth.org/rsh/docs/Radon/RnTherapiesIndex.htm

2. Cohen's radon papers, criticisms, rebuttals: www.phyast.pitt.edu/~blc/

3. More information available at:
http://www.world-nuclear-university.org/html/summer_institute/2007/2007SI-lecture%2

The NYAS-Greenpeace Report

On March 28, 1979, nuclear power's confident assurance of public safety, based on decades of safe operation, was shaken somewhat by the partial meltdown of one of the commercial nuclear power reactors at Three Mile Island. But the complete lack of any personnel or environmental damage, and the thorough overhaul of the whole nuclear enterprise afterwards, dispelled much of the potential fear.

Then, on April 26, 1986, came the fire and meltdown of the Chernobyl reactor. Mishandling by the Soviet authorities and exaggeration by a generally anti-nuclear press and a panic-prone public led to an apocalyptic dimension to the picture. It was now claimed that we were poisoning the only planet we had. We were said to be polluting the human gene pool, and perhaps that of all other creatures as well. This was pictured as not just the end of civilization, but the end of Life itself.

In December 2009, a book like no other in its long history was published in the ***Annals*** series of science books that has been in production at the **New York Academy of Sciences** since 1823. Called *Chernobyl: Consequences of the Catastrophe for People and the Environment,* it is a translation of a book written by Russian environmentalist and Greenpeace activist Alexey Yablokov, with contributions from two other authors, Vassily and Alexey Nesterenko. It is a thick, impressive-looking report based on work from Soviet sources previously unknown in the West.

International scientific work led by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) had reached a near-consensus that radiation deaths from this event would be limited to a few of the plant workers who had stayed to fight the fire, and that **radiation deaths to the public would be few if any**, and that the danger from future radiation exposures would be trivial. Some background information on the general Chernobyl situation is summarized on RSH site:
http://www.radscihealth.org/rsh/docs/UN-Chernobyl/index.html

The NYAS report, in contrast, claimed that **nearly a million deaths had already occurred, and the death-toll would continue to increase, for generations into the future.** That report has effectively been turned over to Greenpeace to use for their own purposes. For a detailed report on this situation and how it came about, see:
http://www.scribd.com/collections/3229384/Chernobyl-and-the-New-York-Academy-of-Sciences

I shall quote from that document below, and readers interested in a more complete story are referred to the link above.

This book is an unprecedented publication by the NYAS for several reasons. We believe it should never have been published by any Academy of Science.

Firstly, it denounces the methods used by the mainstream scientific community as giving "marked underestimates" of deaths and sickness from the Chernobyl accident. International scientific consensus – through painstaking work over many years - is that the accident killed perhaps 56 workers and no members of the public. This book, by contrast, claims that nearly 1 million deaths can be attributed to the accident, using methodology that peer-reviewed literature does not accept. If the book requires that both the methods of science are not to be trusted and the peer-reviewed literature is not to be used, then by

definition it cannot claim credibility as a scientific work.

Secondly, the intellectual provenance of this book lies in research paid for by Greenpeace International whose stated mission on its website is "to halt the expansion of all nuclear power, and the shutdown of existing plants."…

Thirdly, there was no review of the contents of the book by academics whose judgment was uncontaminated by emotional anti-nuclearism. The only Consulting Editor of the book is someone who has long campaigned against nuclear power, with a track record of publishing work about radiation and health that has not been accepted in the wider scientific community because of its flaws, and who holds no academic position, unlike Editors of the other Annals volumes. Aside from biologist Dr. Tim Mousseau, who had proposed the book to the NYAS as an Annals volume, no other academics with special knowledge of Chernobyl were asked to review the work before publication.

Fourthly, the authors overthrow conventional scientific protocols and assumptions, and challenge the disciplines of radiobiology and epidemiology because – they claim – the accident at Chernobyl was too "catastrophic" to allow those methods and those disciplines to be used. Without any sense of nuance and insight as to how the accident came to be called a catastrophe, they rationalize that only their self-made explanatory model is appropriate, and they force data of many kinds into it. … Very significant political history of that part of the world, with attendant high emotions, was also not given consideration. One look at the number of consultants from Ukraine that contributed to the book, compared with the much lower number for Belarussia and none at all from Russia, gives cause for concern, however…

Fifthly, in response to protests about the publication of this book by an Academy of science, the NYAS has sought to justify their action by saying that those who wrote and who contributed to it believe they are doing 'valid science'. This is the only interpretation for a statement put out April 28 2010 on the Annals section of the website, saying that the Academy is "committed to publishing scientific content deemed valid by the general scientific community". … this claim by the NYAS that the people involved in this book are scientists working in ways recognized by the "general scientific community" is nothing more than a leap of faith.

Lastly, activists and certain media outlets have exploited the NYAS name to claim that this work is "the baseline study" on Chernobyl effects – because it was published by the New York Academy of Sciences. This use of their academic and scientific standing for anti-nuclear campaigning appears of no concern to those responsible at the Academy. That the NYAS stamp of approval has been applied, with heavy consequences, to outrageously false information propagated to the public worldwide, is also of no concern apparently. On the contrary, they have taken steps to ensure that this book is replicated widely through issuing a special License to the authors to reprint and republish wherever they like. They have also allowed the original file used for printing at Wiley-Blackwell to circulate freely on the Internet, contrary to the copyright regulation. That file includes the frontispiece list of names of eminent people who serve as Governors of the NYAS who were never consulted about this book in advance of publication. By whose hand these things have happened it is not known – but it surely arises as a consequence of the management of this project from the very beginning. It appears that someone senior in the NYAS wanted this book to be given credibility.

For all these reasons, it seems that those responsible for publishing the Chernobyl Consequences book at the New York Academy of Sciences have crossed the line of the Academy's own constitution and mission. Since there has been no straight answer provided to questions put to them about their decision to publish

this book and to allow its wider circulation, a collection of papers about this publishing event has been assembled on the writing website Scribd.com by Theodore Rockwell and Caroline Webb to enable public scrutiny of their decision-making. Our critique leads to the following suggestions:

1. An independent inquiry should be conducted into how this anomalous publication has occurred.
2. The book is removed from the Annals series and NYAS website.
3. The license to republish given out to the authors should be revoked.

The Collection on Scribd.com includes four different documents, including this one and may be seen at: http://www.scribd.com/collections/3229384/Chernobyl-and-the-New-York-Academy-of-Sciences

BACKGROUND TO THE BOOK

As described in the Preface written by Alexey Yablokov, this book was first assembled as a Greenpeace International report called: *The Chernobyl Catastrophe – Consequences on Human Health*, published on the 20th anniversary of the accident in 2006. Dr. Yablokov served as General Editor of that report, hired by Greenpeace. This report was not only to mark an anniversary however. It was created in response to another report that had been published in 2005 by a group of UN agencies called The Chernobyl Forum. Greenpeace International strongly disputed the findings of the Forum and set about creating an alternative narrative that could produce a large number of deaths, illness and general misery, as fits their fundamentalist belief about nuclear energy and about low-level radiation, namely that no ray of radiation could be safe and no nuclear power plant is safe…

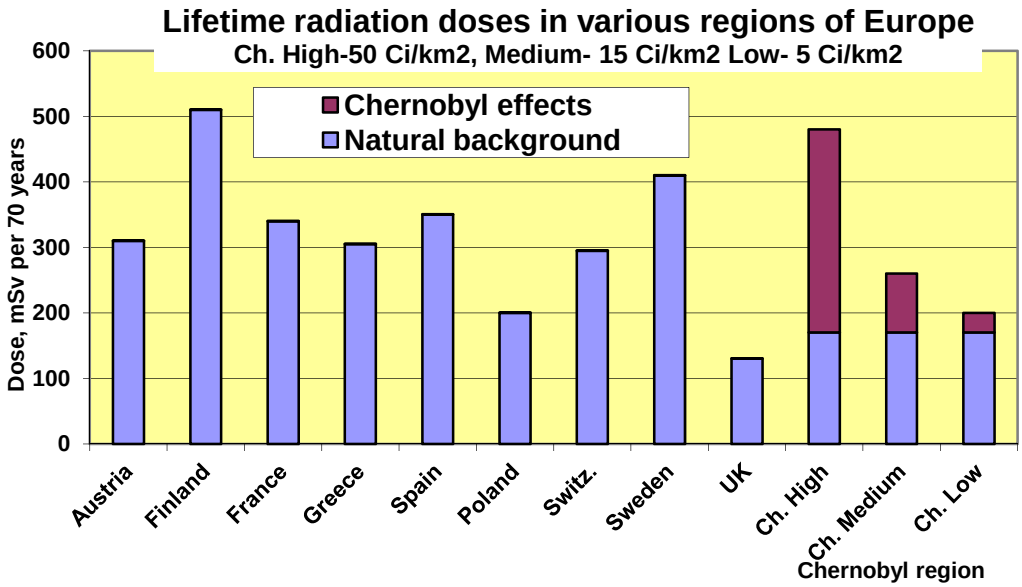
No other Annals volume is in this grubby situation. You will not find copies of the other Annals books being circulated uncontrollably on the Internet. This volume with its wild claims and its non-scientific nature and motivation stands apart from all other production by the Annals Department. Why?

Effects of Radiophobia beyond Nuclear Power

The radiophobia so carefully created and maintained since the beginnings of nuclear power, creates problems far beyond the power business. To summarize:

- Extreme treatment of low-dose radiation has greatly increased cost of all operations involving radiation
- Gas-fired power station needs fewer than 50 operators; the nuclear equivalent uses up to 1000
- Billions needlessly spent on trivial quantities of “nuclear waste” that pose no hazard
- Life-saving nuclear medical procedures being priced off the market and shutting down
- Resulting radiophobia constrains use and scares people away from mammograms, thyroid tests, etc.
- This is not just a question of curbing man-made radiation; it now includes natural materials
- Until recently, persons handling radiation entered the field deliberately. They were specifically trained and paid premium wages for it. Now, EPA defines some *natural* radiation sources as radiation hazards needing remedia*tion*. This puts thousands of *persons* unwillingly into radiation field, with all its burdens.
- *For* natural radon, several million homes and public buildings will have to be “remediated”
- In addition, water treatment plants and various mines now have to deal with “radon problem”
- For solid radioactive materials, the problem is even more complicated

- For patients given radioisotopes internally, their bodies and its effluents are now “hazardous”
- They may not sleep with their spouses or hold their children until the activity decays
- Their feces must be controlled, stored, and shipped as hazardous material
- For water treatment plants exceeding radium limits, each is now legally a radiation facility
- The sludge can no longer be sold as fertilizer; it’s now *hazmat* (hazardous material)
- Operators must be trained, inspected, and keep records like a nuclear plant
- Each small town facility is now under federal control – it’s a new world for them
- Aviation is now said to have a radiation problem, because of cosmic rays at higher altitudes
- EPA and NRC are working up plans to control air crews and warn passengers
- NRC is considering asking for changes in the Atomic Energy Act to cover x-rays and accelerators
- This would include medical, dental, research facilities and many others previously exempt
- Many naturally radioactive materials such as tritium for exit signs may be covered more tightly
- Depleted uranium has become a *cause celebre* as it finds more civilian and military uses
- This is natural uranium from which most of the radioactive component (U-235) has been removed
- Treating harmless quantities of radioactivity as a public hazard constrains their beneficial use
- Researchers are urged to use less effective fluoroscopic techniques to avoid NRC hassles
- Some hospitals have closed their nuclear medicine facilities to avoid burdensome regulations
- Many people avoid lifesaving smoke detectors, medical tests, irradiated food, etc.
- Slightly contaminated materials cannot be recycled, regardless of how trivial the radiation
- Exxon was successfully sued for $1.06 Billion for contaminating land with naturally radioactive sludge
- Subsequently 11 workers sued for being endangered by this natural radiation
- Since coal-fired power plants emit much more radioactivity than any nuclear plant, are they next?
- The granite in NYC’s Grand Central Station and in the nation’s capitol exceeds limits for nuclear plants
- The radioactivity of salad oil exceeds that of many leaks that shut down some nuclear facilities
- Many resorts, especially spas and ski runs, greatly exceed limits set for nuclear facilities.
- Some land near Chernobyl is still off limits, though radiation levels are below many natural areas.



Reference: http://dl.dropbox.com/u/71478013/Jaworowski-2006_comments-Chernobyl-Forum-Report-copyright.pdf

This issue was discussed in a major article in *Nuclear News*, June 1997 "What's Wrong With Being Cautious? By Theodore Rockwell.
http://dl.dropbox.com/u/71478013/Jun97NN%20Rockwell%20Reprint.pdf

And at the Pacific Basin Nuclear Conference, PBNC98
http://dl.dropbox.com/u/71478013/PBNC98.pdf

And at the International Radiation Protection Association, IRPA-10
http://dl.dropbox.com/u/71478013/IRPA-10-Radon.pdf

In 2005, ICRP proposed a major extension of existing regulations, and asked for comments. RSH sent a detailed response, in five pieces, because the length of each comment was limited by the rules. This is available at:
http://www.radscihealth.org/RSH/Docs/Correspondence/ICRP95-TG1-RSHcomments.htm
The ANS Statement on Realism made the following comment on these proposed changes:

- Lauriston Taylor, one of the founders of the ICRP and the NCRP, wrote in 1980: "No one has been identifiably injured by radiation while working within the first numerical standards set by the NCRP and the ICRP in 1934. The theories about people being injured have still not led to the demonstration of injury and, if considered as facts by some, must only be looked upon as figments of the imagination. "
- At the eleventh quadrennial meeting of the International Radiation Protection Association in Madrid, May 27, 2004, the International Commission on Radiological Protection (ICRP) presented the first proposed revision of its position since ICRP-60 was issued in 1990. In apparent agreement with Dr. Taylor's 1980 statement, the ICRP asserts that it "recognizes the need for stability in regulatory systems at a time when there is no major problem identified with the practical use of the present system of protection…" 1
- Despite this assertion, it then proceeds to tighten even further the ALARA-to-zero noose. ICRP reaffirms its position that "there is presumed to be some probability of health effects even at small increments," but proposes nevertheless that it is not necessary to address radiation protection for doses below 0.01 mSv (1 mrem). Na
- ICRP reports are not to be taken lightly. When confronted with the harmful effects of their pronouncements in the real world, ICRP members generally protest that they report only on the science, and that regulatory authorities are free to follow their advice or not. But at Madrid, ICRP was less conciliatory: "These restrictions...should be considered as obligatory, and not maintaining these levels of protection should be regarded as a failure…where action to avert the dose is virtually certain to be justified."
- As instruments become more sensitive, as increasingly extreme practices become the norm, there is no end in sight. After setting extreme requirements, the Commission looks to local authorities to go further: "the Commission therefore recommends that further, more stringent, measures should be considered for each source…The Commission expects that the resulting national values of constraints will be lower than the maximum values recommended by the Commission, but probably not by as much as a factor of ten."
- The ICRP does recommend "optimization," but it defines optimization as simply dose reduction: "the concept of optimization…is to engender a state of thinking in everyone responsible for control of radiation exposures such that they are continually asking themselves the question, 'Have I done

all that I reasonably can to reduce these doses?'" Since radiation dose is often caused by discretionary time spent inspecting and testing in radiation zones, this quixotic quest for zero dose creates an ill-advised incentive to reduce that time for no health benefit, at increased risk of missing a situation (such as corrosion or leakage) important to real safety.

- ICRP also continues to use "collective dose" as a measure of health effects, despite widespread objection. *Groups* do not suffer health effects; only individuals do. ICRP also continues to distinguish between "natural" and "artificial" radiation sources, although there is no scientific basis for doing so. Although it is not discussed explicitly in ICRP's summary handout, ICRP Chair Roger Clarke and others stated that the Commission is not justifying its recommendations on the basis of risk, but simply on the basis of dose limits. They have nominal comparisons to background radiation, which is taken to be 1 mSv (100 mrem). This is the low range of background radiation, and excludes radon. Radon is not included because it has been made subject to radiation protection control. This blurs the rationale for the limits. It obscures the lack of health benefits obtained for the enormous costs committed to radiation protection. This may explain the reason for the change.
- The ICRP states that the aim of its recommendations is "to make value judgments about the relative importan*ce of d*ifferent kinds of risk and about the balancing of risks and benefits. In this, they are no different from those working in other fields concerned with the control of hazards." But in fact, these recommendations are of entirely different type and magnitude than encountered in other fields. Other potentially toxic agents are given a tolerance level, and regulation is thereby made clear and unambiguous. There is no public health and safety basis to treat radiation in a different manner, and ICRP's approach should be vigorously opposed.

On September 16, 2003, the *Washington Post* ran an OpEd of mine, showing how excessive concern for low-level radiation can exacerbate a potentially panicky situation that actually posed no serious danger. It opened as follows:

I was recently invited to observe and offer advice during a revealing drill, spearheaded by the National Academy of Engineering, that tested how well information might be communicated to the public if a "dirty bomb" exploded in Washington. As I watched the interaction of real-life government officials and media decision-makers, I was struck by a glaring deficiency. The rules for radiological emergencies are wholly inappropriate for such an event. They can change a relatively harmless incident into a life-threatening emergency. These rules apply, not only to dirty bombs but also to any casualties involving nuclear power plants or their fuel.

A few minutes into the exercise, a leader of the drill, pleaded for some action, warning that radiation was killing people, and hospitals were being overwhelmed. This bothered me, because it is well-documented by all our official agencies that the radioactivity in dirty bombs is unlikely to seriously hurt anyone…I made this point publicly to the participants, but they said they're getting a very different story from the regulators and their scientists. The rules require a hypothetical, squeaky-clean condition, scrubbing the ground and sidewalks down to far less than the natural radiation background of God's good green earth…But these requirements are inappropriate. We don't treat other spills and leaks so fearfully…

Several participants objected that experts might agree on that, but that the public would panic nonetheless, and that's what we should plan for. At that point, an expert on human behavior got up and said flatly that if you tell people there is no danger, and they have no reason to disbelieve you, they will remain calm…But if you keep telling them you expect them to panic, they will oblige you…Nuclear Regulatory Commission chairman [at that time] Nils Diaz asked that more realistic premises be used to evaluate safety—not looser, not lower, just more realistic. That's a good start. Real safety is based on realistic premises…By assuming otherwise, we create unwarranted terror, and the terrorists win.

During the past few years, **a number of opinion pieces** appeared in various venues, expressing support for the need to reform radiation protection policies. These include:

"Fukushima and the Future of Nuclear Power" by William Tucker in the *Wall Street Journal*

"Let the People of Fukushima Go Home and Get Back to Work" by T. Rockwell in *The American Spectator* Dec 6, 2011

"Chernobyl's Real Victims" by Dr. Roger Bate, on Technical Central Station

"Bad Science in Service of a Bad Hypothesis" published in *Health Physics News,* Feb. 2006

A number of opinion pieces by Theodore Rockwell on this subject were published by *The Scientist*, *Magazine of the Life Sciences*. For example:

"Scientific Integrity and Mainstream Science." 14(5):39 6 March 2000

"Our Radiation Protection Policy Is A Hazard To Public Health" 11(5):9 3 March 1997

"Discussions of Nuclear Power Should Be Based in Reality" 12(6):7 16 March 1998

Naval Reactors Radiological Data: 1954-Present, Over 200,000 persons, Detailed Data For this special ANS Report, the Director, Naval Nuclear Propulsion, four-star Admiral Kirkland H. Donald (USN), has made available for the first time, all relevant radiological data on the more than 200,000 persons exposed to radiation and handling radioactivity in connection with their duty in various aspects of the naval nuclear propulsion program. Each year's reports accumulate and update the data from previous reports, so there is a continuous record from initial operations in 1954 of the Nautilus prototype reactor, to the date of the latest report. The latest Reports have data up through March 2011. This information has always been available to the Congress and other organizations with demonstrated need to know. It is now available through links in this Report on a virtually unrestricted basis. There are five of these reports, briefly described below, available at the following link:
http://www.nnsa.energy.gov/ourmission/poweringnavy/annualreports

The Program Report, labeled simply "The U.S. Naval Nuclear Propulsion Program," bears the Seals of the Department of the Energy and the Department of the Navy. The Program Report summarizes the history and current status of the various components of the NR Program, its submarines, surface ships, R&D and support labs, nuclear component procurement, nuclear equipment suppliers, shipyards, support facilities and tenders, schools and training facilities, and headquarters. It lists the basic data for each of the 231 nuclear powered ships authorized by Congress, and adds some interesting statistics:

The Navy has built 220 of these ships so far, and they have steamed over 145,000,000 miles, with no significant radiological incidents, no radiation deaths or injuries, and no detrimental environmental impact. The 103 naval reactors currently in operation make ~45% of the combat fleet nuclear-powered. With refuelings, the Navy has operated 528 reactor cores, but current reactors are designed to operate for a lifetime of 30 years or a million miles, without refueling, retaining the "nuclear waste" in the interstices of the fuel (giving an indication of the trivial magnitude of the much-touted "nuclear waste problem.")

The four radiological reports that accompany this overall NR Program Report have brightly colored covers and are known colloquially as "The Rainbow Reports" Each of these reports contains on its title page the personal signature of the Director of the Naval Nuclear Propulsion Program, currently ADM Donald. The reports not only tabulate the relevant raw data, but show also various derived information

such as number of persons exceeding various lifetime radiation doses, and comparative numbers from the civilian nuclear power industry and from radiologists, aircraft crews, and physicians exposed to radiation.

The Yellow Report covers Occupational Radiation Exposure to personnel aboard ships, and in shipyards doing repair and refueling of nuclear ships.

The Green Report covers Occupational Radiation Exposure from NR Department of Energy Facilities.

The Blue Report covers Environmental Monitoring and Disposal of Radioactive Wastes from U.S. Nuclear-Powered Ships and Their Support Facilities.

The Tan Report covers Occupational Safety, Health and Occupational Medicine.

In addition to the data, these reports bring out a number of important historical and policy points. We don't have to speculate about possible health effects from possible slight increases in radiation levels around nuclear power plants. *These volumes describe a closely monitored population of nearly a quarter of a million people, over a period of two human generations, with follow-up physical exams and detailed record-keeping, based on individual personal radiation dosimeters.* There is no longer any excuse for basing U.S. radiation policy on the "Gold Standard" of estimated exposures of unmonitored Japanese A-bomb survivors – a demographically different population exposed to a radically different radiation experience.

The Rainbow Reports describe in detail how the radiation doses this population received are small compared to the radiation any of us are exposed to in the course of ordinary living, from natural background sources, dental x-rays, medical diagnosis and therapy, etc. But, more relevant to the purposes of this ANS Report, the *exposures reported here resulted from living and working for months at a time within 100 meters of an operating nuclear power plant, or working in a shipyard, repairing, maintaining and refueling nuclear power plants. These radiation doses are comparable to the radiation exposures the people of Fukushima would experience, if they were allowed to return to their work, their schools and their homes.*

The natural radiation background in many places in the world is considerably higher than around Fukushima. Yet, the people living in these higher radiation areas show no deleterious effects from radiation. The cancer rate in naturally high radiation areas of the world is generally lower than average, not higher. 19

The Yellow Report notes: There have been 279 over-exposures in U.S. commercial nuclear power plants, all prior to 1992; none since then. *No deleterious health effects from these exposures have been detected during the subsequent decades.* The report shows breakdown of these exposures into various groups, and presents analyses of the data. Prior to 1960, the U.S. Federal radiation exposure limit was 15 rad (150 mSv) per year, which was lowered to 5 rad (50 mSv) in 1994. For naval reactors, a firm limit was set in 1967 to 3 rem per quarter, 5 rem per year. From the beginning, all persons in the Naval Reactors program entering a radiation area have been required to wear personal dosimeter badges, that are controlled by a rigorous quality control system. A number of special situations are described, for example:

"There have been a number of cases where a single radium dial (such as on a wristwatch) has caused the entire atmosphere of a submarine to exceed the airborne radioactivity limit…As a result, radium in any form was banned from submarines" To be clear: a radium-dialed watch would not be hazardous in a submarine. This is just another example of the extremes the Naval Reactors program goes to, to ensure

that no basis exists by which one could claim that the program did not meet all applicable radiation protection standards.

The Naval Reactors office participates in the low-level radiation research programs performed by the Energy Department and others, and has also carried on such research within its own facilities. It plans to apply that information to analysis of its large personnel radiation exposure data base as it becomes available.

The Blue Report covers "Environmental Monitoring and Disposal of Radioactive Wastes from U.S. Naval Nuclear-Powered Ships and their Support Facilities." The Summary states:

"Since 1971, the total long-lived gamma radioactivity released each year within 12 miles of shore from all U.S. naval nuclear-powered ships and their support facilities has been less than 0.002 curie; this includes all harbors, both U.S. and foreign, entered by these ships.

"As a measure of the significance of these data, the total quantity of long-lived radioactivity released within 12 miles of shore in any of these last 40 years, is less than the quantity of naturally occurring in the volume of saline harbor water occupied by a single nuclear-powered submarine, or the quantity of naturally-occurring natural radioactivity in the top inch of soil in a half-acre lot. In addition, if one person were able to drink the entire amount of radioactivity discharged into any harbor in any of the last 40 years, that person would not exceed the annual radiation exposure permitted by the Nuclear Regulatory Commission for an individual nuclear worker."

"Environmental monitoring is conducted by the U.S. Navy…This monitoring consists of analyzing harbor sediment, water, and marine life samples for radioactivity…radiation monitoring around the perimeter of support facilities, and effluent monitoring. Environmental samples from each of these harbors are also checked by a Department of Energy laboratory to ensure analytical procedures are correct and standardized.

"Independent environmental monitoring has been conducted by the Environmental Protection Agency in U.S. harbors during the past several decades. The results of these extensive, detailed surveys have been consistent with Navy results."

Data to support all these statements is provided in the Blue Book. It also covers such special cases as:
Loss of USS *Thresher* and USS *Scorpion*
Deactivation of Ingalls Shipbuilding Radiological Facilities
Closure of Charleston and Mare Island Naval Shipyards
Disposal of Decommissioned, Defueled Naval Reactor Plants

One of the Naval Reactors' series of unclassified handbooks on nuclear technology of interest to this ANS Report is the **Reactor Shielding Design Manual**, published in 1956 by the Office of Technology Services, Department of Commerce, U.S. Government. Private editions were then published by McGraw-Hill and VanNostrand, and a Russian language edition by the USSR Ministry of Culture. After several printings of each, these editions all sold out, and poor photo-copies were selling for up to several hundred dollars each. So the U.S. Nuclear Regulatory Commission has now made down-loadable copies available free at:
http://www.osti.gov/bridge/purl.cover.jsp?purl=/4360248-Cr40J8/
<http://www.osti.gov/bridge/purl.cover.jsp?purl=/4360248-Cr40J8/ This 465-page basic textbook shows how permissible radiation levels were determined and how they were applied to

design; how the designs were tested; properties of different shielding materials, including stability under irradiation; and other information of use to radiation protection technology.

Scientific Misconduct: Protecting the LNT by Mishandling the Data

James Muckerheide, founder of the international public interest organization, Radiation, Science & Health, Inc., wrote a paper entitled, "There Has Never Been a Time that the Beneficial Effects of Low-Dose Ionizing Radiation Were Not Known" available on the RSH website.

In that paper, he gives many examples of how widely it was understood and agreed on that low-dose radiation was generally beneficial, not harmful. That situation created a dilemma for the advocates of LNT (Linear, No Threshold, the notion that even low-dose radiation could cause cancer, in proportion to the dose, all the way to zero.) They had to engage in a series of improper measures to create and enforce a regulatory policy based on the arbitrary and unscientific LNT premise.

Myron Pollycove, MD, long-time special advisor to the Deputy Director, Nuclear, USNRC, now retired, wrote an analysis of the chicanery that followed, entitled, "Authors' Misrepresentations of Their Data in Attempts to Support the LNT Hypothesis."
http://dl.dropbox.com/u/71478013/ANS-Cooked%20Books-Pollycove%2009.pdf

Excerpts from that analysis, quoted verbatim, follow below

The current status of LNT theory is summarized in National Council on Radiation Protection and Measurements Report 121 on Collective Dose:
' .. essentially no human data can be said to prove or even to provide direct support for the concept of collective dose with its implicit uncertainties of non-threshold, linearity and dose-rate independence with respect to risk. The best that can be said is that most [sic] studies do not provide quantitative data that, with statistical significance, contradict the concept of collective dose. Ultimately, confidence in the linear no threshold dose-response relationship at low doses is based on our understanding of the basic mechanisms involved ..
[Cancer] could result from the passage of a single charged particle, causing damage to DNA that could be expressed as a mutation or small deletion. It is a result of this type of reasoning that a linear non-threshold dose response relationship cannot be excluded. It is this presumption, based on biophysical concepts, which provides a basis for the use of collective dose in radiation protection activities."

The LNT hypothesis was proposed tentatively more than 40 years ago and has since become firmly established, though still without any supporting low-dose data and contradicted by statistically significant epidemiologic and biologic data. Nevertheless, a *biophysical* presumption is considered sufficient justification for using LNT as the basis for current policy of protecting against levels of radiation far below the *variations* of natural background. Studies initiated with the expectation of demonstrating statistically significant increased risk of cancer at low doses of radiation have failed to do so; some even have shown statistically significant *decreased* risks. Consequent efforts to support the LNT have led to

suppression and misrepresentation of their own contradictory data by authors of several studies:

Nuclear Shipyard Worker Study

This thirteen-year occupational study of the health effects of low-dose radiation was performed by the Johns Hopkins Department of Epidemiology, School of Public Health and Hygiene, reported to the Department of Energy in 1991 and in UNSCEAR 1994. Professor Arthur C. Upton, [former Director, National Cancer Institute]…chaired the Technical Advisory Panel that advised on the research and reviewed results. The results of the study contradict… the LNT hypothesis. From the database of almost 700,000 shipyard workers, including about 107,000 nuclear workers, two closely matched study groups were selected, consisting of 28,542 nuclear workers (NW) with working lifetime doses over 5 mSv (many received doses well in excess of 50 mSv), and 33,352 non-nuclear workers (NNW). Deaths in each of the groups were classified as due to: all causes, all malignant neoplasms, leukemia, lymphatic and hematopoietic cancers, mesothelioma, and lung cancer…

Increased standard mortality ratios (SMRs)... the highly significant decreased NW SMRs are 0.77 (16 standard deviations below NNW SMR 1.02) and 0.95 (4 standard deviations below NNW 1.12, $P < 0.0001$). As shown in Figure 1 the SMRs for death from "all malignant neoplasms" were omitted from the Summary of Findings Table 4.1.A and not reported in UNSCEAR 1994. These risk decrements are inconsistent with the LNT hypothesis and do not appear to be explainable by the constantly invoked "healthy worker effect." The NNW and the NW were similarly selected for employment, were afforded the same health care thereafter, and except for exposure to Co gamma radiation, performed the identical type of work, with a similar median age of entry into employment of about 34 years. This provides evidence with extremely high statistical power that low levels of ionizing radiation are associated with *decreased* risks. The NCRP SC 1-6 Committee, established to evaluate the LNT model and chaired by Professor Upton, in 1998 discounts this highly significant data: "This interpretation [that there was lower total mortality in the NW than in the NNW] ignores the likelihood of occupational selection factors that led some to qualify for radiation work while others did not. The fact that there was a difference for total mortality, and not just for radiosensitive cancers, supports the interpretation that selection factors were operative." The highly significant SMRs for death from "all malignant neoplasms" shown in Table 3.6.B on page 328 of the DOE report are unmentioned, only the insignificant SMRs for leukemia and lymphatic and hematopoietic cancers are alluded to as "radiosensitive cancers." The committee does not consider that the adaptive responses to radiation that stimulate prevention, repair and removal of metabolic DNA alterations, thereby decreasing DNA mutations, also decrease the risk of death from many other diseases in addition to the risk of death from "all malignant neoplasms."

The 10 million dollar 437 page report was never published. An inquiry to DOE elicited the response, "It wasn't in the contract." The author G.M. Matanoski did publish a one-page abstract beginning with, "The Nuclear Shipyard Workers Study (NSWS) was designed to determine whether there is an excess risk of leukemia or other cancers associated with exposure to low levels of radiation. The study compares the mortality experience of shipyard workers who qualified to work in radiation areas .. to the mortality of similar workers who hold the same types of jobs but who are not authorized to work in radiation area." Again, only the statistically insignificant SMRs for deaths from leukemia and lymphatic and hematopoietic cancers are included: "The data clearly indicate that both nuclear worker groups have a lower mortality from leukemia and lymphatic and hematopoietic 'cancers than does the nonnuclear group. All three groups have lower rates than the general population." The last sentence implying a "healthy worker effect" is incorrect. The

SMRs of the nuclear workers for leukemia and lymphatic and hematopoietic cancers, 95% confidence intervals shown within parentheses, are 0.97 (0.65, 1.39) and 1.10 (0.88, 1.37), respectively. The significantly lower NW SMRs for deaths from "all causes" and from "all malignant neoplasms" are unmentioned.

This study with internal comparison of nuclear workers with carefully matched non-nuclear workers was designed by the technical advisory panel to eliminate any "healthy worker effect" from the comparison. Even the non-nuclear workers did not demonstrate "healthy worker effect." Nevertheless, the September 1991 DOE press release states, "The results of this study indicate that the risk of death from all causes for radiation-exposed workers was much lower than that for U.S. males. These results are consistent with other [sic] studies showing that worker populations tend to have lower mortality rates than the general population because workers must be healthy to be hired, and must remain healthy to continue their employment."

Cancer Mortality among Nuclear Industry Workers in Three Countries

This analysis of nuclear worker mortality is based upon studies and nationally combined analyses performed in the U.S., the U.K. and Canada., Seventeen authors present the results of internationally combined analyses of mortality data on 95,673 nuclear workers. The U.S. Naval Shipyard Worker Study with 106,851 nuclear workers is omitted.

The authors conclude, "There was no evidence of an association between radiation dose and mortality from all causes or from all cancers. ..

The authors state that their analysis is based upon 119 deaths though only 36 deaths were selected. Since fewer deaths than expected were observed in 4 of the 7 dose categories, these 86 of 119 deaths are discarded by using one-sided P values. Justification of the use of one-sided P values is stated in Statistical Methods: "**As there was no reason to suspect that exposure to radiation would be associated with a decrease in risk of any specific type of cancer, one-sided tests are presented throughout."** Yet the authors were aware that exposure to radiation *was* associated with a decrease in risk of at least one specific type of cancer, namely "CLL". It was for this reason that the classification "leukemia, *excluding* chronic lymphocytic leukemia (CLL.)" was used for analysis.

After application of one-sided P values only 33 statistically insignificant deaths are distributed among the remaining 3 categories. Another statistical method is used to simulate statistical significance: " .... for leukemia excluding CLL, multiple myeloma and all cases where the test statistic exceeded 1.28 (corresponding to a one-tailed P value of 0.10) and the number of deaths was less than 30, the P value presented was estimated using computer simulations based on 5000 samples, rather than the normal approximation. "

This well-funded International Agency for Research on Cancer… was able to generate only a single spurious association between non-CLL leukemia deaths and cumulative external radiation. This was accomplished by using the small fraction of these deaths selected by one-sided P values and then amplifying these 33 deaths to 5,000 in order to simulate a statistically significant trend P value of 0.046.

Canadian Breast Cancer Mortality between 1950 and 1980 of Patients Fluoroscoped During Treatment for Tuberculosis

The mortality from breast cancer was examined in this medical cohort study of 31,710 women treated for tuberculosis in Canadian sanatoriums between 1930 and 1952. More than 26% had received radiation doses to the breast of 10 cGy or more from repeated fluoroscopic examinations during therapeutic pneumothoraxes. The standardized mortality rates are related to breast radiation doses and presented only in a table. The authors compare linear and linear-quadratic dose-response models fit to the data and conclude, "that the most appropriate form of dose-response relations is a simple linear one, with different slopes for Nova Scotia and the other provinces. "

On the basis of this linear model that includes only non-significant data and excludes the data with the highest confidence limits, the authors predict the lifetime excess risk of death from breast cancer after a single exposure at age 30 to 1 cGy(1rad) to be approximately 60 per million women or 900 per million women exposed to 15 cGy.

The observed data, however, demonstrate with high statistical confidence, a reduction of the relative risk of death from breast cancer to 0.66 (P=0.01) at 15 cGy and 0.85 (P-0.32) at 25 cGy. The study actually predicts that a dose of 15 cGy would prevent 7,000 deaths from breast cancer in these million women. Lauriston S. Taylor, past president of the National Council on Radiation Protection and Measurements (NCRP), considered application of **LNT** hypothesis for calculations of collective dose as, "deeply immoral uses of our scientific knowledge."

Canadian Breast Cancer Mortality between 1950 and 1987 of Patients Fluoroscoped During Treatment for Tuberculosis

This medical cohort study of 31,917 women treated for tuberculosis in Canadian sanatoriums between 1930 and 1952[9] is a revision of the initial study[7] by the second author of the initial study, G.R. Howe. The relative risks are related to breast radiation doses and presented only in tables. The authors conclude, "There is strong linear trend of increasing risk with increasing dose *(P<O.0003)."*

This conclusion is based upon the high dose studies... High doses up to more than 10 Gy are used to extrapolate linearly to risks incurred by routine diagnostic doses to the breast, about 0.002 Gy for current mammography. The introduction attempts to justify this approach: "However, the breast tissue doses of current concern are primarily those associated with routine diagnostic procedures, particularly mammographic screening. Such doses are substantially lower than the average breast tissue dose received by women in the atomic bomb and medical cohort studies [sic]. This necessitates the development of mathematical models for risk projection, based on observations in the high-dose studies, which can then be used to extrapolate to the low doses of current interest."

Mammographic screening doses are not, "substantially lower than the average breast tissue dose received by women in the ... medical cohort studies." Current

mammography doses to the breast are about equal to the 0.002 Gy breast doses delivered in the Canadian medical cohort study by each [back-to-front] fluoroscopic examination in all provinces except Nova Scotia. In Nova Scotia the dose to the breast from each [front-to-back] fluoroscopic examination was increased by a factor of 25 to 0.05 Gy.

Aware of his 1989 medical cohort study finding of reduced relative risks of death from breast cancer following mean cumulative doses of about 15 and 25 cGy, Howe in this 1996 revision attempts to suppress this contradictory data by including them with higher dose data to create a lowest dose category of 0.01-0.49 Sv(Gy)…neither relative risk is statistically significant.

• Studies of the Mortality of Atomic Bomb Survivors. Cancer: 1950-1990 .
The mortality from cancer was examined in this cohort study of 86,572 subjects of which 36,459 doses of less than 20 milliSieverts. *These were considered to have 0 dose and used as controls.* The remaining 50,113 subjects had an estimated 420 excess cancer deaths of which about 86 were due to leukemia and 324 due to solid cancers. The authors conclude, "Excess risks for solid cancer appear quite linear up to about 3 Sv, but for leukemia apparent nonlinearity in dose results in risks at 0.1 Sv… Site-specific risk estimates are given, but it is urged that great care be taken in interpreting these, because most of their variation can be explained simply by imprecision in the estimates." … The authors did not present the usual statistical analysis of this data even though, "the question of 'the lowest dose at which there is a statistically significant excess risk' is of interest to some". This analysis of the data was omitted, "Because of the tendency for the failure to find a significant effect to be equated to 'no effect,' this does not reflect a very cogent approach to inference about low-dose risks."

Most readers, however, are interested in knowing the lowest dose at which there is a statistically significant excess risk... Not only are the observed excess deaths in the 5 cSv category insignificant (P=0.25), but the observed excess deaths in the 15 cSv category are even less significant (P=0.56). The lowest OS 86 dose at which there is statistically significant observed excess risk of solid cancer mortality is 35 cSv (0.2-0.5 Sv) (P=0.03).
The authors' "very cogent approach" **does not use the *observed* excess solid cancer deaths**, but **substitutes estimated excess deaths derived from a model fit that assumes linearity.** Only these estimated excess deaths were presented by the authors at the Annual Meeting of the National Council for Radiation Protection in April 1996 three months before publication of their report. This 1996 RERF Life Span Study Report 1210 was used in November 1996 to mobilize support for the LNT theory. The International Commission on Radiation Protection ICRP) under Chairman Roger Clark and the French Society for Radioprotection reviewed this Life Span Study which includes the 1985-1990 mortality data. The ICRP claimed that analysis of this new data shows a statistically significant increased solid cancer mortality at doses as low as 5 cSv. According to Warren Sinclair, President Emeritus of the NCRP and Chairman of the ICRP Committee 1 which analyses results of health-effects studies, the new results "vindicate" previous recommendations to lower permissible dose limits to 2 rem/year for occupational workers and to 0.1 rem/yr for the general public. "The combination of more data points and a more

precise analysis," Sinclair said, "allowed the RERF researchers to state with confidence that excess cancer risk due to radiation was observed at doses as low as 50 mSv". *The "more precise analysis" does not use the observed excess solid cancer deaths but substitutes estimated excess deaths derived from a model fit that assumes linearity*.
We may conclude that the lowest dose at which there is a statistically significant observed excess risk for solid tumors is greater than 1 Sievert (100rem).

Another attempt to suppress data challenging the LNT was reported by Theodore Rockwell at a Federal Conference on Scientific Misconduct:

As early as 1950, Egon Lorenz of the National Cancer Institute reported that irradiated mice "are comparable with non-irradiated mice as far as weight, coat, and activity are concerned" and that subsequent generations reared and living under exposure of 1.1 r per day "show no damage to chromosomes as evidenced by the raising of 5 to 6 generations with normal litter size and an apparently normal life span." In view of several published statements like this, it is indicative of the political situation that Lorenz wrote in 1950: "It is well known that absorption of ionizing radiation by tissues is connected with damage, no matter how small the dose." This statement was written while Lorenz continued to accumulate data flatly contradicting it.. The data were then characterized in the reports as "anomalous," even though they were statistically significant and were being replicated by other reputable scientists. But funding for such studies soon dried up.

Dr. Allen Brodsky, Diplomate, American Board of Health Physics and Adjunct Professor of Radiation Science, Georgetown University described the situation as follows:

> The belief in a paradigm that any amount of radiation causes harmful effects has biased the design of experiments in radiation biology, and has resulted in the major reviews of biological effects of radiation giving little or no attention to the possibility of hormetic [i.e. beneficial] effects of low levels of radiation.

Dr. Marshall Brucer, the "Father of Nuclear Medicine," put it more bluntly:

> Health Physicists soon learned that their livelihood depended on scaring the pants off Congress…Health Physics, whose only visible means of support was radiation hysteria, trained a group of mathematical manipulators to distort biology.

Dr. Paul Selby, an internationally known genetics researcher at ORNL who has carefully and constructively identified significant problems since 1994 in the Russells' massive "mega-mouse" experimental program, has met with strong and continuing resistance in trying to get these questions resolved. In recent private correspondence he wrote:

> The Russells had refused to deal with a small part of this problem in spite of my efforts to get them to do so over the previous approximately 7 years…I was shocked to discover that the problem was much more serious than I had thought, and that it went all the way back to 1951, Soon after that time my research funding was stopped and I left genetics research at ORNL..(On two occasions I have come very close to being laid off.) A committee of 4 outside experts was brought to ORNL for an ethics investigation…The committee concluded that there was no "deliberate cover-up" for a reason that I consider impossible…The committee agreed that I had uncovered an important issue and that the data should have been reported earlier…My papers were delayed for a number of reasons

> caused by ORNL. One important reason was that I was forbidden to work on them during working hours…One key individual [in UNSCEAR] has told me twice that he will have to be careful in presenting this information to UNSCEAR "because it is the type of information that could put us out of business."…I am hopeful that when my papers appear [they have since been published in *Genetica*] there will be sufficient pressure brought to bear upon DOE that reexamination and reanalysis will actually happen. Unless numerous people put pressure on DOE, this is unlikely to happen.

Dr. Selby reports that just before he left last May for an UNSCEAR meeting, he received a call from Dr. Fred Mettler, head of the US Delegation, saying that persons at ORNL who had originally sponsored his UNSCEAR membership now wanted him removed, but Dr. Mettler would not remove him.

If this information is correct, it appears that a systematic practice of suppressing good news about radiation has been going on for nearly half a century and is still in effect.

In view of all this improper activity by persons in authority, one can feel justified in asking: *Why should we believe you now?* An answer used by diplomats, who can never be certain of the motives of their counterparts is: Trust, then verify. The public should always try to verify for themselves, the truth of any policy purportedly based on science: Look at the data, the analyses, and the scientific conclusions, and decide for yourself. The purpose of this Report is to bring out examples of the relevant data, especially data that is known to have been subject to misrepresentation and suppression. With the data before you, you can decide for yourselves.

President's Special Session
Low-Level Radiation and Its Implications for Fukushima Recovery

Introduction – Scientific Articles

Dr. Eric Loewen requested this booklet of scientific papers for each person attending his ANS President's Special Session. There are thousands of publications on low-level radiation, going back to 1895 and 1896 when x-rays and radioactivity were discovered. The items selected are recent and pertain to the following critical issues we addressed in this session: 1) Radiology specialists and radiobiologists know that the radiation levels around the Fukushima NPP are not hazardous; 2) the evacuated residents are suffering from a psychosis of fear, and 3) authorities are having difficulty complying with a radiation protection recommendation that specifies "as low as reasonably achievable."

With the constraint of a reasonable size booklet, appropriate for ANS members, only a page (or two) is provided for most of the articles. However, both the Table of Contents and the first page of the article provide the link to access the full paper on the Internet. Permission has been obtained from each copyright holder to reprint and download. The first page also shows the permission statement and the journal citation information.

The damaged reactors at Fukushima and the destroyed Chernobyl reactor both caused enormous human suffering—not because of the actual radiation exposures, but the fear of a hypothetical risk of genetic damage and fatal cancer. Since childhood, each person has been taught the concept that any exposure to the smallest dose of ionizing radiation increases this fearful risk.

When ionizing radiation was discovered more than a century ago, everyone was eager to experiment with it. Many beneficial health effects were found---treatments for a wide variety of illnesses; however, overexposures caused burns and a higher risk of cancer. Radiology practitioners were particularly vulnerable because of their repeat exposures when treating different patients. Their professional societies introduced standards in the 1920s to limit the dose received by radiation workers. Compliance with the standards appeared to reduce this risk below the normal cancer risk. The 1931 ICRP standard specified a "tolerance dose" of 0.2 roentgen per day, which is equivalent to the chronic radiation level of 680 mSv/year---a safe dose rate that could be tolerated indefinitely.

"The Road to Linearity: why linearity at low doses became the basis for carcinogenic risk assessment," by Edward Calabrese, describes the ideological, political and unscientific process that resulted in the regulatory transition from the concept of a safe tolerance dose to the concept of cancer and genetic risks kept small compared with other risks in life, and a use of the linear no threshold (LNT) extrapolation from the high doses to zero dose. After implementing this LNT concept for radiation, regulatory organizations began to apply it also in the field of toxicology and pharmacology. Instead of measuring and employing the actual organism's response to a chemical exposure, a hypothetical risk was assumed for a low dose, based on the linear extrapolation of risk from high doses to zero dose.

In the 1980s, research identified that the DNA molecule is not as stable as had been assumed. In fact, the rate of spontaneous DNA damage, due to oxidative and thermal processes, is enormous. The rate of this natural damage is about 2×10^5 events per cell per day in humans. Radiation-induced DNA damage from an ambient 1 mSv per year amounts to about 3×10^{-2} events per cell per day. This is more than **6 million times** lower than the natural DNA damage rate. Very powerful defences have evolved over time that prevent and repair DNA damage. Cells that were not adequately repaired either commit suicide or are removed by other defences. The natural defences address all DNA damage, regardless of the cause. They allow all living things to survive and thrive for their entire lives. Children are not more sensitive to radiation; they have much stronger defences to cope with the added burden of more frequent cell division.

Many research studies have been carried out, from the 1970s until the present, that demonstrate a stimulation of defences in all living organisms by low doses of radiation and their inhibition by high doses. While the direct effect of low-dose radiation on the rate of DNA damage is comparatively small, it has a significant effect on the defences by modulating their activities. For example, Dr. Sakamoto irradiated a population of mice, in 1975, with a sub-lethal dose to suppress their immunological response for some experiments. He was curious to know the minimum dose needed to accomplish this and discovered that irradiation with low doses, 10 to 15 cGy, actually promoted immunological response. This was a complete surprise, and led to many fundamental studies in support of the application of total-body, low-dose irradiation to treat cancer.

There are many radiobiology research experiments that provide considerable evidence to support the hormetic dose-response model---that low-level radiation has the opposite effect of the high-dose radiation, which caused the excess cancer mortality observed in the Japanese Life Span Study survivors. The extrapolation of a high-dose risk to predict a risk at low dose is invalid because of the evidence that demonstrates a health benefit at low dose. All life adapts to environmental changes, including higher radiation.

In light of the information now available, it is clear that the change in radiation protection concept that occurred in the 1950s is not scientifically supportable. Furthermore, this concept is harmful because it causes a psychosis of fear whenever an event occurs that releases any amount of radioactivity. The appropriate corrective action is to revert back to the 1931 concept of tolerance dose and the dose rate limit of about 680 mSv per year for radiation workers.

Based on radiobiological evidence, a level 10,000 mSv/year is the threshold for harmful effects. For nuclear accidents, the appropriate radiation level for evacuations should be “as high as reasonably safe” (AHARS), which could be up to 1000 mSv/year.

In conclusion, I urge you to become familiar with this very important subject. It is the key to the future of nuclear energy and all applications of ionizing radiation.

Jerry M. Cuttler June 2012

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COMMENTARY ON THE APPROPRIATE RADIATION LEVEL FOR EVACUATIONS[1]

Jerry M. Cuttler □ Cuttler & Associates Inc.

□ This commentary reviews the international radiation protection policy that resulted in the evacuation of more than 90,000 residents from areas near the Fukushima Daiichi NPS and the enormous expenditures to protect them against a hypothetical risk of cancer. The basis for the precautionary measures is shown to be invalid; the radiation level chosen for evacuation is not conservative. The actions caused unnecessary fear and suffering. An appropriate level for evacuation is recommended. Radical changes to the ICRP recommendations are long overdue.

Keywords: radiation protection, evacuation, nuclear accident, spontaneous DNA damage, stimulated biodefences

It is very upsetting to read about the on-going fear and hardship suffered by the more than 90,000 residents, who were evacuated from areas surrounding the Fukushima Daiichi Nuclear Power Station (NPS) in Japan, and the enormous economic penalty, including the $55 billion increase in the cost of fossil fuel imports in 2011, due to the shutdown of almost all of the other NPSs (WNA 2012). As of December 1, more than 230,000 people have been screened with radiation meters (IAEA 2011). The "deliberate evacuation area" was based on a projected radiation dose of 20 milliSievert (mSv) per year (METI 2011a, IAEA 2012). The goal aims to keep additional radiation exposure below 1 mSv annually, particularly for children (METI 2011a, 2011b). And a plan for assistance to the residents affected has been developed (METI 2011b).

Japan is complying with international radiation protection recommendations that are based on the International Commission on Radiological Protection (ICRP) policy of maintaining exposure to nuclear radiation as low as reasonably achievable (ALARA). However, the very precautionary measures are highly inappropriate.

As described by Edward Calabrese (2009), the International Committee on X-Ray and Radium Protection was established by the Second International Congress of Radiology in 1928 to advise physicians on radiation safety measures, within a non-regulatory framework.

[1]Permission received to publish article appearing in March 2012 issue of the Canadian Nuclear Society Bulletin.

Address correspondence to Dr. Jerry Cuttler, 1781 Medallion Court, Mississauga, Ontario, Canada L5J2L6; Phone:1-416-837-8865; E-mail: jerrycuttler@rogers.com

Radiation protection was based on the "tolerance dose" (permissible dose) concept. The initial level was 0.2 roentgen[2] (R) per day in 1931, based on applying a factor of 1/100 to the commonly accepted average erythema dose of 600 R, to be spread over one month (30 days).[3] It was used as a means to determine the amount of lead shielding needed. Any harm that might occur from exposures below the tolerance level was acceptable. However, geneticists strongly believed the theory that the number of genetic mutations is linearly proportional to radiation dose, that mutagenic damage was cumulative and that it was harmful. They argued that there was no safe dose for radiation; safety had to be weighed against the cost to achieve it.

To avoid adverse effects, early medical practitioners began to control their exposures to x-rays. For example, the British X-ray and Radium Protection Committee was formed in 1921. A study of those who joined a British radiological society revealed a significant health benefit (Smith and Doll 1981). Table 1 shows the ratio of observed/expected numbers of deaths of pre-1921 radiologists (in social class 1) and the ratio of post-1920 radiologists. A reduction from 1.04 to 0.89 is apparent for all causes of death and from 1.44 to 0.79 for cancer deaths. Note that the pre-1921 radiologists had a 44% higher cancer mortality than other men in social class 1, while the post-1920 radiologists had a 21% lower cancer mortality.

After the bombing of Hiroshima and Nagasaki in World War II and the start of the nuclear arms race, geneticists greatly amplified their concerns that exposure to radiation in medical products and atomic bomb fall-out would likely have devastating consequences on the human population's gene pool. Hermann J. Muller was awarded the Nobel Prize in 1946 for his discovery of radiation-induced mutations. In his Nobel Prize Lecture of December 12, he argued that the dose-response for radiation-induced germ cell mutations was linear and that there was "no escape from the conclusion that there is no threshold" (Calabrese 2011c, 2012).

There was great controversy and extensive arguments during the following decade regarding the past human experience, the biological evidence and the strong pressures from Muller and many other influential scientists who migrated from science to politics. The International Committee for Radiation Protection and the national organizations changed their radiation protection policies in the mid-1950s. They reject-

[2]The "equivalent dose" that corresponds to an exposure of 1 R depends on the energy of the x- or γ-radiation and the composition of the irradiated material. For example, if soft tissue is exposed to 1 R of γ-radiation, the dose would be approximately 9.3 mSv (Henriksen and Maillie 2011).

[3]In September 1924 at a meeting of the American Roentgen Ray Society, Arthur Mutscheller was the first person to recommend this "tolerance" dose rate for radiation workers, a dose rate that could be tolerated indefinitely (Inkret et al 1995). This level corresponds to 680 mSv/year.

TABLE 1. Observed and expected numbers of deaths from cancer and all other causes among radiologists who entered the study prior to 1921 or after 1920.

Cause of death	Observed (O) and expected (E) numbers of deaths					
	Entry prior to 1921			Entry after 1920		
	O	E	O/E	O	E	O/E
All causes	319	(1) 334.42	0.95	411	541.77	0.76***
		(2) 308.03	1.04		461.14	0.89*
		(3) 327.97	0.97		469.97	0.87**
All neoplasms	62	(1) 49.11	1.26*	72	114.93	0.63***
		(2) 43.07	1.44**		91.07	0.79*
		(3) 35.39	1.75***		68.65	1.05
Other causes	257†	(1) 285.31	0.90*	339†	426.84	0.79***
		(2) 264.96	0.97		370.07	0.92
		(3) 292.58	0.88*		401.32	0.84**

(1) Based on rates for all men in England and Wales.
(2) Based on rates for social class 1.
(3) Based on rates for medical practitioners.
† includes one death with unknown cause.

*P < 0.05, **P < 0.01, ***P < 0.001 } One sided in direction of difference.

ed the tolerance dose concept and adopted the concept of cancer and genetic risks, kept small compared with other hazards in life. The belief in low-dose linearity for radiation-induced mutations was accepted. The acute exposure, high-dose cancer mortality data from the Life Span Study on the Hiroshima-Nagasaki survivors was taken as the basis for predicting the number of excess cancer deaths to be expected following an exposure to a low dose of radiation or to low level radiation. However, the biology is very different from this picture. Professional ethics require a proper scientific foundation for estimating health risks (Jaworowski 1999, Calabrese 2011a).

Throughout the 20th century, an enormous amount of research has been underway in biology, on genetics and on the effects of radiation on DNA. A very important article, a commentary by Daniel Billen, was published in the Radiation Research Journal (Billen 1990), which is highly relevant to the great concern about the cancer or genetic risk from radiation. Permission was received from Radiation Research to republish it here (appended).

This article points out that "DNA is not as structurally stable as once thought. On the contrary, there appears to be a natural background of chemical and physical lesions introduced into cellular DNA by thermal as well as oxidative insult. In addition, in the course of evolution, many cells have evolved biochemical mechanisms for repair or bypass of these lesions."

Spontaneous DNA damage occurs at a rate of ~ 2 x 10^5 natural events per cell per day. Compare this with the damage caused by nuclear radia-

tion. The number of DNA damaged sites per cell per cGy is estimated to be 10-100 lesions, 100 to be conservative. A radiation level of 1 mSv delivered evenly over a year would cause on average less than 10 DNA damaging events per cell per year or 0.03 events/cell/day. This is 6 million times lower than the natural rate of DNA damage that occurs in every person. And this information has been known for more than 20 years.

The radiation in the environment around the Fukushima Daiichi NPS is shown in Figure 1 (MEXT 2011). It is interesting to note that the radiation received by the plant workers, Table 2 (JAIF 2012), did not exceed the tolerance level specified in 1931 for radiologists.

Recently, Calabrese discovered that Muller had evidence in 1946 that contradicted the linear dose-response model at low radiation levels. Muller did not mention this in his Nobel Prize lecture, suggesting that he still wanted the change in radiation protection policy to proceed, from

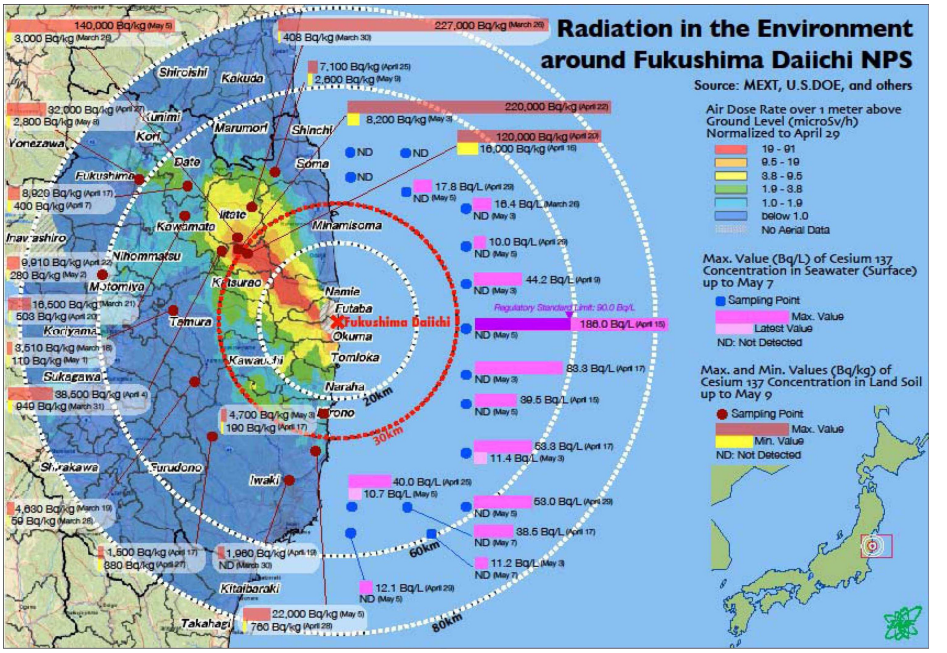

FIGURE 1. Radiation in the Environment around the Damaged Fukushima Daiichi NPS.

TABLE 2. Radiation Exposures of the NPS Workers from 2011 March 11 until December 31.

	Number of Workers	Radiation Dose (mSv)
	135	100 - 150
	23	150 - 200
	3	200 - 250
	6	250 - 678
Total	167	

the tolerance dose concept to a linear-no-threshold risk of cancer and congenital malformations (Calabrese 2011b, 2011c, 2012).

How can ICRP recommendations still be based on protecting against genetic risk at this level, when human suffering and economic costs are so great? The ICRP has been progressively tightening its recommendations for occupational and public exposures, from 50 and 5 mSv/year (ICRP 1958) to 20 and 1 mSv/year (ICRP 1991). Instead of ALARA, the radiation level for evacuation should be "as high as reasonably safe," AHARS (Allison 2009, 2011). For nuclear accidents, the 20 mSv/y level could be raised 50 times higher to 1000 mSv/y, which is similar to the natural radiation levels in many places (Jaworowski 2011). And when low-dose/level radiation stimulation of the biological defences against cell damage and cancer is considered (Luckey 1991, UNSCEAR 1994, Cuttler 1999, Pollycove and Feinendegen 2003, Tubiana et al 2005, Cuttler and Pollycove 2009), Figures 2 and 3, there is no reason to expect any increase in cancer risk. It is very difficult to understand why the ICRP recommendations have not changed accordingly. There would have been no need for this evacuation.

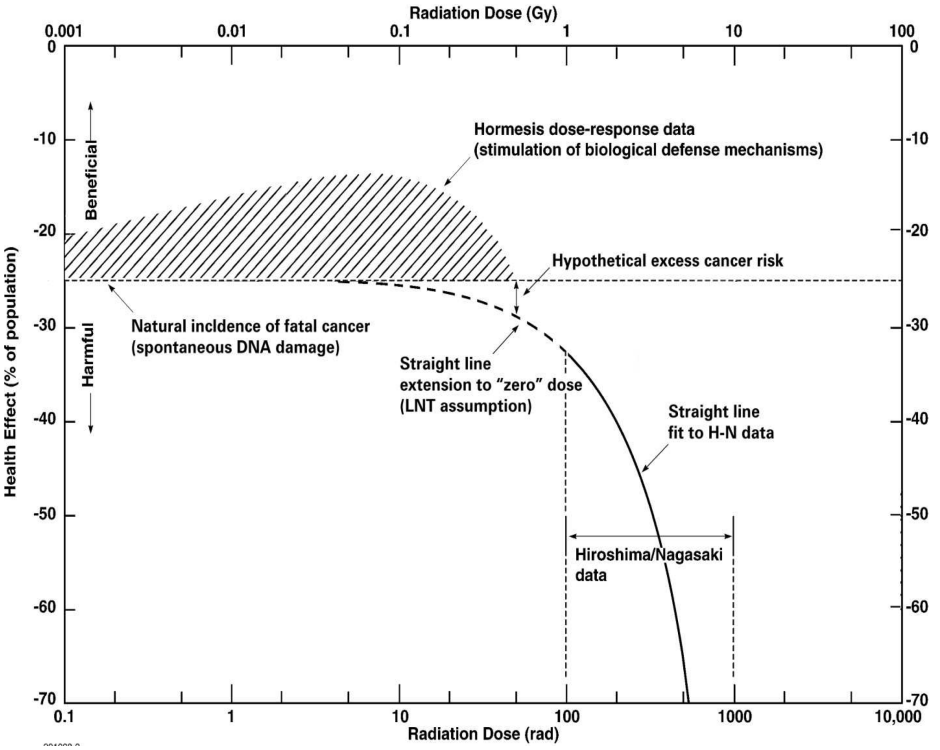

FIGURE 2. Dose-Response for Short-Duration Radiation Exposure (Cuttler 1999).

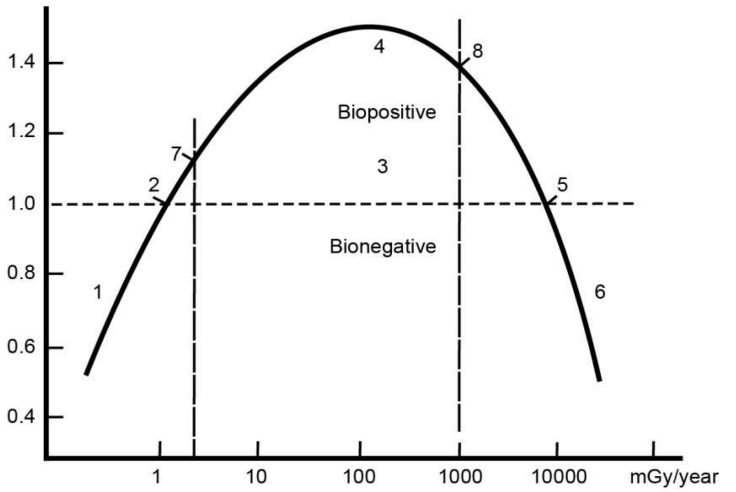

FIGURE 3. Idealized Dose-Response Curve for Continuous Exposure (Luckey 1991). 1 deficient, 2 ambient, 3 hormetic, 4 optimum, 5 zero equivalent point, 6 harmful 7 ALARA, 8 AHARS.

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RADIATION RESEARCH 124, 242–245 (1990)

COMMENTARY

Spontaneous DNA Damage and Its Significance for the "Negligible Dose" Controversy in Radiation Protection

DANIEL BILLEN[1]

Oak Ridge Associated Universities, Medical Sciences Division, P.O. Box 117, Oak Ridge, Tennessee 37831-0117

BILLEN, D. Spontaneous DNA Damage and Its Significance for the "Negligible Dose" Controversy in Radiation Protection. *Radiat. Res.* 124, 242–245 (1990).

One of the crucial problems in radiation protection is the reality of the negligible dose or *de minimus* concept (*1–4*). This issue of a "practical zero" and its resolution is central to our understanding of the controversy concerning the existence of a "safe" dose in radiological health. However, for very low levels of environmental mutagens and carcinogens including low doses of low-LET radiations (less than 1 cGy or 1 rad), spontaneous or endogenous DNA damage may have an increasing impact on the biological consequences of the induced cellular response. It is this issue that is addressed in this communication.

The following discussion is intentionally limited to a comparison of low-LET radiation since its effects are due primarily to indirect damage in cellular DNA brought about by OH radicals. Indirect effects of low-LET radiation under aerobic conditions are reported to account for 50–85% of measured radiation damage in cells (*5, 6*). High-LET radiation, on the other hand, produces unique DNA damage (*7*) primarily by direct effects (*5*) which is less likely to be properly repaired (*7*).

Spontaneous or intrinsic modification of cellular DNA is ubiquitous in nature and likely to be a major cause of background mutations (*8*), cancer (*9*), and other diseases (*10*). The documentation of this intrinsic DNA decay has increased at a rapid pace in recent years and has not gone unnoticed by contemporary radiobiologists. Setlow (*11*) and more recently Saul and Ames (*12*) summarized the findings of Lindahl and Karlstrom (*13*) and others (*14*) which suggest that approximately 10,000 measurable DNA modification events occur per hour in each mammalian cell due to intrinsic causes.

The current radiation literature will be interpreted to show that ~100 (or fewer) measurable DNA alterations occur per centigray of low-LET radiation per mammalian cell. Therefore every *hour* human and other mammalian cells undergo at least 50–100 times as much spontaneous or natural DNA damage as would result from exposure to 1 cGy of ionizing radiation. Since background radiation is usually less than 100–200 mrem (1–2 mSv)/y, it can be concluded, as discussed by Muller and Mott-Smith (*15*), that spontaneous DNA damage is due primarily to causes other than background radiation.

"INTRINSIC" OR "SPONTANEOUS" DNA DAMAGE

DNA is not as structurally stable as once thought. On the contrary, there appears to be a natural background of chemical and physical lesions introduced into cellular DNA by thermal as well as oxidative insult. In addition, in the course of evolution, many cells have evolved biochemical mechanisms for repair or bypass of these lesions.

Some of the more common "natural" DNA changes include depurination, depyrimidination, deamination, single-strand breaks (SSBs), double-strand breaks (DSBs), base modification, and protein–DNA crosslinks. These are caused by thermodynamic decay processes as well as reactive molecules formed by metabolic processes leading to free radicals such as OH, peroxides, and reactive oxygen species.

Shapiro (*14*) has recently discussed and summarized the frequency at which various kinds of spontaneous DNA damage occur. Spontaneous DNA damage events per cell per hour are shown in Table I and were estimated from the data presented by Shapiro [Table II (*14*)].

For single-stranded DNA of mammalian cells at least 8×10^3 damage events occur/cell/h, whereas for double-stranded DNA there were $\sim 6 \times 10^3$ damage events per hour (Table I). While the ratio of single-stranded DNA to

[1] Guest Investigator, Medical Sciences Division. Oak Ridge Associated Universities.

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TABLE I
Estimated Spontaneous DNA Degradation Events (Cell/h)[a]

Reaction	Single-strand DNA	Double-strand DNA
Depurination	4000	1000
Depyrimidination	200	50
Deamination of cytosine	4000	15
Chain break resulting from depurination	—	1000
Direct chain break	—	4000

[a] Calculated from Shapiro (*14*).

double-stranded DNA varies with phase of the cell cycle, it is reasonable to assume that double-stranded DNA is the usual configuration for most cellular DNA at any one time. From the data summarized in Table I it is not unreasonable to suggest that, at a minimum, the spontaneous DNA damage is of the order of $6–10 \times 10^3$ events/cell/h and to use 8×10^3 DNA damage events/cell/h as a reasonable average for the purpose of discussion. This allows a calculation of 1.9×10^5 spontaneous cellular DNA damaging events/cell/day or 7×10^7 per year in mammals including humans (Table II). The lifetime load of spontaneous DNA damage events per cell is then $\sim 5 \times 10^9$ if an average life span of 75 years is allowed for humans.

DNA DAMAGE INDUCED BY IRRADIATION

Several recent reviews summarize the types and quantities of alteration of DNA in cells caused by exposure to low-LET radiation (*16–18*). The reader should refer to these for references to the original works from which the reviews were drawn.

The estimate of about 100 DNA events/cell/cGy used in this discussion is based on information contained in the reviews by Ward (*16, 20*) and assumes the molecular weight of the mammalian genomic DNA to be 6×10^{12} Da, constituting about 1% of the cell weight.

Ward [Table II (*16*)] lists the amount of energy deposited in various DNA constituents/cell/Gy. From this table a total of 13.3 DNA events/cGy is calculated. His estimate of damaged DNA sites/cell/cGy is 10–100. I chose the 100-lesion estimate to make as reasonable a conservative comparison with spontaneous DNA damage as possible (Table II). This number of damaged sites would include both direct and indirect DNA damage.

SPONTANEOUS VS INDUCED DNA MODIFICATIONS AND THEIR BIOLOGICAL CONSEQUENCES

Wallace has recently reviewed the nature of the DNA lesions caused by active oxidizing species produced both naturally and by low-LET radiation (*17*). Oxidizing radicals and especially OH radicals resulting from either cause produce similar types of DNA lesions (*17–19*). The enzymes involved in their repair are similar whether the DNA damage is produced spontaneously or by radiation. However, radiation is known to induce an error-prone repair system in bacterial cells and perhaps in mammalian cells as well (*21, 22*).

DNA glycosylases and endonucleases are involved in the repair of base damage. Other nucleases are available for sugar damage repair (*17*). Recognition of the damage site by the appropriate enzymes is dependent not on the initiating event but on the chemical nature of the end product. These end products appear to be similar whether induced by natural causes or radiation (*17*). It would seem reasonable to conclude that, due to common oxidizing radicals, many of the qualitative changes in DNA are quite similar for radiation-induced or spontaneous DNA damage.

TABLE II
DNA Damage Events per Mammalian Cell

	Spontaneous DNA damage events			
Character of event	Per second	Per hour	Per year	DNA damage/cGy[a]
Single-strand breaks	1.4	$\sim 5 \times 10^3$	$\sim 4.4 \times 10^7$	10
Double-strand breaks				0.4
Depurination and/or		$\sim 1.5 \times 10^3$	$\sim 1.4 \times 10^7$	
base lesions	0.8	$\sim 1.25 \times 10^3$	$\sim 1.1 \times 10^7$	9.5
Total events	2.2	$\sim 8.0 \times 10^3$	$\sim 7 \times 10^7$	~20
cGy equivalents (1 cGy = 100 events)[b]	0.022	8.0×10^1	7×10^5	

[a] From Ward (*20*).

[b] Since other radiation-induced DNA damage such as DNA–protein crosslinking and base modifications (*18*) occur, 100 events/cGy is used as a "ballpark" value for ease of comparison with spontaneous events.

The quantity and distribution of each class of lesion may, however, differ significantly. As indicated earlier there would appear to be relatively more DNA strand breaks than other lesions resulting from spontaneous causes as compared to radiation insult. A good portion of these may result from depurination (Table I) with production of 3′ OH termini ("clean ends") as part of the repair process.

Many of the DNA strand breaks caused by low-LET radiation are incapable of serving as primer for DNA polymerase (*23*). However, endo- and exonucleases exist which can restore these blocking ends to clean ends and allow completion of the repair process (*17*).

A strong correlation exists between DNA DSBs and lethality in mammalian cells for low-LET radiation. While the quantity of DSBs produced by ionizing radiation is fairly well documented, this is not true for spontaneous DSB production in mammalian cells.

In spontaneous DNA decay, formation of a DSB is likely to be the result of single-strand events occurring in close proximity on each daughter strand and leading to cohesive ends which can be repaired easily by a ligation step.

A survey of the literature on the doubling dose for mutagenesis in eukaryotes exposed to low-LET radiation indicates a range of 4 to 300 cGy and for carcinogenesis a range of 100 to 400 cGy. Using the "ballpark" value of approximately 100 DNA events/cell/cGy, this would represent a range of 400 to 40,000 induced DNA damage events per doubling dose. Using 100 cGy as the approximate doubling dose, a total of 1×10^4 DNA damage events would be required to induce mutations in numbers equal to that observed in nature. This is approximately the number of DNA events (8.0×10^3) produced spontaneously in each cell/h (Table II).

THE NEGLIGIBLE DOSE CONTROVERSY

The comparison of low-LET radiation-induced DNA damage with that which occurs spontaneously indicates (Table II) that a relatively large number of DNA damage events can occur spontaneously during the lifetime of mammalian and other cells.

Dose protraction over a period of weeks or months would lead to an increasing ratio of spontaneous DNA damage events to those caused by irradiation. By extrapolation from high doses and high dose rate as discussed by Ward (*16, 20*), 1 cGy delivered in 1 s would cause 40–50 times as many DNA damaging events per cell as that caused spontaneously during the same time span (Table II). However, 1 cGy delivered evenly over 1 year would cause (on average) less than 1 DNA damaging event per cell/day. This can be compared to $\sim 2 \times 10^5$ natural events caused per cell/day.

From these numbers, it seems reasonable to suggest that there does exist a "negligible" dose in the range of our terrestrial background annual radiation dose of ~ 1 mSv (~ 10 DNA events/cell/year). This can be compared to the approximately 7×10^7 DNA events/cell/years produced by spontaneous causes.

Adler and Weinberg (*24*) have proposed that the standard deviation of the background irradiation (~ 0.2 mSv) be used as an acceptable additional dose due to human activities. This would lead to ~ 2 additional induced DNA damaging events/cell/year as compared to $\sim 7 \times 10^7$ spontaneous DNA damage events. Considering the magnitude of the spontaneously induced DNA changes in each human cell, it is not unreasonable to predict that 0.2 mSv delivered over a year would have negligible biological consequences.

When temporal considerations are factored in, it becomes clear that spontaneous DNA damage in mammalian cells may be many orders of magnitude greater than that caused by low and protracted radiation doses, especially in the terrestrial background range of 1–2 mSv (100–200 mrem) per year. It is important that further studies on the effects of both ionizing radiations and spontaneous events on DNA decay and repair be conducted to better understand the practical health consequences of low and protracted doses of radiation (*2, 9, 25*).

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REVIEW ARTICLE

The road to linearity: why linearity at low doses became the basis for carcinogen risk assessment

Edward J. Calabrese

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Abstract This article assesses the historical foundations of how linearity at low dose became accepted by the scientific/regulatory communities. While the threshold model was used in the 1920s/1930s in establishing radiation health standards, its foundations were challenged by the genetics community who argued that radiation induced mutations in reproductive cells followed a linear response, were cumulative and deleterious. Scientific foundations of linearity for gonadal mutations were based on non-conclusive evidence as well as not being conducted at low doses. Following years of debate, leaders in the genetics community participated in the U.S. National Academy of Sciences (NAS) (1956) Biological Effects of Atomic Radiation (BEAR) BEAR I Committee, getting their perspectives accepted, incorporating linearity for radiation-induced mutational effects in risk assessment. Overtime the concept of linearity was generalized to include somatic effects induced by radiation based on a protectionist philosophy. This affected the course of radiation-induced and later chemically-induced carcinogen risk assessment. Acceptance of linearity at low dose from chemical carcinogens was strongly influenced by the NAS Safe Drinking Water Committee report of 1977 which provided the critical guidance to the U.S. EPA to adopt linear at low dose modeling for risk assessment for chemical carcinogens with little supportive data, much of which has been either discredited or seriously weakened over the past 3 decades. Nonetheless, there has been little practical change of regulatory policy concerning carcinogen risk assessment. These observations suggest that while scientific disciplines are self correcting, that regulatory 'science' fails to display the same self-correcting mechanism despite contradictory data.

Keywords Threshold · Dose response · Risk assessment · Carcinogen · Mutagen · Mutation · Linearity · Somatic mutation hypothesis

E. J. Calabrese (✉)
Environmental Health Sciences Division,
Department of Public Health, University of Massachusetts,
Morrill I, N344, Amherst, MA 01003, USA
e-mail: edwardc@schoolph.umass.edu

Part 1: Fear of radiation-induced mutagenicity lead to linearity at low doses in risk assessment

Introduction

The acceptance of linearity at low dose for carcinogen risk assessment is the most significant risk assessment policy decision of the past century. It has had far reaching political, economic, technological and public health implications. Given the significance of this risk assessment policy, it is important to assess the historical foundations of the linearity at low dose concept and how it became accepted by the scientific community and integrated into government regulatory polices for radiation and chemical carcinogens.

Part 1 of this article will demonstrate that the linearity at low dose concept was principally developed by geneticists following the discovery of X-ray induce mutations in Drosophia by Hermann J. Muller in 1927. While the data supporting the linearity concept during this period of concept consolidation will be shown to be very limited, non-conclusive and not even remotely close to what we might call a low dose today, key researchers in the genetics community accepted this concept to be true and used it to generate concerns that exposure to radiation in medical products and atomic bomb fall-out would likely have devastating consequences on the human population. This paper is an assessment

of how this process originated and how it affected the assessment of radiation induced cancer. It will provide an evaluation of the historical foundations of radiation health standards under the leadership of the National Committee for Radiation Protection and Measurements (NCRPM) and its predecessor organization, the American X-ray and Radiation Protection Committee, with particular emphasis on the concept of the tolerance dose and its etymological offspring, the permissible dose. Within this context an assessment is provided as to how the concept of radiation-induced genetic injury was considered in the occupational health standard setting process in the time framework before and after World War II. The paper will then assess how the concern over radioactive fall-out trumped most earlier discussions of mutation and radiation health standards, making it a very high political and scientific national priority. It was within this new public crucible that the debate over low dose linearity occurred with its eventual acceptance. Part 2 of this paper assesses how the concept of linearity at low dose for chemical carcinogens became accepted into government policy and risk assessment practices. Broad and in depth evaluations of the historical foundations of the dose response relationship for chemicals and radiation have been previously published but have not focused on mutagencity (Calabrese 2004, 2005a, b, 2008; Calabrese and Baldwin 2000a, b, c, d, e).

Historical foundations of radiation health standards: before the tolerance dose

The International Committee on X-Ray and Radium Protection was established by the Second International Congress of Radiology in 1928 to advise physicians on radiation safety measures, within a non-regulatory framework. The first International Congress of Radiology met in 1925 with the goal of re-establishing lines of communication between opposing countries during World War I. Each country was to send a representative who would promote the recommendations of the International Committee in their home countries. The U.S. Bureau of Standards was asked to provide this representative, selecting Lauriston Taylor, an assistant physicist in the X-ray section of the Bureau. The leadership of the Bureau of Standards in this area would later become a political issue within the U.S. government in the 1950s, leading President Eisenhower to create the Federal Radiation Council, an organization with more direct accountability than a voluntary organization operating under the aegis of the Bureau of Standards without any legal authority over its actions and products. After the International Congress in 1928 Taylor established a national committee on radiation protection. This U.S. committee was to contribute to the international development of radiation protection standards and activities and to advance them within the U.S. Despite the fact that Taylor was a federal employee the committee was considered non-governmental and advisory to government and industry. The group was called the American X-ray and Radium Protection Committee, with the name changing two decades later following World War II to the NCRPM. Membership was based on having representatives from various relevant national organizations, consistent with the practice of the International Congress. The first full meeting of this national Committee was held on 18 September 1929. The first report of this committee was published in 1931, recommending various safety procedures and exposure monitoring activities for those who work with X-rays, such as the periodic wearing of a dental X-ray film for the qualitative estimation of exposure and the need for complete blood counts. This report did not contain an exposure standard such as the roentgen unit, but rather standards were achieved in terms of lead-equivalent insulation. Committee activities were subsequently directed toward developing a set of recommendations for working with radium within medical settings (Taylor 1971; Whittemore 1986).

When the tolerance dose concept was king

Within the context of the radium evaluation the committee determined that the best indicators of radiation effects were skin changes within the tips of the fingers, with a reddening and shiny appearance of the skin around the fingernails. An exposure of 600 r was commonly accepted as the average erythema dose, that dose producing a reddening of the skin. The number 600 r was derived from a 1927 poll of radiotherapists who gave an average erythema dose of 550 r, which was then rounded up to 600 r in order to account for background scatter radiation (Jolly 2003).

The concept of a tolerance dose was initially proposed in the U.S. by Mutscheller (1925), advocating a value of 1/100 of the erythema dose in 30 days; it was used as a means to calibrate the amount of lead shielding needed. Despite the concept of a tolerance dose, Mutscheller argued that there was no safe dose to radiation but that safety had to be weighed against the costs to achieve it. In effect, he sought a type of equilibrium in which there would be a dose to which the worker could be exposed without noticeable harm. In a practical sense a tolerance dose specifying the maximum tolerable exposure could set the minimal protection needed, thereby providing a limit on the shielding an employer would have to provide. The tolerance dose concept would go on to provide the foundation for future radiation safety standards (Taylor 1971; Whittemore 1986).

Other researchers also presented similar data during this time period (Sievert 1925; Barclay and Cox 1928). Each of the groups selected a different time interval to describe the tolerance dose. However, when normalized the derived

tolerance doses were quite similar. The derivation of the tolerance dose utilized the concept of a "safety" factor to reduce exposure via a fixed fraction below the estimated minimal toxic level.

The International Committee for Radiation Protection (ICRP) recommended a tolerance dose for occupational radiation exposure, which was officially adopted at the Stockholm Congress of 1928. This ICRP standard, which was based on Mutscheller's safety factor of 1/100 of an erythema dose, remained the principal foundation for international and U.S. prewar radiation standards (Jolly 2003). No specific numerical standard was established for exposure but guidance was provided for calculating the thickness of lead shielding used in X-ray production.

The first report on radiation standards published by the NCRPM was in 1931 and designated as the National Bureau of Standards Handbook 15. The report was principally based on the 1928 ICRP recommendations. It contained shielding tables but no tolerance dose/exposure standard. By 1934, when the NCRPM issued its second report (NBS Handbook 18) several important new developments occurred. Most notably, this report offered a specific radiation exposure standard, in effect, the first attempt to develop an explicit tolerance dose (Whittemore 1986). This effort was lead by Professor G. Failla who developed data at Columbia University Medical School on occupational radium exposures that could be safely tolerated, using skin and blood changes as biological markers. The findings indicated that 0.6 r/month would be a safe dose. This exposure rate was one-thousandth of the 600 r value, and was believed by Failla to be a dose to which workers could be continuously exposed for a number of years without safety concerns, especially since it had a tenfold larger safety factor than the Mutscheller recommendation. This information, which was provided to the Committee in 1932, was based on the belief that there is a balance between injury and tissue repair (Whittemore 1986). The assumption of an equilibrium between injury and repair suggested that there was a biological threshold of radiation which could be safely absorbed/administered for an indefinite time. Even though the Committee accepted the basic clinical findings of Failla and the safety factor concept, they settled on a higher tolerance dose, that is, use of a lower safety factor. The report stated that a safe whole body exposure is 0.1 r/day for hard X-rays, and could be used to guide radium protection practices. The dose of 0.1 r/day was the result of a somewhat crudely conservative rounding down of the figure based on the work of Mutscheller nearly a decade earlier (Jolly 2003).

In the time between when the radium report was finalized and when it was printed, the Committee adopted the concept of a "tolerance dose", it being the first major concept change in the Committee's approach to radiation safety. In fact, the adoption of a tolerance dose of 0.1 r/day for X-rays and gamma rays was inserted into the preface (Whittemore 1986). The 0.1 r/day rate was proposed since it was consistent with other national values such as Germany (Taylor 1971).

In the U.S., the Committee was using the term tolerance dose in correspondence and discussion but up to 1933 it had not been used in any formal reports (Whittemore 1986). However, the tolerance dose was adopted in 1933 but it was not widely seen until the publication of a revised handbook 3 years later, the delay being related to the unfunded nature of the voluntary activity of the Committee. According to Whittemore (1986), the underlying assumption of the tolerance dose was that ionization was proportional to biological effect. The Committee archives indicate that their concept of tolerance dose was one in which any harm that might occur from exposures below the tolerance level was acceptable (i.e. tolerable), and not that such effects were nonexistent. Nonetheless, the use of a specific numerical limit was frequently interpreted to mean that there was a threshold of radiation exposure below which no harm occurred, even though the tolerance dose did not equal threshold dose in the view of the Committee. While the respective publications on X-ray and radium protection marked the completion of the specific goals for which the Committee was originally formed, it did not disband but continued to respond to questions from the public and government (Whittemore 1986).

Radiation-induced mutation: the key discovery for the eventual acceptance of low dose linearity

The concept of low dose linearity for radiation-induced mutations developed relatively soon after the report by Muller (1927) in *Science* that X-ray treatment profoundly increased the occurrence of sex-linked mutations in *Drosophila*. Follow up studies were published by several investigators (i.e. Hanson, Oliver) working under the direction of Muller and several others (e.g. Stadler). While it is generally believed that Muller did not adequately address the concept of the dose response in his initial work, a closer look reveals that he did consider the issue. In his historic study Muller initially experimented with the heterozygous sc v f × bb strain of *Drosophila* females and homozygous sc v f males. In this experiment dose was based on the differing time periods (12, 24, 36, 48 min) during which the flies were exposed to X-rays. Doses resulting from 36 to 48 min duration were generally high enough to cause sterility in a high percentage (70–80%) of the males. While there was only one mutant observed at the lowest dose, the mutation rate markedly increased at the next highest dose and continued to progressively increase with the duration of exposure. While Muller did not replicate this experiment,

he re-ran the same experimental concept this time using his C1B technique which was more sensitive than the other model. In this second experiment, he opted to use only the 24 and 48 min exposure durations/doses. Based on the data presented, a non-linear dose response occurred in his first experiment with the four doses whereas there was little capacity to assess dose response with only two doses in the second experiment; in this case there was a dose response proportionality seen for the two doses but it also was not linear with Muller characterizing the increase a being close to the $\sqrt{2}$ rather than a doubling (twofold increase) (Muller 1928). Thus, in the 1927 and 1928 papers Muller did not claim a direct linear relationship but rather a curvilinear one that was yielding a relationship that was most likely a response being related to the square root of the X-ray energy absorbed. Muller (1927) went on to discuss some biological implications of the lack of a linear relationship. He then emphasized the need for additional research to assess the nature of the dose response for a wide range of doses.

Muller encouraged Oliver and Hanson, who were working in his laboratory, to follow up on the dose response question. In the case of Oliver he extended the doses to five and explored a lower dose range, including 3.5, 7.0, 14 min., 28 and 56 min (Oliver 1930, 1931). At the lowest dose tested, the occurrence of mutant lethals was 5.7-fold greater than the control values. Nonetheless, there was a generally linear response across the range of doses studied. The lowest dose tested was still quite high, being the equivalent of 275 r. These findings, which were obtained using the C1B method, were not fully consistent with the earlier C1B experimental data of Muller but more substantial, having explored a lower dose range.

In the case of Hanson the research used the C1B method with exposure to radium. In several studies Hanson did the equivalent of a dose times time ($D \times T$) experiment and found a constant outcome, supporting what he called a proportionality function. In several cases a "dose response" was explored to a limited extent via the use of two doses. In each case a linear appearing relationship occurred (Hanson and Heys 1929). In one case using radium a large number of doses were employed with a generally linear relationship being exhibited. However, even at low dose the absolute exposure levels were quite high. Other researchers have also explored the dosage issue in the years immediately after the 1927 report of Muller. Weinstein (1928), using the same methods of Muller and his C1B strain, did not show a proportionality response using two doses (24 and 48 min). In the case of Stadler (1930) with barley seed germination he claimed a linear dose response using with X-rays. This study, which used 15 doses of X-rays over a 15-fold dose range (2–30 min exposures), failed to show the linearity at the low doses. The findings would be more supportive of a threshold. The author acknowledged this observation but discounted it because "in other experiments with low dosage mutations have been found". However, no data were presented or reference cited that would permit an evaluation of this statement.

In the case of studies that addressed the shape of the dose response, the issue was not experimentally resolved by the early 1930s. The fact is that Muller's landmark papers did not support this relationship; this was also the case for the follow up studies by Weinstein and Stadler, who employed a 15 dose study. The strongest study supporting linearity was by Oliver (1930) using 5 doses. This was a stronger study than that of Weinstein but can not be directly compared to the first Muller experiment with a different fly model and the work of Stadler with plants. Even in the case of the Oliver study the lowest dose tested was very high (i.e. 275 r). Other research showing a $D \times T$ equals a constant response was not designed to test the nature of the dose response but dose equivalency, yet it was used to imply support for the linear interpretation. Despite such limited data and lack of overall consistent findings (Table 1) Muller nonetheless surprisingly and incorrectly firmly concluded that mutation frequency "is exactly proportional to the energy of the dosage absorbed. There is, then, no trace of a critical or threshold dosage beneath which the treatment is too dilute to work" (Muller 1930). According to his biographer Elof Carlson (1981), Muller maintained this same perspective nearly a decade later in this report to the Medical Research Council of Great Britain. Yet one has to wonder what Muller actually believed based on a letter to Robley Evans, an MIT professor criticizing the low dose linearity hypothesis. In his letter to Evans in 1949, Muller stated that "many of the quantities are only very roughly known even for *Drosophila*, and we are admittedly extrapolating too far in applying this to man, but it is all we can do in our present state of ignorance and we must meanwhile remain on the safe side." Such a comment strongly suggests that Muller was guided more by a precautionary public health philosophy rather than the science with respect to the extrapolation of his findings for various types of extrapolations including across species and from high to low dose. It is interesting to note that in his book on the history of genetics, Sturtevant (1965) also supported the linearity interpretation of Muller citing the research of Oliver, Standler and Hanson/Feys, neglecting the even stronger evidence of a lack of linearity and failing to address the extremely high doses used by these early investigators.

While the genetics community was nearly unanimous in their belief of low dose linearity for genetic injury, Singleton of the Brookhaven National Laboratory was one who questioned the linearity hypothesis. He reported a non-linear relationship between mutation rate and dose rate, with

Table 1 Dose response mutagenicity data at the time of linearity concept consolidation (Circa 1927–1934)

Reference		# Doses		
Supportive of linearity				
Oliver (1930)	*Drosophila*	5 doses	X-ray	Lowest dose 275 r
Hanson and Heys (1932)	*Drosophila*	2 doses	Radium	Lowest dose 6,315 r
Hanson et al. (1931)	*Drosophila*	13 doses	X-ray	Lowest dose 445 r
Timofeeff-Ressovsky et al. (1935)	*Drosophila*	5 doses	X-ray	Lowest dose 1,400 r
Timofeeff-Ressovsky et al. (1935)	*Drosophila*	5 doses	X-ray	Lowest dose 1,400 r
Not supportive of linearity				
Muller (1927, 1928) (Exp 1)	*Drosophila*	4 doses	X-ray	
Muller (1927, 1928) (Exp 2)	*Drosophila*	2 doses	X-ray	
Weinstein (1928)	*Drosophila*	2 doses	X-ray	
Hanson (1928)	*Drosophila*	2 doses	X-ray	
Hanson and Heys (1929)	*Drosophila*	2 doses	X-ray	
Stadler (1930)	Barley	15 doses	X-ray	
Serebrousky and Dubinin (1930)	*Drosophila*	3 doses	X-ray	

disproportional increases at higher doses. These data suggested the need for more than one ionization to produce a detectable effect (i.e. mutation), thus challenging the linearity at low dose concept (Singleton 1954a, b; Richter and Singleton 1955). In fact, 17 April 1955 an article in the New York Times provided the opportunity to challenge the warning of Sturtevant concerning genetic damage. Singleton stated that "there probably is a safe level of radiation, below which no genetic changes occur." According to Jolly (2003), the findings of Singleton, a well accomplished genetic researcher, were generally ignored because they were in conflict with the dominant intellectual paradigm of low dose linearity.

From tolerance to permissible dose: incorporating genetic hazards into risk assessment

In 1932, Failla prepared a memorandum to the committee in which he referred to Muller's (1927) historic paper which demonstrated that X-rays induced mutations in fruit flies. Despite the fact that X-rays were shown to cause mutations at high doses, Failla did not respond to the mutation data with particular concern at this time, suggesting low doses radiation may even be essential for life. In contrast, an unnamed committee member wrote to Taylor in 1935 suggesting a reduction in the tolerance dose from 0.1 to 0.05 r/day, based on acceptance of the cumulative nature of radiation induced genetic effects received over a very long period of time. It was thought that this letter may have come from Newell who made this identical suggestion to the committee in 1940 (Whittemore 1986).

The findings that were discussed related to the effects of X-rays on fruit flies and their extrapolation to humans. However, there was no clear consensus on how to use this new information. At the December 1938 meeting of the Committee, it was proposed to amend the paragraph on tolerance dose to read "The generally accepted tolerance dosage is taken as 10^{-5} r/s for 7 h a day. Geneticists pointed out that because of the cumulative effect of X-rays the tolerance dose should not exceed 10^{-6} r/s (Whittemore 1986, see footnote 300)". The committee then suggested several practical ways in which this change in tolerance dose could be achieved via workplace and engineering modifications. By December 1940, the proposal was modified to where there was now sufficient agreement that it could be brought to the entire Committee. The minutes of that meeting reveal that Newell made the proposal to change the tolerance dose to the 10^{-6} r/s. The committee wrote that "it was decided to include a paragraph explaining the reason for the lower tolerance dose, pointing out that under the old concept we were concerned only with injury to the bone marrow, whereas today there is sufficient evidence for us to be concerned about genetic injuries" (Whittemore 1986, see footnote 305).

This recommended value became known and discussed before the formal publication of the official committee report, being cited in professional journals (Cowie and Scheele 1941) and generating letters to Taylor from representatives of interested professional societies, such as the Radium Society (Whittemore 1986). Despite the fact that the decision to support the change had been made at a meeting of the committee, a key member of the committee had not attended the meeting, being unaware of the change. Thus, in June 1941 Failla wrote to Taylor expressing his disapproval of the decision and the scientific and technical reasons supporting his position, including his view of the

implications of the Muller mutagenicity data. While Failla appreciated the logic of the decision to reduce the tolerance dose, he was opposed to lowering it for genetic reasons. He believed that the current tolerance dose provided adequate protection from genetic damage. He specifically wrote that: "To be sure, the smaller the dose the less the genetic damage but the possible damage from 0.1 r/day is so slight that one can just as well stop at this point" (Whittemore 1986, see footnote 320). Failla was not challenging a linear/non-threshold perspective but the practically of detection).

Failla was principally concerned with the likelihood that as soon as genetic hazards became the basis for setting the tolerance dose, there would be no logical or natural stopping point short of zero. He continued by stating that: "if we bring in the genetic criteria then there is no limit at all and 0.02 r/day is just as arbitrary as 0.1 r/day." (Whittemore 1986, footnote 321). Failla may have been motivated by the fact that he oversaw radium cancer treatment at Columbia University and he believed that the new proposal would seriously affect the capacity of such treatments to be continued. This is because the technician literally had to hold a vial of radium via tweezers adjacent to the location of the tumor for prolonged periods (Whittemore 1986).

Failla challenged the committee decision by demanding proof that radiation exposure at the tolerance dose caused genetic damage in people. He specifically stated that: "I should like to see that evidence members of the Committee have in support of the new tolerance dose. I do not know of anything in the published literature which warrants the change." (Whittemore 1986, see footnote 327). In so doing, Failla shifted the burden of proof in the debate. This issue came to a head in the 29 September 1941 meeting of the Committee in Cincinnati, Ohio. While there were many issues that related to the proposed change in the tolerance dose, including legal, administration and personnel, the scientific debate focused on the uncertainty of extrapolating from fruit flies to humans and the further uncertainty over possible genetic effects seen after several generations. As for the shape of the dose response, the members agreed that no natural threshold had yet been demonstrated for mutations. In fact, they believed that Muller's research suggested the possibility of there being no threshold. The committee acknowledged that it was possible that no dose was safe from genetic injury. However, this specific point was turned around to favor the Failla position. "With regard to the genetic effects of X-rays, it was agreed that genetic effects of some order are produced from any size dose, and therefore there is a valid question as to whether a further factor of 10 is vitally important from a genetic point of view." (Whittemore 1986, see footnote 371).

It was proposed that the Committee take cognizance of the fact that genetic injury has no threshold of safety, thus placing this type of injury in a class apart from those in which a safe dosage exists. This situation was agreeable to the Committee which accepted the perspective being offered by the genetics community, that no tolerance dose exists for radiation-induced mutation. The bottom line was that the Committee simply did not have the data to justify reducing the tolerance dose. Thus, the committee revised its decision, with Failla prevailing. However, as one might suspect, there was some concern that they would be viewed as ignoring Muller's warnings. So they decided to replace the term tolerance dose with a new concept called the maximum permissible dose. It was felt that the term tolerance dose was generally thought to be one which could be tolerated without any damage; this was not believed to be the case with genetic damage, which was assumed to be cumulative. The committee thought that a dose that could be "permitted" could still injure, but only to an "acceptable" degree. It was recommended therefore that in the future the term 'permissible dose' be employed. It was to be a term that was not necessarily completely safe but one that also considered practical features. Whether the public or professionals actually appreciated the important differences between a tolerance dose and a maximally permissible dose is not clear, but it was an important change for the committee. According to Whittemore (1986), the name change was principally cosmetic as it was generally believed that a quasi-governmental recommended exposure standard, what ever the name, was a "safe" level of exposure, even if this is not what the committee intended. It should be noted that even though the committee had decided to drop the term "tolerance dose" and refer only to "permissible dose", this change in terminology was not formally published. This failure to publish the change in terminology would lead to a new debate over such terminology concerns immediately following WWII.

Post World War II: genetic concerns becoming the driving factor

The Committee did not function during World War II but reconvened soon after, acquiring the name NCRPM. In late 1946, the NCRPM created two new subcommittees, one to develop a permissible dose for external radiation and the other to derive permissible doses for radioactive emitters within the body. While the Committee did not place a high priority on addressing concerns with genetic effects prior to the war, it did so in 1947 as it was pressured by a principal funding source, the U.S. Atomic Energy Commission (AEC), to take action. In fact, the AEC requested that the NCRPM add a geneticist to the committee, specially suggesting the recent Nobel Prize winner, Hermann Muller. According to Whittemore (1986), the long term political implications of an explicit consideration of genetic hazard were probably not appreciated in 1947 since exposure stan-

dards were occupational exposure limits, rather than public health standards.

In the 1947 draft report, Failla decided that the term tolerance dose should be replaced by the term permissible dose, thereby revisiting the pre-WWII position that had been agreed upon but never formalized and published in the open literature. He asserted that the tolerance dose concept was based on two questionable assumptions. The first being that the tolerance dose concept assumes the existence of a threshold dose below which no injury is caused by radiation (it is odd that he asserted this as nearly a decade before his NCRPM committee had a much more flexible toxicological interpretation of the Tolerance Dose concept as noted above.). The second assumption is that there is no accumulation of injury even after many years of exposure. That is, it assumes there is no cumulative effect. In fact, Failla noted that experiments with animal models revealed that "there is no threshold dose or recovery in the case of certain genetic changes induced by radiation." (Whittemore 1986, see footnote 245). This led him to conclude that 'it has been recognized for some years that the concepts of tolerance dose and tolerance dose rate should be abandoned." (Whittemore 1986, see footnote 246). Rejecting the threshold concept for genetic effects, Failla stated further that "it is sounder to assume that some damage may result from exposure to ionizing radiation no matter how low the single or daily dose may be" (Whittemore 1986, see footnote 247).

Failla believed that a change in terminology would represent a shift in toxicological assumptions: that is, the maximum permissible dose would indicate the likelihood of some, but presumably, negligible injury rather than the assumption of no injury which was inherently assumed with the tolerance dose concept. The term negligible injury (e.g. one adverse effect/illness per population unit per lifetime) was not defined. Taylor forwarded the report of Failla to the AEC, with the standard unchanged despite the change in terminology with no evidence that Muller ever reviewed this preliminary report despite his membership on the committee (Whittemore 1986). Thus, early in 1948 the NCRPM reaffirmed the current limit of 0.1 r/day, within the framework of a permissible dose rather than as a tolerance dose. Less than a year latter the dose would be decreased to 0.3 rem/week, a change that occurred as an agreement amongst the U.S., Canada and Great Britain (Taylor 1971). This was a change for which the NCRPM, while conceptually agreeing to, needed to develop a supportive scientific rationale. The justification of the change in exposure standard as occurred in 1948 would not be published for 6 years, with 1954 being the official year of its reporting. The delay in the finalization has been credited to a combination of institutional factors, intellectual disputes and personality conflicts (Whittemore 1986). Strange as it may seem, the change in standard, while not official for six years, was readily leaked and a widely adopted, thus taking pressure off the Committee for finalization. This process also clearly reflected the limitation of a voluntary activity with no public accountability.

As noted above the NCRPM had long been aware of the fact that radiation exposure had the potential to cause mutation. In fact, just prior to the war, the Committee had for a brief period lowered the tolerance dose for genetic reasons. However, the only record of this temporary lowering of the tolerance dose were articles published in 1941 (Cowie and Scheele 1941; Henshaw 1941). This was the recommended standard that was opposed by Failla and the committee later reversed. When the new committee "found" these articles in the early 1950s, it was remembered more as a "misprint", than evidence of a policy shift. But in the post war era there was a new focus on genetic effects with a desire by groups such as the AEC "to include representation of the genetic viewpoint." (Whittemore 1986, see footnote 258). This concern of the AEC originated within its Advisory Committee for Biology and Medicine principally because of the fact that the workforce would now be engaged for the foreseeable future in numerous activities involving exposure to radiation and the size of this workforce would be likely to markedly increase.

In the prolonged period between the development of the new exposure standard and publication of the official NCRPM report the key intellectual challenge dealt with how to address reproductive genetic hazards induced by radiation. There was essentially no disagreement on the shape of the dose response; it was assumed however to be linear, especially at low doses. How to extrapolate the findings in insects and other models in a quantitative manner to humans was a major problem. Catcheside (1946, 1948) of Great Britain claimed an extrapolation breakthrough and a way out of this predicament. He proposed the existence of an interspecies mutational constant for the rate of induced mutation per roentgen per individual gene when adjusted for differences in lifespan as expressed in terms of the spontaneous mutation rate per generation rather than per year. In so doing, he claimed that he could predict the rate of human mutation due to radiation based on data from experimental animal studies.

Prior to WWII the key biological receptor for the radiation exposure standard was the occupationally exposed individual and the occurrence of non-genetic somatic damage. The concern with genetic damage would re-orient attention to the population gene pool as the receptor. If this were the case then it was important to know not only the dose response but also the size of the exposed population. One could also assess the impact of an occupational standard on both the individual for non-genetic somatic damage and on the population gene pool. Based on Catcheside's analysis, a 50 r lifetime exposure for the entire population

would increase the mutation rate by 2% per generation. If only a relatively small proportion (~1%) of the population would have a radiation exposure approaching the occupation standard the mutation rate would increase by only about 0.2% in the first generation, a rate that could barely, if at all, be detected, thereby making it sound acceptable. Such reasoning created a framework within which the population gene pool could be reasonably protected by the current occupational exposure standard. This perspective lead Taylor (1971) to indicate that the new standard of 0.3 r/week is one that is safe for the individual and will not reveal any discernable impact on the population for many generations.

Despite these insightful intellectual vignettes, Failla's subcommittee could still not find consensus on the matter. This led him to create a subcommittee to his subcommittee, which was composed of two eminent geneticists, Curt Stern at the University of Rochester and Hermann Muller at the University of Indiana and Nobel Prize recipient. While the two geneticists proposed an exposure value for the whole population of reproductive age (5 r for the first 30 years), Failla required them to provide a written justification (Whittemore 1986). In fact, the first draft of Failla's subcommittee had been approved by Dr. Donald Charles, a geneticist at the University of Rochester. Yet this wasn't good enough as the AEC wanted the perspective and support of Muller, not only for his prominence but also because of his publically expressed health concerns. This document was never provided by Stern and Muller, leaving the Failla justification of 1954 without the key genetics piece. Even though the genetics subcommittee failed to offer their report, the NCRPM standard contained two parts, one based on the occupation exposure and then 0.1 of that level to protect the population gene pool, that is, limiting the damage to a certain percentage increase in mutation rate over generations.

An insight into why Muller and Stern may not have completed their assignment to Failla is revealed in their separate letters to Sturtevant (Jolly 2003). Muller's letter clearly reflects his frustration with the NCRPM and its reluctance to incorporate elements of genetic risk assessment into the recommendations for their permissible exposure. Similar concerns were expressed by Stern who wrote: "In the U.S. Bureau of Standards report Muller was willing to permit 20 or 30 r total dose for a population. I was shocked and wanted it down to about 3 r if applied to millions. The outcome was that the whole section on this topic was dropped."

The NCRPM position was soon overshadowed by the NAS/NRC publication of the Biological Effects of Atomic Radiation (BEAR) Report in 1956 which affirmed that genetic mutation needed to be viewed as a public health hazard. It also introduced the concept of linearity at low dose which they applied to mutations of reproductive cells. The BEAR I report assessed mutation risk by employing the concept of doubling dose (i.e., dose of radiation that doubled the background or spontaneous rate, assuming a linear relationship at low doses). It proposed a population-based exposure level of 10 r above background to the reproductive glands. This exposure level was the geometric mean of a value proposed by Muller (20 r) and Curt Stern (5 r). In the end, the BEAR Committee report formed the basis for future radiation protection policies. Their report provided the intellectual basis that lead to the adoption of non-threshold cancer risk assessment policies for both ionizing radiation and chemical carcinogens.

The BEAR I committee was born out of the fall-out controversy and the need for an authoritative scientific assessment that was independent of the financial and political influence of the AEC. Despite this fact the committee's recommendations were broad, affecting medical as well as environmental exposures to radiation. In many respects the BEAR I Committee provided relief and opportunity for some in the genetics community who had come to believe that genetic hazards were being broadly marginalized. Jolly (2003) claimed that the genetics community saw this as their opportunity to finally get around roadblocks placed by the AEC, some in the medical community and the NCRPM, as these groups tried to down play the radiation-mutation hazard. The committee would take liberties with their charge, aggressively asserting the fundamental importance of mutation as a public health issue, its linear dose response and the need to establish population and worker exposure standards that would minimize harmful impacts on the present and future generations. The committee created an attitude that finally radiation induced damage would be seen as linear, cumulative and deleterious and that new medical practices and exposures standards would be established to protect the public.

Low dose linearity for radiation-induced cancer

Even though he was not a cancer researcher Muller was very supportive of the somatic mutation hypothesis for cancer starting with his 1927 landmark paper. This interest in the linkage of mutation and cancer continued unabated as seen in his presentation at a 1937 conference in Paris in which he advocated the study of the relationship between genetic mutation and carcinogenesis, saying that "it is but a logical step" to conclude that carcinomas, sarcomas and leukemias are causally related to radiation induced mutation (Carlson 1981).

By the late 1950s the scientific and political dynamic had changed significantly because of concern associated with radioactive fallout. The major emerging issue was no longer principally genetic mutation but somatic injury, such

as cancer, especially due to exposure to strontium-90 which could be concentrated in bone. The debate had shifted to the shape of the dose response for cancer with the underlying mechanism of somatic mutation. Interest was now focused on the current generation rather than a perspective of many generations into an unclear future. The fundamental question arising from the fall-out issue galvanized into whether or not there was a threshold for biological effects from low dose exposures. The public debate over the public health implications of radiation fall-out could probably be said to have publically can started when Sturtevant, a professor of genetics at the California Institute of Technology and President of the Pacific Division of the AAAS, gave a presidential address in 1954 challenging a recent statement of AEC Secretary Admiral Strauss (1954) that current levels of radioactive fallout would not have a public health impact.

The Strauss position was based on the 13th semiannual report to Congress in 1953 in which the AEC stated that "no person has been exposed to a harmful amount of radiation from fallout. In general, radioactivity resulting from fallout has been many times below levels which could cause any injury to human beings, animals or crops, etc. Fall-out radioactivity is far below the level which could cause a detectable increase in mutations or inheritable variations" (Jolly 2003). After his presentation at the conference Sturtevant (1954) published a paper in the journal *Science* on the topic. A key conclusion was that the frequency of mutations was believed to be directly proportional to the dosage of radiation. Thus, lacking a threshold, the implication was clear that there could be no safe exposure and that Strauss was seriously incorrect and misleading the public.

It is ironic that the AEC report which provided the basis of the Strauss statement actually supported the linearity at low dose concept but argued that the level of fallout was too low to be biologically detectable. Thus, in principle the AEC and Sturtevant were in agreement but it nonetheless lead to a major confrontation. Furthermore, in another 1953 report the AEC explicitly suggested the LNT model for Sr^{-90} induced cancer. In this report they stated that the bone-retention and radioactive properties of Sr^{-90} make it a high carcinogenic hazard; they further indicated that a given amount of exposure above the threshold (which may be zero) fixed in the bone will result in an increase in the incidence of bone cancer (AEC-World Wide Effect of Atomic Weapons: Project Sunshine 1953, p.4 as cited in Jolly 2003, p. 154). Again there was a strong basis for agreement on fundamental principles between the AEC and the genetics community.

This visible challenge to the Secretary of the AEC by Sturtevant soon raised the public health concerns of fallout to a heightened level. Of particular note was the paper of future Nobel Prize winner E. B. Lewis, a geneticist who had received his Ph.D. under the direction of Sturtevant, in the journal *Science* who made a case of radiation induced leukemias as being a linear (and not threshold) at low doses. It may be also relevant to note that Lewis may have been first introduced to the linearity at low dose concept by Clarence P. Oliver at the University of Minnesota who started him in the late 1930s on his university research with *Drosophila*. About 7 years prior to this time Oliver had been a student of Muller, demonstrating a linear dose response for X-rays as noted above. In December, 1956, Muller wrote to the NAS BEAR Genetics panel concerning a draft of the Lewis paper. Muller noted that Lewis estimated the number of new cases of leukemia induced by fall-out worldwide by the year 2000 would be 80,000 (Jolly 2003). The cancer risk assessment aspect was an important new direction since the prior debates on low dose linearity dealt principally with reproductive genetic damage. The low dose linearity concept was strongly endorsed in an accompanying editorial in *Science* by its editor-in-chief (DuShane 1957) as seen in a quote from his paper:

> "Ed Lewis shows that there is a direct linear relationship between the dose of radiation and the occurrence of leukemia. Thanks to Lewis it is now possible to calculate –within narrow limits– how many deaths from leukemia will result in any population from any increase in fallout or other source of radiation. And for the individual it is possible to calculate the probability of death from leukemia as a result of any particular dose of radiation. We are approaching the point at which it will be possible to make the phrase 'calculated risk' for radiation mean something a good deal more precise than the 'best guess'. It is apparent that the atomic dice are loaded. The percentages are against us and we ought not to play unless we must assure other victories" (DuShane 1957)

Such a statement from the editor in Chief of *Science* was as significant as it was inappropriate, being, at best, a gross overstatement of the capacity to predict risks from ionizing radiation at low doses, and even possibly wrong. Yet such comments from the editor in Chief of such a prestigious journal strengthened the position of Lewis, considerably enhancing its likelihood of being broadly accepted within scientific and governmental domains as well as by the legislature, media and general public.

The Lewis paper was crucial in the public debate over low dose linearity as it quickly lead to a major story in *Life Magazine* (10 June 1957), becoming the object of an debate on the national TV program Meet The Press (May 26, 1957-interview of Admiral Lewis Strauss, Secretary of the Atomic Energy Commission) (Lipshitz 2005), and testifying at Congressional Hearings (3 June 1957) on the topic. It

Table 2 Criticisms of the Lewis (1957) key linearity paper concerning radiation and leukemia

Atomic bomb survivors and leukemia
The doses used by Lewis (1957) were believed to be very uncertain and likely highly biased. The survivors were placed into dosage groups based on distance from the hypocenter, with considerable possibility of misclassification (Court-Brown 1958a).
While Lewis (1957) reported a linear-dose response for leukemia, Mole (1958) reported that systemic errors in the estimation of dose are generally in the same direction, implying that the dose response is actually curvilinear rather than linear at low dose. In fact, such uncertainties in dose estimates at that time prevented most investigators from over-interpreting the findings.
The data used by Lewis was "grouped" together based on distance from the hypocenter as noted above. For example, all subjects greater than 1,500 m from the hypocenter were grouped together. However, later investigators broke this group up into three more groups—> 2,500, 2,000–2,500, and 1,500–2,000 m. Only the survivors in the higher exposure group (1,500–2,000 m) displayed leukemia. Yet by grouping all three together it supported his linearity at low dose relationship. Subsequent investigators raised the possibility of their being a threshold for the leukemia response. In fact, the data could have also fit an hormetic dose response model.
Ankylosing Spondylsis (AS)
Lewis (1957) presented evidence of a linear relationship for leukemia and X-ray treatment therapy in patients with AS and then extrapolated these findings to the general public. The doses used were all high especially as compared to diagnostic assessments. In fact, in only two patients were the doses to the bone marrow less than 470 r.
There were several criticisms of this approach. These include that an adequate control group was not available (Court-Brown 1958a). Thus, the spontaneous rate of AS patients to radiation-induced leukemia was assumed to be the same as healthy people. However, there are some reasons to think that this may not be the case and that their susceptibility to radiation induced leukemia may be different than the general population.
It is necessary to know whether the susceptibility of AS patients to radiation-induced leukemia is the same as healthy people. Inflamed connective tissue is generally viewed as being considerably more sensitive to radiation-induced sarcoma than is normal tissue (Glucksmann et al. 1957). It may also be true that the physiological state of the bone marrow of AS patients may affect the capacity of radiation to induce leukemia. While speculative, these concerns should have lead to more caution in the application of a dose response in AS to the healthy general population.
Court-Brown (1958a) made several key assumptions about the latent period and that dose fractionation would not affect the course of the disease. With these assumptions they derived a linear relationship of radiation exposure with leukemia. While Court-Brown (1958a) used this approach as a working model in their paper, a subsequent paper by Court-Brown (1958b), after reading criticisms of Picho (1958), amended their views indicating that while there was still a straight line relationship, it intercepted the dose axis not at the origin but it intercepted the dose axis at 100 r, supporting the threshold response (Lamerton 1958).
This was also the case concerning leukemia and thymic enlargement in which X-ray exposure enhanced the risk of the disease. For example, Lewis indicated that the average absorbed dose to the entire lymphatic system is estimated as 100–300 rad. Using these dose estimates, Lewis developed a dose response relationship for X-rays and leukemia that would be predictive of very low dose exposures. This attempted to extrapolate very high single exposures to low doses of a chronic nature. Lamerton (1958) indicated that such studies lacked a proper control group of untreated infants with enlarged thymus glands, seriously limiting the capacity to interpret the findings.
Other areas of evaluation
The Lewis paper presented data on leukemia amongst radiologists. While this was useful in helping to establish that X-rays may cause leukemia in this group of physicians, there was no application to the issue of dose response. Therefore the data were not directly related to the issue of linear or threshold dose response relationships.

also lead to Lewis being appointed to the NCRPM and NRC committees on ionizing radiation (Lipshitz 2005) where he effectively advocated for the acceptance of linearity at low dose.

The extent to which the Lewis perspective was accepted surprised his detractors who at first dismissed his paper as seriously technically flawed with a geneticist analyzing epidemiological data and being unaware of important sampling and statistical methodological nuances (Kimball 1958). According to Mole (1958) the publication of detailed criticisms of the Lewis paper would "hardly have been worthwhile if his conclusions had not gained a wide currency as a quantitatively accurate assessment." While these papers were correct in their principal criticisms of his flawed approach to exposure estimation related to the atomic bomb survivors and in extrapolating risks of cancer to the general public from persons with various pre-existing disease conditions (Mole 1958; Lamerton 1964), they misunderstood the power of the fear of cancer on the development of a cancer risk assessment paradigm (Table 2). These events helped to establish the linearity threshold concept and the somatic mutation theory mechanism as scientifically credible and of considerable importance for the public health of the country, even though there were a number of high level researchers who disagreed with Lewis (e.g. Brues 1958; Finkel 1958; Mole 1958; Kimball 1958; Lamerton 1964).

Shortly after the publication of the Lewis paper in *Science* U.S. Congressional Hearings were initiated on the effects of radioactive fallout on humans. In some ways it was a referendum on the question of what is the nature of the dose response for radiation-induced cancer (e.g. bone cancer and leukemia as the principal concerns). While the majority of the expert testimony did not support the linear non-threshold

theory for low level long term somatic effects, the Congressional Committee left unresolved the question of whether there was a threshold or "safe" level for exposure to these cancerous endpoints (JCAE 1957). Congress renewed the debate on the issue of low dose linearity in 1959 and once again was unable to resolve this issue. However, the final summary report, while still equivocating on which model was most correct, quoted the strikingly equivocal testimony of K. Z. Morgan that only certain types of effects such as genetic mutations, leukemogenesis and life shortening were without a threshold (JCAE 1959). However, Morgan would also state that "it would be ultraconservative and at least with respect to genetic mutation, it would be incorrect to assume a linear relationship between dose and effect all the way from high chronic dose rates of 400 rad/30 years to background dose rates of about 4 rad/30 years". More hearings in 1960 by Congress lead to additional testimony by E. B. Lewis who continued to make his case for a linear hypothesis as the foundation of protection standards. The Joint Committee on Atomic Energy (JCAE) continued to meet during the 1960s (JCAE 1960a) on various aspects on the low dose fall out issue, edging progressively closer to the linear non-threshold hypothesis for low level long term effects with each succeeding series of hearings (Kathren 1996).

Sandwiched in between these initial hearings were the efforts of the NCRPM to clarify the dose response question. In addressing this issue in December of 1958 the NCRPM committee stated that "it was not possible to establish the exact character of the dose response curve. Lacking sufficient unequivocal information, the committee believes it would be desirable to take a conservative position and to assume a non-threshold linear dose response relationship" (Whittemore 1986). This effort by the NCRPM was particularly significant for several reasons. First, it created a committee of those on opposing sides of the linearity at low dose question, best seen in the personalities of E. B. Lewis and Austin Brues. This committee found a way to create an acceptable compromise, while giving plausible face-saving deniability to each leading player. The Committee got Lewis to agree that his advocacy for linearity at low dose was scientifically unconvincing at best and seriously flawed at worse. On the other hand, Brues came to accept that there was also not enough data to make a convincing argument for the threshold model. An agreement was reached that no model was scientifically superior with the available data. Consequently, the NCRPM Committee decided that as a matter of protectionist public health philosophy that the conservative linearity at low dose model should be accepted. In essence, Lewis had lost a battle but won the important policy war. The position of the NCRPM with its now cooperating antagonists on the same page was published in the journal *Science* (NCRPM 1960), with subsequent and mutually supportive testimonies at the 1960 Congressional Hearings by Lewis (1960) (see JCAE 1960b) and Brues (1960) (see JCAE 1960c). It was this policy based compromise on linearity at low dose that would have a profound influence on the actions of subsequent expert committees and regulatory agencies for the remainder of the twentieth century and first decades of the twenty-first century.

Other influential groups were also very involved in the low dose linearity debate, including the UNSCEAR (1958) which gave its version of a confusing picture, providing partial support for both a threshold or linear relationship, which lead them to conclude that either model could fit the atom bomb leukemia data. This view was quickly challenged by the NAS Committee on Pathology who supported a threshold interpretation, in contrast to the genetics committee (NAS/NRC 1959). This was followed by a report by the U.S. Federal Radiation Council (FRC) (1960) which adopted the NCRPM position as lead by Lewis and Brues, that the linear at low dose model, while not validated, provided an upper bound of risk, and should be accepted as policy. This idea that would come to be insidiously adopted throughout the reminder of the twentieth century in many countries for both radiation and chemical carcinogen risk assessment. UNSCEAR continued to assess the dose response question with subsequent reports in 1962, 1964 and 1972 indicating that even though there was considerable uncertainty with the low dose extrapolated values of the linear model, the extrapolated linear curve provided the upper limit of the estimate risk, in line with the comments of the FRC (1960) and the ICRP (1966).

While regulatory agencies and advisory groups were weighing in on the nature of the dose response in the low dose area so to were some individuals who offered views that were counter to those of linear at low dose leaders such as E. B. Lewis. For example, in the years following the Lewis paper, Lamerton (1964), in the presidential address of the British Institute of Radiology, stated that "an approach which I hope will not be taken is to extrapolate from available data at high doses on the most pessimistic assumptions possible, that is, the assumption of no threshold and linear relationship between incidence and dose, not only for genetic effects where the assumptions may well be correct, but all the possible hazards envisaged for the individual. This, for instance, was the approach of Lewis (1957) in consideration of the leukaemogenic hazard of environmental contamination arising from fall out. In this way a figure is obtained for numbers of leukaemias, bone tumors, a shortening of life span and as many other effects as one chooses, relating to a given type of radiation exposure and one would say "this is the maximum possible cost of such a procedure."

> "Such an approach is, I believe, quite wrong. The figures derived may have no relation to reality, and if

we adopted the criterion of "maximizing pessimism" as Mole has called it, for the other possible hazards of life on which our information is incomplete, such as chemical contamination of the atmosphere, tobacco smoke, consumption of saturation fats, food additives, even the effects of social changes, we should all have died many deaths by the now."

This period was characterized as one of dueling experts (Table 3), individuals of considerably high stature within the scientific community. These included the likes of multiple Nobel Prize winners on opposing sides of the question, and others with considerable experience on the topic of mutation, cancer and dose response. A limited sampling of such experts reflects a broad spectrum of perspectives. However, in general, it appears that the data to support the linearity at low dose perspective was generally viewed as lacking but the fear that it may be true was a motivating factor. It was a situation in which the science could only take one so far, allowing intuition and fear into the policy equation. This was also a time which preceded the discovery of DNA repair in the early 1960s (Setlow 1964) and the later insights into the concept of adaptive response (Samson and Cairns 1977; Olivieri et al. 1984) and how they might affect the predictions of the dose response in the low dose zone.

The issue of linearity at low dose for radiation induced cancer was occurring during the later part of the 1950s. Ironically, the Delaney "Amendment" to the 1958 Food Additives Amendment in the U.S. became law on 26 April 1958. It stated that "no additive shall be deemed to be safe if it is found to induce cancer when ingested by man or animal, or it is found, after tests which are appropriate for the evaluation of the safety of food additives, to induce cancer in man or animals". This Delaney clause was later inserted into the Color Additives Amendment of 1960, following the cranberry crisis of 1959 (White 1994). Despite their parallelism in time there was no apparent interaction between the development of a linearity at low dose methodology for radiation induced cancer and the science underpinning the decision to prevent adding carcinogens to food.

Table 3 Dueling experts—quotations

George Beadle (1957) Nobel Prize for Biology and Medicine	Are gene mutations in body cells responsible for some or all malignancies? The answer is not known. This question is important, for if gene mutation is indeed responsible, one might well expect a direct linear relation between exposure of the cells of an individual to ionizing radiation and the chance of developing a malignancy such as leukemia. A linear relation at all levels of exposure would mean that there is a real hazard seen at levels as low as those of background. Present radioactive fallout from testing of nuclear weapons is perhaps only one-tenth of background, but if the relation is linear at all levels, this would increase the incidence of malignancy by a small but real amount. On the other hand, if there is a threshold below which no effect is produced and if that threshold level is higher than background plus medical radiation plus fallout, there maybe little to worry about in their regard. Presently available data for man are insufficient to answer the question of linearity at all levels. The data are consistent with a linear relationship but are also consistent with the hypothesis that there is a threshold at low levels. (source: Caron 2003, page 30, see ref. 37; Beadle 1957)
Jacob Furth, President of the American Association for Cancer Research, and longtime researcher on leukemia	"The statement that there is no threshold injurious dose to somatic cells, and every irradiation, no matter how small will cause cancer and leukemia, as is stated by some geneticists, is mere speculation. This applies to the statement that even background irradiation is leukemogenic. The available facts allow argumentation on both sides. In my opinion, the statements that background irradiations will induce leukemia are contrary to observations and the reverse is more likely." (source: Caron 2003, page 47, see ref. 29; Furth 1957)
Dr. L. H. Hampelmann, University of Rochester	Stated that while there is a definite relationship between leukemia and radiation at high dosages, but that "the data at hand is insufficient to allow one to conclude that this relationship also holds for low-dose levels." (source: Caron 2003, page 47, see ref. 29)
Walter Selove, Chairman of the Federation of American Scientists' committee on radiation hazards and associate professor of physics at the University of Penn	He noted that the linear relationship had been demonstrated at high doses of radiation for leukemia. However, it was not certain what the nature of the dose response would be at low doses. (source: Caron 2003, page 45, see ref. 29)
EB Lewis, Cal Tech Professor, Nobel Prize Winner in 1995	"This is presumptive evidence that the relationship between incidence of induced leukemia and dose of radiation is either linear or approximately linear….these data provide no evidence for a threshold dose for the induction of leukemia." (source: Caron 2003, page 27; Lewis 1957)
AW. Kimball (1958) JNCI paper	Lewis failed to prove the linearity hypothesis because there were insufficient data "to support any conclusion about the shape of the dose-response curve, particularly in the low-dose region." (source: Caron 2003, page 56 and 57, see ref. 58; Kimball 1958)

During this period Delaney began to interact with Dr. Wilhelm Hueper, an NCI scientist, and leading expert on environmental and industrial carcinogens. Hueper offered a very strong protectionist philosophy to Delaney along with powerful credentials, thereby allowing Delaney to proceed. Since scientists were unable to define what a safe level of exposure to carcinogens may be along with not understanding their mechanisms of action, Delaney asserted that there was no risk worth taking with respect to chemical carcinogens, and that chemicals "did not have rights". In the case of radiation, there was a different concept of risk evolving which related to permissible risk that could now be estimated with the linear model. The Delaney amendment, inspired by the strong views of Hueper, were to lead to the prevention of possible exposures. The FDA would later modify the Delaney amendment to address the concept of a de mininus risk, so that carcinogens could be added to the food supply if they were estimated to have a risk less than a certain value (e.g. one in a million/lifetime), following a linearity at low dose model. Thus, in time the radiation and food additive risk perspectives converged. It should be noted that Committee 17 of the Environmental Mutagen Society (EMS) attempted to have the Delaney Amendment generalized to include chemical mutagens in the early 1970 s but failed to achieve this goal, falling back to the earlier guidance of the 1956 BEAR I committee that assessed genetic risks within the context of a doubling dose framework that was still consistent with the linearity at low dose model (Drake et al. 1975; Drake 1978).

Part 1: Conclusion

The acceptance of linearity at low dose has had a long history that is rooted in radiation-induced mutation. This article showed that in the 1930s–1950s geneticists strongly believed that the shape of the dose response for mutagens was linear, that mutagenic damage was cumulative and that it was harmful. While the evidence supporting linearity for radiation was limited and not based on low doses, the genetics community nonetheless asserted their beliefs and concerns into high level governmental deliberations, especially those sponsored by the U.S. NAS, but not limited to them. Their cause received a tremendous boost when H. J. Muller received the Nobel Prize in 1946 for his discovery of radiation induced mutations. Muller used the acclaim associated with the award to highlight his concerns about genetic damage caused by radioactive fall-out.

The concept of low dose linearity of reproductive cell mutation was endorsed by the BEAR I committee, leading to its further acceptance within the scientific and regulatory communities. The concept of low dose linearity was eventually generalized to encompass somatic genetic endpoints within the context of the somatic mutation theory based on a public health protectionist philosophy rather than a scientifically acceptable predictive dose response model. This lead to linearity at low dose becoming the framework for assessing radiation induced cancer risks.

PART 2: How EPA came to adopt linearity at low dose for chemical carcinogens

Introduction

Perhaps the most significant risk assessment decision that has been made occurred when the U.S. EPA decided that chemical carcinogens should be assumed to act in a linear at low dose manner. This critical judgment added huge costs to society via a wide range of regulations and exposure standards and created the basis for innumerable legal disputes between government, industry and other parties, all without the scientific capacity of validating whether this decision was correct or not. As far as the U.S. EPA was concerned, they took their signal on how to estimate risks following exposures to chemical carcinogens from the 1977 U.S. National Academy of Sciences (NAS) Safe Drinking Water Committee (SDWC) report, Drinking Water and Health. This NAS SDWC was established by federal legislation (i.e. Safe Drinking Water Act of 1974) in order to provide guidance to the U.S. EPA on the public health implications of contaminants in community drinking water. On the question of carcinogen risk assessment, this committee recommended a linearity at low dose approach which was adopted by the Agency, became policy, and has, for most practical considerations, remained such to the present, affecting how carcinogens were to be assessed by other U.S. federal agencies, state regulatory agencies, the legal system and many other countries.

It will be shown that the NAS SDWC report which recommended the adoption of linearity at low dose for carcinogen risk assessment was poorly documented on this most critical point, with the decision on the choice of risk assessment model being principally based on a protectionist precautionary philosophy. The suite of unifying principles supporting the decision of linearity at low dose included a mixture of testable and non-testable assumptions. In the more than 30 years since the publication of this far-reaching report each of the testable assumptions has been generally discredited and/or severely weakened. Yet there has been little regulatory response to this profoundly altered scientific landscape. This analysis suggests that while science is an inherently self-correcting discipline, that government regulatory actions, based in large part on scientific evidence, does not follow a similar self correcting process.

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EFFECTS OF COBALT-60 EXPOSURE ON HEALTH OF TAIWAN RESIDENTS SUGGEST NEW APPROACH NEEDED IN RADIATION PROTECTION

W.L. Chen □ National Yang-Ming University, 155 Li-Nong Street, Sec. 2, Pei-tou, 112 Taipei, Taiwan

Y.C. Luan, M.C. Shieh, S.T. Chen, H.T. Kung, K.L Soong, Y.C. Yeh □ Nuclear Science & Technology Association, 8F, No. 182, Sec. 2, Beisin Road, Sindian City, Taiwan

T.S. Chou, S.H. Mong, J.T. Wu, C.P. Sun □ Nuclear, Biological and Chemical Protection Society, 11F-5, 110 Cheng-Tu Road, Taipei ,Taiwan

W.P. Deng □ Institute of Biological Materials, Taipei Medical University, 250 Wu-Hsing Street, Taipei, Taiwan

M.F. Wu, M.L. Shen □ National Taiwan University, Taipei, Taiwan 10764

□ The conventional approach for radiation protection is based on the ICRP's linear, no threshold (LNT) model of radiation carcinogenesis, which implies that ionizing radiation is always harmful, no matter how small the dose. But a different approach can be derived from the observed health effects of the serendipitous contamination of 1700 apartments in Taiwan with cobalt-60 ($T_{1/2}$ = 5.3 y). This experience indicates that chronic exposure of the whole body to low-dose-rate radiation, even accumulated to a high annual dose, may be beneficial to human health. Approximately 10,000 people occupied these buildings and received an average radiation dose of 0.4 Sv, unknowingly, during a 9-20 year period. They did not suffer a higher incidence of cancer mortality, as the LNT theory would predict. On the contrary, the incidence of cancer deaths in this population was greatly reduced—to about 3 per cent of the incidence of spontaneous cancer death in the general Taiwan public. In addition, the incidence of congenital malformations was also reduced—to about 7 per cent of the incidence in the general public. These observations appear to be compatible with the radiation hormesis model. Information about this Taiwan experience should be communicated to the public worldwide to help allay its fear of radiation and create a positive impression about important radiation applications. Expenditures of many billions of dollars in nuclear reactor operation could be saved and expansion of nuclear electricity generation could be facilitated. In addition, this knowledge would encourage further investigation and implementation of very important applications of total-body, low-dose irradiation to treat and cure many illnesses, including cancer. The findings of this study are such a departure from expectations, based on ICRP criteria, that we believe that they ought to be carefully reviewed by other, independent organizations and that population data not available to the authors be provided, so that a fully qualified epidemiologically-valid analysis can be made. Many of the confounding factors that limit other studies used to date, such as the A-bomb survivors, the Mayak workers and the Chernobyl evacuees, are not present in this population exposure. It should be one of the most important events on which to base radiation protection standards.

Address correspondence to Y.C. Luan, Nuclear Science & Technology Association, 8F, No. 182, Sec. 2, Beisin Road, Sindian City, Taiwan. E-mail: nbcsoc@hotmail.com

I. INTRODUCTION

An extraordinary incident occurred 22 years ago in Taiwan. Recycled steel, accidentally contaminated with discarded cobalt-60 sources ($T_{1/2}$ = 5.3 y), was formed into construction steel for more than 180 buildings containing about 1700 apartments, and also public and private schools and small businesses, in Taipei City and nearby counties. About ten thousand people occupied these buildings for 9 to 22 years. While this construction occurred during 1982-84, most of the buildings were completed in 1983.[1, 2] In this preliminary assessment, we consider 1983 to be the first year of the incident. The radioactive state of the buildings was gradually discovered, beginning on July 31, 1992.[2] Less than 100 contaminated apartments were identified in 1992. The number increased to more than 200 in 1993; then to a total of 896 in 1995, 1206 in 1996, and 1277 in 1997. An intensive research program was conducted in 1998, and more than 1600 apartments were finally documented by the Atomic Energy Council (AEC) of Taiwan. After approximately four cobalt-60 half-lives, most of the apartments now have relatively low levels of radiation, less than 5 mSv (500 mrem) per year, and are still in use today. Half of the residents in apartments with high radiation levels have been evacuated, starting in 1996. They all lived in these buildings for at least nine years, with some staying as long as 22 years.

II. MEASUREMENT OF APARTMENT DOSE RATES

Dose-rates were measured with very accurate GM survey meters calibrated in dose-equivalent units, μSv/hr. Doses were carefully determined using an AEC procedure specifically designed for this project. For evaluating the average dose to the residents, their average occupancy time was conservatively taken as 12 hours in living rooms, 8 hours in bedrooms, and 4 hours at other locations (i.e., half of the residents assumed to be outside 8 hours/day).[1] The dose evaluations were used to classify the apartment dwellers into three cohorts, based on contamination level (average dose rate), for government remedial measures and care:[3]

- High contamination cohort (~11%): > 15 mSv/y
- Moderate contamination (~9%): 5-15
- Low contamination cohort (~80%): 1-5

III. NUMBER OF PEOPLE AFFECTED

More than 1600, who lived in apartments that were highly and moderately radioactive (dose rate > 5 mSv/y), were registered, and more than 2400, in the apartments with low radioactivity (1 to 5 mSv/y).

AEC studies, beginning in 1992, indicated that the average dose rate in 20% of the apartments was more than 5 mSv/y. Assuming the remaining 80% of the apartments had the same occupancy rate, the number in those apartments was estimated to be $1600 \times 0.8/0.2 = 6400$, giving a total of approximately 8000 residents.

A kindergarten child, who had occupied a radioactive classroom, died of leukemia in 1996, and another pupil died of leukemia in 2000. As a result, about two thousand students were registered as affected. In international symposia in Taiwan and Japan, specialists recommended increasing the number of affected people to approximately 10,000. Therefore, we used this number in this assessment.

The number of affected people is open to some discussion. The Radiation Safety and Protection Association in Taiwan (RSPAT) estimated that the total number of residents might as high as 15,000, but such a figure would include persons present in the public areas of the buildings who would have received only very short-term exposures.

IV. ESTIMATE OF DOSES IN APARTMENTS

An estimation of the integrated doses to the residents was necessary to assess the health effects of the radiation exposures. Several dose reconstruction studies have been carried out and reported in national and international journals. Some used thermo luminescent detectors (TLDs) at different positions of the body;[4] some used suspended TLDs in air;[5] some relied on TLD necklaces,[6] and some used Rondo phantoms.[7] Our evaluation used a simplified method to approximate the doses received by the residents and to modify the AEC doses, estimated by the task team from the Institute of Nuclear Energy Research (INER), with reasonable factors.

In December 1996, the AEC estimated that 20% of the residents received an annual (1996) dose in the range from 5 to 160 mSv, therefore, 80% of the residents received a dose of less than 5 mSv.[1] A crude estimate of the average 1996 dose for each cohort is:

- High cohort (~11%): $(160 + 15)/2 =$ 87.5 mSv
- Medium cohort (~9%): $(15 + 5)/2$ 10
- Low cohort (~80%): $(5 + 1)/2$ 3

Therefore, in 1996, the mean annual dose received by all the residents was about 13 mSv (i.e., $87.5 \times 0.11 + 10 \times 0.09 + 3 \times 0.80$), and the maximum dose was 160 mSv.

For the year 1983, we calculate the mean dose to be about 74 mSv and the maximum to be about 910 mSv. Adjusting the mean dose for a residency factor of 0.7 and a correction of 0.95 to TLD doses gives 49 mSv.

The individual mean dose from 1983 until 2003 was 0.40 Sv for all cohorts. For the high cohort, the mean dose was 4 Sv, with a maximum of 6 Sv, assuming half of the residents moved out in 1996. The doses are summarized in Table 1.

A detailed reconstruction of individual doses for residents of medium and low contamination apartments was recently published.[8] These reconstructed doses are several times lower than the maximal doses assessed by the AEC.

V. OBSERVED HEALTH EFFECTS

Medical Examinations

Residents with annual doses greater than 5 mSv received medical examinations in AEC contracted hospitals,[1] and those with annual doses of 1 to 5 mSv were provided examinations by the city of Taipei.[9] Residents of apartments that had normal background radiation (< 1 mSv/y) received medical examinations on request. Additionally, thirteen of the highly exposed residents were sent to Mazda Hospital in Hiroshima, Japan, to undergo the medical examination protocol conducted for the survivors of the atomic bombing.[10]

Health Effects

Although many of the residents had received quite high total doses of radiation, the medical examinations did not reveal the presence of any harmful radiation sickness syndromes—as were seen in survivors of the atomic bombing or in acutely irradiated reactor workers following the Chernobyl accident.[11, 12]

When the residents in one of the highly radioactive buildings sued the government for compensation, the concerned hospitals testified that they had no evidence that the radiation had caused any harmful effects.[1] When a kindergarten child who had attended a school with a radioactive window frame later died of leukemia and another pupil who was in a radioactive classroom also died of leukemia, the media reported the opinion of a radiation specialist that a few children were shorter in stature

TABLE 1: Annual and accumulated doses

Cohort	Number of people	Mean annual dose in first year 1983 (mSv)	1983 to 2003 individual dose (mSv)	1983 to 2003 "collective dose" (person-Sv)
High	1,100	525	4000	2,660*
Medium	900	60	420	378
Low	8,000	18	120	960
Averaged	10,000	74	600	6,000
Adjusted	10,000	49	400	4,000

*From July 1996, 50% of residents relocated.

than average and that some children showed indications of abnormal thyroids. These reports were not substantiated in our study.

Cytogenetic Damage

Because many chromosomal aberration studies were conducted on the Japanese atomic bomb survivors and on reactor workers following the Chernobyl accident, a number of chromosome aberration analyses were conducted on irradiated residents. All those who received annual dose rates greater than 15 mSv/y or accumulated doses greater than 1 Sv were asked to give a blood sample for chromosomal aberration studies. Analyses of these samples were carried out by the INER Laboratory.

No significant aberrations were observed, compared with test results of new employees of INER.[13] Reports were also published in the AEC annual R & D achievements symposium and in several international journals. The reports indicated that no chromosome changes and no dose-effect relationships were observed.[14, 15] One group of specialists, studying the residents in the Min-Sheng Villa—a highly radioactive building, found that the frequency of micronuclei formation was higher than that seen in controls and that the lymphocytes of another group of residents were different from those of the control group.[16, 17]

The interpretation of these findings is that low-dose and low-dose-rate gamma radiation from any source of radiation induces cellular changes, but there is no indication that these changes produced any adverse health effect. The overall conclusion of the AEC is that the chromosome aberration studies indicated that groups that received higher doses seemed to have lower levels of chromosome aberrations.[1]

Comparison with ICRP Models

The "collective dose" of the exposed population is approximately 4000 person-Sv. Had the exposure been short term (acute), the linear no-threshold (LNT) hypothesis of radiation carcinogenesis would predict $4000 \times 7.8 \times 10^{-2} = 312$ "stochastic" *excess* cancer fatalities, with a latency of approximately 20 years. Since it was a chronic exposure, a hypothetical risk reduction factor between 2 and 10 could be applied.[18]

From the experience of the Life Span Study (LSS) of the Radiation Effects Research Foundation (RERF), such hypothetical excess solid cancers deaths would be difficult to discern from the natural (spontaneous) cancer deaths of the residents, especially after 20 years. But *excess* leukemia deaths, which have a much shorter latency period, should be readily observable, especially among those who received a total dose greater than 1 Sv.[19] Based upon the ICRP model, 70 *excess* leukemia and solid cancers deaths would be reasonably expected after 20 years, in addition to the number of spontaneous cancer deaths. In fact, a total of only two leukemia and only five solid cancer deaths were actually

observed. The AEC did not attribute the two (child) leukemia deaths to radiation exposure.

Assuming that the exposed population has the same age distribution as the population of Taiwan in 2002, about 40% of them were in the reproductive age range, and their collective dose would be 40% × 4000 = 1600 person-Sv. For this dose, the standard ICRP model predicts that $1600 \times 1.3 \times 10^{-2}$ or 21 children with observable congenital malformations would be born, in *excess* of the usual number of children born with such hereditary defects.[18] In fact, only three children in total were born with congenital heart disease, and they are still in good condition. No other congenital malformations were observed.

In these comparisons, the health effects observed strongly contradict the predictions of the ICRP models. The actual number of cancer deaths and the actual number of congenital malformations are many times *smaller* than the numbers expected based on the natural incidence of cancer mortality and natural incidence congenital malformations (see below), whereas the ICRP models predict numbers in *excess* of the natural incidences.

Comparison of Health Effects: Exposed vs Non-Exposed

The mean cancer mortality in Taiwan during the period 1983-2002 (Figure 1) is 116 deaths per 100,000 person-years.[20] (The rising incidence is likely due to the increasing life expectancy of the population as in most modern countries.) Assuming that the cancer mortality in 2003 is the same as in 2002, the number of spontaneous cancer deaths that would be expected among the 10,000 people, over 20 years, would be 232 deaths (10,000 × 20 × 116/100,000).

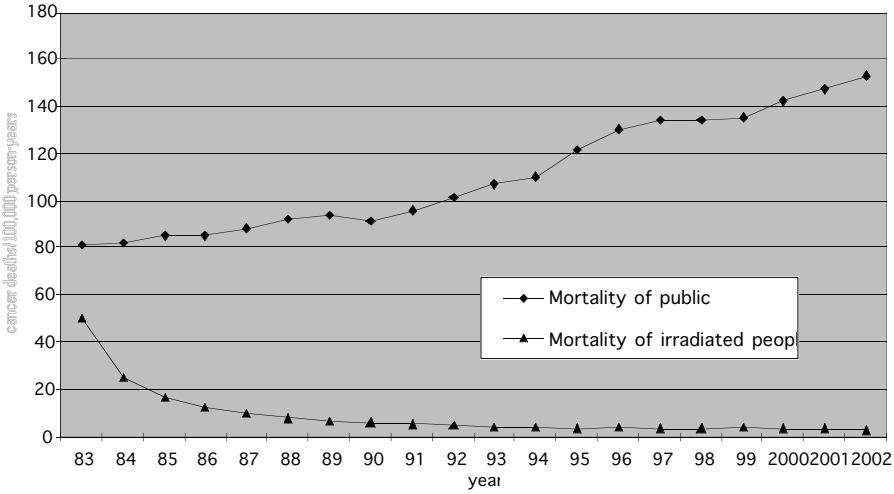

FIGURE 1. Cancer mortality of the general public and of the irradiated people

TABLE 2: The natural, predicted and observed results in 20 years

Result	No.	Notes
Natural (expected) cancer deaths	232	Includes 4-5 leukemia
Natural (expected) congenital malformations	46	All congenital diseases
ICRP model predicted cancer deaths	302	232 natural plus 70 caused by radiation
ICRP model predicted congenital malformations	67	46 natural plus 21 caused by radiation
Observed cancer deaths	7	3% of general public cancer death rate
Observed congenital malformations	3	6.5% of general public congenital disease rate

Based on the investigation conducted by the RSPAT,[10] the total number of cancer deaths among these residents is only 7 in 200,000 person-years or 3.5 deaths per 100,000 person-years—only 3% of the rate (i.e., 116) expected for the general population!

The cancer mortality rate of the exposed population is also shown in Figure 1. Both the cancer deaths and the cancer mortality rate differences have high statistical significance ($p < 0.001$). The mortality rate from all causes was not studied; only cancer mortality and congenital malformations were of interest in this population.

While there is no complete, official prevalence rate for congenital malfunctions in Taiwan, some estimates are available. Based upon partial official statistics[20] and hospital experiences described in the media, there are about 23 cases per 1000 children, including two infant deaths attributed to congenital malfunctions in 1000 births, about two cases of Down's syndrome and about 0.4 cases of cerebral palsy per 1000 children.

Assuming a population of 2,000 children under the age of 19 among the residents, an incidence of about 46 children with congenital abnormalities would be expected. Yet in fact, only three children, who are still in good condition, were observed to have congenital malformations (heart disease).[10] The congenital abnormality rate for this population appears to be only 6.5 percent of the rate for general population (3/46). This difference is also highly significant ($p < 0.001$).

Table 2 summarizes the comparisons between exposed and non-exposed populations.

VI. DISCUSSION

The results of this study strongly suggest that whole-body chronic irradiation, in the dose rate range that the apartment residents received, caused no symptomatic adverse health effects, such as radiation sickness, or the increased cancer or increased congenital disease that are predict-

ed by ICRP theories. On the contrary, those who were exposed had lower incidences of cancer mortality and congenital malformations.

In such studies, it is very important to examine the confounding factors that could possibly affect the comparisons being made between the exposed population and the general population of Taiwan. Are there qualitative differences in the two populations? Although it is a critical factor, the age distribution of the exposed population has not yet been determined, and it was assumed that the age distribution of the exposed population is the same as that of the general Taiwan population.

However, the 2000 students who were included definitely have a different distribution. Those in kindergarten are ages 3-5, and those in elementary school are 6-12. Their average cancer mortality is only 2-4 persons/100,000. They should not be included in the affected cohort, and should be subjects of a separate study. If the students are not included, the expected and predicted cancer death rates in the 8000-person cohort would be 20 percent lower than those in the 10,000 person cohort, and the number of cancer deaths would be five, as shown in Table 3. But the number of congenital malformations will remain the same because the 2000 students were not born in the affected apartments.

Another important consideration is standard of living, as this affects diet and quality of medical care. This factor was reviewed and it determined that the residents have approximately the same distribution of income as the general populace.

How can such dramatic reductions in cancer and congenital defects be explained?

Radiation scientists, medical practitioners and toxicologists have long recognized beneficial health effects from acute, whole-body exposures to low doses and from chronic exposures to low dose rates of ionizing radiation. Many scientists over the past century have studied this phenomenon of radiation hormesis. It is an adaptive response of biological organisms to low levels of radiation stress or damage—a modest overcompensation to a disruption—resulting in improved fitness. Recent assessments

TABLE 3: The natural, predicted and observed results in 20 years (students not included)

Result	No.	Notes
Natural (expected) cancer deaths	186	Includes 4-5 leukemia
Natural (expected) congenital malformations	46	All congenital diseases
ICRP model predicted cancer deaths	242	186 natural plus 56 caused by radiation
ICRP model predicted congenital malformations	67	46 natural plus 21 caused by radiation
Observed cancer deaths	5	2.7% of general public cancer death rate
Observed congenital malformations	3	6.5% of the general public congenital disease rate

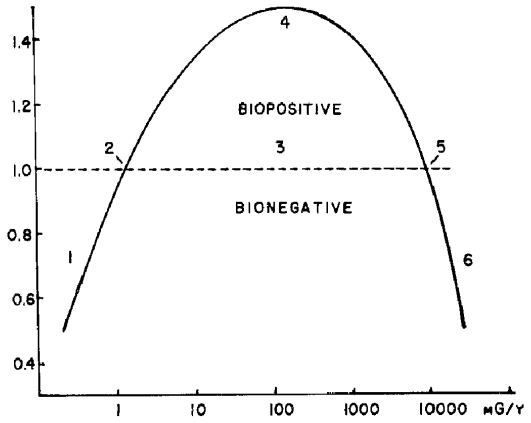

FIGURE 2. Idealized, complete dose-response curve. The ordinate indicates approximate responses compared with the controls. The abscissa suggests mammalian whole-body exposures as mGy/y. The numbered areas are: (1) deficient, (2) ambient, (3) hormetic, (4) optimum, (5) zero equivalent point, and (6) harmful.

of more than a century of data have lead to formulation of a well-founded scientific model.[21–24]

Living organisms have very capable defense mechanisms, which are significantly affected by radiation.[24] The typical, non-linear shape of the effect is shown Figure 2.[23] Unlike the adverse effects of increased rates of cancer and congenital disease associated with chronic dose rates greater than about 10 Gy/year or acute doses greater than about 0.3 Sv, which are "stochastic" and have long latency periods, the beneficial effects of low doses are typically observed very soon after the initial radiation exposure and affect all the individuals exposed. In the case of chronic exposure, significant biopositive effects are observed over a wide range of dose rate: four orders of magnitude, from 1 to 10,000 mGy/y. Hence similar beneficial effects would be expected for all three exposure cohorts. Recent studies on humans suggest that acute exposures can be employed to treat cancers and prevent metastases.[25]

The concept of beneficial health effects following any exposures to ionizing radiation is very controversial, because the LNT hypothesis of radiation carcinogenesis, which is based on the Hiroshima-Nagasaki LSS linear extrapolation to zero dose, is very well established. However, the evidence presented in this assessment is quite different than the LSS evidence and more relevant to chronic population exposures to long-lived radioactive contamination. Accordingly, an official, government-sponsored detailed epidemiological study ought to be carried out on these residents to address uncertainties arising from the assumption made in this study, and such studies have been promised.[26–28]

Methods used for dose estimation in this review are simplified. They are probably as accurate as the estimation methods used in the review of

the effects of radiation on the health of the Japanese atomic bomb survivors and of the public affected by the Chernobyl accident. In 1997, Cardarelli *et al*, estimated the doses could be up to five hundred times the natural background rate.[4] In 1998, Tung *et al*, estimated that the maximal annual dose rate in 1983 was as high as 600 mSv/y and that, in 1996, the individual doses ranged from few mSv to several Sv.[5] Even so, we believe that refined dose assessments would not significantly affect the conclusions.

VII. CONCLUSIONS AND RECOMMENDATIONS

The observation that the cancer mortality rate of the exposed population is only about 3 percent of the cancer mortality rate of the general public (2.7 percent if the student are excluded) is particularly striking and is consistent with the radiation hormesis model. This assessment suggests that chronic radiation may be a very effective prophylaxis against cancer.

The findings of this study are such a departure from those expected by ICRP criteria that it is important that they are carefully reviewed by other, independent organizations and that population data not available to the authors be provided, so that a fully qualified epidemiologically valid analysis can be made. Many of the confounding factors that limit other studies used to date, such as the A-bomb survivors, the Mayak workers and the Chernobyl evacuees, are not present in this population exposure. It could be and should be one of the most important studies on which to base radiation protection standards.

The LNT hypothesis of radiation carcinogenesis results in the notion that all exposures to any amount of radiation are potentially harmful. Because this hypothesis is very well established and because many strong radiation protection organizations are in place, scientists and government officials are very reluctant to seriously consider the implications of the radiation hormesis phenomenon, which has very important public health consequences.

The medical evidence from this exposure clearly suggests that current radiation protection policies and standards are inappropriate. We therefore recommend that the radiation protection authorities change them to accurately reflect the actual benefits and hazards of exposures to radiation. This would have very important consequences for all the nuclear risk assessments carried out and the public attitudes toward all applications of nuclear and other technologies that involve ionizing radiation. Fear of small doses of radiation is the basis for political barriers blocking the construction of nuclear power plants and nuclear waste management facilities.

Medical treatments with long-term low dose rate ionizing radiation or with acute low dose exposures could be employed to prevent and control serious illnesses with no symptomatic side effects.[25] For example, the evi-

dence suggests that an annual supplement of whole-body radiation—50 mSv in several fractionated exposures—to elderly volunteers would stimulate their defences and provide protection against the scourge of cancer. Unfortunately, physicians are generally not taught and are consequently not aware of the phenomenon and the scientific evidence. In view of the major efforts in most countries to understand cancer and find new treatments and cures, we recommend that all medical scientists pay careful attention to the results of this 20-year "serendipitous experiment" on this exposed population.

Over the past 25 years, medical and radiation biology scientists in Japan have been carrying out many studies designed to reveal both beneficial and adverse health effects of low doses of radiation on animals and humans.[29] Scientific investigations on low-dose effects have been underway in recent times in many other countries. However, in most cases, the experiments are either not designed to detect beneficial health effects or, when such effects are observed, they are ignored.[21] We recommend that radiation biologists and medical scientists pay close attention to studies that indicate evidence of hormetic effects.

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PROFILE OF THE AUTHORS

WL Chen Director, Department of Medical Radiation Technology, National Yang-ming University; Head, Radiation Protection Department of AEC, and former Head, Health Physics Division of INER

YC Luan Senior Scientist and Manager of Radiation Protection, NUSTA; consultant to NBC Society, and former Manager, Radioactive Waste Management Plant and Manager, Cobalt-60 Irradiation Plant of INER, AEC

MC Shieh General Secretary, NUSTA; Professor of National Chung-Kung University, and former Manager, Uranium Conversion Project of INER, AEC

ST Chen Senior Scientist and Head, Nuclear Reactor Engineering, NUSTA, and former Director, Nuclear Engineering Division of INER, AEC

HT Kung Senior Scientist and Nuclear Material Manager, NUSTA, and former Manager, Nuclear Fuel Fabrication Plant of INER, AEC

KL Soong Senior Scientist, NUSTA, and former Senior Scientist and Leading Scientist, Geology and Mineralogy Research Project of INER, AEC

YC Yeh Secretary General, Chinese Nuclear Society; Senior Scientist, NUSTA, and former Director, Analysis Center of INER, AEC

TS Chou Head, Radiation Research Group, NBC Society; Professor of Feng Chia University, and former Head, Chemical Engineering Division of INER, AEC

SH Mong Head, Protection Research Group, NBC Society; former NBC consultant to Saudi Arabia, and Commandant, Army NBC School, Taiwan

JT Wu Biology Consultant, NBC Protection Society, Taiwan; Professor of Pathology, School of Medicine, University of Utah, USA, and Medical Director, Special Chemistry and Reagent Development Laboratory at ARUP

CP Sun Board Member, NBC Protection Society, and Assistant Professor of Risk Analysis, National Chiao Tung University

WP Deng Associate Professor, Biological Material Institute, Taipei Medical University, and former Associate Professor, Graduate Institute of Biomedical Materials, Harvard University, USA
MF Wu Professor of Pathology and Director, Animal Testing Center, College of Medicine, National Taiwan University, Taipei
ML Shen Professor, Biometry Division, Department of Agronomy, National Taiwan University, Taipei

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THE SPECIAL RELATIONSHIP BETWEEN THE JAPANESE AND RADIATION

J. M. Cuttler

Despite being the only country to have suffered the devastating effects of nuclear bombs, Japan has embraced the peaceful use of nuclear energy to provide a substantial portion of its electricity. Prior to the March 2011 tsunami, 54 reactors accounted for about 30% of the country's total production (47.5 GWe of nuclear capacity). There were plans to increase this to 50% by 2030 because Japan has few natural resources of its own. It depends on imports for about 84% of its primary energy needs.

Both the Hiroshima and Nagasaki bombs were detonated at high altitude to avoid significant neutron irradiation of the ground, which would increase the radioactive fallout. The bombs killed between 150,000 and 200,000 of the total population of 429,000. The 1950-2020 Life Span Study on the cancer mortality of the survivors has a study cohort of 86,572 people. They are roughly half of the survivors who were within 2.5 km of target locations. It is estimated that less than 800 of the cohort will have died of radiation-induced cancer by the end of the study in 2020. There is no apparent increase in incidence of congenital malformations. (About 36,000 of the cohort were far enough away not to have received significant radiation exposure.)

After the bombing, many well-meaning scientists, disregarding the extensive knowledge and experience of the previous 60 years, invented and disseminated scares about adverse effects (higher incidence of cancer mortality and defective children) in people who are exposed to low radiation from fallout. Their objective was to stop the arms race and bomb testing. This was achieved. However, 50 more years have passed and the public is still deluded into believing the myths about the adverse health effects of low level (human-made) radiation. The psychosis of fear affects all peaceful applications of nuclear technologies, such as supply of nuclear energy, medical diagnostic scans and radiation treatments for cancer and other serious illnesses. The Japanese people who actually experienced the trauma of atom bombs are especially fearful.

Professor Don Luckey at the University of Missouri reviewed extensive radiobiological studies on a wide variety of living organisms. He published scientific papers and two remarkable books, *Hormesis with Ionizing Radiation* (CRC 1980) and *Radiation Hormesis* (CRC 1991) pointing out that low intensity radiation generally stimulates biological defences, while high radiation inhibits them. This dose-response behaviour is called hormesis (from the Greek word to excite). The first International Symposium on Radiation Hormesis was held in Oakland, California in 1985.

Meanwhile, in Japan, Dr. Kiyohiko Sakamoto's fundamental studies on the effects of low dose radiation on cancer started in 1975 with an experiment to determine the minimum dose required to suppress the immunological response. He discovered to his surprise that irradiation with a low dose, 10 to 15 cGy (rad), actually promoted immunological response. This led him to perform a series of experiments, over 12 years, that was funded by the Japanese Federal Government.

The Three Mile Island Accident occurred just before the International Congress of Radiation Research, held in Tokyo in 1979. One of the papers presented evidence of the lower incidence of lung cancer and the longer lifespan of people living in some high radiation regions of China, compared to people living in low radiation regions. This started additional Japanese research into low dose radiation health effects at 14 universities and 2 research institutes. The bio-positive effects that were studied include: cell rejuvenation, cancer treatment and prevention, stress moderation, diabetes treatment, gene repair, p53 stimulation, hypertension, radiation adaptive response, effect of radon on inflammation, immune system stimulation, A-bomb survivor health.

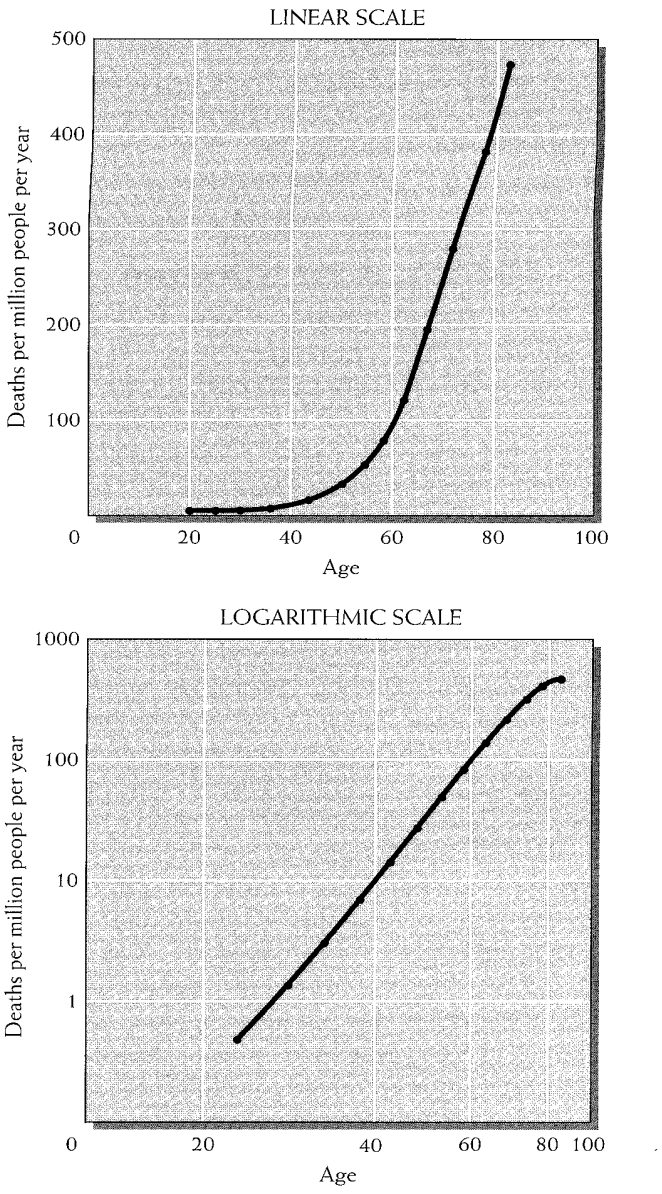
The remarkable scientific results have been and are being published in many international journals by many laboratories around the world; however, the information on beneficial effects is being generally ignored by the mainstream radiation protection community, and by the media, who are focused on radiation scares and reporting the expressions of social fear and outrage.

From the late 1970s through the 1990s, Professor Sakamoto has applied total-body or half-body low-dose irradiation treatment to ovarian cancer, non-Hodgkin's lymphoma, liver cancer, colon cancer, prostate cancer recurrence and other cancers with remarkable success, due to immune system stimulation.[1] Approximately 200 patients were treated. This form of treatment is not effective for aged patients or advanced cancer cases. Wider application in Japan is prevented by the a-bomb survivors who receive disability pensions and by physicians who believe that low dose radiation increases the risk of cancer.

[1] Sakamoto K. 2004. Radiobiological Basis for Cancer Therapy by Total or Half-body Irradiation. Nonlinearity in Biology, Toxicology, and Medicine 2:293-316. See http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2657505/

WHY IRRADIATION SELDOM LEADS TO CANCER, REGARDLESS OF DOSE

Figure 1 illustrates the dramatic increase in colon cancer mortality with age.[1] It is apparent that most cancers are due to internal causes---the progressive accumulation of endogenous mutations and the ageing of our bio-defences.



Actual annual U.S. death rate from colon cancer in relation to age, 1986.

Figure 1 - Colon cancer mortality

Since the discovery of x- rays in 1895 and radioactivity in 1896, scientists and medical practitioners have observed the generally improved condition of organisms that were exposed to low doses or low levels of these radiations, evidence of beneficial health effects. In many cases they have measured stimulation of cellular and overall system defences. They have also observed that exposures to high doses or high levels of radiation are followed by adverse health effects. Measurements have shown inhibitions of defences.

After being indoctrinated our entire lives to believe that (human-made) radiation is a serious cancer hazard---exposures to be kept as low as reasonably achievable (ALARA), it was very surprising to learn that among the more than 2000 radium dial painters who accumulated radium in their bones, no cancers were observed below an integrated alpha dose of about 1000 rad (10 Gy). Even among those dial painters who were above this high threshold, not all had cancers.

Many papers and books were published before the 1950s about curing serious infections and other diseases using a series of low dose (50 to 100 rad) irradiations. A large dose of radioiodine has been used for more than 60 years as the first-line therapy for hyperthyroidism, and three studies showed a decrease in overall cancer

[1] Varmus H and Weinberg RA. 1993. Genes and the Biology of Cancer. Scientific American Library. NY

incidence and mortality. The Canadian breast cancer study indicated about 30% lower breast cancer mortality for those TB patients whose integrated fluoroscopy exposures were in the 0.10 to 0.30 Gy range. The Life Span Study on the cancer mortality of the many Hiroshima-Nagasaki survivors reveals that the number of excess cancer deaths is remarkably low. The lower death rate in the exposed group is unexpected. Twenty-eight of the 134 firefighters at Chernobyl, who were treated for acute radiation syndrome, died within months; however, the 106 who recovered have a mortality of about 1% per year---roughly the same as the normal mortality of comparable unexposed firefighters.

Many people believe that children are especially vulnerable to ionizing radiation. Several studies have been carried out to assess the susceptibility of children to radiation-induced thyroid cancer. A CDC study estimated that between 0.5 and 2.6 million US children received nasal radium irradiation, as a standard medical practice, from 1945 through 1961 to shrink adenoids, Figure 2. The doses seem rather high, 20 Gy at contact and 2 Gy at 1 cm, from each applicator; however, the incidence of cancer deaths is remarkably low. Another study of 14,351 infants after radiotherapy for high blood vessel concentration in the skin revealed a total of 17 eventual thyroid cancer deaths. And an evaluation of seven major studies that included 58,000 exposed children could not resolve the issues. One was a study of 10,834 children who received x-ray therapy for ringworm infection of the scalp. Because of the high rate of natural occurrence of thyroid cancer, it is difficult to attribute thyroid cancers to radiation exposure.

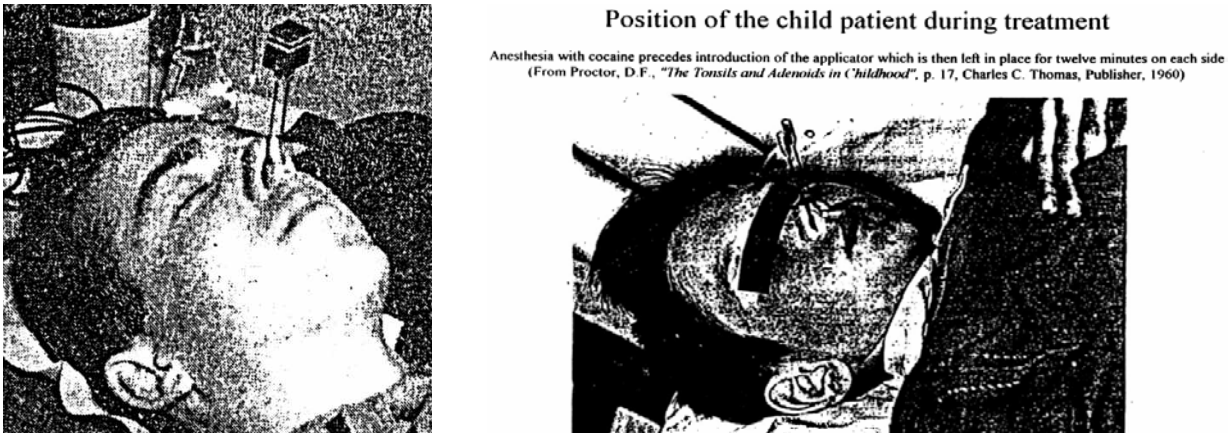


Figure 2 - US children receiving nasal radium irradiation

In the 1990s, Dr. Kiyohiko Sakamoto treated more than 200 cancer patients in Japan with total-body or half-body low dose irradiations (TB/HB LDI).[2] The dose fraction was usually 150 mGy, delivered twice each week for 5 weeks---a total of 1500 mGy (150 rad) with no symptomatic side effects. Most patients achieved long-lasting cures; however, the treatments were stopped by protests from Hiroshima-Nagasaki bomb survivors who receive disability pensions. One cancer

[2] Sakamoto K. 2004. Radiobiological Basis for Cancer Therapy by Total or Half-body Irradiation. Nonlinearity in Biology, Toxicology, and Medicine 2:293-316. See http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2657505/

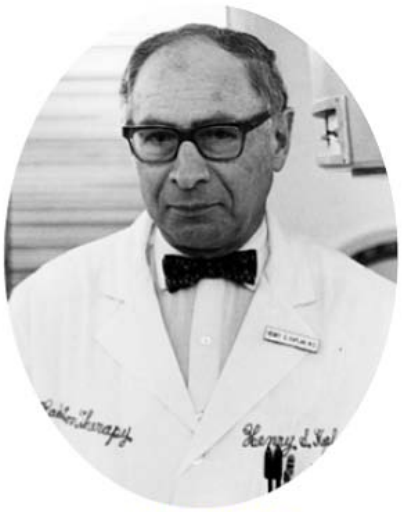
patient was given HB-LDI therapy at the Johns Hopkins Medical Center, Baltimore in 1999 and a booster in 2000. In Canada, since 2009, three cancer patients have received this treatment, one as a prophylaxis to prevent the recurrence of cancer.

Finally, there is the very important evidence of the accepted, safe radiation treatments to cancer patients following surgical removal of a tumour. A typical radiotherapy treatment gives a dose of 1 Sievert (100 rem) each day for several weeks (greater than 20,000 mSv spread over a month) to a large area of nearby healthy tissue. The organs recover by using the interval of a day to repair the radiation-induced cell damage and to remove and replace the cells not adequately repaired.

Nuclear radiation does not appear to be a significant contributor to cancer initiation in humans. It does, however, modulate our very powerful bio-defences. Low doses or low levels enhance their performance resulting in longer lifespans and lower cancer mortality. High doses or high levels have the opposite effect.

From page 195 in the book Radiation and Health, available at:
http://www.mn.uio.no/fysikk/tjenester/kunnskap/straling/radiation-health-2012.pdf

Henry Kaplan was the first one to use a linear accelerator at Stanford Hospital in San Francisco in 1957. The patient was a boy (Gordon Isaacs) that was suffering from a tumor in his eye (retinoblastoma). The treatment saved the child's sight and he lived the rest of his life with his vision intact.
Below is a picture taken during the treatment.



Henry Kaplan
(1918 – 1984)

Fifty years and about 50 million patients later, medical linear accelerators have become the backbone of radiation therapy for cancer worldwide. Roughly half of all cancer patients receive radiation therapy, primarily from the rays generated by a linear accelerator.

Jerry Cuttler April 12, 2012

DOSE-RESPONSE

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Nuclear Energy and Health

And the Benefits of Low-Dose Radiation Hormesis

Jerry M. Cuttler and Myron Pollycove

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NUCLEAR ENERGY AND HEALTH

And the Benefits of Low-Dose Radiation Hormesis

Jerry M. Cuttler □ Cuttler & Associates Inc., Mississauga, ON, Canada

Myron Pollycove □ School of Medicine, University of California San Francisco, San Francisco, CA

□ Energy needs worldwide are expected to increase for the foreseeable future, but fuel supplies are limited. Nuclear reactors could supply much of the energy demand in a safe, sustainable manner were it not for fear of potential releases of radioactivity. Such releases would likely deliver a low dose or dose rate of radiation, within the range of naturally occurring radiation, to which life is already accustomed. The key areas of concern are discussed. Studies of actual health effects, especially thyroid cancers, following exposures are assessed. Radiation hormesis is explained, pointing out that beneficial effects are expected following a low dose or dose rate because protective responses against stresses are stimulated. The notions that no amount of radiation is small enough to be harmless and that a nuclear accident could kill hundreds of thousands are challenged in light of experience: more than a century with radiation and six decades with reactors. If nuclear energy is to play a significant role in meeting future needs, regulatory authorities must examine the scientific evidence and communicate the real health effects of nuclear radiation. Negative images and implications of health risks derived by unscientific extrapolations of harmful effects of high doses must be dispelled.

Keywords: sustainable nuclear energy, radiation health effects, radiation hormesis, social acceptance, regulatory implications

INTRODUCTION

As populations grow and developing countries strive for a higher standard of living, the rate of energy consumption rises, as shown in Figure 1. By 2030, global energy demand is projected to increase by 50%, with electricity generation nearly doubling worldwide—an annual increase of 2.4% (IEA 2003, IEA 2008, DOE/EIA 2008a, 2008b). Nuclear energy is receiving much attention today because of concerns about our energy sources. Environmental groups are urging large reductions in our combustion of coal and hydrocarbons (the source of 88.6% of our primary energy) to reduce the increasing concentration of carbon dioxide in the atmosphere. While the impact of carbon dioxide emissions on global warming is controversial, the pollution from large-scale burning of coal and other fuels is generally recognized as having an adverse impact on air quality and health. Sharply rising oil and gas prices both generate and

Address correspondence to Jerry M. Cuttler, Cuttler & Associates Inc., 1781 Medallion Court, Mississauga, ON, Canada, L5J2L6; 1 416 837 8865, jerrycuttler@rogers.com

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COMMENTARY ON USING LNT FOR RADIATION PROTECTION AND RISK ASSESSMENT

Jerry M. Cuttler □ Cuttler & Associates Inc., Mississauga, ON, Canada

□ An article by Jerome Puskin attempts to justify the continued use of the linear no-threshold (LNT) assumption in radiation protection and risk assessment. In view of the substantial and increasing amount of data that contradicts this assumption; it is difficult to understand the reason for endorsing this unscientific behavior, which severely constrains nuclear energy projects and the use of CT scans in medicine. Many Japanese studies over the past 25 years have shown that low doses and low dose rates of radiation improve health in living organisms including humans. Recent studies on fruit flies have demonstrated that the original basis for the LNT notion is invalid. The Puskin article omits any mention of important reports from UNSCEAR, the NCRP and the French Academies of Science and Medicine, while citing an assessment of the Canadian breast cancer study that manipulated the data to obscure evidence of reduced breast cancer mortality following a low total dose. This commentary provides dose limits that are based on real human data, for both single and chronic radiation exposures.

Jerome Puskin's perspective on the use of the linear no-threshold (LNT) assumption for radiation protection and risk assessment (Puskin 2009) raises the question: does the U.S. Environmental Protection Agency (EPA) really protect the public or only the established worldwide practice of protecting people from radiation, which costs hundreds of billions of dollars a year? EPA exposure limits are many orders of magnitude below the levels where there is evidence of harm (Jaworowski 1999, Sanders 2010), leading to inappropriate restrictions on the use of nuclear energy to generate electricity and on the use of ionizing radiation in medicine to diagnose serious illnesses. Harmless and beneficial doses should not be regulated. Living organisms can adapt and have adapted to natural radiation, which ranges in intensity from about 0.1 to more than 70 rem per year.

The assumptions and models employed by the EPA are not based on modern biological science. The LNT assumption of radiation carcinogenesis, formulated more than 50 years ago, was originally based on experiments that were carried out on fruit flies in the mid-1920s (Muller 1954). At that time, it appeared to be reasonable for estimating cancer risk because this risk was considered to be proportional to mutation rate, which was found to be proportional to radiation dose in high dose ranges. Radiobiologists now know that organisms have defenses against

Address correspondence to Jerry M. Cuttler, Cuttler & Associates Inc., Mississauga, ON, Canada. Email: jerrycuttler@rogers.com

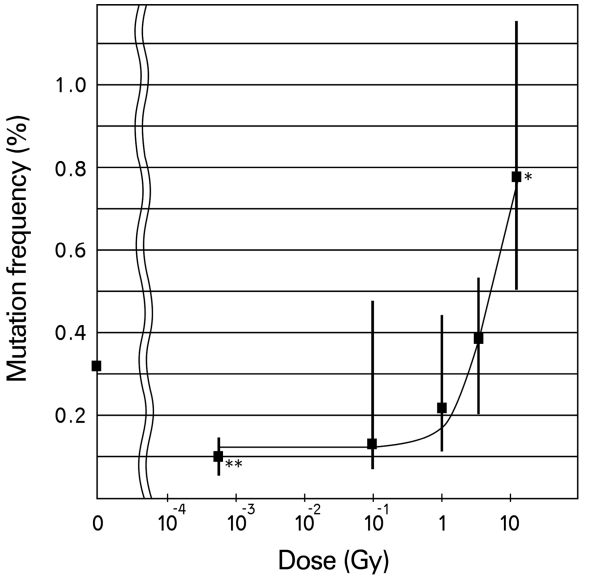

FIGURE 1

DNA damage and that these can be stimulated by low doses. Although the LNT assumption is still widely accepted, it does not reflect reality, and its continued use is causing great social harm, particularly by constraining wider use of nuclear energy and CT diagnostic scans (Scott et al. 2008).

Since the mid-1980s, the Central Research Institute of the Electric Power Industry in Japan has been carrying out remarkable studies on health effects of radiation. Their recent research has demonstrated a threshold at about 1 Gy[†] for x-ray-induced DNA mutations in fruit flies and activation of repair by low-dose irradiation, which reduced background mutation (Koana et al. 2004, Koana et al. 2007). Gamma ray irradiation of fruit flies at a dose rate of 22.4 mGy per hour reduced lethal mutation frequency below that in the control flies (Ogura et al. 2009), as shown in Figure 1. The original basis for the LNT assumption has therefore been shown to be invalid.

In selecting reports from scientific advisory bodies, the EPA appears to have omitted Scientific Annex B in UNSCEAR 1994, which assessed 192 scientific publications that provide evidence of beneficial health effects of low doses or low dose rates of radiation. The EPA also did not select the report of the French Academy of Science (Académie des sciences 1997), or the joint report of the French Academies of Medicine and Science (Tubiana et al. 2005) both of which raise doubts about the validity of the LNT hypothesis at low doses. A more recent publication in

[†]1 Gy (joules/kg) = 100 rad = 100 rem for x rays

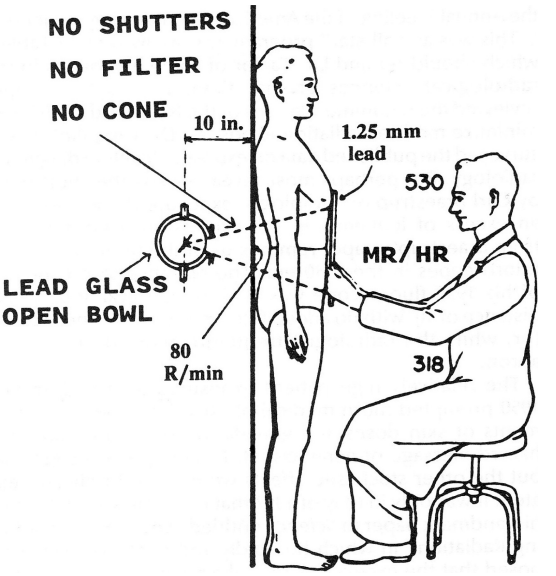

FIGURE 2

Radiology points out that the LNT relationship is inconsistent with data (Tubiana et al, 2009).

Lauriston Taylor, former president of the National Council on Radiation Protection and Measurements (Taylor 2010), denounced the use of a procedure to calculate the expected number of deaths per year resulting from x-ray diagnoses, as follows (Taylor 1980): "These are deeply immoral uses of our scientific heritage." Unfortunately, this advice was ignored when scientists assessing the Chernobyl accident projected up to 28,000 excess cancer deaths using the LNT assumption and high-dose Hiroshima-Nagasaki data (Catlin et al. 1987). "No one has been identifiably injured by radiation while working within the first numerical standards set by the ICRP in 1934 (safe dose limit: 0.2 rad per day)" (Taylor 1980). Yet members of the U.S. public are limited to 0.5 rem per *year*.

The LNT methodology, as it is generally applied by radiation protection organizations, was tested by a comprehensive study of radon levels in U.S. homes. It failed the test (Cohen 1995).

Puskin cites the Howe and McLaughlin 1996 assessment of the Canadian breast cancer study of tuberculosis (TB) patients (Miller et al. 1989) as support for the LNT model, which has been fitted to the Hiroshima-Nagasaki life span study data. However, this assessment manipulated the breast cancer mortality data in a manner that concealed the evidence of protection by low doses that Edward Webster revealed in his Lauriston S. Taylor lecture to the NCRP (Webster 1992). Figure 2 shows

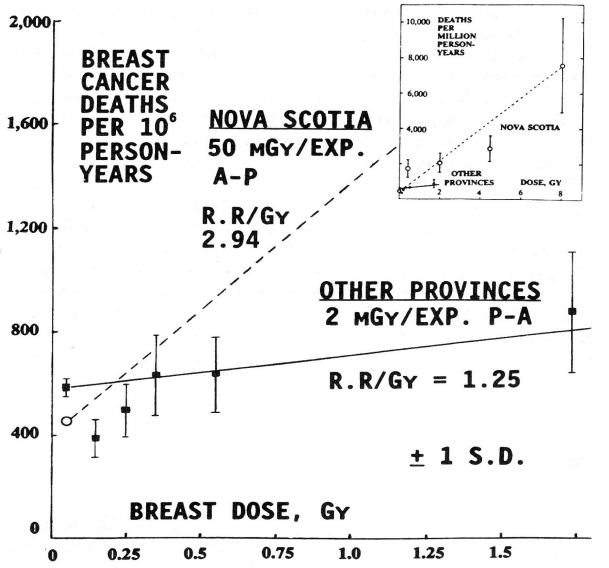

FIGURE 3

the configuration for the fluoroscopy examinations. Figure 3 is Webster's graph of the Miller et al. data for patients treated for TB between 1930 and 1952. The Nova Scotia patients received a breast dose of 50 mGy (5 rad) per exposure. The patients in the other provinces received a dose of 2 mGy per exposure. Webster fitted straight lines to the high dose data points, and he extended the lines to the breast cancer death rate of the unexposed subjects. The number of exposed subjects in the "other provinces" is 12,094, while the number of unexposed subjects is 17,557. The graph suggests that women who received a total breast dose of 0.15 Gy (15 rad) have a death rate one-third *lower* than the breast cancer death rate for unexposed women.

The Howe-McLaughlin study combined three low-dose data ranges, averaging risk over the wide dose interval 0.01 to 0.49 Gy, and thus obscured the evidence that low doses of radiation provide the benefit of reduced breast cancer mortality. This evidence is highly relevant to the risk of mammography performed repeatedly over a long period of time. This manipulation of low-dose data is one of several "tricks" that epidemiologists have been using over the years to obscure evidence of radiation hormesis (Scott et al. 2008, Scott 2008).

A recent review of nuclear energy and health (Cuttler and Pollycove 2009) concludes: "Based upon human data, a single whole body dose of 150 mSv (15 rem) is safe. The high background of 700 mSv/year (70 rem/year) in the city of Ramsar, Iran is also a safe dose limit for continuous chronic exposure. Both dose limits are also beneficial."

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WHAT BECOMES OF NUCLEAR RISK ASSESSMENT IN LIGHT OF RADIATION HORMESIS?

Jerry M. Cuttler □ Cuttler & Associates Inc., 1781 Medallion Court, Mississauga, ON L5J2L6, Canada

□ A nuclear probabilistic risk or safety assessment (PRA or PSA) is a scientific calculation that uses assumptions and models to determine the likelihood of plant or fuel repository failures and the corresponding releases of radioactivity. Estimated radiation doses to the surrounding population are linked inappropriately to risks of cancer death and congenital malformations. Even though PRAs use very pessimistic assumptions, they demonstrate that nuclear power plants and fuel repositories are very safe compared with the health risks of other generating options or other risks that people readily accept. Because of the frightening negative images and the exaggerated safety and health concerns that are communicated, many people judge nuclear risks to be unacceptable and do not favour nuclear plants. Large-scale tests and experience with nuclear accidents demonstrate that even severe accidents expose the public to only low doses of radiation, and a century of research has demonstrated that such exposures are beneficial to health. A scientific basis for this phenomenon now exists. PRAs are valuable tools for improving plant designs, but if nuclear power is to play a significant role in meeting future energy needs, we must communicate its many real benefits and dispel the negative images formed by unscientific extrapolations of harmful effects at high doses.

I. NUCLEAR RISK ASSESSMENT

Nuclear engineers calculate the likelihood of all possible accidents at a nuclear power plant and the resulting probability that people nearby might be harmed by such accidents. The discipline is called probabilistic risk or safety assessment (PRA or PSA). The best known study, completed thirty years ago, was sponsored by the NRC and directed by N. Rasmussen at MIT.[1] It was based on the method known as fault tree analysis.

The PRA starts with the initiating event and is followed by an "event tree". The first probability is the probability that event will be initiated. Then the first branch in the event tree is examined and the probability that each option will occur is entered. Then the next branch in each option is examined and the probabilities that each possibility will occur are entered, and so forth. Finally, the probabilities of the paths that lead to the accident are summed to obtain the probability of the accident.

The NRC has set the following two safety goals in terms of the probability of a human fatality:

Address correspondence to Jerry M. Cuttler, Cuttler & Associates Inc., 1781 Medallion Court, Mississauga, ON L5J2L6, Canada. E-mail: jerrycuttler@rogers.com

- The probability that a person living near a nuclear power plant will die soon after a nuclear accident from the radiation released in the accident must be less than 0.1% of the total probability that a person will be killed in any accident.
- The probability of death from cancer for any member of the public following an accident must be less than 0.1% of the total probability that a person will die of cancer from all causes.

Since the average probability per year that a person will die from all accidents is about 5×10^{-4} or one chance in 2000, the first safety goal means that the probability per year that the person living next to a nuclear plant will die soon after a nuclear accident from the radiation released in the accident must be 1000 times less, that is less than one chance in two million.

The most extensive study of reactor safety ever conducted, NUREG-1150, was completed by the NRC in 1990.[2] Five specific PWR and BWR nuclear plants were studied. The analysis was broken down into four fundamental parts:

- The frequency of core damage
- Radioactive source term inside containment
- The probability of containment failure
- Calculated off-site consequences.

For one of the plants, the average probability of core damage per year from all potential internal accident scenarios is 4×10^{-5} per year or one chance in 25,000 per year. The range of calculated probabilities (5-95% certainty) is not greater than one chance in 8000 and not less than one chance in 140,000 per year. Next the amount of radioactive material that can get out of the fuel and into containment is considered, with particular focus on iodine-131, cesium-137 and strontium-90. The next steps address the ways that radioactivity can escape or be released from containment and the off-site consequences, which depend on weather conditions, surrounding population density, the extent and timing of evacuation, and the damage to health due to exposure to the various radionuclides that reach the people. The final step links cancer risk to radiation exposure. It uses the linear, no-threshold (LNT) model of radiation carcinogenesis.

The significant results of the NUREG-1150 are:

	Surry (PWR)	Peach Bottom (BWR)	NRC Safety Goal
Average probability of an individual early fatality per year	2×10^{-8}	5×10^{-11}	5×10^{-7}
Average probability of an individual latent cancer death per year	2×10^{-9}	4×10^{-10}	2×10^{-6}

For both the PWR and the BWR, the calculated probabilities for damage to the public are far below the safety goals. These results hold for all the reactors analyzed and for the range of probabilities calculated in addition to the average results. In addition, it was determined that the likelihood per year of an accident large enough to cause at least one early fatality to the public is in the range of one in one million to one in one billion per year.

II. WHY ARE PEOPLE SO CONCERNED ABOUT NUCLEAR SAFETY?

These scientific PRA calculations show that nuclear plants are very safe and, if the "unsolved problem" of managing used nuclear fuel (above or below ground) is also considered,[3] nuclear power generation is much safer than fossil-fired generation. So why are people so concerned about the safety of nuclear power generation?

Firstly, as discussed later, the radiation protection authorities have grossly exaggerated the hazards due to low doses of radiation, in terms of congenital malformations and death from cancer, which are very negative images for public perception of nuclear technology. There is no scientific evidence to support these postulated adverse health effects in nearby populations following even worst-case accident scenarios. There is no evidence of an increase in the incidence of adverse genetic effects, even among the Japanese atom bomb survivors.[4] On the contrary, as discussed in Section V, there is recent evidence suggesting that the incidence of congenital malformations after exposure to low dose rate radiation is lower than the spontaneous incidence. As for cancer, the evidence suggests that a lower incidence of cancer mortality can be expected instead of a higher incidence. So, there is no scientific justification for the "as low as reasonably achievable" (ALARA) requirement; the radiation scare that has been created is not warranted.

Secondly, the probabilities for events and the associated radiation doses, calculated in PRAs, are much greater than are really likely to occur. Safety analysts make very conservative assumptions in creating accident scenarios, "just to be on the safe side". They do not take adequate credit for the high degree of quality and safety assurance provided by the use of nuclear standards in the design, manufacture (with nuclear-grade materials) and construction of nuclear facilities. Adequate credit is not allowed for the high standards employed in the operation, inspection and maintenance of nuclear facilities, which include upgrades due to feedback of operational experience from other facilities. Calculations of the movement of radioactivity to nearby people are pessimistic. The analysis methodologies employed are very conservative. Yet concerns are often expressed about the need to "improve" nuclear safety, which have created increased anxiety in a public that has been taught to fear any exposure to radiation. This has been recognized. Recently, an evolution-revolution

has begun in safety analysis technology to examine assumptions and conservatisms in order to model reality more accurately.[5]

Comparisons by the nuclear industry between calculated nuclear risks and other risks that people accept will not persuade the public to accept nuclear technologies because the industry continues to inform people that any amount of radiation is dangerous and that the safety of nuclear facilities has to be improved. Consequently, people make adverse judgments about the acceptability of nuclear risks, which translates into considerable public reluctance to accept nuclear generation.

III. WHAT ARE THE OBSERVED HEALTH CONSEQUENCES OF NUCLEAR ACCIDENTS?

So-called "nuclear accidents" generally do not harm people, as do automobile or airplane accidents, so better terminology is required. Consider the consequences of the 1986 Chernobyl disaster,[6, 7, 8] which is about the worst imaginable nuclear accident—well beyond the design basis of modern reactor designs. Approximately 40% of the reactor core and most of its radioactivity were released to the surroundings. The nearby population was evacuated soon after the event. These people received an average whole body radiation dose of 0.015 Gy (1.5 rad)(1 Gray = 1 joule/kg = 100 rad). Several thousand cases of operable thyroid cancer (possibly naturally-occurring occult thyroid cancers) were detected in the screening process, but no excess leukemia or other cancers were observed during the following 14 years. These data are being reviewed continually, and the new evidence continues to confirm these observations.

Psychological stress was the major adverse health effect due to fear of the potential consequences that the radiation protection authorities have been predicting. The permanent relocations have been very stressful. Throughout the world, there was widespread fear of the radioactive contamination and there were very strong social and political reactions. The economic consequences were severe in the Ukraine and somewhat less so in the neighbouring countries.

IV. EVOLUTION OF RADIATION PROTECTION RECOMMENDATIONS

For more than a century, beneficial health effects have been observed following acute exposures to small doses or chronic exposures to low dose rates of ionizing radiation.[9] Why have attitudes toward all nuclear technologies been clouded by the negative images of the risk of cancer and congenital malfunctions for the past 50 years? Even diagnostic X-ray exposures are resisted.

The early radiation protection recommendations were tailored to avoid burns and late effects from acute doses of radiation. This involved defining a safe limit for exposures (e.g., 0.2 R/d in 1934 and 0.3 R/wk in 1951). By 1955, this threshold concept was rejected by the International

Commission on Radiological Protection (ICRP) in favour of the concept of cancer and genetic risks, kept small compared with other hazards in life. "Since no radiation level higher than natural background can be regarded as absolutely 'safe', the problem is to choose a practical level that, in the light of present knowledge, involves negligible risk."[10] This change in philosophy was brought about by new biological information—epidemiological evidence of *excess* cancer malignancies among radiologists and indications of *excess* leukemia cases in the survivors of the atomic bombings at Hiroshima and Nagasaki—"stochastic effects", whose probability of occurrence, not the severity, was assumed to be proportional to the size of the dose.[10]

This is the origin of the linear, no threshold (LNT) model of radiation carcinogenesis. It derives from the hypothesis that a single impact of ionizing radiation on a cell causes an alteration, which could develop into a mutation, which could eventually become the first cancer cell in a tumor, which could cause death. The likelihood of this transformation, from a normal cell to organism death, is assumed to be proportional to dose. Following exposure to a range of high doses, statistically significant data on the number of cancer deaths in a population (the Hiroshima-Nagasaki survivors) in *excess* of the naturally-occurring (spontaneous) number expected were fitted by a straight line. It was then extended to zero dose through the low dose region, < 0.5 Gy, where there was no statistically significant evidence of adverse effects.

The LNT model for an acute exposure to low LET radiation is shown in Figure 1.[11, 12] It is still employed to calculate the excess number of cancer fatalities in a population following its exposure to a low dose from a

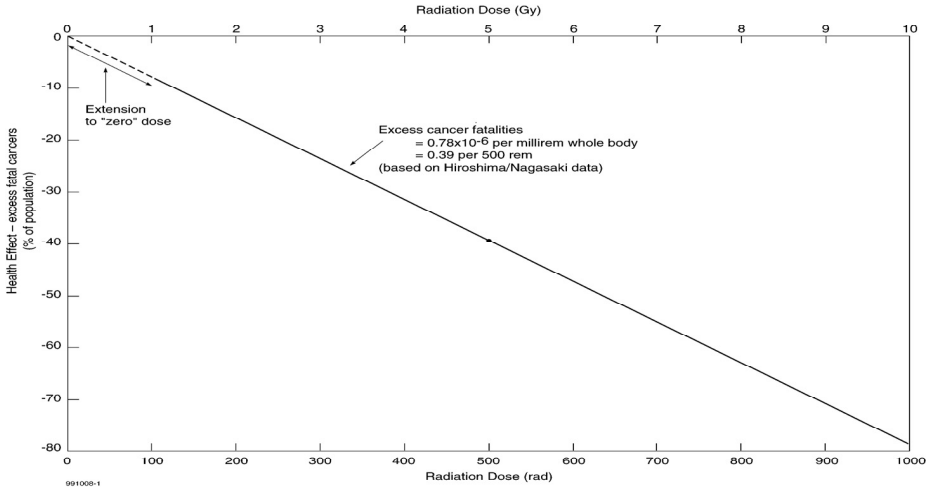

FIGURE 1. The linear, no threshold (LNT) dose-response model for low LET radiation-induced cancer[11, 12]

(human-made) source of radiation. (A risk reduction factor, in the range from 2 to 10, may be applied to the integrated dose of a chronic exposure at a low dose rate.) The increase in the average dose (above background) received by this population due to the source is evaluated. This "collective dose" is multiplied by the slope of the LNT line to predict the number of people, *in excess* of the number of spontaneous cancer deaths (about a quarter of the population), who will die from cancer. And for a person, the incremental exposure he/she received is multiplied by this factor to determine his/her increased risk of dying from cancer.

But why were the beneficial health effects, observed in prior years,[9] ignored during the 1930-50s when recommendations evolved to protect radiation workers? To understand the answer, we have to consider the social and political environment at that time. Scientists were agonizing over their roles in the development and actual use of A-bombs in war. The creation of large stockpiles of more powerful nuclear weapons in several countries raised enormous moral issues and fears about their potential use. People realized they could not "put the genie back in the bottle", and many campaigned against A-bomb development, testing and production, and for nuclear disarmament. Figure 2 is an example of the concerns that

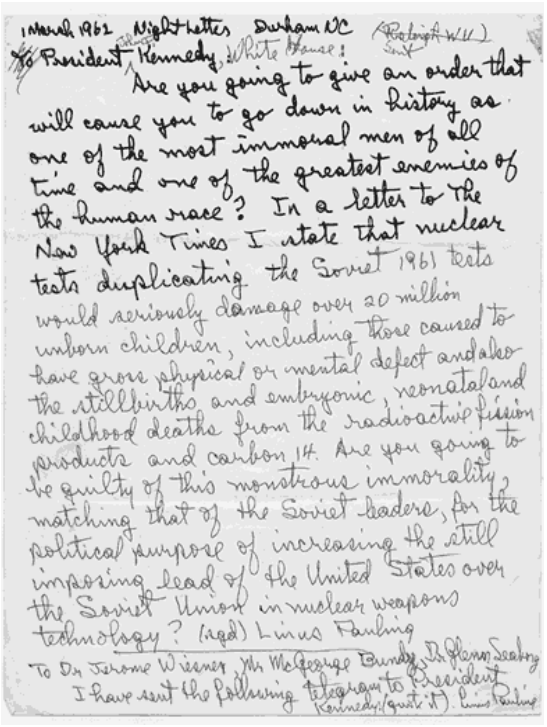
1 March 1962 Night letter Durham NC
To President Kennedy, White House:
Are you going to give an order that will cause you to go down in history as one of the most immoral men of all time and one of the greatest enemies of the human race? In a letter to the New York Times I state that nuclear tests duplicating 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 leaders, for the political purpose of increasing the still imposing lead of the United States over the Soviet Union in nuclear weapons technology? (sgd) Linus Pauling
To Dr Jerome Wiesner, Mr McGeorge Bundy, Dr Glenn Seaborg
I have sent the following telegram to President Kennedy (quote it) Linus Pauling

FIGURE 2. Professor Linus Pauling's telegram to President J.F. Kennedy, March 1, 1962[13]
After winning the Nobel Prize in Chemistry in 1953, Pauling became science's most prominent activist against nuclear weapons testing, a movement which led to the 1963 ban on above-ground testing and Pauling's Nobel Peace prize.

were expressed by some scientists and others about potential, long-term adverse health effects following exposures to very small amounts of radioactive fallout.[13]

These concerns were based on political agendas; there was (and is) no scientific basis for such statements. Once such concerns are created about small amounts of radiation, it is very difficult to change attitudes back to a scientific approach. Over the past 60 years, many research programs were carried out to study adverse biological effects, measured at high doses and extrapolated linearly to zero dose. Observations of beneficial health effects were either ignored or suppressed. The experiments were generally not designed to observe beneficial effects.[14]

V. IS THE LNT MODEL VALID?

Intensive, wide-ranging research has been carried out on the effects of radiation on living organisms, including humans.[15, 16, 17] Generally, cellular stimulatory effects are observed following low doses—short-term exposures in the range 0.01-0.50 Gy (1-50 rad)—while damaging or lethal cellular effects are observed following high doses. This biphasic radiation dose response is known as radiation hormesis, an adaptive response of biological organisms to low levels of stress or damage—a modest overcompensation to a disruption–resulting in improved fitness.[18, 19] "The hormetic model is not an exception to the rule—it is the rule."[20]

Recent discoveries indicate that oxidative DNA damage occurs naturally to living cells at an enormous rate. Survival to old age depends on the performance of a very capable damage-control biosystem, which prevents, repairs, or removes almost all the DNA alterations.[21, 22] Figure 3 illustrates the very powerful antimutagenic performance of this biosystem.[23] Those DNA alterations not eliminated by this protective system are residual mutations, a very small fraction of which eventually develops into cancer.

The rate of DNA mutations caused directly by background radiation compared with the rate produced by endogenous oxygen metabolism is extremely small. Nevertheless, radiation has a very important effect on the damage-control biosystem. While high doses decrease biosystem activity, causing increased cancer mortality, low doses stimulate biosystem activity causing lower-than-normal cancer mortality. Stimulation of the immune system increases the attack and killing of cancer cells (including metastases) globally.[24] These stimulatory effects reduce or delay significantly the incidence of cancers due to oxidative DNA damage or other causes.

The evidence of hormetic effects of radiation exposure on cancer has lead to recent applications of whole-body, low-dose irradiation therapy for cancer, with no symptomatic side effects.[25]

What about individuals who, because of their genetic makeup, are radiation sensitive and cancer prone? Research has been carried out on

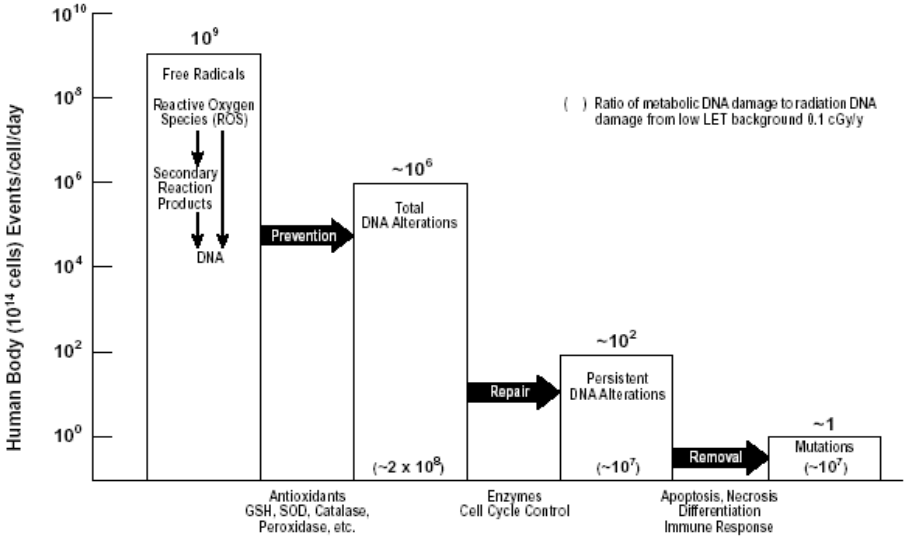

FIGURE 3. Antimutagenic DNA damage-control biosystem[23]

genetically modified mice that model such people.[26] It demonstrated that a low dose of cobalt-60 radiation affected cancer latency, reducing the rate at which spontaneously initiated cells progressed to malignancy. The effect of this adaptive response persisted for the lifespan of all the animals that developed tumors.

Even chronic exposures appear to be a very effective prophylaxis against cancer and congenital malfunctions, based on a study of about 8,000 residents who lived 9-20 years in 1700 apartments contaminated with cobalt-60 in Taiwan.[27] They unknowingly received doses, which averaged 0.4 Sv.

About 186 spontaneous cancer deaths were expected in this population, plus 56 radiation-induced deaths according to the ICRP's LNT model. But only five cancer deaths were observed (2.7% of the cancer mortality of the general population). Forty-six cases of spontaneous congenital malfunctions were expected, plus 21 radiation-induced cases according ICRP models. Only three cases (heart disease) were observed. In 1983, the average cobalt-60 dose was about 74 mGy, and the maximum was about 910 mGy. This is well inside the range of biopositive effects for chronic radiation exposure shown in Figure 4 (Figure 9.1 in Reference 16).

The conclusions regarding the health of these apartment residents, presented by the fourteen authors of this study, are preliminary because the age distribution of this population has not yet been determined. The authors assumed that it is the same as that of the general Taiwan population because these 8,000 people appear to be representative of the general population. Another important consideration is standard of living, because this affects diet and quality of medical care. This factor was

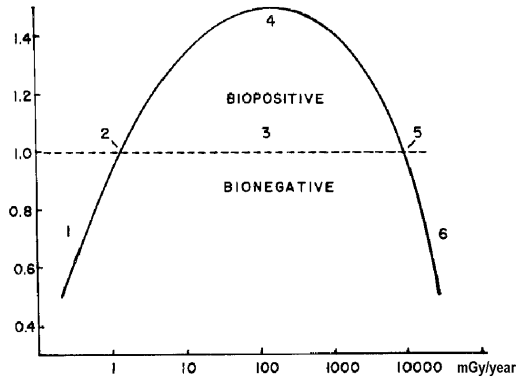

FIGURE 4. Idealized, complete dose-response curve.[16] The ordinate indicates approximate responses compared with the controls. The abscissa suggests mammalian whole-body exposures as mGy/y. The numbered areas are: (1) deficient, (2) ambient, (3) hormetic, (4) optimum, (5) zero equivalent point, and (6) harmful.

reviewed, and it was determined that the residents have approximately the same distribution of income as the general public.

The findings of this study are such a departure from those expected by ICRP criteria that it is important that they are reviewed by other independent organizations, and that population data not available to these authors be provided, so that a fully qualified, epidemiologically valid analysis can be made. Many of the confounding factors that limit other studies used to date, such as the A-bomb survivors, the Mayak workers and the Chernobyl evacuees, are not present in this population exposure. It could be and should be one of the most important studies on which to base radiation protection standards.

VI. CONCLUSIONS

Instead of dwelling on hypothetical risks of cancer from extrapolations, discussions about nuclear safety should point out the beneficial health effects of low doses of radiation. Realistic, worst-case damage to a nuclear reactor and its fuel will cause few if any deaths in the surrounding population.

The adverse health consequences of a nuclear accident that we should expect are the harmful effects that an interruption in the supply of electricity might cause and the cost to repair or replace the power plant, which could divert precious resources away from important public health-care programs. In general, there would be no need for long-term mass evacuation and the associated emotional stress that would result.

Probabilistic safety assessments should only be used to identify weaknesses in design and operation—for corrective actions to avoid power plant failures. PRAs should not be used to assess health risks because it is not ethical to scare people with frightening myths. The health consequences of

low doses of radiation are known to be beneficial, and this knowledge should be shared with the public. Precautionary measures for potential nuclear emergencies, such as mass evacuation plans and exercises, are not warranted. They would be more appropriate for natural gas explosions and releases of chemicals, which are much more of a safety concern.

If nuclear power is to play a significant role in meeting future energy needs, we must communicate its many real benefits and dispel the negative images from unscientific extrapolations of harmful effects at high dose.

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EDITORIAL: IS AIRPORT BODY-SCAN RADIATION A HEALTH RISK?

Jerry M. Cuttler □ Cuttler & Associates Inc., Mississauga, ON, Canada

> *History will remember the inhabitants of this (20th) century as the people who went from Kitty Hawk to the moon in 66 years, only to languish for the next 30 years in low Earth orbit. At the core of the risk-free society is a self-indulgent failure of nerve.*
>
> *—Buzz Aldrin, Apollo 11 astronaut*

The USA is under attack by an ideologically-driven enemy who cleverly exploits vulnerabilities in America's free society to inflict national suffering and fear. One such area is the enormous volume of airline travel. It is still an easy target, in spite of the elaborate procedures and the advanced technologies that have been employed over the years to detect highjackers and suicide bombers at the many congested airports. Luggage has been x-rayed for decades, and now passengers.

Passengers who complained about long delays and objected to careful body searches are now challenged by their fear of receiving a very mild dose of x-rays. Even medical practitioners and scientists who should know better are expressing concerns about risks of cancers and congenital malformations and about harm to a fetus.

X-rays were discovered 115 years ago by Wilhelm Roentgen and have been applied ever since on humans and a very wide variety of other biological organisms in countless research studies, diagnostic procedures and medical treatments. The doses and dose rates have ranged from the lowest possible to highly lethal levels. All organisms, since the beginning of life on Earth, have been exposed to the ubiquitous sea of natural radioactivity and cosmic radiation. As a result of our extensive studies and experience, we know more about the effects of ionizing radiation on health than any other perturbing agent or substance. Many radiobiologists understand how a low dose or a low chronic dose rate can stimulate protective processes in cells, tissues, and organs leading to improved health and that a high dose delivered at a high dose rate can inhibit natural defenses leading to morbidity and loss of life (UNSCEAR 1994; Edwards and Lloyd 1996; Tubiana *et al.* 2005).

Address correspondence to Jerry M. Cuttler, Cuttler & Associates Inc., Mississauga, ON, Canada. Email: jerrycuttler@rogers.com

The ionizing radiation dose chart in Figure 1 (Metting 2010) although not intended to be highly accurate is an excellent reflection of some of the scientific knowledge developed over the past century. The dose range spans more than six orders of magnitude. The low doses relate to medical diagnostics and to the radiation regulations and guidelines. The moderate doses pertain to space travel, the atomic bomb survivors and cancer epidemiology; the high doses to the acute radiation syndromes and to cancer radiotherapy.

Over the past forty years, many researchers have been studying important and in some cases novel bio-positive effects occurring in the range from 1 to 100 mSv when exposure is brief and over a much wider dose range when exposure is protracted (Luckey 1991; Wolf 1992; Sakai *et al.* 2003; Tubiana *et al.* 2005; Bauer 2007; Day *et al.* 2007; Feinendegen et al 2007; Liu 2007; Ogura *et al.* 2009).

Based upon human data, a single whole-body dose of 150 mSv (15 rem) is safe. The high natural radiation level of 700 mSv per year (70 rem/year), corresponding to a 70-year lifetime dose of 49 Sv in Ramsar, Iran, is also safe. Both these single and continuous doses are also beneficial (Cuttler and Pollycove 2009). This conclusion is applicable to humans of all ages and to sensitive, cancer-prone individuals.

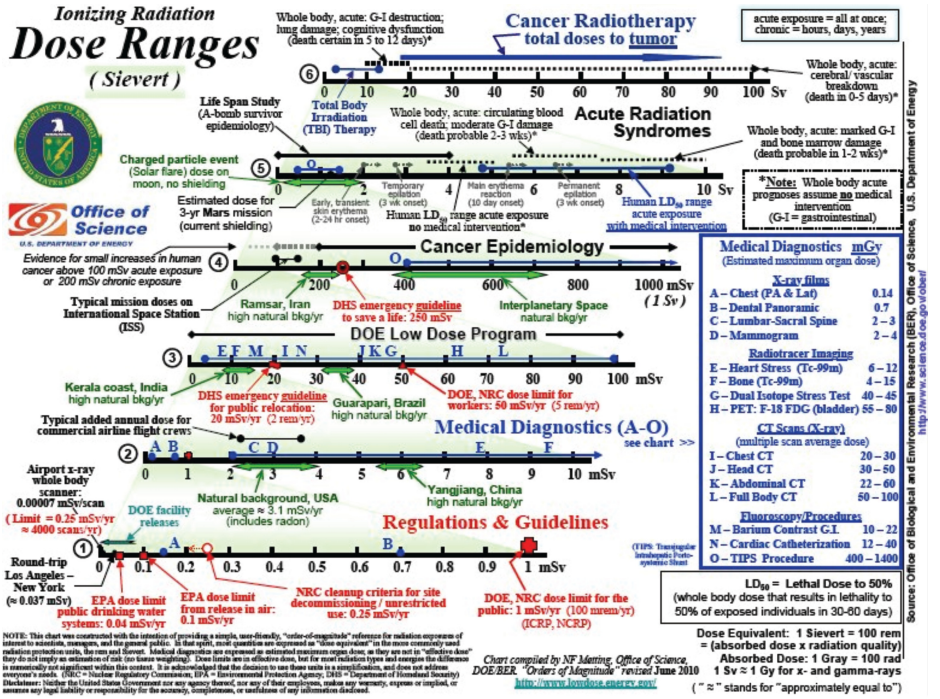

FIGURE 1. Ionizing Radiation Dose Ranges (Metting 2010)

The whole-body airport scanner employed by the U.S. Transportation Security Administration is based on an advanced imaging technology, which measures x-rays that are Compton scattered back from the surface of the passenger's body (JHU-APL 2010). Each scan takes a few seconds and irradiates a passenger with a low energy (28 kilovolt) dose of about 5 microrem (HPS 2010) or 0.05 microSv. It is three million times smaller than the safe dose of 150 mSv. How can there be any concern about possible adverse health effect? There certainly is an enormous margin to increase the dose for improved scan penetration or image quality, if required.

To understand the pervasive radiation phobia, we need to consider its origin. During the first half of the 20th century, the hazardous aspects of ionizing radiation were controlled by defining a safe limit for occupational exposures—mainly radiologists. The limit set in 1934 was 0.2 rads per day (2 mSv/day for x-rays); it was lowered in 1951 to 0.3 rads per week (or 156 mSv/year). The whole approach changed after the use of nuclear weapons to end World War II and the start of the nuclear arms race with the development, testing and production of larger and larger bombs. Strong political opposition arose against this military build-up. Related to this were thoughts about the consequences of radiation-induced damage in the cells of living organisms. Studies had been carried out on the mutation of cells in fruit flies caused by x-rays. By 1955, the safe threshold concept was arbitrarily rejected by the International Commission on Radiological Protection (ICRP) and the concept of linear no-threshold (LNT) cancer and genetic risks was accepted instead. According to this assumption, even a near-zero dose of radiation can be harmful. The science of radiation biology had thus become politicized, and with this came a very heavy economic burden of regulatory scrutiny and licensing on all the users of radiation-emitting equipment and substances.

In this new approach, a graph of excess cancer mortality versus radiation dose can be drawn for the Life Span Study cohort of the Hiroshima and Nagasaki bombing survivors. (There have been a few hundred deaths from cancer, in excess of the expected number, in the ~ 87,000 cohort.) Below a dose of about 500 mSv, the statistics are very poor. Nevertheless, a risk of excess cancer is assigned throughout the low dose range by extending a straight line from the data above 1000 mSv to zero dose. This is the LNT assumption of radiation carcinogenesis. In spite of countless and repeated studies designed to find risk, there is no statistically significant evidence of a cancer risk below a dose 100 mSv. The extensive evidence of beneficial effects in this range is disregarded or concealed (Cuttler 2010; Jaworowski 2010).

In 1959, in its first publication, the ICRP introduced for the first time a dose limit for the general population, based on LNT. Its value of 5 mSv per year was then decreased in 1990 to 1 mSv per year. This level is about

three orders of magnitude below natural radiation doses received by people living in several high natural radiation areas, where no adverse radiation effects were ever observed.

Dr. Roger Clarke, then chairman of the ICRP, stated in 2001 (Clarke 2001): "Since no radiation level higher than natural background can be regarded as absolutely 'safe,' the problem is to choose a practical level that, in the light of present knowledge, involves negligible risk." However, the ICRP has not followed this principle.

From early childhood, people have been carefully taught that ionizing radiation is dangerous and this delusion of risk has become ingrained as a "meme" over the past 50 years. It is the basis for the on-going phobia and ostensibly authoritative statements, such as, "no amount of radiation is small enough to be harmless." Radiobiologists have been studying radiation effects for more than a century, but their scientific evidence of no harm or improved health is being ignored or rejected because of the adverse indoctrination. Perhaps the social pressure to continue improving air travel security without undue hassle will lead to social awareness and acceptance of the many benefits of ionizing radiation.

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HEALTH EFFECTS OF LOW LEVEL RADIATION: WHEN WILL WE ACKNOWLEDGE THE REALITY?

J. M. Cuttler □ Cuttler & Associates Inc., Mississauga, Ontario, Canada

□ The 1986 April 26th Chernobyl event was the worst nuclear power accident—it killed 31 people. Its significance was exaggerated immensely because of the pervasive fear of ionizing radiation that has been indoctrinated in all of humanity. In reality, our environment includes radiation from natural sources, varying widely in intensity, to which all living things have adapted. The effect of radiation on organisms is primarily on their damage control biosystem, which prevents, repairs and removes cell damage. Low doses stimulate this system, while high doses inhibit it. So low doses decrease the incidences of cancer and congenital malformations; high doses have the opposite effect. Efforts by radiation protection organizations to lower exposures to (human-made) radiation to as low as reasonably achievable (ALARA) provide no benefit. They only create inappropriate fear—barriers to very important applications of nuclear technology in energy production and medicine.

Keywords: Chernobyl, radiation hormesis, LNT hypothesis

At the 20th anniversary of the Chernobyl disaster, the media commemorated the event with many stories designed to draw attention to its causes and consequences. The most important element was our fear of radiation. Did the media expose the fraud of the linear-no-threshold (LNT) hypothesis of radiation carcinogenesis (and congenital malformations)—the principal cause of this fear?

The fear stems from the common belief that any dose of radiation increases the likelihood of the dreaded diseases: cancer and congenital malformations. No one questions the fact that any dose (1 Gray = 1 joule of ionizing radiation energy per kilogram of tissue) damages cells, and that large doses of radiation are harmful. Cancer and congenital malformations are diseases of living organisms, so it is essential to study the biology of organisms to understand how these diseases arise and determine whether this fear is based on myth or reality. In plain language, the LNT hypothesis—the linear extrapolation of the incidences of these diseases from the high dose range to the low dose range—is contradicted by a very large amount of evidence that has been accumulated since the discovery of ionizing radiation, more than a century ago. Some of this evidence appears in the references listed in this paper, and it is very important that the reader examine the evidence. The scientific method requires that a hypothesis be rejected or modified if just one fact contradicts the hypoth-

Address correspondence to J. M. Cuttler, Cuttler & Associates Inc., Mississauga, Ontario, Canada. Email: jerrycuttler@rogers.com

esis. Scientific fraud occurs when this hypothesis is retained and employed, against the advice of technical societies, to predict the number of excess cancer deaths that will occur following a population exposure to radiation in the low dose range, specifically the prediction of 4000 excess cancer fatalities following the Chernobyl accident. This fraud is not only an affront to science; it is a very serious moral issue because there is a large amount of evidence, some in the references, that low doses of radiation are stimulatory. Predictions of cancer deaths and birth defects caused unnecessary suffering to many millions because their exposures were in the dose range where beneficial health effects are expected.

Radiation biologists and medical practitioners have known, since the discovery of X-rays in 1895, that low doses of radiation stimulate *all* organisms, usually resulting in beneficial health effects (Calabrese and Baldwin 2000). They also observed that high doses are harmful and defined limits (e.g., 0.2 R/d in 1934 and 0.3 R/wk in 1951) (Clarke 2001).

By 1955, the ICRP rejected this threshold concept in favour of a concept of cancer and genetic risks kept small compared with other risks in life. It assumes that no radiation level higher than natural background can be regarded as absolutely *safe*, as it continues to seek a practical level that involves negligible risk (Clarke 2001). The basis for this assumption is epidemiological evidence of excess cancer incidence among British radiologists and the survivors of the atomic bombings at Hiroshima and Nagasaki (H-N).

There is no evidence in the H-N survivors of excess congenital malformations; there is no evidence of excess cancer deaths in the dose range (0 to 0.5 Gy) (Kondo 1993). The ICRP addresses the lack of low-dose evidence by its LNT hypothesis, which extrapolates a straight line from the H-N high-dose data through the no-evidence range to zero dose. A risk reduction factor (2 to 10) is used for chronic exposures. Physics and mathematics are used, but not biology. Applying this model to calculate excess cancer deaths in large populations exposed to low doses produces alarming results.

Evidence has been presented that cancer mortality of British radiologists decreased *below* that of other physicians after dose control measures were introduced in 1920 (Smith and Doll 1981; Berrington et al. 2001; Cameron 2002). Evidence has been presented that cancer mortality of the H-N survivors is *lower* than unexposed groups (Kondo 1993). And many thousands of scientific publications provide evidence of improved health and *reduced* risk of cancer and congenital malformations following low-dose exposures (Calabrese and Baldwin 2000; Kondo 1993; Luckey 1991; UNSCEAR 1994; Liu et al. 1987; Liu 2003; Makinodan and James 1990; Sponsler and Cameron 2005; Mitchel 2007; Feinendegen 2005). There is no evidence that an acute exposure below 0.1 Gy increases risk (HPS 2001; Jaworowski 2004; French Academy of Sciences – French

National Academy of Medicine 2005). The ICRP appears to disregard the on-going accumulation of evidence that contradicts the LNT model, as it advocates a precautionary approach to avoid exposure to any amount of radiation.

Many scientists support this attitude. Physicians are taught the LNT ideology, and they advise their patients accordingly. High doses of radiation to destroy tumor cells are acceptable, however low doses to prevent, detect or cure serious diseases (Pollycove 2007) are shunned because of fear of the hypothetical risks. Government authorities follow "international standards", that is, the ICRP recommendations of ever-tightening dose constraints. Extreme preparedness measures increase public fears of radiation, relative to other commonplace hazards that are more dangerous. This fuels the radiation scare and makes society more vulnerable to the threat of terrorist "dirty bombs". It has become very difficult to change perceptions about radiation.

What is the basis for this unscientific behaviour? The phenomenon of low dose stimulation and high dose inhibition (hormesis) has been known from the late 1800s; however it fell into disrepute because of its early and close association with the controversial medical practice of homeopathy (Calabrese 2005). The LNT hypothesis appeared soon after the H-N bombing, at a time when many scientists were agonizing over their roles in developing the A-bomb. There was intense political activity

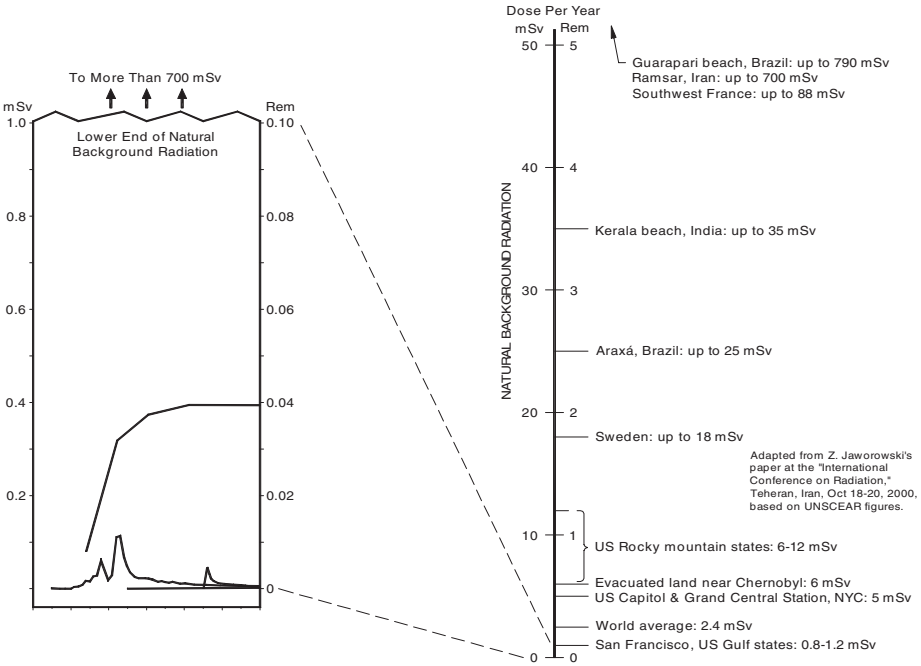

FIGURE 1. Comparing average annual dose: natural versus human-made radiation (Rockwell 2003)

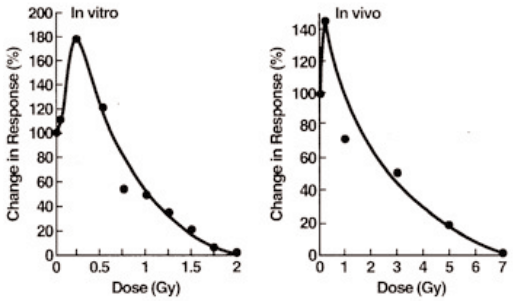

FIGURE 2. Immune system response to radiation. Mouse splenic cells primed with antigenic sheep red blood cells (Mackinodan and James 1990)

to stop bomb development, testing and production. Greatly exaggerating the consequences of exposure to low doses of (human-made) radiation "fallout" (Figure 1) was understandable and did produce the desired results (Jaffe 2003). International agreements and controls were established, which resulted in major reductions of stockpiles and risks of nuclear weapons proliferation. Having achieved this very important political objective in the 1960s, one might have expected the reality of the biology to eventually become public knowledge. However, the deception continued for the rest of the 20th century, and it continues into the 21st century in spite of the mounting evidence and the improved understanding of radiation biology (Figures 2 and 3).

The anti-nuclear activity has expanded to encompass opposition to nuclear energy and nuclear medicine (Cuttler 2007; Cuttler and Pollycove 2003). The economic, environmental and political dimensions of what is happening are very significant. Arising in the 1970s, environmental ideologies have become a dominant influence in society. Naïve

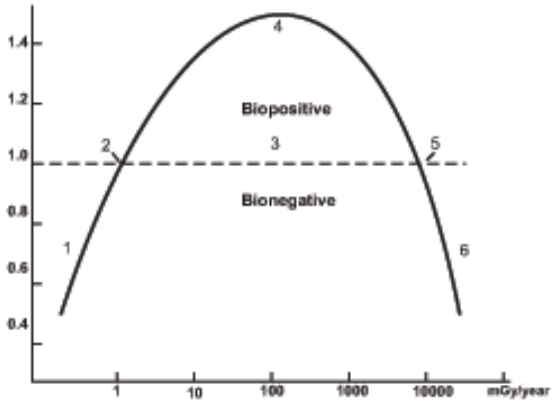

FIGURE 3. Idealized, complete dose-response curve (Luckey 1991). The ordinate indicates approximate responses compared with the controls. The abscissa suggests mammalian whole-body exposures as mGy/year. The numbered areas are: (1) deficient, (2) ambient, (3) hormetic, (4) optimum, (5) zero equivalent point, and (6) harmful.

scientists cannot fathom why environmentalists oppose nuclear energy, which produces relatively small amounts of "waste" that are well managed (and can be recycled). A prime concern is exposure risk to low level radiation, after many thousands of years.

By far the greatest exposure to low level radiation is radon gas from natural uranium in the environment. A scientific test of the LNT model, as normally used, disproved the hypothesis—cancer mortality *decreases* as radon concentration increases (Cohen 1995). Instead of discarding (or modifying) the LNT hypothesis, defenders of the hypothesis criticized the test, and the authorities continue to accept ICRP recommendations (Tubiana 2006).

Scientists are not satisfied with data; they want an explanation of the mechanism of the radiation hormesis dose-response relationship. Pollycove and Feinendegen (2003) have provided this. For more than 15 years, biologists have known that the greatest cause of cell damage (many orders of magnitude greater than any other cause) is the normal oxygen metabolism. The air we breathe damages our cells. All living organisms have a very powerful damage control biosystem that prevents, repairs and removes cell damage, or they could not exist. A low dose of radiation (0.001 to 0.3 Gy) produces a small amount of damage. This triggers increased damage control system activity, which deals not only with the trivial radiation damage, but *also* with the much larger endogenous cell damage, resulting in *less* cancer overall. Hormesis is overcompensation to a disruption in homeostasis. Conversely, a high dose of radiation decreases the activity of this biosystem (more cancer). It is the effect of the radiation on the damage control biosystem that determines the response. The cell damage caused by the radiation is not important.

The recent Chernobyl Forum (IAEA 2005) determined that:

- 31 reactor staff and emergency workers died (28 of them from high radiation within four months after the accident)
- another 19 of the 106 who recovered from high acute radiation exposure died of liver cirrhosis, emphysema, etc., during the following 18 years (conforms to *normal* mortality of ~1%/yr)
- the surrounding population and most of the cleanup workers received doses comparable to doses many people receive from background radiation
- 4000 excess cancer deaths are expected (based on the LNT model)
- no radiation-induced increase in mortality occurred
- 4000 cases of thyroid cancer were identified in the screening begun immediately after the accident; nine deaths.

Dr. Theodore Rockwell pointed out in his launch of The Realism Project (Rockwell 2004) that the nuclear community agonizes over its

inability to communicate its message to the public, but it cannot overcome a basic problem. "Our credibility is continually undermined by ostensibly authoritative statements that no amount of radiation is small enough to be harmless and that a nuclear casualty could kill as many as hundreds of thousands of people. *That* message we *have* communicated, and therefore the public and the media are not wholly to blame for the resulting public fear of radiation and all things nuclear. We cannot expect people to believe our assurances of safety so long as we acquiesce in terrifying messages to the contrary.... Although the case is persuasive that the worst realistic nuclear casualty is less harmful than that of nuclear power's serious competitors, the evidence has not yet been assembled into an overall documented statement and evaluation.... The action urgently needed now is to prepare the case, and then discuss it within our own ranks.... Until that happens, the status quo will prevail."

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SHIFTING THE PARADIGM IN RADIATION SAFETY

Mohan Doss □ Fox Chase Cancer Center

□ The current radiation safety paradigm using the linear no-threshold (LNT) model is based on the premise that even the smallest amount of radiation may cause mutations increasing the risk of cancer. Autopsy studies have shown that the presence of cancer cells is not a decisive factor in the occurrence of clinical cancer. On the other hand, suppression of immune system more than doubles the cancer risk in organ transplant patients, indicating its key role in keeping occult cancers in check. Low dose radiation (LDR) elevates immune response, and so it may reduce rather than increase the risk of cancer. LNT model pays exclusive attention to DNA damage, which is not a decisive factor, and completely ignores immune system response, which is an important factor, and so is not scientifically justifiable. By not recognizing the importance of the immune system in cancer, and not exploring exercise intervention, the current paradigm may have missed an opportunity to reduce cancer deaths among atomic bomb survivors. Increased antioxidants from LDR may reduce aging-related non-cancer diseases since oxidative damage is implicated in these. A paradigm shift is warranted to reduce further casualties, reduce fear of LDR, and enable investigation of potential beneficial applications of LDR.

Keywords: Radiation safety, Low dose radiation, LNT model, Immune system, Antioxidant stimulation, Aging-related diseases

INTRODUCTION

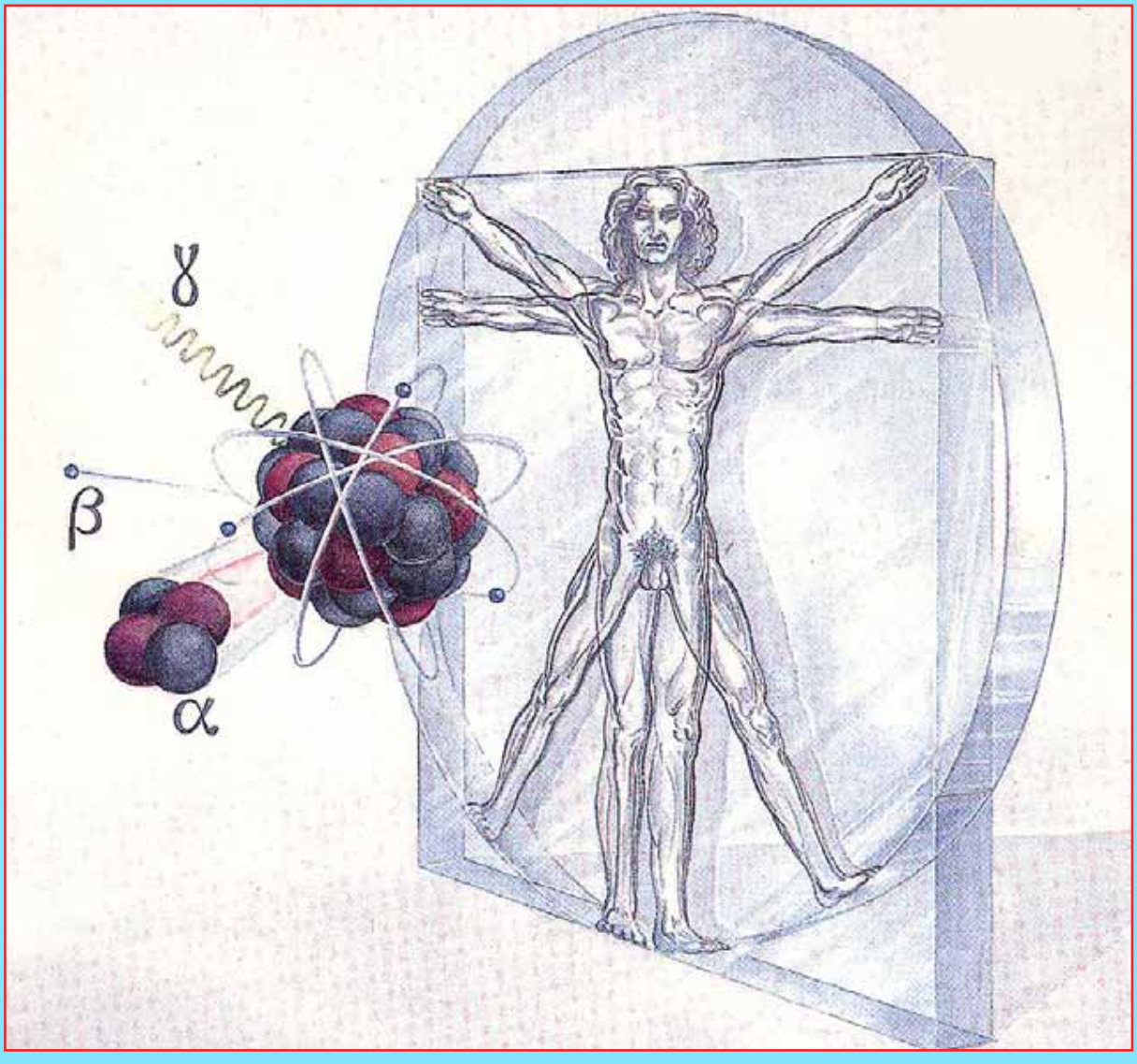
Whereas the carcinogenic nature of high dose radiation is well established, the health effects of low dose radiation are still being debated. The current radiation safety paradigm is based on the linear no-threshold (LNT) premise that even the smallest amount of radiation may cause DNA damage and mutations increasing the risk of cancer. An analysis of the historical foundation of the LNT model shows that the no-threshold model was adopted in the 1950s due to carcinogenic concerns following the observation of excess leukemias in atomic bomb survivors, but without much supporting data at low doses since most of the radiobiological data available at the time was for high doses, e.g. observed increase in leukemias in atomic bomb survivors and observed increase in mutations in drosophila subjected to radiation (Calabrese, 2009). The decision to adopt the LNT model may also have been influenced by the political movements of that time period to stop the development of nuclear weapons (Jaworowski, 2010b). Recent measurements have shown a U-shaped dose response curve for X-ray induced mutations in drosophila

Address correspondence to Mohan Doss, Diagnostic Imaging, Fox Chase Cancer Center, 333 Cottman Avenue, Philadelphia, PA 19111; Phone: 215 214-1707; E-mail: mohan.doss@fccc.edu

http://www.mn.uio.no/fysikk/tjenester/kunnskap/straling/radiation-health-2012.pdf

Radiation and Health

by
Thormod Henriksen
and
Biophysics group at UiO



Preface

The present book is an update and extension of three previous books from groups of scientists at the University of Oslo. The books are:

I. Radioaktivitet – Stråling – Helse

Written by; Thormod Henriksen, Finn Ingebretsen, Anders Storruste and Erling Stranden.
Universitetsforlaget AS 1987
ISBN 82-00-03339-2

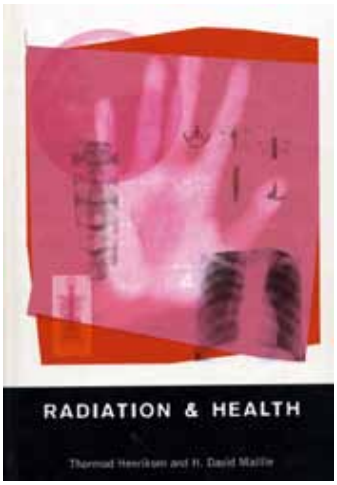
I would like to thank my coauthors for all discussions and for all the data used in this book. The book was released only a few months after the Chernobyl accident.

II. Stråling og Helse

Written by Thormod Henriksen, Finn Ingebretsen, Anders Storruste, Terje Strand, Tove Svendby and Per Wethe.
Institute of Physics, University of Oslo 1993 and 1995
ISBN 82-992073-2-0

This book was an update of the book above. It has been used in several courses at The University of Oslo. Furthermore, the book was again updated in 1998 and published on the Internet.
The address is: http://www.mn.uio.no/fysikk/tjenester/kunnskap/straling/

III. Radiation and Health



Written by Thormod Henriksen and H. David Maillie
Taylor & Francis 2003
ISBN 0-415-27162-2

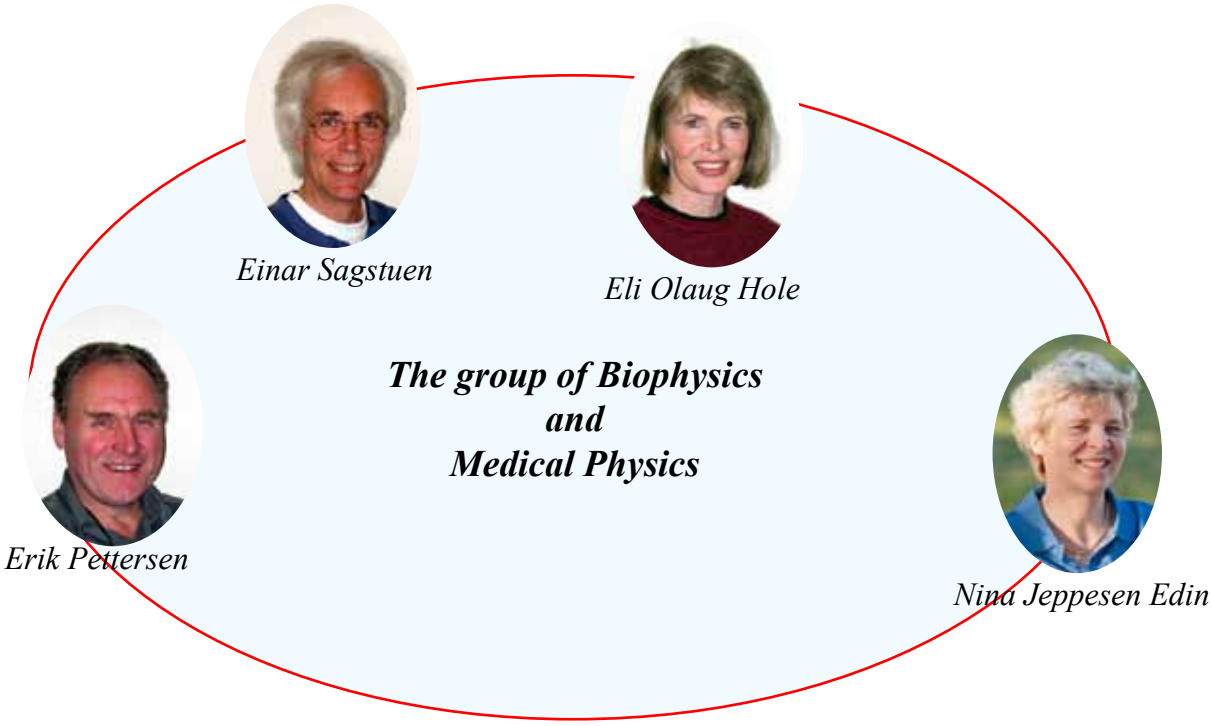
This English written book was mainly a translation from the books above. I would like to take this opportunity to thank David for all help with the translation.

The three books concentrated to a large extent on the basic properties of ionizing radiation. Efforts were made to describe the background radiation as well as the release of radioactivity from reactor accidents and fallout from nuclear explosions in the atmosphere. These subjects were of high interest in the aftermath of the Chernobyl accident.
During the later years a large amount of research and interesting new results within radiobiology have emerged. The purpose of the present is book is therefore to include some interesting applications of radiation in medicine as well as some of the exciting mechanisms in radiobiology.

In this update the basic radiation physics and radiobiology is included. Furthermore, some applications of radiation in medicine will be highlighted.

It would be impossible to embark on this project unless heavy support from my active colleagues at the "group of Biophysics and Medical physics" at The University of Oslo. The group is engaged in research with the aim to attain information about the physical processes taking place in cells and tissue when irradiated. This include the formation of radical ions and how they lead to the known biological endpoints. The group members (professors Eli Olaug Hole and Einar Sagstuen) are using magnetic resonance (ESR) to study radical formation, secondary processes and fate.
Other members of the group (professor Erik Pettersen) are using mammalian cells in culture. The interests are the control mechanisms working in the cell cycle. Of particular interest is the effect of small radiation doses. These studies are of importance for environmental problems as well as within cancer treatment.

The group have close cooperations with active radiation therapy (professor Dag Rune Olsen and Eirik Malinen) and diagnostic (associate professor Hilde Olerud.).



I take this opportunity to thank all my coworkers with the previous books as well as the members of the biophysics group with the present book which is published on Internet.
In order to discuss some results and models I have used illustrations published on Internet without further permission.

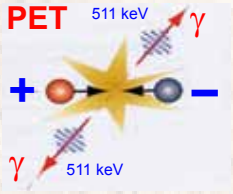
University of Oslo, 2009
Updated 2012

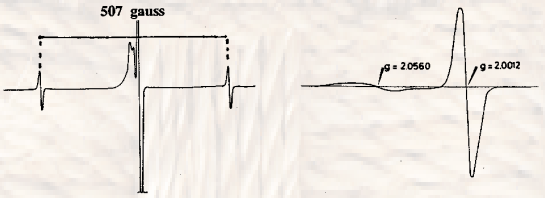
Thormod Henriksen

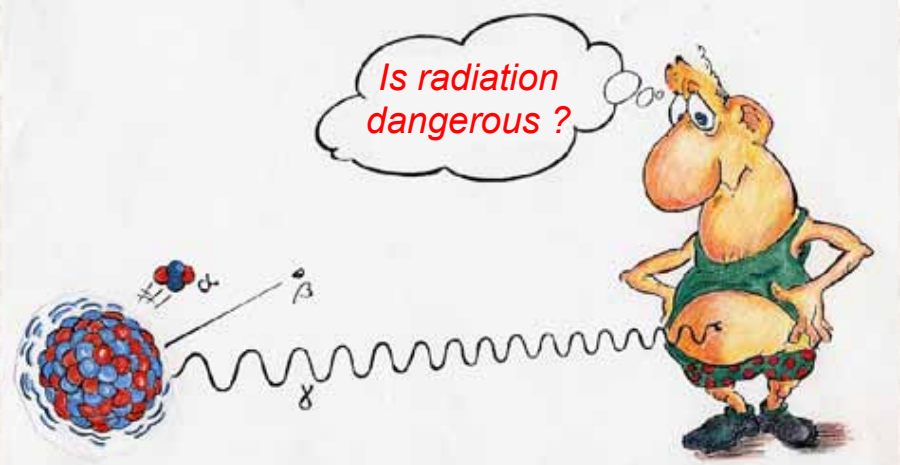
Contents

Part I

Radiation – doses







RADIATION RISK AND ETHICS

The established worldwide practice of protecting people from radiation costs hundreds of billions of dollars a year to implement and may well determine the world's future energy system. But is it right?

Zbigniew Jaworowski

The psychosomatic disorders observed in the 15 million people in Belarus, Ukraine, and Russia[1] who were affected by the April 1986 Chernobyl accident are probably the accident's most important effect on public health.[2] These disorders could not be attributed to the ionizing radiation, but were assumed to be linked to the popular belief that any amount of man-made radiation—even minuscule, close to zero doses—can cause harm, an assumption that gained wide currency when it was accepted in the 1950s, arbitrarily, as the basis for regulations on radiation and nuclear safety.

It was under the same assumption that an *ad hoc* Soviet government commission decided to evacuate and relocate more than 270 000 people from many areas of the former Soviet Union where the 1986–95 average radiation doses from the Chernobyl fallout ranged between 6 and 60 millisieverts. (See the box on page 28 for the definition of the sievert.) By comparison, the world's average individual lifetime dose due to natural background radiation is about 150 mSv. In the Chernobyl-contaminated regions of the former Soviet Union, the lifetime dose is 210 mSv—and in many regions of the world it is about 1000 mSv.[3] The forced evacuation of so many people from their—presumably—poisoned homes calls for ethical scrutiny. Examining the physical and moral basis of that evacuation action and other radiation policies is the subject of this article.

As they have developed over the last three decades, the principles and concepts of radiation protection seem to have gone astray and to have led to exceedingly prohibitive standards and impractical recommendations. Revision of these principles and concepts is now being proposed by an increasing number of scientists and several organizations. They include Roger Clarke, who chairs the International Commission on Radiological Protection, the Health Physics Society, and the French Academy of Sciences. In addition, in April this year, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) decided to study a possible revision of the basic dosimetric and biological concepts and quantities generally being applied in radiation protection. In the years to come, such reevaluations may trigger what I believe will be welcome changes in the basic worldwide approach to radiological protection.

Natural and man-made radiation

We are all immersed in naturally occurring ionizing radiation. Radiation reaches us from outer space and it comes from radionuclides present in rocks, buildings, air, and even our own bodies. Each flake of snow, each grain of soil, every drop of rain—and even every person on this planet—emits radiation. And every day, at least a billion particles of natural radiation enter our bodies.

ZBIGNIEW JAWOROWSKI *is a professor at the Central Laboratory for Radiological Protection in Warsaw, Poland, and has served on the United Nations Scientific Committee on the Effects of Atomic Radiation.*

The individual dose rate of natural radiation the average inhabitant of Earth receives is about 2.2 mSv per year. In some regions—for example, parts of India, Iran, and Brazil—the natural dose rate is up to a hundred times higher. And no adverse genetic, carcinogenic, or other malign effects of those higher doses have ever been observed among the people, animals, and plants that have lived in those parts since time immemorial.[4,5]

In the case of man-made radiation, the global average dose has increased by about 20% since the beginning of the 20th century—mainly as a result of the broader application of x-ray diagnostics in medicine. Other major sources of man-made radiation, such as nuclear power, nuclear weapons tests (figure 1), and the Chernobyl accident, have contributed only a tiny proportion—less than 0.1%—to that increase.

In the regions of the former Soviet Union that were highly contaminated by the fallout from the Chernobyl accident, the increased radiation dose rate for local inhabitants is far less than the dose rate in areas of high natural radiation (see figure 2). In those places, the entire man-made contribution to radiation dose amounts to a mere 0.2% of the natural component.

Three and a half billion years ago, when life on Earth began, the natural level of ionizing radiation at the planet's surface was about three to five times higher than it is now.[6] Quite possibly, that radiation was needed to initiate life on Earth. And it may be essential to sustain extant life-forms, as suggested by experiments with protozoa and bacteria.[7]

At the early stages of evolution, increasingly complex organisms developed powerful defense mechanisms against such adverse radiation effects as mutation and malignant change. Those effects originate in the cell nucleus, where the DNA is their primary target. That evolution has apparently proceeded for so long is proof, in part, of the effectiveness of living things' defenses against radiation.

Other adverse effects—which lead to acute radiation sickness and premature death in humans—also originate in the cell, but outside its nucleus. For them to take place requires radiation doses thousands of times higher than those from natural sources. A nuclear explosion or cyclotron beam could deliver such a dose; so could a defective medical or industrial radiation source. (The malfunctioning Chernobyl reactor, whose radiation claimed 28 lives, is one example.)

The concern about large doses is obviously justified. However, the fear of small doses, such as those absorbed from the Chernobyl fallout by the inhabitants of central and western Europe, is about as justified as the fear that an atmospheric temperature of 20 °C may be hazardous because, at 200 °C, one can easily get third-degree burns—or the fear that sipping a glass of claret is harmful because gulping down a gallon of grain alcohol is fatal.

According to recent studies, by far the most DNA damage in humans is spontaneous and is caused by ther-

FIGURE 1. ATMOSPHERIC NUCLEAR tests, like the one shown here (XX-27 Charlie, a 14 kiloton device exploded over Yucca Flats, Nevada, on 30 October 1951), released radioactive fallout but did not lead to high average doses of radiation—even for the inhabitants of Nevada. (Photo courtesy of US Department of Energy.)

modynamic decay processes and by reactive free radicals formed by the oxygen metabolism. Each mammalian cell suffers about 70 million spontaneous DNA-damaging events per year.[5] Only if armed with a powerful defense system could a living organism survive such a high rate of DNA damage.

An effective defense system consists of mechanisms that repair DNA, and other homeostatic mechanisms that maintain the integrity of organisms, both during the life of the individual and for thousands of generations. Among those homeostatic mechanisms are enzymatic reactions, apoptosis (that is, suicidal elimination of changed cells), cell cycle regulation, and intercellular interactions.

Ionizing radiation damages DNA also, but at a much lower rate. At the present average individual dose rate of 2.2 mSv per year, natural radiation could be responsible for no more than about 5 DNA-damaging events in one cell per year.

Perhaps we humans lack a specific organ for sensing ionizing radiation simply because we do not need one. Our bodies' defense mechanism provides ample protection over the whole range of natural radiation levels—that is, from below 1 mSv to above 280 mSv per year.[3,4] That range is much greater than the range of temperatures—about 50 K—that humans are normally exposed to. Increasing the water temperature in your bath tub by only 80 K, from a pleasant level of 293 K to boiling point at 373 K (that is, by a factor of only 1.3), or decreasing it below freezing point (that is, by a factor of 1.07), would eventually kill you.

Because such lethal high or low temperatures are often found in the biosphere, the evolutionary development of an organ that can sense heat and cold has been essential for survival. Organs of smell and taste have been even more vital as defenses against dangerously toxic or infected food. But a lethal dose of ionizing radiation delivered in one hour—which for an individual human is 3000 to 5000 mSv—is a factor of 10 million higher than the average natural radiation dose that one would receive over the same time period (0.00027 mSv). Compared with other noxious agents, ionizing radiation is rather feeble. Nature seems to have provided living organisms with an enormous safety margin for natural levels of ionizing radiation—and also, adventitiously, for man-made radiation from controlled, peacetime sources.

In short, conditions in which levels of ionizing radiation could be noxious do not normally occur in the biosphere, so no radiation-sensing organ has been needed in humans and none has evolved.

Why radiophobia?

If radiation and radioactivity, though ubiquitous, are so innocuous at normal levels, why do they cause such universal apprehension? What is the cause of radiophobia—the irrational fear that any level of ionizing radiation is dangerous? Why have radiation protection authorities introduced a dose limit for the public of 1 mSv per year, which is less than half the average dose rate from natural radiation and less than 1% of the natural dose rates in many areas of the world? Why do the nations of the world spend hundreds of billions of dollars a year to maintain this standard?[9]

Here I propose some likely reasons:

▷ The psychological reaction to the devastation and loss of life caused by the atomic bombs dropped on Hiroshima and Nagasaki at the end of World War II.

▷ Psychological warfare during the cold war that played on the public's fear of nuclear weapons.

▷ Lobbying by fossil fuel industries.

▷ The interests of radiation researchers striving for

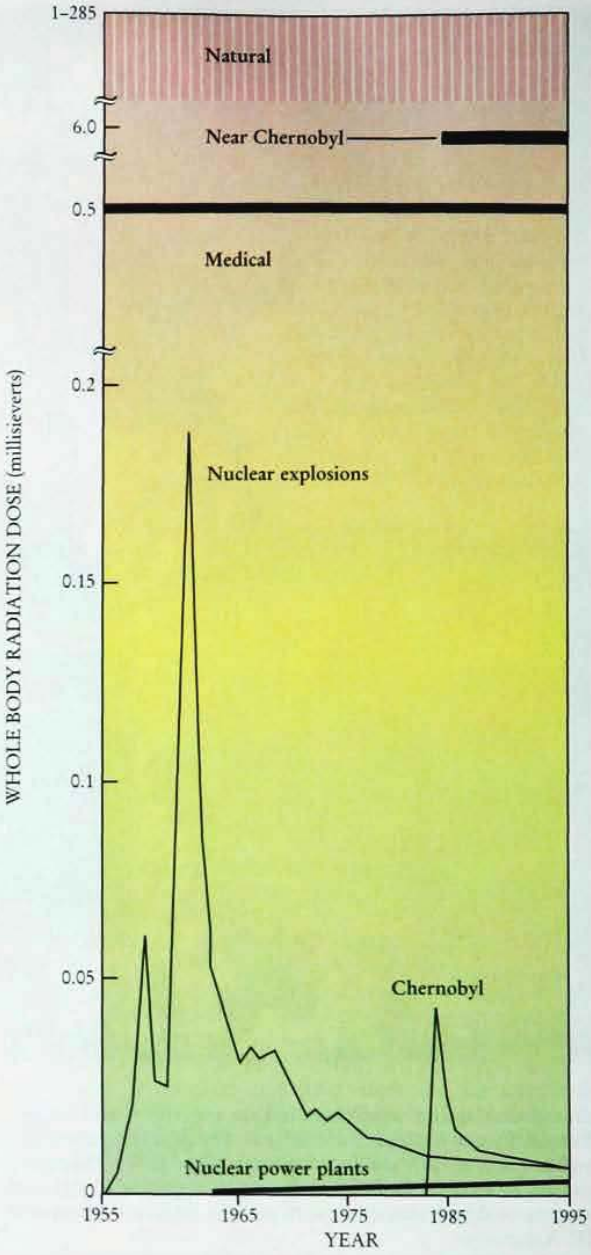


FIGURE 2. AVERAGE INDIVIDUAL GLOBAL RADIATION DOSE in the 1990s from nuclear explosions, the Chernobyl accident, and commercial nuclear power plants combined was about 0.4% of the average natural dose of 2.2 mSv per year. In areas of Belarus, Ukraine, and Russia that were highly contaminated by Chernobyl fallout, the average individual dose was actually much lower than that in the regions with high natural radiation. The greatest man-made contribution to radiation dose has been irradiation from x-ray diagnostics in medicine, which accounts for about 20% of the average natural radiation dose. Natural exposure is assumed to be stable. The temporal trends in medical and local Chernobyl exposures are not presented. (Based on data from UNSCEAR.)

recognition and budget.

▷ The interests of politicians for whom radiophobia has been a handy weapon in their power games (in the 1970s in the US, and in the 1980s and 1990s in eastern and western Europe and in the former Soviet Union).

▷ The interests of news media that profit by inducing public fear.

▷ The assumption of a linear, no-threshold relationship between radiation and biological effects.

Since nuclear weapons are regarded as a deterrent, naturally the countries that possess them wish to make radiation and its effects seem as dreadful as possible. Not surprisingly, national security agencies seldom qualify or correct even the most obviously false statements, such as "Radiation from a nuclear war can annihilate all mankind, or even all life," or "200 grams of plutonium could kill every human being on Earth."[10]

The facts say otherwise. Between 1945 and 1980, the 541 atmospheric nuclear tests that were performed together yielded an explosive energy equivalent to 440 megatons of TNT (1.8×10^{24} joules). After all those explosions, despite the injection into the global atmosphere of about 3 tons of plutonium (that is, almost 15 000 supposedly deadly 200-gram doses), somehow we are still alive! The average individual dose of radiation from all these nuclear explosions, accumulated between 1945 and 1998, is about 1 mSv, which is less than 1% of the natural dose for that period.

In the heyday of atmospheric testing, 1961 and 1962, there were 176 atmospheric explosions, with a total yield of 84 megatons. The maximum deposition on Earth's surface of radionuclides from those explosions took place in 1964. The average individual dose accumulated from the fallout between 1961 and 1964 was about 0.35 mSv.

At its cold war peak of 50 000 weapons, the global nuclear arsenal had a combined potential explosive power of about 13 000 megatons, which was only 30 times larger than the megatonnage already released in the atmosphere by all previous nuclear tests. If that whole global nuclear arsenal had been deployed in the same places as the previous nuclear tests, the average individual would have received a lifetime radiation dose of about 30 mSv from the ensuing worldwide fallout. If we use the years 1961 and 1962 as a yardstick instead, the dose would have risen to about 55 mSv. And even exploding all the nuclear weapons in just a few days rather than over a two-year period would not change that estimate by very much. Clearly, 55 mSv is a far cry from the short-term dose of 3000 mSv that would kill a human.

Of course, the approach taken above, based as it is on averages, fails to account for the immense loss of life and human suffering caused by the mechanical blast, fires, and local fallout that follow nuclear explosions in highly populated areas. However, no matter what the losses to those areas might be, it is certain that human and other life on Earth would survive even an all-out global nuclear war.

A-bomb survivors and linear no-threshold

The survivors of the atomic bombing of Hiroshima and Nagasaki who received instantaneous radiation doses of less than 200 mSv have not suffered significant induction of cancers.[11] And so far, after 50 years of study, the progeny of survivors who were exposed to much higher, near-lethal doses have not developed adverse genetic effects.[12]

Until recently, such findings from the study of A-bomb survivors had been consistently ignored. In place of the actual findings—and driving the public's radiophobia—has been the theory of linear no-threshold (LNT), which presumes that the detrimental effects of radiation are proportional to the dose, and that there is no dose at which

Values of Individual Truncated Natural Dose Commitment

Human Species	Time since first appearance (years)*	(generations)	Dose commitment (sieverts)
Early Modern *Homo sapiens*	130 000	4300	286
Archaic *Homo sapiens*	400 000	13 300	880
Homo erectus	1 800 000	60 000	3960
Homo habilis	2 400 000	80 000	5280

**The Cambridge Encyclopaedia of Human Evolution*, Cambridge U. P., Mass. (1994).

the effects of radiation are not detrimental.

It was LNT theory that the International Commission on Radiological Protection chose, in 1959, as the basis for its rules of radiation protection. At that time, applying LNT theory was regarded as an administrative decision, based on practical (not to mention political[13]) considerations. Adopting a linear relationship between dose and effect, along with no threshold, enabled doses in individual exposures to be added and enabled population-averaged quantities to be evaluated, and made the administration of radiation protection generally easier. Furthermore, the policy undertone—that even the smallest, near-zero amounts of radiation could cause harm—was politically useful at the time: It played an important part in effecting first a moratorium and then a ban on atmospheric nuclear tests. LNT theory was and still is the pillar of the international theory and practice of radiation protection.

Over the years, however, what started as just a working assumption for the leadership of ICRP came to be regarded—in public opinion and by the mass media, regulatory bodies, and many scientists, and even by some members of the ICRP—as a scientifically documented fact.

The absurdity of the LNT was brought to light after the Chernobyl accident in 1986, when minute doses of Chernobyl radiation were used by Marvin Goldman, Robert Catlin, and Lynn Anspaugh to calculate that 53 400 people would die of Chernobyl-induced cancer over the next 50 years.[14] The frightening death toll was derived simply by multiplying the trifling Chernobyl doses in the US (0.0046 mSv per person) by the vast number of people living in the Northern Hemisphere and by a cancer risk factor based on epidemiological studies of 75 000 atomic bomb survivors in Japan. But the A-bomb survivor data are irrelevant to such estimates, because of the difference in the individual doses and dose rates. A-bomb survivors were flashed within about one second by radiation doses at least 50 000 times higher than those which US inhabitants will ever receive, over a period of 50 years, from the Chernobyl fallout.

We have reliable epidemiological data for a dose rate of, say, 6000 mSv per second in Japanese A-bomb survivors. But there are no such data for human exposure at a dose rate of 0.0046 mSv over 50 years (nor will there ever be any). The dose rate in Japan was larger by 2×10^{15} than the Chernobyl dose rate in the US. Extrapolating over such a vast span is neither scientifically justified nor epistemologically acceptable. Indeed, Lauriston Taylor, the former president of the US National Council on Radiological Protection and Measurements, deemed such extrapolations to be a "deeply immoral use of our scientific heritage."

Radiation dose and eternity

An offspring of the LNT assumption is the concept of dose commitment, which was introduced in the early 1960s. At that time, the concept reflected the concern that harmful hereditary effects could be induced by fallout from nuclear tests. After almost four decades, the concept of dose commitment is still widely used, although both the concept and the concern ought to have faded into oblivion by now.

UNSCEAR, which first used "dose commitment" in 1962, defined it as "the integral over infinite time of the average dose rate in a given tissue for the world population, as a result of a given practice—for example, a given series of nuclear explosions." Such integration requires making some daring assumptions and having a superhuman omniscience about population dynamics and environmental changes for all the eons of time to come. Later, in a humbler frame of mind, UNSCEAR introduced the so-called truncated dose commitment, limited arbitrarily to 50, 500, 10 000 or many millions of years. However, the original "infinite" definition is still retained in recent UNSCEAR documents.

To accept the definitions of dose commitment and of collective dose, we must also accept the following premises:

- ▷ An LNT relationship between absorbed dose and risk to an individual.
- ▷ The additivity of risk (by means of the additivity of dose) during the lifetime of an individual.
- ▷ The additivity of risk (dose) across individuals of the same generation.
- ▷ The additivity of risk (dose) across the lifetimes of individuals over any number of generations.
- ▷ The expectation that late harm due to a dose accumulated over many years or generations (dose commitment) be the same as the harm done by an instantaneous dose of the same magnitude.
- ▷ The expectation that late harm due to a given value of collective dose or dose commitment calculated for a large number of people exposed to trifling doses be the same as that calculated for a small number of people exposed to large doses. (This expectation is contrary to the common practice of diluting or dispersing noxious agents below dangerous levels.)

In 1969, UNSCEAR advised making the level of natural radiation a convenient reference for comparing dose commitments from man-made sources. However, during the three decades since the introduction of the dose commitment concept, UNSCEAR has not followed its own advice. The collective dose commitment for the world population from natural sources, truncated to 50 years (650 000 000 man Sv), was published for the first time in UNSCEAR's 1993 report. But why stop at 50 years—when, for man-made radiation, UNSCEAR estimates the dose commitments over infinite time? It is easy to calculate the individual dose commitment from past exposures to natural radiation for periods comparable to those used for calculating man-made sources of radiation. In making the calculation, one may assume that during the past several million years the natural radiation dose rate has been the same as is now—that is, 2.2 mSv per year.

In the table on this page are presented the values of truncated natural dose commitment for various periods

Definition of the Sievert

Adapted from Scientific Unit Conversion *by François Cardarelli, Springer-Verlag, London (1997).*

The sievert (Sv) is the SI-derived unit of equivalent radiation dose. An equivalent dose of 1 Sv is received when the actual absorbed dose of ionizing radiation, after being multiplied by the dimensionless factors Q (the so-called quality factor) and N (the product of any other multiplying factors), is 1 joule per kilogram. In this scheme, the relationship between the absorbed dose of radiation D and the dose equivalent H is, therefore, given by $H = QND$. Both Q and N are stipulated by the International Commission on Radiological Protection. Also known as the relative biological efficiency, Q depends on the nature of the radiation and has a value of 1 for x rays, gamma rays, and beta particles; 10 for neutrons; and 20 for alpha particles. N is a factor that takes into account the distribution of energy throughout the dose.

The unit is named after the pioneering Swedish clinical physicist Rolf Maximillian Sievert (1896–1960) and superseded the rem (short for rad equivalent mammals or man), which corresponds to 0.01 Sv for x rays of energy ranging from 200 to 250 keV.

since the putative appearance of some of our ancestors. One may compose a similar table for the collective truncated dose commitments for the global populations integrated over the past generations, information that is also given in the table. One may also calculate the future natural dose commitments of our descendants for tens or thousands of generations.

Each of us is burdened with these values of dose commitment. Do these values represent anything real, or are they just an academic abstraction? What are the medical effects of these enormously high doses?

In an international study, the collective dose for the world population from nuclear dumping operations in the Kara Sea (part of the Arctic Ocean), truncated to the year 3000 AD, has been estimated to be about 10 manSv.[15] Let us explore the implications of that value, which may be equivalent to:

- 10 Sv in 1 person in 1 day (lethal acute effect), or
- 10 Sv in 1 person in 1 year (chronic effect—for example, cancer),
- 0.5 Sv in 20 people in 1 day (chronic effect), or
- 10^{-5} Sv in 1000 people in 1000 years (no biological or medical concern), or
- 2×10^{-12} Sv per each of 5×10^{9} people now living and their descendants from 33 generations in 1000 years (no concern).

Obviously, the use of collective dose obliterates information on the patterns of dose deposition in space and time, which are of major importance for estimating their biological effects, in terms of risk to humans. Individual doses cannot be additive over generations, simply because humans are mortal, and the dose dies when an individual does. Similarly, individual doses cannot be added for individuals of the same generation because we do not contaminate one another with a dose that we have absorbed. The presence of biological repair processes and the multistage process of cancer induction render the linear addition of small contributions of individual dose to estimate the associated risk of cancer occurrence highly unlikely. Collective dose and dose commitment cannot have any biological meaning.

The large values of collective doses and collective dose commitments that have often been published were derived from minuscule individual doses. For example, UNSCEAR's calculations include the following: 100 000 man Sv from nuclear explosions during the past 54 years, 205 000 man Sv for the global population in the next 10 000 years from power reactors and reprocessing plants, 600 000 man Sv from Chernobyl fallout in the Northern Hemisphere for eternity, and 650 000 000 man Sv for the world's population from natural radiation in the past 50 years. These large values, terrifying as they are to the general public, do not imply that individuals or populations are harmfully burdened by nuclear explosions, nuclear power plants, Chernobyl fallout, or nature. In fact, they provide society with no relevant biological or medical information. Rather, they create a false image of the imminent danger of radiation, with all its actual negative social and psychosomatic consequences. If harm to the individual is trivial, then the total harm to members of his or her society over all past or future time must also be trivial—regardless of how many people are or will have been exposed to natural or man-made radiation. The intellectually invalid concepts of collective dose and dose commitment deserve to be hacked off with William of Occam's razor.

Enter hormesis

The LNT theory is contradicted by the phenomenon of hormesis—that is, the stimulating and protective effect of small doses of radiation, which is also termed adaptive response. The first report on hormetic effects in algae appeared more than 100 years ago.[16] More recently published hormetic effects include A-bomb survivors' apparent lower-than-normal incidence of leukemia and their greater longevity.[17] Although more than 2000 scientific papers had been published on radiation hormesis, the phenomenon was forgotten after World War II and was ignored by the radiation-protection establishment. It was only in 1994 that UNSCEAR recognized and endorsed the very existence of radiation hormesis. It caused a revolutionary upheaval of radiology's ethical and technical foundations.

Many radiologists have come to realize that their overreaction to theoretical (actually imaginary) health-harming effects of radiation is unethical in that it leads to the consumption of funds that are desperately needed to deal with real health problems. Applying the no-threshold principle for the alleged protection of the public has led to the imposition of restrictive regulations on the nuclear utilities, restrictions that have virtually strangled the development of environmentally benign nuclear energy in the US and in other countries. My own country, Poland, spent billions of dollars on the construction of its first nuclear power reactor—only to abandon the project after what I regard as the politically motivated manipulation of public opinion by means of the LNT theory.

Each human life hypothetically saved in a Western industrial society by implementation of the present radiation protection regulations is estimated to cost about $2.5

billion. Such costs are absurd and immoral—especially when compared to the relatively low costs of saving lives by immunization against measles, diphtheria, and pertussis, which in developing countries entails costs of $50 to $99 per human life saved.[18] Billions of dollars for the imaginary protection of humans from radiation are actually spent year after year, while much smaller resources for the real saving of lives in poor countries are scandalously lacking.

A practical alternative

There is an emerging awareness that radiation protection should be based on the principle of a practical threshold—one below which induction of detectable radiogenic cancers or genetic effects is not expected. Below such a threshold, radiation doses should not require regulation. Nor is any regulation required for extreme levels, such as those experienced at Hiroshima and Nagasaki, where dose rates were extremely high.

The practical threshold to be proposed could be based on epidemiological data from exposures in medicine, the nuclear industry, and regions with high natural radiation. The current population dose limit of 1 mSv per year could then be changed to 10 mSv per year or more. Individual doses could be evaluated at any level below the practical threshold, but radiation-protection authorities would be required to intervene only if individual doses above the threshold were involved. Adopting a practical threshold would be an important step taken toward dealing with radiation rationally and toward regaining the public's acceptance of radioactivity and radiation as blessings for mankind.

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RADIATION HORMESIS - A REMEDY FOR FEAR

Zbigniew Jaworowski
Central Laboratory for Radiological Protection,
ul. Konwaliowa 7, Warsaw 03-195, Poland
home: ul. Sadowa 9, 05-520 Konstancin, Poland
voice: +48-22-754-4434, fax: +48-22-711-7447
email: jaworo@clor.waw.pl

ABSTRACT

Personal reflections on radiation hormesis for the past fifty years are presented. The causes of ignoring and rejections of this phenomenon by international and national bodies and by radiation protection establishment are analyzed. The opposition against nuclear weapons and preparations for nuclear war was probably the main factor in inducing the concern for adverse effects of low doses of ionizing radiation, a byproduct of activism against the nuclear weapon tests. UNSCEAR was deeply involved in preparation the scientific basis for cessation of nuclear test, and contributed to elaboration of the LNT assumption, which is in contradiction with the hormetic phenomenon. However, this authoritative body recognized also the existence of radiation hormesis, termed as "adaptive response". The political and vested interests standing behind exclusion of hormesis from the current risk assessment methodology are discussed.

Key Words: hormesis, radiation, adaptive response, hormetic, linearity, risk assessment

I began working with ionizing radiation in 1953, as a medical doctor - radiotherapist at the Institute of Oncology in Gliwice. At that time my colleagues and I were not interested in protecting ourselves from radiation. Our main concern was to cure our patients by irradiating their tumors with high doses while protecting their healthy tissues outside the tumor volume against harmful collateral effects. This approach resulted in a permanent loss of papillary lines on my fingers, and on those of my colleagues. I estimate that my body must have absorbed a dose of some 600 mGy from such professional and from subsequent medical exposures. Perhaps this is why at the age of 82 years I am still active in winter and summer outdoor sports (I must however admit that the very persistence in such activity might be the real cause of its duration). In the early 'fifties at the Institute of Oncology we treated some advanced cases of leukemia with fractionated whole body or hemi body irradiations, up to a total dose of 2 grays, exposing both neoplastic and healthy tissues. The palliative results were positive. I believed that this effect was partly due to the stimulation of the defense system of the patients' healthy tissues, but I did not think of this as being a "hormetic effect". In fact, the term "hormesis" had been coined ten years earlier (Southam and Erlich, 1943) but was not widely used. Hormetic effects were known to exist since the end of the 19th century(Calabrese et al., 1999), and while after World War II they were mentioned in some 20 articles each year (Brucer, 1987), they were clearly out of the mainstream interest of radiologists. Whole- and hemi-body radiotherapy were soon forgotten at our Institute, due to the exaggerated fear of irradiating healthy tissues even with small doses, only recently to regain some recognition (Wojcik et al., 2002).

It was the Cold War period with its massive production and incessant testing of nuclear weapons. Strontium-90 and caesium-137 fallout from atmospheric tests polluted the whole planet and, together with the terrifying prospect of a global nuclear war, induced worldwide radiophobia. People were quite rightly scared of large lethal doses of radiation from local tropospheric fallout, deposited over distances of hundreds of kilometers from the sites of nuclear explosions. But later they also became scared of small doses of radiation arising from the global stratospheric fallout of nuclear tests in the atmosphere. The fear of lethal doses was a highly cherished element of the deterrence value of nuclear weapons, loudly voiced by their owners. One of the more important examples was the excellent handbook of Glasstone, demonstrating the disastrous effects of atomic weapons, published by the United States Department of Defense and the Atomic Energy Commission (Glasstone, 1957). But it was the leading physicists responsible for inventing the nuclear weapons, having realized how dangerous were their inventions, who instigated the fear of small doses. In their noble, wise and highly ethical endeavor to stop preparations for atomic war, and the "hysterical" amassment of enormous arsenals of nuclear weapons, they were soon followed by many scientists from other fields. The general strategy was to attack the crucial component of military nuclear efforts of the time – atmospheric nuclear testing. Later on, this developed into opposition against atomic power stations and all things nuclear. Although the arguments of physicists and of their followers were false, they were effective: atmospheric tests were stopped in 1963 (Rusk et al., 1963), only to be moved underground. However, this was achieved at a price –a terrifying specter of small, near zero radiation doses endangering all future generations had emerged. This specter became a long-lived and worldwide societal affliction, nourished by the linear non-threshold (LNT) assumption, according to which any dose, even that close to zero, would contribute to the disastrous effect. Radiation hormesis is an excellent remedy for this affliction, and it is perhaps for this reason that this phenomenon has been ignored and discredited over the past half century. What happened fifty years ago still influences the current thinking of the decision makers and of those who elect them. Therefore, let us dwell upon it for a while.

In March 1950, over a year before the first American H-bomb explosion on May 8th 1951, Albert Einstein estimated that "*radioactive poisoning of the atmosphere* (by H-bombs) *and hence annihilation of any life on earth, has been brought within the range of technical possibilities*" (Einstein, 1950). In the same year Hans Bethe, the former head of the Theoretical Physics Division of the Manhattan Project, and a major contributor to the development of the Hiroshima- and Nagasaki-type fission nuclear weapons, warned on television that H-bomb clouds *"could annihilate life on earth*" (Anonymous, 2005).

Similar statements were later repeated in innumerable publications, and captured in popular books and movies of the 1950s, such as *On the Beach, Fail-Safe,* and *Dr. Strangelove.* I demonstrated that such statements were unjustified (Jaworowski, 1999). If the whole global nuclear arsenal at its peak of 50 000 warheads and 13 000 megaton explosive power were to be exploded over a few days, the average individual would have received a life-time (70 year) radiation dose of about 55 mSv ensuing from the worldwide fallout, a far cry from the short-term dose of 3000 to 5000 mSv that will most likely kill a human or induce an epidemic of chronic post-irradiation diseases.

Eight years later, Linus Pauling, the chemistry Nobel laureate, virtually repeated what Einstein and Bethe had said, by stating that merely the preparation for thermonuclear warfare (and not the war itself) would destroy most of the planet's living creatures (Pauling, 1958). In a telegram of 1st March 1962 to President J.F. Kennedy, on the effects of nuclear tests, he estimated the genetic effects of small radiation doses from fission products and carbon-14 dispersed by nuclear tests: "*I state that nuclear tests .... would seriously damage over 20 million unborn children, including those caused to have gross physical or mental defect, and also the still births and embryonic, neonatal and childhood death*". Pauling's telegram started with a question: "*Are you going to give an order* (to continue the tests) *that will cause you to go down in the history as one of the most immoral men of all time and one of the greatest enemies of the human race?*" Perhaps the impact of this telegram was reflected in President Kennedy's statement: "*Today every inhabitant of this planet must contemplate the day this planet may no longer be habitable*". For this social activism, four years later Pauling received his Nobel Peace Prize.

Interestingly, two inventors of nuclear weapons were also honored with peace rewards. Andrey Sakharov, the father of the Soviet H-bomb, was awarded the Nobel Peace Prize in 1975. In 1978, Samuel Cohen, inventor of the neutron bomb, was awarded the Peace Medal by Pope Paul VI. In the same year, the next Pope, John Paul II congratulated him: "*Mr. Cohen, I trust you are working for peace*" (Cohen, 2005).

On the other side of the Iron Curtin the Soviets were competing with Americans in mass production and testing of fission and fusion weapons. They also built vast arsenals of conventional weapons, preaching worldwide peace at the same time. In the midst of this arms race in 1958, Andrei Sakharov, the father of the first Soviet H-bomb (1953) and of its next more sophisticated and more powerful version (1955), published an astonishing paper in Russian (Sakharov, 1958). After eleven years this paper was re-published in English in Moscow (Sakharov, 1969), and 32 years later - in the United States (Sakharov, 1990).

Most certainly publication of Sakharov's paper in the Soviet Union would not have been possible without prior consent or instigation of the highest authorities, perhaps as a Soviet peace stage in the Cold War drama. Sakharov's paper revealed two important messages on the hydrogen bomb. The first was a description of the fundamental fusion reactions occurring during the explosion of such a bomb (available for the first time in the open literature of the Soviet block, one year after their declassification by Glasstone), of its neutron flux and of the rate of the ensuing radiocarbon (^{14}C) production in the atmosphere. The second message was the calculation of radiation dose from globally dispersed carbon-14 (0.375 mSv per caput). Assuming a future global equilibrium population of 30 billion people, Sakharov estimated a "collective dose commitment"[1], truncated to 8000 years (i.e. to the approximate life-time of ^{14}C), from radiocarbon and other radionuclides produced or dispersed in the atmosphere by nuclear tests up to about 1958. Sakharov concluded that the dose commitment from the weapons tests would result in 500,000 to one million victims of serious hereditary disorders and cancers. In his calculations Sakharov used the LNT principle, with a risk factor for hereditary effects based on data from *Drosophila melanogaster* fruit fly experiments (Muller, 1954). These and similar data were based on high dose X-, gamma- and beta-ray irradiations, ranging between 2.7 and 43.5 Gy (Oliver, 1930; Muller, 1946), which after extrapolation to zero dose, became a basis for the assumption that mutation frequency increases linearly with dose without any threshold. This assumption was adhered to in many later genetic experiments (Sankaranarayanan and Sobels, 1976; UNSCEAR, 1962).

However, the linearity assumption was not confirmed by early epidemiological surveys of Hiroshima and Nagasaki survivors (UNSCEAR, 1962), nor by later studies (UNSCEAR, 2000; UNSCEAR, 2001), in which no hereditary disorders were found in the progeny of highly irradiated parents. For estimation of carcinogenic radiation effects, studies of somatic cells are more relevant than those on germ cells. The results of early experiments with *Drosophila* male germ cells irradiated with X-rays do not agree with new findings in which somatic mutations in the *Drosophila* clearly showed a threshold around 1 Gy (Koana et al., 2004). Koana et al. also found a threshold (below which no increase in mutation frequency is detected in spermatocytes and spermatogonia) between 0.2 and 10 Gy (Koana et al., 2007; Koana et al., 2004). In the 0.2 Gy dose group and at low dose rate of 0.05 Gy/min these authors observed hormetic effects (40% less lethal mutations than those in sham-irradiated flies).

Over several decades the early experiments on mice carried out at Oak Ridge National Laboratory formed the basis for genetic risk estimates, for which the doubling dose for mosaic mutations was believed to be 1 Gy. Reevaluation of the Oak Ridge data demonstrated that in these experiments the frequency of spontaneous mutations was underestimated. The true doubling dose ranged in fact between 5.4 and 7.7 Gy. As the doubling dose increases, estimates of hereditary risk decrease. Therefore, the estimate of risk to humans based on old experiments using mice is probably at least 5 times too high (Selby et al., 2004; Selby, 1998). After perusal of Selby's revision the United Nations Scientific Committee on the Effects of Atomic Radiation decided that "*the prudent way forward is*

1 Four years later UNSCEAR defined the dose commitment to the world's population as a sum of radiation doses from a practice (for example, a series of nuclear tests) over endless generations and an infinite time period (UNSCEAR, 1962). I argued that this speculative concept, as well as that of collective dose, both related to LNT, have no biological meaning, and obliterate information required for realistic risk assessments (Jaworowski, 1999).

to abandon the use of an entirely mouse-data-based doubling dose estimate" (UNSCEAR, 2001). The Committee cited also the doubling dose in humans as ranging between 3.4 and 4.5 Gy, this being estimated from the Hiroshima and Nagasaki data (a strange conclusion, since Japanese data had shown no adverse genetic effects of bomb irradiation). Yet, the Committee decided that it "*will use the round figure of 1 Gy in risk estimation*".

However, at the time when Pauling and Sakharov announced their estimates of thousands and millions of genetic victims of nuclear tests, UNSCEAR, after three years of deliberation, did a more balanced and competent job in its first report, published at the end of 1958 (UNSCEAR, 1958). It accepted the possibility of zero increase in leukemia incidence – assuming a threshold, and that 150 000 cases would ultimately occur for non-threshold calculations. The Committee's estimation of the ultimate genetic defects was between 2500 and 100 000 cases (UNSCEAR, 1958).

UNSCEAR was established in 1955 by a resolution of the General Assembly of the United Nations. The Committee reports directly to the General Assembly, and its formal terms of reference are strictly scientific. Over its following five decades the Committee had diligently strived at estimating the effects of small radiation doses from all kinds of sources, and became an unquestionable authority on the matter of radiation effects in humans and their environment. However, as appears from the general conclusions of its 1958 report, the Committee was concerned mainly with the effects of nuclear tests, fulfilling a political task: to help in "*the cessation of contamination of the environment by explosions of nuclear weapons*". The effects of high radiation doses in nuclear war were never a subject of UNSCEAR studies. Later the emphasis of the Committee's work was on other types of exposure, and its publications became a foundation for the international radiation protection recommendations and national regulations.

In 1958 the Committee presented an ambivalent approach to LNT, which reflects the mixed opinion of its members on this subject. This is exemplified by conflicting statements such as: on theoretical grounds, if one ionization suffices to cause the effect, then "*this sort of effect has no threshold – which means that any dosage, however small, is effective in producing some alteration. On the contrary, if several ionization events are needed, the dose effect curve is sigmoid. In this case there is a threshold*". For mutational hazards the Committee was less prone to accept a threshold, stating that "*biological effects will follow irradiation, however small is amount*". However, it acknowledged that "*the studies of mutations in bacteria, Drosophila, and mice do not extend as low as the background radiation, and much uncertainty remains*".

The cautious approach of the Committee is best seen in the general conclusions of the 1958 report, among which one can read that "*Many effects of radiation are delayed; often they cannot be distinguished from effects of other agents; many will develop once a threshold dose has been exceeded...*", or "*the possibility cannot be excluded that our present estimates exaggerate the hazards of chronic exposure to low levels of irradiation*". Support for the LNT approach was most strongly worded in a *votum separatum* of the Soviet delegation (UNSCEAR, 1958). The criticism of LNT in this document was less explicit, but not among some of its authors. Professor W.V. Mayneord, one of the leading radiologists and head of the British delegation at the first session of UNSCEAR in March 1956, stated later "*I have always felt that the argument that because at higher values of dose an observed effect is proportional to dose, then at very low doses there is necessarily some 'effect' of dose, however small, is nonsense*" (Mayneord, 1964).

A similarly cautious approach was evident in the next 1962 UNSCEAR report. While stating that "*the relationship between dose and effect at cellular and subcellular levels does not give any indication of the existence of threshold doses and leads to the conclusion that certain biological effects can follow irradiation, however small the dose may be*", the Committee also observed that "*When dose effect relationships are studied at higher levels of organization, ... it is now being increasingly realized that the situation may be more complex, since many factors play a part between the occurrence of the primary event and the final manifestation of radiation damage*" and that therefore "*a simple mathematical relationship is unlikely to apply*".

In its first report of 1958 the Committee noticed adaptation and the possibility of repair of genetic material, but had not discussed these effects. In that document hormesis is clearly evident in a figure presenting survival times of gamma-irradiated mice and guinea pigs at dose rates of 5 mGy per week (page 162), and also in a table showing leukemia incidence in the Hiroshima population, which was lower by 66.3% in survivors exposed to 20 mSv, compared to the unexposed group (p. 165). This evidence of radiation hormesis was not commented upon. 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.

I tried to understand the reasons why was such a policy continued long after its original aim, i.e. stopping atmospheric tests of nuclear weapons, has been achieved. It seems to me that the driving force was (and still is) the vested interests of the radiation protection establishment and of the antinuclear power lobby, both concerned that demonstration of the beneficial effects of small radiation doses, and thus of the existence of a threshold for harmful effects occurring near this dose region, will destroy their *raison d'etre*. Refraining from studying or even acknowledging the existence of the phenomenon of hormesis may be regarded as non-scientific and political influences in the field of radiological sciences (Taylor, 1980); (Weinberg, 1972; Weinberg, 1985).

Ionizing radiation is very widely used in many walks of life. Only in its medical applications, some 330 million people are being exposed every year at low doses for radiodiagnostic purposes, and another 5 million undergo radiotherapy at high doses (UNSCEAR, 2000). Since its discovery until 1992 there were only 402 fatal victims among medical professionals (Molineus et al., 1992), and between1944 and 2001 only 134 fatalities occurred in all radiation accidents (Toohey, 2002). This indicates that radiation is a rather innocuous and not very lethal agent, a fact that the public is not aware of well enough.

Major human activities, including nuclear incidents, increase the radiation exposure of the global population to very low levels above natural background, well beyond those at which any hormetic effects may be apparent. For example, in the record year of 1963, the maximum average annual radiation dose to the global population from nuclear test fallout was 0.113 mSv (UNSCEAR, 2000). Until 1982 in its reports to the General Assembly, for comparing radiation exposures from the most important man-made and natural sources, instead of radiation dose units, the Committee used "units of days equivalent exposure to natural sources". I protested many times against this practice, and finally radiation units were used, but never in graphic form. Years ago I prepared a figure comparing these exposures in sievert units, based exclusively on data from UNSCEAR documents (Figure 1). At several sessions I proposed that the Committee publish such a figure in its report to the General Assembly, but to no avail. The official reason for rejection was the difficulty in making this figure understandable to laymen, but the real explanation offered to me on the side was: "*Visual perception is the most effective, and such a figure may make the politicians at the UN General Assembly think that the vast effort and resources spent on radiation protection of the population are excessive, and the very existence of UNSCEAR might be at stake*".

Reluctance to demonstrate clearly how unimportant is any radiation hazard to population from nuclear industry, the Chernobyl accident, nuclear explosion tests and medical irradiation, in relation to the broad range of natural radiation exposure, at which no adverse health effects were ever observed, reflects a "vested group interest" approach. However, what is published, are staggering and terrifying values of "collective doses" from these same sources (for example 2 330 000 man Sv per year from X-ray medical examinations – UNSCEAR, 2000), which are meaningless results of multiplying of innocuous tiny individual doses by 5.8 billion people. A "collective dose" of 14 000 000 man Sv per year from natural sources is not given for comparison and balancing in the public's mind of millions of man-made man-sieverts.

I was disappointed that the phenomenon of hormesis was ignored in all UNSCEAR documents since its first report. Therefore, in 1980, as chairman of the Committee, I suggested that it was the duty of UNSCEAR to peruse the large body of publications on radiation hormesis, some 1200 articles, published since the beginning of the century, to assess whether this phenomenon is real, and if so, how might it influence the methodology of risk estimates. A large review on this literature had already been published by then (Luckey, 1980), and the Committee had it in its library. The proposal was supported only by the delegation of Poland, and UNSCEAR rejected it. Every following year I repeated this proposal in vain, until after the Chernobyl accident of 1986, in 1987, it finally gained support, first from the representatives of France and Germany, and then from other delegations. Seven years later UNSCEAR published a report, rubberstamping the existence of the phenomenon of radiation hormesis, termed as "adaptive response" (UNSCEAR, 1994).

It was difficult for the Committee to overcome its own prejudices on radiation hormesis, and to produce a balanced report. Along the way, the Committee rejected two rather one-sided drafts of the report, prepared by the late Dr. Hylton Smith, the Scientific Secretary of ICRP, a body which strongly supported LNT and rejected hormesis. However, working for a few years on the report, Dr. Smith changed his initially negative approach to radiation hormesis, and finally produced an excellent, unbiased treatise on this yet unfathomed matter, demonstrating his scientific integrity. When the Committee finally endorsed the report, from the rostrum came this comment of UNSCEAR's Scientific Secretary: "*We are now in total disarray!*". During the Committee's 1995 session, the IAEA observer, Dr. Abel J. Gonzalez, reacted in a more vehement mood, scorning UNSCEAR for publishing its 1994 report, and arguing that this report contradicted the freshly issued Agency's Interim Edition of the "International Basic Safety Standards" (IAEA, 1994). My answer was that UNSCEAR is an independent body, our terms of reference being not regulations but science. I continued that scientific integrity of the Committee and its separation from non-scientific influences are essential for preserving UNSCEAR's role as the objective authority on the matter of ionizing radiation, and that it is not the role of IAEA to instruct UNSCEAR on its duties.

UNSCEAR's 1994 report had a considerable impact on science, reflected among others in the BEIR VII (BEIR-VII, 2005), and French Academy of Sciences - National Academy of Medicine (Tubiana et al., 2005) documents, supporting research on radiation hormesis. It also influenced regulatory bodies, as reflected by publications of the former ICRP chairman (Clarke, 1999) and by his proposals of scrapping some standards and principles based on LNT, such as "*Collective dose*", presented at the 10th International Congress of IRPA at Hiroshima in 2000. These proposals were rejected by the Congress (Webb, 2000), although many speakers supported them, claiming that LNT assumption is incorrect in view of the hormesis phenomenon (Anonymous, 2000). But the implications of hormesis for radiation protection include more issues than were discussed at this Congress, such as dose additivity, tissue weighting factors, radiation weighting factors, the sievert definition of effective dose and dose rate effectiveness factor (DDREF) and ALARA, all closely intertwined with the LNT approach (see e.g. (Cook and Calabrese, 2006; Mitchell, 2006).

During the fourteen years which had elapsed since the UNSCEAR report on adaptive response was issued, several new professional scientific journals and societies have emerged, covering the rapidly developing field of hormetic science. Important new information on radiation hormesis has also appeared in a great number of peer-reviewed publications. At the 2007 session of UNSCEAR the Polish delegation proposed that the Committee should critically review this new matter, which is of vital importance for the philosophy and practice of radiological protection. As in the past, the Committee did not agree to include such a study in its current program of work. I hope that, as in the past, the Committee will soon reconsider this issue.

Threshold or no threshold - that is the question, posed in the UNSCEAR 1958 report, and still unresolved. The no-threshold principle, seemingly simplifying radiation protection procedures (or its

bureaucracy), has not only enormously increased their cost, but most importantly, is the culprit who created the universal fear of low levels of ionizing radiation. Among the disastrous consequences is the present lack of public acceptance of nuclear energy, the only realistic means of satisfying the future needs of humanity.

Proponents of the no-threshold philosophy often claim that one can never, with any finite experiment, prove that a given environmental factor is totally harmless. Thus, even if no effect is observed, such as is the case with hereditary disorders in Hiroshima and Nagasaki, one can only state that there is a certain probability that in fact there is no effect. Then the precautionary principle is invoked, and unrealistically low exposure standards are coined. To claim this position with a clear conscience, LNT protagonists should first falsify the elementary model of Feinendegen-Polycove (Feinendegen, 2005) which provides a logical and mathematical basis for radiation hormesis.

The hormesis concept transcends that of a dose threshold. In the absence of hormesis, the existence of a true threshold might be impossible to demonstrate rigorously because of the statistical difficulty of absolutely proving equality of effect in an epidemiological study. If however a deficit is observed in the irradiated population, as is the case in hormesis, there may be a statistically significant difference at an acceptable confidence level (Webster, 1993). The very existence of radiation hormesis phenomenon proves the existence of radiation thresholds and falsifies LNT. This is why hormesis is the best remedy for the mass psychological affliction called radiophobia, and, by the same token, this is why it is ignored by the influential part of the radiation protection establishment, against a vast factual evidence and the benefit of society.

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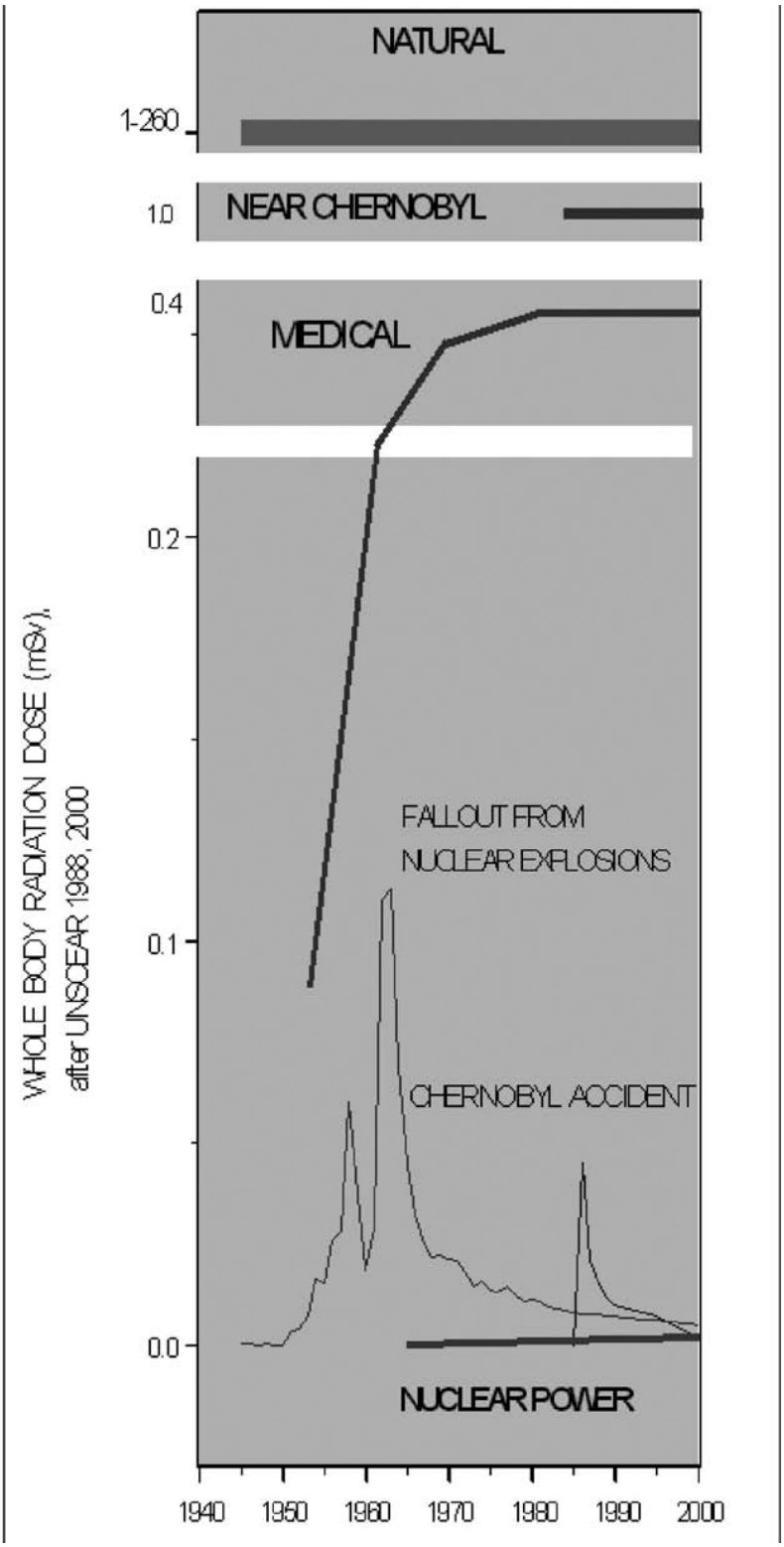
FIGURE 1.

Exposures of global population from major radiation sources, and of inhabitants of regions highly contaminated by radioactive fallout after Chernobyl accident. After (UNSCEAR, 1988; UNSCEAR, 2000).



WNA Personal Perspectives

The Chernobyl Disaster and How It Has Been Understood

Zbigniew Jaworowski

Zbigniew Jaworowski
Central Laboratory for Radiological Protection
Ul. Konwaliowa 7, 03-194 Warsaw, Poland
Voice: +48-22-754-4434; fax +48-22-711-7147
jaworo@clor.waw.pl

Professor Zbigniew Jaworowski is a retired chairman of the Scientific Council of the Central Laboratory for Radiological Protection in Warsaw, and former chair of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). He was born in Krakow, Poland, and graduated as a physician in 1952 at the Medical Academy in Krakow. In 1963 he received his PhD in natural sciences, and in 1967 his DSc in natural sciences.

In the 1950s he studied chemical carcinogens before working as a radiotherapist at the Oncological Institute in Gliwice. From 1958 to 1970 he worked in the Institute of Nuclear Research in Warsaw as a head of the Laboratory of Radiotoxicology, including a stint at the Research Cancer Institute in London as a stipendiary of the International Atomic Energy Agency (IAEA) measuring content of ^{210}Pb in bones of British population and in hair of Polish uranium miners.

From 1970 to 1987 he was head of the Department of Radiation Hygiene in the Central Laboratory for Radiological Protection in Warsaw. He then worked briefly at the Biophysical Group of the Institute of Physics, University of Oslo, the Norwegian Polar Research Institute in Oslo, as a visiting professor at the National Institute for Polar Research in Tokyo, and in the Institute for Energy Technology at Kjeller near Oslo.

Dr. Jaworowski was a member of UNSCEAR from 1973 to 2010, and was its chairman 1980-82. He was participant or chairman of about 20 Advisory Groups of International Atomic Energy Agency (IAEA) and of the United Nations Environmental Programme (UNEP). He has published about 300 scientific papers and four books, and has participated in writing and editing 10 published scientific documents of UNSCEAR, IAEA and UNEP.

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ABSTRACT

The Chernobyl accident was probably the worst possible catastrophe of a nuclear power station. It was the only such catastrophe since the advent of nuclear power 55 years ago. It resulted in a total meltdown of the reactor core, a vast emission of radionuclides, and early deaths of 31 persons. Its enormous political, economic, social and psychological impact was mainly due to deeply rooted radiophobia induced by the linear non-threshold (LNT) assumption on radiation health effects. It was an historic event that provided invaluable lessons for nuclear industry and risk philosophy. The accident demonstrated that using the LNT assumption as a basis for protection measures and radiation dose limitations was counterproductive, and led to sufferings and pauperization of millions of inhabitants of contaminated areas. The projections of thousands of late cancer deaths based on LNT are in conflict with observations that in comparison with general population of Russia, a 15% to 30% deficit of solid cancer mortality was found among the Russian emergency workers, and a 5% deficit of solid cancer incidence among the population of most contaminated areas.

Introduction

Ten days after two steam and hydrogen explosions blew up the Chernobyl nuclear reactor in Ukraine in April 1986, the fire that melted its core died out spontaneously. But the drama of this catastrophe still flourishes, nourished by politics, authorities, media and interest groups of ecologists, charitable organizations and scientists. It lives in the collective memory of the world and propagates real health, social and economic harm to millions of people in Belarus, Russia and the Ukraine. It is exploited in attempts to strangle development of atomic energy, the cleanest, safest and practically inexhaustible means to meet the world's energy needs. The world's uranium resources alone will suffice for thousands of years (IAEA 2008).

Chernobyl was indeed an historic event, but it is the only nuclear power station disaster that ever resulted in an occupational death toll, albeit a comparatively small one. A vast environmental dispersion of radioactivity occurred but it did not cause any scientifically confirmed fatalities in the general population. The worst harm to the population was caused not by radiation, and not to flesh, but to minds.

This Chernobyl disaster provided many invaluable lessons. One of them is a recognition of the absurdity of LNT which assumes that even near zero radiation dosage can lead to cancer death and hereditary disorders. Chernobyl was the worst possible nuclear power catastrophe. It happened in a dangerously constructed nuclear power reactor with a total meltdown of the core and ten days of free emission of radionuclides into the atmosphere. Probably nothing worse could happen. Yet the resulting human death toll was small, compared with major accidents involving other energy sources.

Dispersal of radioactive material

Highly sensitive monitoring systems that had been developed in many countries for the detection of fallout from nuclear weapons enabled easy detection of minute amounts of Chernobyl dust, even in remote corners of the world. The assumption that even these traces might be dangerous added to global epidemics of fear induced by the accident.

Radioactive debris was dispersed into the troposphere and stratosphere of the Northern Hemisphere up to at least 15 km altitude (Jaworowski and Kownacka 1994).[1] Such a high vertical distribution and mixing enabled a small portion of Chernobyl debris to pass over the equatorial convergence and into the Southern Hemisphere (Philippot, 1990) and on to the South Pole (Dibb *et al.* 1990).[2]

Enormous amounts of radionuclides entered the air from the burning reactor. Yet the total emission was 200 times less than from all of the 543 nuclear warheads exploded in the atmosphere since 1945. The highest estimated radiation dose to the average member of the world population from these atmospheric warhead explosions was 0.113 mSv recorded in 1963 (UNSCEAR 1988). During the first year after the accident, the average dose received by an inhabitant of the Northern Hemisphere was estimated by UNSCEAR (2000a) as 0.045 mSv, *i.e.*, less than 2% of the average global annual natural dose (2.4 mSv/year).

[1] On the first few days after the accident the concentrations of radiocesium measured at this altitude over Poland (maximum 36.1 mBq/m^3 STP) was 2 to 6% of that at the ground level.

[2] This was not in agreement with computer models of nuclear accidents that projected a maximum uplift of fission products to below 3000 m altitude ApSimon HM, Goddard AJH, Wrigley J, and Crompton S. 1985. Long-range atmospheric dispersion of radioisotopes - II. Application of the MESOS model. Atmospheric Environment 19: 113-125, ApSimon HM and Wilson JJN. 1987. Modelling Atmospheric dispersal of the Chernobyl release across Europe. Boundary-Layer Meteorology 41: 123-133.

Figure 1: Chernobyl disaster and LNT

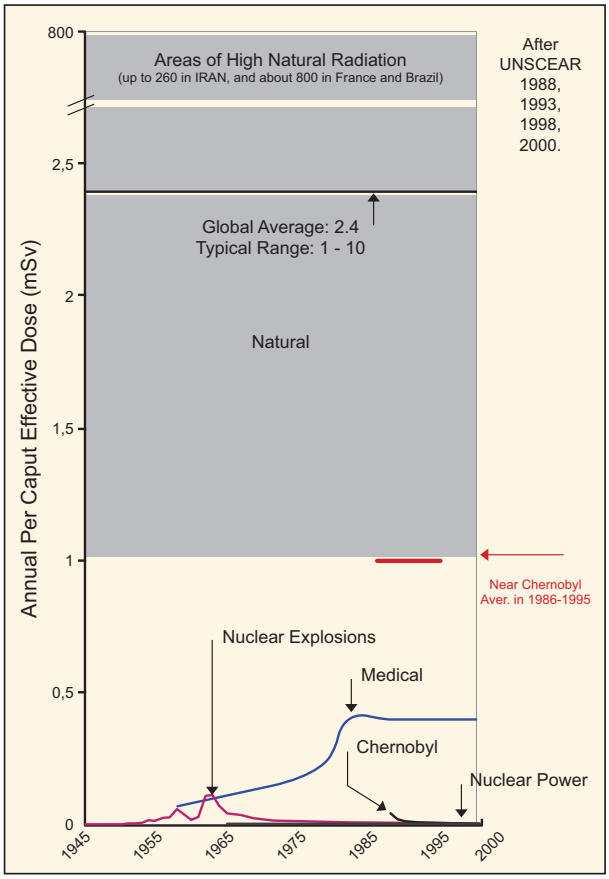


Figure 1. Worldwide and local (near Chernobyl and in areas of high natural radiation) average annual radiation doses from natural and man-made sources. Based on UNSCEAR (1988, 1993, 1998, 2000b).

People living in the most contaminated areas of the former Soviet Union received an average individual annual whole body radiation dose over the decade 1986-95 of 0.9 mSv/year in Belarus, 0.76 mSv/year in Russia, and 1.4 mSv/year in Ukraine (UNSCEAR 2000b). All these doses dwarf in comparison with natural radiation doses in some parts of the world which, for example, in Ramsar, Iran reach >400 mSv/year (Mortazawi *et al.* 2006) and in Brazil and south-western France reach up to more than 700 mSv/year (UNSCEAR 2000b) (Figure 1).

However, responses to the accident were based mainly on LNT criteria, leading to unreasonable levels of action, and arguably doing more harm than good.

Other radiation exposure and effects

Comparison of these 1986-95 doses from contaminated areas along with epidemiological observations should be the basis of realistic estimates of the latent medical consequences of the Chernobyl accident, rather than using risk factors based on LNT. This fact, and the comparatively minute health consequences, were apparent soon after the catastrophe (Jaworowski 1988), but this information was not shared with the public. Recently the well-known environmentalist James Lovelock spent a lot of time dispelling all the usual myths that surround the Chernobyl accident and stated that for many years the scientists who could have challenged the nonsense about the catastrophe chose to keep quiet (Murphy 2009).

Some parts of the Earth's surface have high natural radiation background, but no harmful health effects have ever been detected in these areas. This is consistent with other studies of the incidence of cancers in populations exposed to radiation from anthropogenic sources. In the United States and in China, for example, the incidence of cancers was found to be lower in regions with high natural radiation than in regions with low natural radiation (Frigerio *et al.* 1973; Frigerio and Stowe 1976; Wei *et al* 1990). Among British radiologists exposed mainly to x-rays, the mortality from all causes including cancer is lower by about 50% than that in the average male population of England and Wales (Berrington *et al.* 2001). Also, in other population groups exposed to low doses of ionizing radiation[3], a lower percentage of malignant tumours has been observed (Cohen 2000; Luckey 2003; UNSCEAR 1994).

A Taiwan study of several thousand residents of apartments contaminated with cobalt-60 in reinforcing steel who had been chronically exposed to gamma rays for up to 20 years with total doses estimated to

[3] *i.e.*, patients diagnosed with ^{131}I and X-rays, dial painters, chemists and others exposed to ingested or inhaled radium or plutonium, persons exposed to higher levels of indoor radon and A-bomb survivors.

Warsaw, 5 January, 2006

COMMENTS OF DR. ZBIGNIEW JAWOROWSKI
REPRESENTATIVE OF REPUBLIC OF POLAND IN UNSCEAR
"CHERNOBYL'S LEGACY: HEALTH, ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS"
THE CHERNOBYL FORUM

1. GENERAL COMMENTS:

The apparent aim of the document is to dispel irrational psychosis of fear among the population in the three countries most affected by the Chernobyl accident, and among the public elsewhere. Except for 31 early fatalities, psychosis is the most grave and wide impact of this accident, both at the regional and global scale. It caused the greatest medical, economic and societal harm. The document rightly (although not explicitly) stresses that in the contaminated areas the vast majority of about 5 million inhabitants receives now irradiation from the Chernobyl fallout corresponding to a lifetime dose less than 70 mSv, which is lower than the average global natural lifetime radiation dose of 170 mSv, and many times lower than the natural doses in many regions of the world, and that therefore most of the excessive restrictions imposed during the past twenty years should be removed. The statements about lack of increase of solid cancers, leukaemia, the number of stillbirths, adverse pregnancy outcomes and delivery complications, refuting the false information on disastrous medical effects of Chernobyl accident, disseminated en masse over the past twenty years, are also valuable. There is no need to list here many other statements which are right and most helpful. We shall limit our comments to these parts of the text that need correction and to items that are lacking.

In spite of so many right statements this document may result in continuation of the mass anxiety and radiophobia. Some of information in this document is in apparent contradiction to the earlier statements of UNSCEAR. Therefore one has to object against a statement that this document is the result of "consensus view"[1] of eight organisations, including UNSCEAR.

The document incorrectly presents the real causes of the accident, and of its worst psychological, societal and economic effects. It is clear that these effects were not due to ionising radiation, but rather due to excessive remedial measures, and a massive, global scale radiophobic propaganda. This is recognized in "Chernobyl's legacy…" report, in which the authorities of the former USSR, and of post-soviet countries are slightly and politely criticized for implementation of these measures and for their undue continuation during so many years. However, the report does not explain that these measures were based on recommendations published in documents of international organizations, that these recommendations were based on the LNT (linear non-threshold) assumption, and were utterly exaggerated. At example ICRP Publication No. 40 (1984) recommended for relocation in major radiation accidents a first year dose of 50 mSv. This would correspond to a long-term (or lifetime) dose of about 150 mSv. This policy was followed, and even "improved," by the Soviet authorities. In reality, perhaps the most important lesson of Chernobyl is that these recommendations and the assumption lead to disastrous effects, by not taking into account that the recommendations themselves involve non-radiological risks, incredibly high costs, and other forms of harm, all of which need to be balanced against the radiological benefits. This balancing should occur at

[1] The last paragraph of the Summary states: "This report is a consensus view of the eight organisations of the UN family and of three affected countries."

the level of formulation of the recommendations, and not be deferred to a time of emergency and to persons involved in its remediation. The Chernobyl accident exposed a failure of the ALARA principle.

The reservations of Polish delegation pertain mostly to statements on radiation induced health effects and evacuation measures. In this respect UNSCEAR, as the most authoritative international body in the matter of effects of ionizing radiation, should clearly present its stand. The text of the document does not agree with the opinion of the Committee expressed on these subjects during the fifty-third session. Especially strong protests were expressed by a majority of members against presenting such values as projected 4000 radiation induced late cancer fatalities, and 50 deaths allegedly caused by acute irradiation. Thus, the "Chernobyl's Legacy ..." report in its present form cannot be regarded as expressing "a consensus view" of UNSCEAR, as stated in the Summary, even though some members might be of different opinion.

In light of the arguments presented above, Polish delegation would certainly vote against presenting the Chernobyl Forum conclusions as agreed with UNSCEAR. The Chernobyl case is too serious, and position of UNSCEAR should be discussed and voted during UNSCEAR's regular sessions. Also, UNSCEAR has no mandate to produce documents on matters other than sources and effects of ionising radiation (we had this discussed many times during sessions). Thus we are not able to consent on the Chernobyl Forum documents which deal with matters other than radiation.

Members (Representatives) of national delegations are entitled to publish their personal opinions, also on UNSCEAR texts, but they cannot represent UNSCEAR as a Committee - only themselves, personally.

Is there any document concerning by-laws of UNSCEAR to check this interpretation?

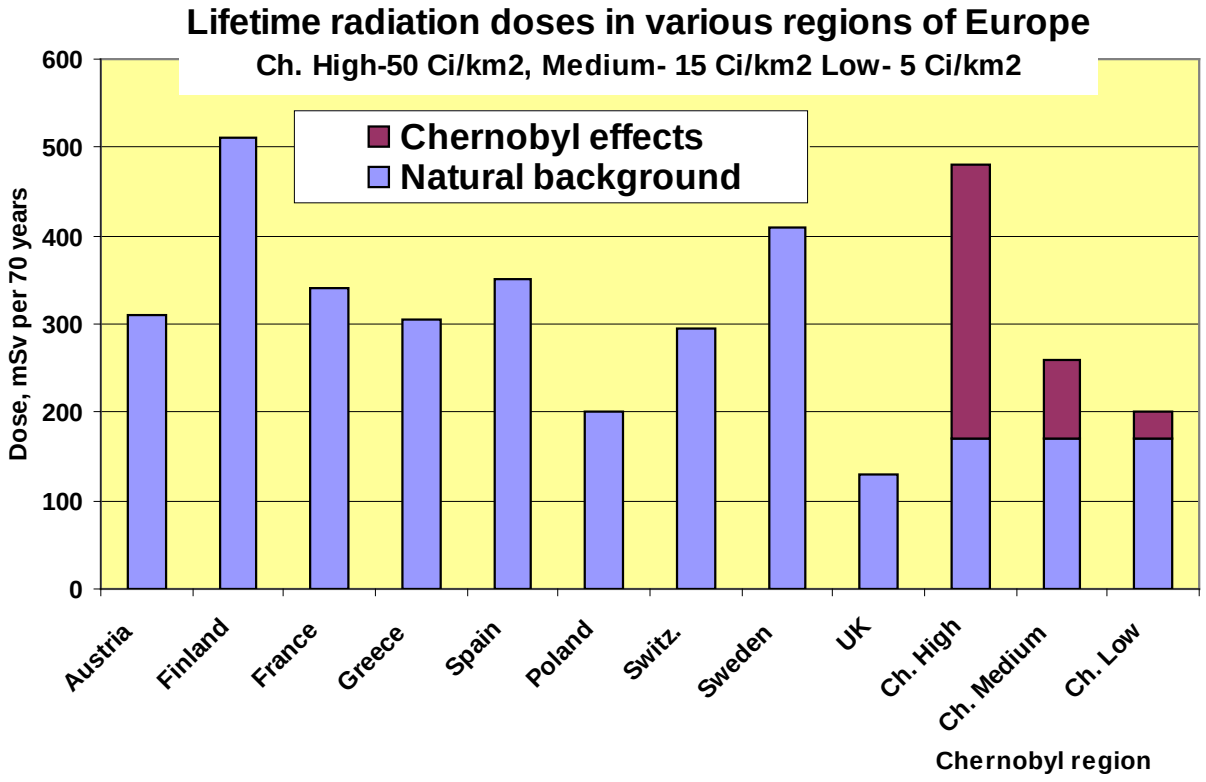
Except for its first report of 1958, UNSCEAR refrained from presenting in its publications numerical projections of late carcinogenic effects of low radiation doses, in recognition of their weak scientific basis. This long standing policy UNSCEAR should apply in the case of Chernobyl Forum documents, if they are to be presented as expressing a consensus. Even in its 1958 report UNSCEAR recognized this weakness, and for projections of leukaemia incidence from nuclear test fallout the Committee presented as equally uncertain two types of estimates: (1) for the non-threshold assumption (400 – 2000 cases per year), and (2) for threshold assumption (zero cases). Later years brought an abundance of information on stimulatory and adaptive responses to low radiation doses, as well as experimental and epidemiological data (reviewed inter alia in UNSCEAR 1994 report), and explanation of the repair mechanisms, which all suggested existence of the phenomenon of radiation hormesis (beneficial effects of low level ionising radiation). These findings should be taken into account in estimation of health consequences of exposure of the public to the Chernobyl fallout. The data collected by UNSCEAR since 2000 (e.g. in A/AC.82/R.650) show that in the three post-soviet countries the incidence of all cancers combined in exposed population was by 2 – 70 per cent lower than in non-exposed population, and in recovery operation workers from Russia and Ukraine by up to 30 per cent lower. This information needs to be included in the "Chernobyl's Legacy …" document if it is to fulfil its declared task.

1.1. Excessive evacuation measures.

The draft of report shows symptoms suggesting that in order to obtain approval of Russian government, the reasons of the accident have not been mentioned at all. Further on, probably

in order to avoid possible displeasure of the three governments, several statements indicating criticism towards the excessive evacuation measures and unjustified inclusion of 7 million people into the ranks of "Chernobyl victims" have been deleted. These statements should be kept if the document aims in presenting objective truth about Chernobyl accident and its consequences. In the interest of this truth – and in this case it is the same as the practical interest of humanity – some statements should be included in the report to make it clear that the tragedy of so many people was not due to radiation, but rather due to exaggerated fear of radiation, fed up by various organisations promoting LNT hypothesis.

The report is not presenting the dose levels on which the prescribed relocation of 850 000 people, and implemented relocation of about 400 000 was based. At first, relocation was performed in areas where the lifetime (70 years) dose from Chernobyl fallout might be higher than 350 mSv (5 mSv/year). Later this limit was changed to 150 mSv (i.e. 2.1 mSv/year), and then to 70 mSv (1 mSv/year) (Ilyin, L.A. Chernobyl : Myth and Reality, Moscow, Megapolis, 1995; Filyushkin, I.V. Health Physics Vol. 71, pp. 4-8, 1996). A dose of 1 mSv causes in each human body about 0.2 damage of DNA per year, or 14 damages per 70 years. The normal rate of spontaneous, natural damages of DNA of the same type as those induced by ionising radiation is about 70 million in each cell per year (lower estimate). This shows absurdity of relocating hundreds of thousands of people to protect them from a trifle number of DNA damages added to a virtual tsunami of their spontaneous rate, against which evolution provided us with extremely efficient defence mechanisms.



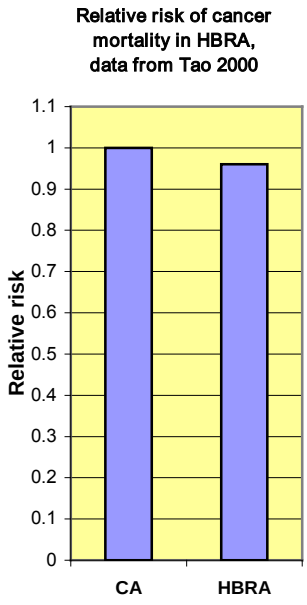
In the present version of the report in the chapter on ***"How have the governments responded to the challenges of Chernobyl?"*** in the third paragraph the statement *"as…knowledge on the nature of the risks has grown more sophisticated, the basis on which the zones are defined has been called into question"* has been deleted. And yet the report stresses in several points that the *"level of radiation is similar to natural background levels in some other European countries."* A look at Fig. 1 showing lifetime doses in several European countries and in Chernobyl regions of low, medium and high contamination level shows clearly that the

decisions of evacuation of hundreds of thousands of inhabitants from those regions were utterly wrong! If they should be treated as right, then the government of Finland should evacuate the whole Finnish population, and governments of Sweden or France should evacuate very large areas in their countries. So a statement, which at least suggests that the basis on which the zones were defined is questionable, should be maintained. Please note, that it does not even say that the governments of the three countries were wrong at the time. The statement is very mild, and refers to *"knowledge which has grown more sophisticated"* since the accident, so the reader can understand that the decisions of that time in the past are not criticised, but simply that they would not be taken today.

In accordance with IAEA Basic Safety Standards, Annex V, 1996 permanent resettlement should be considered if the lifetime dose is projected to exceed 1000 mSv. In our opinion this action level is too low. In some regions of the world such doses people receive from natural background radiation in few years time without evidence of any harm. However, even if this current IAEA action level had been applied in the Soviet Union, the unspeakable tragedies of hundreds of thousands of people, economic and societal ruin of millions of inhabitants, and country scale losses of the order of tens or hundreds billion US dollars would not have occurred. Thus, UNSCEAR should question unjustified criteria for evacuation, criticise the historically taken decisions, or at least to indicate that they would not be taken nowadays.

1.2. Total number of fatalities due to Chernobyl

Another major point of concern is "*the total number of people that could have died or could die in the future from cancer induced by the Chernobyl originated whole body exposure over the lifetime*", estimated as 4000 in the section entitled, ***"How many people died as a result of the accident and how many more are likely to die in the future?"*** The report stresses that the claims of hundreds of thousands of victims are exaggerated. In several places it is stated that there has been no increase of solid cancers, nor any other radiation induced diseases among the general population with the exception of thyroid cancers, but nevertheless it is said that *"according to bio-statistical projection"* …this number *"is estimated to be around 4000."* Let us clarify this statement. Is it based on *"projection"* of the observed trends? Apparently no, because as indicated above, there is no increase of mortality among the general population. The basis for this *"projection"* is the LNT hypothesis, which has been shown to be invalid for low doses, such as natural doses to the population of Finland, Sweden, China etc. Fig. 2 dealing with China High Background Radiation Area shows that the 80 000 inhabitants of that area, who receive lifetime radiation doses higher by about 300 mSv than the people in control area (CA), enjoy slightly better health and certainly do not justify any predictions that additional two or three hundred mSv over the lifetime will induce additional premature deaths (data from [Tao 2000]).



The 4000 projected deaths were apparently calculated for about 600 000 persons, with an average annual radiation dose of about 1.9 mSv, and a cancer risk factor of 5% per Sv. Several UN organisations, including UNSCEAR, and the former chairman of ICRP advised against making such calculations, based on LNT and collective dose. Just publishing this number will be harmful and petrify the Chernobyl fears. No efforts (as proposed in the "Chernobyl's legacy…") to explain to the public all intricacies of the easy-chair-elucubrations

of radiation risk assessments, and comparing them with other risks or spontaneous level of cancer deaths, etc. will help. The past twenty years proved that this is impossible, and a kind of day-dreaming. Making such calculations was defined by one of the founders of radiological protection Dr. Lauriston S. Taylor as the "deeply immoral uses of our scientific heritage" (Some non-scientific influences on radiation protection standards and practice. Health Physics, 32:851-874, 1980). This statement fits some parts of the Chernobyl Forum documents.

Also incorrect is presenting a number of 50 “current” fatalities as all caused by acute irradiation. It appears that from among 134 heavily irradiated persons, 28 died soon after the accident due to acute radiation disease, and 106 persons remained alive. From among these 106 persons 22 died during the next 19 years, which gives the mortality rate of 1.09% per year, i.e. slightly higher than mortality rate in Poland in 2000 of 0.98%, but much lower than the average mortality rate in 2000 in Belarus (1.4%), Russia (1.38%) and Ukraine (1,65%) (Statistical Yearbook of the republic of Poland, 2001, Warsaw, Central Statistical Office, p. 734). In Table 9, p. 24, UNSCEAR draft report on "Health Effects due to Radiation from the Chernobyl Accident" (A/AC.82/R.650) it is clear that among 17 Chernobyl survivors of the acute radiation syndrome who died until 2001, only 4 or 5 persons died because of neoplastic diseases. Thus in 2001 this group mortality structure was 24% or 29% of cancer deaths among all mortality causes, i.e. not much different from the values of 23.0% for Poland in 1999, or 25.2% in Austria, and 26.1% in Germany, both in 1990 (Zatoński, W. et al. Atlas of Cancer Mortality in Central Europe, IARC Scientific Publications No. 134, Lyon, 1996, p. 175; Zatoński W. et al., Cancer in Poland in 1999, Report of The Maria Skłodowska-Curie Memorial Cancer Center and Institute of Oncology, Warsaw, 2002). Presenting these fatalities as caused by the Chernobyl radiation is a misuse of science.

Therefore the statements on 4000 + 50 Chernobyl fatalities should not be approved by UNSCEAR .

The authors of the Forum report speak in another place (section on ***"Do people living in the affected regions have an accurate sense of the risks they face?"*** p. 23) about *"misconceptions and myths about the threat of radiation."* They stress that these misconceptions promote *"a paralysing fatalism among residents."* This is very much true. But then, is it not the duty of UNSCEAR, as the most authoritative body in the world in matters of "Effects of Atomic Radiation" to say clearly that the residents have no more reason to be afraid than the people in Finland? And to add that actually the people in Finland, Sweden and France, where the radiation is high, are among those nations that enjoy the longest life expectances in the world? If UNSCEAR will not say it, who will?

1.3. Recommendations to governments

In view of the above discussion Polish delegation presents the following comments to this chapter. Seven million people are now included in the cohort of Chernobyl victims, what testifies that the whole approach to the post-accident situation was wrong. Now time came to say it aloud, and to allow the people to return to their villages, to establish realistic radioactivity limits for milk, meat or mushrooms, at the levels that ensure a true safety, and to break the vicious circle of fear, despair and need.

The Forum Report says in page 21 *"the Soviet government adopted a very cautious policy with regard to the level of radioactive contamination that was considered acceptable..."* But today we know that this "policy" was wrong, and according e.g. to BSS 1996, should not have been adopted. Also in the summary of the International Conference "Decade after Chernobyl" in Vienna on 9-12 April 1996 [Summary 96] the conclusion No. 66 speaks about *"erroneous*

decisions taken by the government at that time." In 1996, at an international conference with the participation of Russian representatives, it was possible to speak about committed errors. Why should we not be able to repeat it today?

The recommendation to the three governments should be: ***"revise your policy and adopt radiation limits according to the knowledge we have today, not according to the fears born in the aftermath of the accident**."*

1.4. The effects of low radiation doses

In page 23, section ***"Do people living in the affected regions have an accurate sense of the risks they face?"*** the Forum Report writes that people *"still lack the information"* and speaks about *"misconceptions and myths about threat of radiation"* and *"unresolved controversies surrounding the impact of low dose radiation on health."*

Is it not the right time to withdraw the LNT as the basis for evaluation of the situation in Chernobyl? To tell those people in Chernobyl that the hypothesis used for regulations and administrative aims, does not mean any practical danger? To show them examples of other populations and their health records? UNSCEAR did point to possible benefits of low dose radiation more than a decade ago [UNSCEAR 94]. Now with the vast new information from the experimental and theoretical work, UNSCEAR should address the issue once again. The example of the French Academy of Science and the French Academy of Medicine [Acad. 05] which has officially stated that low level radiation does not involve health risks should be followed. This would be the best service that the international community can give to the people around Chernobyl.

2. DETAILED COMMENTS

2.2 In paragraph 3 of the Summary of the "Chernobyl's legacy…" *"the number of emergency and recovery workers who died due to radiation sickness and subsequent diseases"* is given as 50. It is not correct: see discussion above.

In addition, please, note that the statement *"of various causes"* is NOT equivalent to *"due to radiation sickness and subsequent diseases."* In the [Summary 96] the conclusion No. 14 said that *"…over the last decade additional 14 patients died. Their deaths were not due to ARS, so they cannot be directly ascribed to the effects of radiation."* Today the number of people who died has risen, but it is still people who died due to *various causes*, and consequently their deaths should not be ascribed to radiation. There is no reason to change this position in the present Forum Report. It would be better to write in the Summary just the sentence which is in the text on p. 7. It is more precise.

2.3 Further on in paragraph 3 there is the statement about 4000 premature deaths. It is discussed above. It should be deleted, as not based on any facts, but only on a doubtful LNT hypothesis, which led to disastrous post-Chernobyl effects. Against its aim, by this statement the "Chernobyl's Legacy…" will continue fuelling the radiation hysteria among population of contaminated areas. Instead we propose to state: *"The observations during the twenty years that have passed since the accident do not indicate any significant increases in radiation induced mortality among the general population."*

2.4 Paragraph 6. *"Countermeasures… were on the whole timely and adequate."* [UNSCEAR 2000] report and later the report of [UNDP 02], but also the main body of report as it was

presented in September 2005 in Vienna [Forum 2005], stress rather that the restrictions should be lifted. Thus the [UNDP 2002] report says on p. 19, paragraph 24:

*"As far as possible **people should be allowed to take their own informed decisions** about where they wish to live, even if those decisions may lead to them facing a measure of increased risk. Studies should be undertaken to establish how far the present regime of **restrictions could responsibly be relaxed**,…"*

Indeed, the UNSCEAR 2000 report provides coefficients for evaluation of lifetime doses since 1986 till 2056 (without evacuation). The results are shown in Fig. 1 above. It is evident that the measures were not *"timely and adequate"* but excessive and mostly unnecessary. In the main body of the Forum report presented in September 2005, in page 7, there is the text quoted above. We propose to keep this text in the main body of the report and also to put it into the summary.

2.5 Page 3 Highlights

Paragraph 1, first line

The term "disaster" is not appropriate for an accident that caused 31 immediate deaths and probably no additional deaths over the next twenty years. Even the mass media (e.g. International Herald Tribune) acknowledged that it was *"a major industrial accident, but not a disaster."* The term *"disaster"* could have been used originally immediately after the accident, when the expected number of fatalities was counted in hundreds of thousands, which has been clearly shown to be erroneous. The Forum report should not use the terminology which is contrary to its own summary of the effects of this accident. Today the term "disastrous consequences" can be only used in the context of social and economic consequences of wrong decisions taken by authorities, which forced hundreds of thousands of people away from their homes and developed psychosis of fear and depression in 7 million of people qualified as "Chernobyl victims." It is not the radiation doses, but the fear of radiation that has devastated lives of so many people.

2.6 Page 3, Preface

Paragraph 1. This paragraph (especially a citation from IAEA: "foremost nuclear catastrophe in human history") strongly suggests to an uninformed reader that the accident was caused by a **nuclear explosion**. It should be clearly stated that the cause of the accident was not a nuclear explosion, but a dramatic power surge, with a resulting explosion of steam and hydrogen. At this point one should add that the principal cause of the accident was a unique combination of errors in the reactor design, with an inherent unsafe features of the reactor physics, not found in any other types of power reactor. The lack of safety culture and a human error were important but secondary, and in any other type of reactor they would not have resulted in such severe consequences. From the point of view of human losses the Chernobyl accident was a minor event as compared with many other industrial catastrophes. We propose to delete the quotation from IAEA *"foremost nuclear catastrophe"* and to use the space for the above comment.

2.7 Page 4 section on *"**How much radiation …**"*

Paragraph 3. … *"…received high doses…"* and "*as a result 28 of them died within first four months from radiation and thermal burns, and another 19 died over the years up to 2004."* See comments above (p.5).

We propose to rewrite this paragraph so that it does not suggest that those deaths were due to radiation exposure.

2.8 Page 5 first paragraph below box

The contemporary readers, and the future historians, need to know what were the doses avoided by implementing mass evacuation.

2.9 Page 5, last two lines from the bottom . The sentence on natural radiation in India, Iran, Brazil and China: *"Some residents in these areas receive over 25 mSv per year from the radioactive materials in the soil on which they live…."* This is an essential information, which would help to fight radiophobia, the declared aim of this report. It shows that the individual doses of the order of 1 mSv or a few mSv are without importance. In the proposed text this sentence is deleted, which demonstrates the state of mind of the editors. We propose to keep it as it is, and show the reader reality, rather than imaginary and terrifying numbers of radiation fatalities.

2.10 Page 6 section ***"How many people died…"***

First paragraph, line 4 – the word *"highly"* should be added before the word *"exaggerated…"*

2.11 page 6, section "***How many people died…"*** First paragraph line 7

"Estimated number of fatalities 4000…." This is discussed above. We propose to delete it.

2.12 Page 7. section on ***"What diseases have already resulted…."***

Paragraph 2. This paragraph comments the estimate of 4000 fatalities. We propose to remove it together with this estimate.

Paragraph 4, the report says about recovery workers:

… about 5% of fatalities that occurred in 1991–1998 in the cohort under study of 61 000 Russian workers exposed to an average dose of 107 mSv can be caused by radiation-induced diseases. The absolute number of deaths in this cohort attributable to radiation caused by solid cancers, circulatory system diseases and leukaemia was estimated to be about 230 cases.

Summing up together fatalities due to neoplastic diseases, with circulatory ones which are about twice a high as the neoplastic ones, is improper. A two-fold increase in chronic lymphatic leukaemia (deemed not to be caused by radiation) among the Russian emergency workers, suggests that also an increase in number of other deaths registered in this group may have a non-radiation cause. The conclusion that 230 death was caused by an average dose of 107 mSv is unfounded, and highly improbable. Again a LNT fear mongering?

2.13 Page 7. section on ***"What diseases have already resulted…."*** *Thyroid cancer in children*

UNSCEAR documents clearly show that the registration rate of "Chernobyl" thyroid cancers increased not only in children, as was initially expected, but also in adults. In Belarus the incidence rate (SIR) for adult population ranged in 1995-1999 between 3.21 and 11.8, and in recovery operation workers between 3.10 and 6.65. These values of SIR were much higher

than among those exposed as children or adolescents in 1992-1997, which ranged between 0.25 and 1.75 (A/AC.82/R.639, Tables 8, 13 and 14). The average thyroid dose estimated for evacuated population of Belarus and Ukraine was 470 mGy, and for residents of the contaminated areas who were not evacuated were exceeding 2000 mGy for the most exposed infants, and for adults about 100 mGy. The average dose for the population of the three republics is estimated to be 7 mGy (A/AC.82/R.650). This should be compared with the average thyroid dose of 1,100 mGy (maximum 40,000 mGy) received from iodine-131 by 34,000 Swedish patients. Among these patients, there was no statistically significant increase in thyroid cancers in adults and children, who have not been thought to have cancer before treatment with iodine-131 (Holm et al., 1988; Hall et al., 1996). In fact, an opposite effect was observed; there was a 38% decrease in thyroid cancer incidence as compared with the non-irradiated adult population. In a smaller British study of 7417 patients receiving iodine-131 with radiation doses up to 300 000 mSv, a 17% deficit of cancers was observed (Franklyn, J.A., The Lancet, 353 (June 19, ; 2111-2115, 1999). In the contaminated Bryansk oblast in Russian Federation, the number of thyroid cancers registered in the years before the Chernobyl accident (1982 – 1983) for the age groups under 20 years was reported as zero (A/AC.82/R.650). In Polish females, for the years 1983 to 1986 in the age group of 0 to 15 years, the number of thyroid cancers ranged between zero and 10, and was similar in the years after the Chernobyl accident, ranging in 1995 between zero and 7, and in 1996 between zero and 4. This difference between the two countries may be a result in difference of the diagnostic methods and health service organization. The sudden rise in thyroid cancer incidence rate was observed in the Bryansk oblast already in 1987, i.e. one year after the accident (UNSCEAR, 2000). This is not in agreement with the latency of 8-10 years after irradiation observed earlier for these cancers. Most probably the increased number of thyroid cancers in population of the contaminated areas is due to dramatic change in diagnostic services.

The maximum incidence rate of the "Chernobyl" thyroid cancers in children and adolescents of 0.027% was registered in 1995 in the Bryansk oblast, Russia. In Minsk region, Belarus, the normal incidence of occult thyroid cancers is 9.3% (Furmanchuk, A.W. et al. Histopathology, 23:319-325, 1993).

The normal level of the occult thyroid cancers for the age group of 0 – 15 years is in Finland 2.4%, and for whole population 35.6% (Fransila, K.O. and H.R. Harach, *Occult papillary carcinoma of the thyroid in children and young adults - A systematic study in Finland*. 1986. 58: p. 715-719). The difference between this maximum and data from Finland is by a factor of about 90 for children, and > 1000 for adults. This shows an enormous potential for the screening effect. The occult thyroid cancers have the same histopathology and invasiveness as the "Chernobyl" cancers.

We propose to state that "about 4000 thyroid cancer cases registered since 1987 among people exposed as children, adolescents and adults, are probably a screening effect."

Paragraph at the bottom: *"…we can be reasonably certain that most of thyroid cancer incidence can be attributed to radiation"*. The increased registration of thyroid cancers in the contaminated areas, among the relocated people and emergency workers is most probably a typical screening effect. The above statement is certainly incorrect.

2.16 page 11 end of paragraph 3 *"the radionuclide contamination expected to be of significant interest."* What is meant by *"significant interest"*? Should the reader understand that it is only scientific interest, dealing with migration processes, or should he fear radiological hazards

due to Pu and Am? According to UNSCEAR 2000 report population is not endangered by these nuclides.

2.17 page 13, end of first paragraph *"milk may still be produced with Cs 137 activity concentrations that exceed national action levels of 100 Bq per kilogram."* These levels are more restrictive than the levels recommended by the IAEA or in force in the EU. If we take 500 Bq per litre of milk as in the EU, then the restrictions on milk drinking can be lifted. Regulations are not issues of concern for UNSCEAR, but should not "Chernobyl's Legacy …" point this out?

2.18 Page 16, section ***What were the radiation induced effects on plants and animals?***

Forum report speaks about *"numerous acute adverse effects"* on animals and plants at distances up to 30 km from the release point. However, in paragraph 4 it says *"No adverse radiation induced effect has been reported in plants and animals exposed to a cumulative dose of less than 0,3 Gy during the first month of the accident."* The dose higher than 0.3 Gy could be accumulated only in some special spots of the secluded territory. It would be misleading to suggest that such doses were typical for the distances up to 30 km from the plant. It seems therefore more appropriate to write about animals *"living in some spatially limited spots within the higher exposure areas, i.e. at distances up to 30 km etc."*

2.19 Page 19 Paragraph 2

"Large sums continue to be paid out in the form of social benefits for as many as 7 million recipients in the three countries."

In view of the comparisons of radiation doses in Chernobyl vicinity with other European countries, shown above, and taking into account that the radiation doses obtained by these 7 million people are negligibly small, it should be stressed that the approach used by governments involved must have been wrong, since it resulted in such a mismanagement of the situation, in loss of enormous amounts of money, and in development of feeling of helplessness and dependency on social aid among millions of people.

2.21 Page 20 bottom *"Anxiety over the effects of radiation on health shows no sign of diminishing."*

Again, it is the role of UNSCEAR to stress that the governments of the three countries should change their excessively restrictive regulations and thus give an impulse for hope in the communities around Chernobyl. Also, UNSCEAR is the best international organisation to clarify the health effects of low doses and make sure that they are correctly presented to the populations involved.

2.22 Page 21 paragraph last but one

The sentence proposed to be deleted should be kept in place, and used also in the summary, as remarked above. It says

"…as…knowledge on the nature of the risks has grown more sophisticated, ***the basis on which the zones are defined has been called into question …."***

It should be remembered that the decisions about zones were taken under conditions of incomplete knowledge, uncertainty of further developments of the situation, and strong political and emotional stress. Since then it has been postulated by various international bodies that the decisions concerning intervention zones should not be left to administration acting after the accident but rather pre-established in regulations in force.

The experience of Chernobyl has shown that too cautious approach leads to disastrous detrimental effects of enormous scale. Certainly no one will defend today the sequence of decisions which have resulted in mass evacuations and declaring seven million people as victims of Chernobyl. The sentence should therefore remain in the text.

2.23 Page 22 and 23 Several sentences criticising the situation and indirectly the government have been deleted "*corruption played a role*", "*the system created perverse incentives*", "*scarce funds and abuses*" …"*entitlements distributed unevenly,*" These deletions are fully acceptable, the criticism of governments in this way does not serve any useful purpose. The important is to show that radiation is not as bad as believed, because this has influence on the way people think about their future.

2.24 Page 23 section ***"Do people living in the affected regions have an accurate sense of the risks they face?"***

This question is discussed in general comments

2.25 Page 29, section on ***Remediation and countermeasures***, paragraph 3 …*"where radionuclide concentrations in milk still exceed national action levels"*

The governments in question should be advised to change these action levels.

2.26 page 32 paragraph 2 – why is it proposed to cross out *"health recuperation, free meals for children, free medicine"* ?

Zbigniew Jaworowski, MD, PhD, DSc

Representative of Republic of Poland in UNSCEAR

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WHOLE-BODY LOW DOSE IRRADIATION PROMOTES THE EFFICACY OF CONVENTIONAL RADIOTHERAPY FOR CANCER AND POSSIBLE MECHANISMS

S.Z. Jin, X.N. Pan, N. Wu, G.H. Jin, S.Z. Liu □ Jilin University Health Sciences Center, Changchun, China

□ The purpose of the present study was to explore the possibility of establishing cancer radiotherapy protocols that could promote treatment efficacy at a reduced radiation dose. Mouse models of melanoma (B16) and Lewis lung carcinoma (LLC) were used in the experiments. Conventional local radiotherapy was combined with low dose whole-body irradiation (LDWBI) in the presence or absence of gene therapy by intratumor injection of a recombinant plasmid Egr-mIL-18-B7.1 (E18B). After a number of trials with different combinations it was found that a protocol of 2-week treatment with 2 x (E18B + 2 Gy + 0.075 Gy x 2) was found to be able to promote treatment efficacy at a reduced radiation dose. In this protocol local irradiation with 2Gy was administered 24h after intratumor injection of 10 μg of the plasmid E18B followed by LDWBI with 0.075 Gy every other day for 2 sessions in 1 week, and the procedure was repeated for another week. When this combined treatment was compared with conventional radiotherapy, i.e., 2Gy every other day 3 times in one week repeated for 2 weeks, the treatment efficacy was improved, as judged by increased average survival rate, reduced mean tumor weight, reduced pulmonary metastasis and suppressed intratumor capillary growth with a 2/3 reduction of radiation dose. Immunologic studies showed stimulated natural killer (NK) and cytotoxic T lymphocyte (CTL) activity as well as increased interferon-γ (IFN- γ) secretion in this combined treatment group as compared with the group receiving local treatment alone. It is suggested that up-regulation of host anticancer immunity by LDWBI and the initiation of expression of immune genes by both the local large dose and LDWBI are important factors in the realization of improved cancer control.

Keywords: low dose whole-body irradiation, conventional radiotherapy, gene therapy, cancer

I INTRODUCTION

Radiotherapy is the most commonly used local treatment of cancer. However, the large dose needed for local control often limits its successful use. In some cases of more advanced disease, such as nonresectable lung cancer, radiotherapy in combination with chemotherapy may improve the treatment result to some extent, but the toxicity is not easily tolerated. Therefore, exploration of more effective and safer treatment modalities is needed. In view of the stimulatory effect of low dose radiation (LDR) on anticancer immunity (Liu 2003) an experimental study of the effect of low dose whole-body irradiation (LDWBI) on the

Address correspondence to Prof. Shu Zheng Liu, Jilin University Health Sciences Center, Changchun 130021, China. Email: drliusz@yahoo.com

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CANCER CONTROL RELATED TO STIMULATION OF IMMUNITY BY LOW-DOSE RADIATION

Shu-Zheng Liu □ Department of Radiation Biology, Jilin University School of Public Health, 8 Xinmin Street, Changchun 130021, China, drliusz@yahoo.com

□ Previous studies showed that low dose radiation (LDR) could stimulate the immune system in both animal and human populations. This paper reviews the present status of relevant research as support to the use of LDR in clinical practice for cancer prevention and treatment. It has been demonstrated that radiation-induced changes in immune activity follows an inverse J-shaped curve, i.e., low dose stimulation and high dose suppression. The stimulation of immunity by LDR concerns most anticancer parameters, including antibody formation, natural killer activity, secretion of interferon and other cytokines as well as other cellular changes. Animal studies have revealed that LDR retards tumor growth, decreases cancer metastasis, and inhibits carcinogenesis induced by high dose radiation. These effects of LDR on cancer control were found to be related to its stimulation on immunity. The experimental data may well explain the efficacy of the clinical trial of LDR in the treatment of cancer.

I. INTRODUCTION

Carcinogenesis induced by environmental agents is a problem of concern to the public and scientific bodies. Ionizing radiation is one among these environmental agents. It is well known that most carcinogens are immunosuppressants. Ionizing radiation is one of these when delivered at moderate to high doses. Immune surveillance is one of the most important defense mechanisms in the body monitoring the development of cancer. As reviewed in previous reports low dose radiation (LDR) enhances immune functions.[1, 2] The significance of these immunologic changes in radiation-induced cancer is still a question of debate. In UNSCEAR 1994, it is stated, "the immune system may not play a major role in moderating human radiation oncogenesis, although immune function in certain organs may ensure that some early neoplastic cells are eliminated before they become established".[3] NCRP Report No. 136 states, "in the ultimate instance of cancer *in vivo*, the adaptive response may take the form of an immune surveillance of pre-neoplastic cells. This is certainly a possibility, but it is difficult to design laboratory experiments to test it". [4] In a recent commentary article on radiation hormesis, it is recognized that "under appropriate conditions, exposure to X-rays or gamma rays at doses below those causing immunosuppressive effects has

Address correspondence to Shu-Zheng Liu, Department of Radiation Biology, Jilin University School of Public Health, 8 Xinmin Street, Changchun 130021, China. E-mail: drliusz@yahoo.com

been observed to augment various immune responses in mice..." but "the mechanisms of the observed enhancement remain to be elucidated in full...".[5] These statements accept the importance of experimental data on LDR-induced enhancement of immunity and its surveillance of cancer formation on one hand and question its significance in cancer control on the other.

There have been accumulating data disclosing the cellular and molecular mechanisms of LDR-induced activation of anti-tumor immunity in animal models, as reviewed in Reference 1. LDR increases cellular antioxidant activity; facilitates DNA damage repair; reduces malignant transformation and mutagenesis, and stimulates immune surveillance.[6-10] All these may contribute to the effect of LDR on the reduction of cancer incidence. There have been experimental studies illustrating: a) the suppressive effect of LDR on tumor growth, metastasis and carcinogenesis, b) the increased anti-cancer immunity, including enhanced NK and CTL activity, and c) the increased IFNγ and IL-2 secretion. All these data point to the significance of enhanced immune responses in cancer control.[11-23]

II. LOW DOSE RADIATION AND IMMUNITY

Stimulation of immunity by low dose radiation is manifested in various aspects.[1] Table 1 shows the immunologic parameters studied in the author's laboratory demonstrating up-regulation of immune functions in animal models exposed to single as well chronic irradiation.[24-36] As illustrated in this table, most immunologic parameters are stimulated after whole-body irradiation (WBI) by doses within 0.1 Gy, using a dose-rate within 15 mGy/min. The NK (natural killer) activity of splenocytes was assessed with the ^{125}I-UdR release method using YAC-1 cells as targets in C57BL/6J mice. Significant stimulation was observed after WBI with both 75 and 500 mGy. For most immunologic parameters of splenocytes, doses above 500 mGy may exert an inhibitory effect. But with NK activity, 500 mGy showed an even higher stimulatory effect than 75 mGy. This is obviously related to the relatively higher radio-resistance of the NK cells. This is also the case with macrophages. WBI with 75 mGy caused a 32% increase of the secretion of IL-12 (see Table 1), with higher increases after doses above 1 Gy (not shown). The inhibitory effect of peritoneal macrophages on the growth of tumor cell line S180 was increased by 52% after WBI with 75 mGy. The specific CTL activity was assayed in C57BL/6J mice bearing Lewis lung carcinoma; a 40% increase of cancer suppressive effect was observed. The ADCC (antibody-dependent cell-mediated cytotoxicity) activity is a specific reaction to P815 cancer cells, assessed with the ^{125}I-UdR release method. These four parameters are directly related to anticancer immunity. The PFC (plaque forming cell) reaction denotes the capacity of antibody formation in response to sheep RBC as antigen. This is a T-dependent reaction, which was found to be stimulated by both

TABLE 1. Immune functions stimulated by low dose radiation in mice

Immunologic Parameter	Dose (mGy)	Dose-rate (mGy/min)	Change (%)	*P* value
NK activity	75	12.5	+19	<0.05 (28)
	500	510	+45	<0.01 (28)
Mac activity[1]	75	12.5	+52	<0.05 (33)
CTL[2]	75	12.5	+40	<0.01 (13)
ADCC[3]	75	12.5	+31	<0.05 (31)
PFC reaction[4]	75	12.5	+74	<0.05 (47)
	65	15 (μGy/min)	+16	<0.05 (47)
	100	12.5	+50	<0.05 (31)
T cell proliferation[5]	77	12.7	+101	<0.01 (32)
	106	12.7	+101	<0.01 (32)
	75	12.5	+130	<0.01 (27)
	75	12.5	+142	<0.01 (25)
G-CSF secretion[6]	50	12.5	+58	<0.01 (33)
	75	12.5	+52	<0.01 (33)
	100	12.5	+42	<0.05 (33)
IFNγ secretion	75	12.5	+30	<0.05 (26)
	100	12.5	+31	<0.05 (26)
IL-2 secretion	75	12.5	+33(d2)	<0.05 (31)
	75	12.5	+66(d7)	<0.05 (31)
IL-10 secretion	75	12.5	–61	<0.01 (35)
IL-12 secretion	75	12.5	+32	<0.05 (36)
IL-18 secretion	75	12.5	+90(24h)	<0.05 (pc)
	75	12.5	+185(48h)	<0.01 (pc)
TNFα secretion	75	12.5	+358	<0.01 (30)
IL-1β secretion	75	12.5	+72	<0.01 (31)

All data represent experimental results obtained 24h after LDR except otherwise specified. 1. Macrophage antitumor activity assayed with S180 cells; 2. Specific cytolytic T lymphocyte activity of splenocytes assayed with Lewis lung cancer cells; 3. Antibody-dependent cell-mediated cytotoxicity of splenocytes assayed with P815 cells; 4. Mice were immunized with sheep RBC on day 4 after WBI and plaque-forming cells were counted on day 9; 5. T cell proliferation was measured with ^{3}H-TdR incorporation in the presence of Con A 5 μg/ml; 6. G-CSF was assayed with RIA. Reference numbers are given in parenthesis; pc=personal communication).

acute and chronic low dose radiation. Under very low dose rate, 15 μGy/min, a cumulative dose of 65 mGy increased the response significantly – by 16%. The measurement of T cell proliferation is an indication of activation and clonal expansion of the T lymphocytes, representing immune activation. Four sets of data are shown in Table 1, the first two of which are from experiments on Balb/c mice. These mice are relatively sensitive to ionizing radiation. The third and fourth sets of data are from Kunming mice, which show a response to ionizing radiation comparable to that of C57BL/6J mice, as tested in our laboratory. It is interesting to note that after an acute dose of 75-106 mGy, at the dose rate of 12.5-12.7 mGy/min, both strains of mice responded with an increase in T cell proliferation of more than 100%. However, for the Balb/c mice, this dose would have no effect in T cell proliferation if the dose rate were 200 mGy/min.(32) Other authors have also noted this strain difference of lym-

TABLE 2. Important Intracellular signal molecules stimulated by low dose radiation[1]

Signal Molecule	Dose (mGy)	Dose-rate (mGy/min)	Change (%)	P value
$[Ca^{2+}]_i$	75	12.5	+133	<0.001
Calcineurin	75	12.5	+70	<0.01
PKCα	75	12.5	+54	<0.001
PKCβ1	75	12.5	+163	<0.001
PKCβ2	75	12.5	+72	<0.01

1 Changes occurring in thymocytes 24h after WBI with 75 mGy; $[Ca^{2+}]_i$ was measured in the presence of 5 μg/ml of Con A. Methods are given in references 39 and 41.

phocyte proliferation in response to radiation.[37] The secretion of cytokines was stimulated in favor of differentiation of the T_{H1} subset. Activation of T lymphocytes is related to the up-regulation of surface molecules CD2, CD3 and CD28 after LDR.[1, 2, 27, 38] In response to these changes, intracellular signal transduction is facilitated.[39-44] Among these, the up-regulation of PKC and $[Ca^{2+}]_i$ forms the most important intracellular molecular basis of T lymphocyte stimulation (Table 2).

III. EFFECT OF LOW DOSE RADIATION ON CANCER CONTROL[11-23]

It was shown that irradiation with low dose X-rays decreased the growth rate and metastasis of implanted B16 melanoma and Lewis lung cancer in C57BL/6J mice. As shown in Figure 1, the effect of WBI with 0.075 Gy (given 24h before implantation of Lewis lung cancer cells) on tumor growth is manifested as: decrease in tumor size by ~50% (column 1); increase in mean survival time by ~40% (column 2), and decrease of 30-day mortality rate by ~40% (column 3).[11, 18, 31]

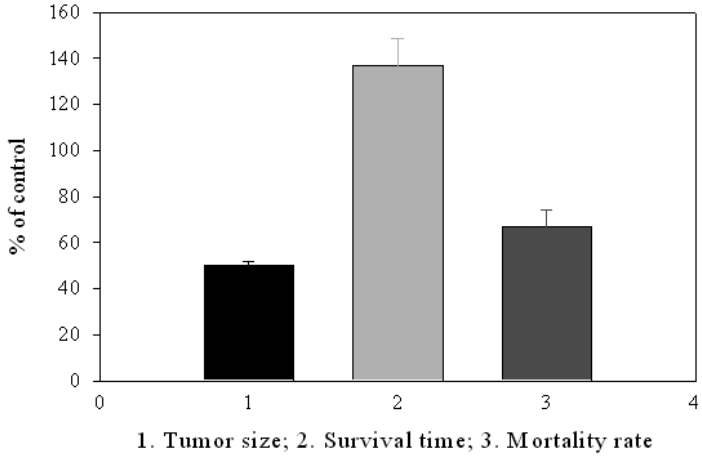

FIGURE 1. Effect of low dose radiation on Lewis lung cancer (0.075 Gy WBI, 24 h before tumor implantation)

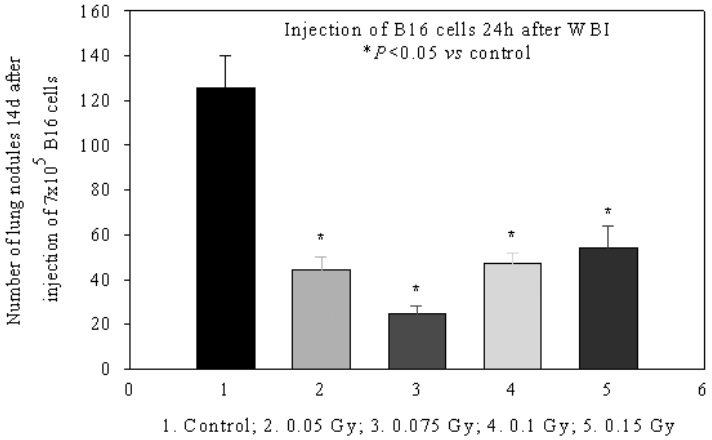

FIGURE 2. Low dose radiation reduces cancer metastasis (Injection of B16 cells, i.v., 24 h after WBI with different doses of X-rays)

Figure 2 shows the reduction of pulmonary metastasis of B16 melanoma cells after WBI with 0.05-0.15 Gy (intravenous injection of B16 cells 24 h after irradiation, showing significant reduction of lung nodules of cancer cells 14d after injection)[12, 14, 15]. Figure 3 shows the effect of LDR on the efficacy of mitomycin C (3 mg/kg body weight) on the growth of Lewis lung cancer cells implanted to mice. WBI with 0.075 Gy, 6 h before chemotherapy, further reduced the tumor size (column 3 compared to column 2)[16, 17, 23]. Figure 4 shows the alleviation of immune suppression caused by tumor burden (Lewis lung cancer implantation) by LDR, as demonstrated by the recovery of the lowered NK activity after LDR in tumor-bearing mice.[13]

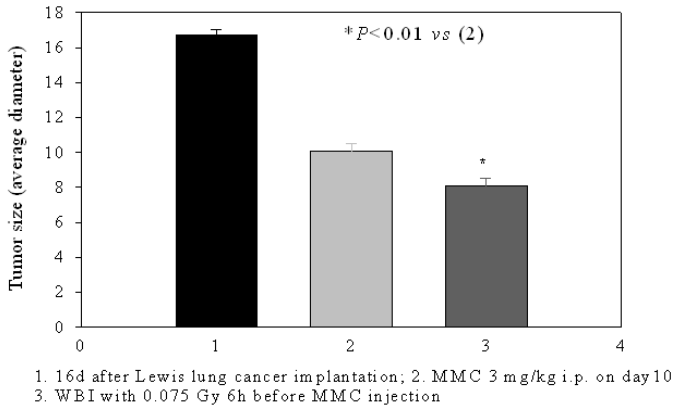

FIGURE 3. Low dose radiation increases efficacy of cancer chemotherapy

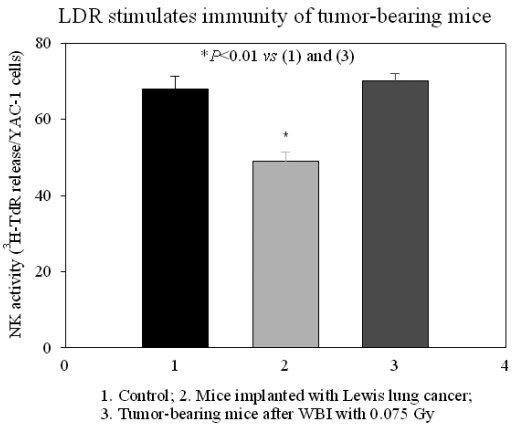

FIGURE 4. Low dose radiation stimulates immunity in tumor-bearing mice

In a well recognized model of thymic lymphoma, induced by fractionated WBI (1.75 Gy once a week for 4 consecutive weeks) in C57BL/6J mice, a low dose of radiation (0.075 Gy), 6-12 hours preceding each fractionated high dose radiation (HDR), could reduce the lymphoma incidence from 43.3% in the control (exposed to only the HDR) to 15.1% (HDR being preceded by 0.075 Gy with an interval of 6h) and 17.6% (HDR being preceded by 0.075 Gy with an interval of 12h) in 6 months after the fractionated exposures. These inhibitory effects of LDR on cancer growth and cancer induction are accompanied with immunologic stimulation.[11, 19, 21, 22]

Clinical application of LDR in the treatment of cancer has shown enlightening results. When patients with non-Hodgkin's lymphoma under chemotherapy were given total body or half body (to the thorax) LDR in a regimen of 0.1 Gy 3 times a week or 0.15 Gy 2 times a week for 5 consecutive weeks with a total dose of 1.5 Gy, the survival rate in 9 years rose to 84% from 50% of the control with chemotherapy alone ($P < 0.01$). The LDR-treated patients also showed enhanced anti-cancer immunity.[45]

In an area of high natural radioactivity with the exposure rate 3 times as high as that in the adjacent control area in south China with epidemiological survey having been continued for 31 years, the cancer mortality rate was found to be slightly lower than that among the inhabitants in the control area.[46] Examination of the peripheral blood of the inhabitants showed increased reactivity of the lymphocytes to PHA and enhanced DNA damage repair capability as shown by increased UDS of the lymphocytes.[47] There were increased chromosome aberrations in the blood samples implicating DNA damage.[46] It is supposed that the balance between radiation damage and defense mechanisms under this circumstance results in no increase or even lowering of cancer mortality in spite of the long term exposure of the inhabitants to the low level radiation.

IV. CONCLUDING REMARKS

The stimulation of immunity by LDR concerns most anticancer parameters, including antibody formation, NK activity, CTL activity, macrophage activity, ADCC activity, secretion of interferon and other cytokines as well as other cellular changes. Animal studies have revealed that LDR retards tumor growth, decreases cancer metastasis, and inhibits carcinogenesis induced by high dose radiation. These effects of LDR on cancer control were found to be related to its stimulation on immunity. The experimental data may well explain the efficacy of the clinical use of LDR in the treatment of cancer. This paper reviews the present status of relevant research on effects of low dose radiation on anticancer immunity as support to its trial in clinical practice.

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Documented optimum and threshold for ionising radiation

T.D. Luckey

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

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

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

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

1 Introduction

To live in harmony with ionising radiation we must consider the complete dose-effect relationships for continuous exposures. The average background level of ionising radiation for the world is about 2 mSv/y; this does not include medical or cosmic

Nuclear law stands on thin ice

T. D. Luckey

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

Abstract: Revealing the questionable actions of many radiobiologists exposes the Achilles heel of nuclear law. Documentation of systematic deception is reason enough to change nuclear law. Much evidence comes from mis-statements by seven committees for the Biologic Effects of Ionizing Radiation (BEIR). These fraudulent interpretations led ignorant physicians, the media and government officials to accept the 'linear no threshold' (LNT) dogma. These misrepresentations are fully rebutted by rational interpretation of data. The best data comes from exposed nuclear workers. Eight independent epidemiological studies, involving almost 12 million person-years, consistently showed that increased exposure to ionising radiation was associated with decreased cancer mortality rates. These questionable actions kept ionising radiation from its role in abundant health.

Keywords: atomic bomb victims; BEIR reports; cancer; lifespan; misinformation; nuclear workers; radiation effects.

Reference to this paper should be made as follows: Luckey, T.D. (2008) 'Nuclear law stands on thin ice', *Int. J. Nuclear Law*, Vol. 2, No. 1, pp.33–65.

Biographical notes: Sir Samurai T. D. Luckey, PhD, is Emeritus Professor of the University of Missouri, MO, USA and Honorary Professor of the Free University of Herborn, Germany. He has a BS (1941) in chemistry from Colorado State University and both an MS (1944) and PhD (1946) in biochemistry/nutrition from the University of Wisconsin. His thesis included the first use of dietary antibiotics for animals. His group at Notre Dame University achieved the first reproduction in germfree animals. From 1954 to 1968, he was Chairman of the Department of Biochemistry, University of Missouri, Columbia, MO. He was guest lecturer for Group 6 Astronauts and was nutrition consultant to NASA for Apollos 11–17. In 1984, he was knighted, *Ritter von Greifenstein*, for his world leadership in intestinal microecology. In 2003, he was made Honorary Samurai for giving Japan the concept of radiation hormesis for health.

1 Introduction

> "The exact contrary of what is generally believed is often the truth." Jean de le Bruyere (1645–1696)

Hormesis is the biphasic effect of any agent upon physiological processes. Small doses are biopositive; large doses are bionegative. The inflection point is the threshold.

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Biological Effects of Ionizing Radiation: a Perspective for Japan

T. D. Luckey

http://www.jpands.org/vol16no2/luckey.pdf

Most of the world press assumes that all radiation is harmful. If the Japanese government acts on this presumption in responding to the nuclear reactor damage from the March 2011 earthquake and tsunami at Fukushima, Japan's already reeling economy will be crushed by tremendous unwarranted expense. Japan should learn from Chernobyl what Mikhail Gorbachev understood too late: "The nuclear meltdown at Chernobyl 20 years ago…was perhaps the real cause of the collapse of the Soviet Union five years later."[1]

Ionizing radiation is hormetic. The concept of hormesis, which is not generally understood by news media and governments, is that small doses are beneficial, while large doses are harmful. This effect is known to occur for about 40 essential nutrients, all drugs, and most other agents. Both chronic and acute exposures to ionizing radiation exhibit hormesis. Consideration of the full spectrum, beneficial as well as harmful, of the biological effects of ionizing radiation is vital to understanding the importance of nuclear fallout.

There are thousands of scientific papers showing benefit from low doses of ionizing radiation.[2,3,4] Japan could consult its own world renowned scientist, Dr. Sadao Hattori,[5] retired director of research for the Central Research Institute of Electric Power Industry of Japan. Instead, there is a tendency to rely on the Radiation Effects Research Committee (RERF) in Hiroshima, which spends millions of dollars searching for the harm from ionizing radiation, and is not a reliable source of information about the health benefits from ionizing radiation.

Ionizing Radiation Is Essential for Life

Experiments with appropriate shielding in brine shrimp,[6] protozoa,[7,8] and mice and rats[9] have produced convincing evidence that ionizing radiation is essential for life. In Luckey's study of protozoa and Kuzin's of mice and rats, researchers replaced natural (radioactive) potassium with the non-radioactive potassium-39 to produce radiation deficiency. These reports suggest that ionizing radiation is also an essential agent for humans.

The concept that we live with a radiation deficiency is supported by more than 2,000 scientific papers showing that low-dose irradiation stimulates the well being of laboratory animals and humans.[3,4] The data indicate that ambient levels of ionizing radiation throughout the world, 3 mSv/y,[10, p 198] are insufficient for vibrant health. For example, evidence suggests that if we received adequate ionizing radiation, cancer would be a rare disease .

Chronic Exposure

A complete dose-response curve (Figure 1) shows the optimum ionizing radiation rate associated with the minimal cancer death rate and maximal life span: about 100 mGy/y.[11] The zero equivalent point (ZEP), the rate that divides healthful from harmful effects, is about 10,000 mGy/y. Exposure rates greater than ZEP may produce symptoms of radiation sickness and death.

Evidence for this concept comes from Taipei.[12] In 1982-1984, radioactive cobalt-contaminated steel was used for girders in an apartment complex. During the next two decades about 10,000 people lived in this enriched radioactive environment. The average dose received was 50 mSv/y. This dose is close to the optimum dose of 100 mSv/y. (Sv and Gy are about equal in the new evaluation.)[13] The cancer death rate for these apartment

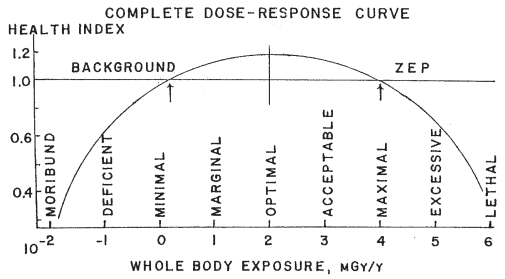

Figure 1. A Spectrum of the Effects of Ionizing Radiation. The complete dose-response curve for ionizing radiation includes radiation deficiency, radiation optimum, and radiation toxicity (modified from Luckey 1991,[3] Figure 9.3, p 230). The ordinate indicates a relative index of health. The abscissa provides the power of the exposure with the base of 10. The background is about 3 mGy/y and the zero equivalent point (ZEP) is about 10 Gy/y.

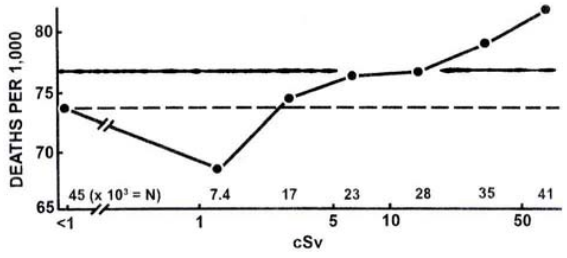

Figure 2. Cumulative Cancer Mortality Rates. Cancer mortality rates per 1,000 survivors of Hiroshima and Nagasaki are displayed for estimated radiation exposure. Numbers above the abscissa indicate thousands of people included in each point; i.e. the number receiving a dose ≤ *x*. The dashed horizontal line represents the RERF "in-the-city control," 3-10 km from ground zero. The mortality rate for those exposed to about 1 cSv is significantly less than that for the RERF control ($P<.01$). The solid line represents the cancer mortality rate of people in villages northwest of Hiroshima.

dwellers was only 3.5 per 100,000 person years; 116 deaths per 1,000 person years were anticipated from consideration of controls. Although thorough studies have not been made, it appears that chronic low-dose irradiation decreases cancer mortality rates. Lung cancer mortality rates as a function of indoor radon concentrations in the U.S. support this view.[14]

Acute Exposure

Conclusions about the effects of acute exposure are generally based on data on the Japanese survivors of the atomic bombs (see Figure 2).[15] The RERF compared the cancer mortality of Hiroshima and Nagasaki survivors with that of people who were 3-10 km from ground zero ("in-the-city controls"). These controls received some radiation from the bombs, and many went into the bombed areas while residual radiation was high. Total [all-cause] "mortality rates in 120,321 atomic bomb survivors were not increased at doses <490mSv."[16, p46]

The cancer mortality rate of the 7,430 survivors of Hiroshima and Nagasaki who received 10-19 mSv was 68.5% ($P<.01$) of that of controls.[17] The 28,423 survivors (69% of all survivors) who received <200 mSv had 76.6 cancer deaths per 1,000 people (see Figure 2). This was close to the value, 77 cancer deaths per 1,000 people, found for the unexposed people in villages northwest of Hiroshima.[18] Note that this "out of city" control population had more cancer deaths per 1,000 people than the RERF "in the city" control cohort, a comparison that RERF never makes.

Exposures greater than 200 mSv showed increased cancer death rates commensurate with increasing dose. Thus the ZEP for acute ionizing radiation was about 200 mSv. Radiation sickness was caused by exposures >2,000 mSv.

More evidence comes from 23 young Japanese fishermen who received fallout from the explosion of a hydrogen bomb at Bikini Island in March 1954. All suffered severe radiation sickness. Whole body doses were 170-590 cSv (1,700–5,900 mSv), according to Eisenbud's Table 12.1.[10] Thyroids received 300-1,000 cSv. The man who received the largest dose died 206 days following exposure. The others survived for more than two decades with no cancers.

Triage for Radiation

The above information provides a tentative guide for the treatment of people exposed to different amounts of chronic and/or acute ionizing radiation. Triage following a nuclear accident or explosion provides the most good for the most people. Triage for people with acute radiation exposures usually involves consideration of other problems also, such as psychological reactions, physical disabilities, injuries from flying debris, and/or inadequate food, water, and housing.

The major concern here is trauma caused by direct irradiation; this contributes about 5% of the total harm from atomic bombs.[19] Triage also includes radiation from many external and internal radionuclides; this accounts for about 10% of the total harm from a nuclear explosion. Blast and heat cause about 80% of the total harm. These guidelines are of limited value in nuclear accidents.

Radiation triage is relatively simple for people with chronic exposures from external sources. People exposed to less than 10 Gy/y (about 1 mGy/h) from external radiation can immediately help those less fortunate. People exposed to 2-10 mGy/h for prolonged periods should be placed under observation. Reddening of the skin (as in sunburn) is symptomatic of minor excess radiation. People exposed to 11-100 mGy/h for an extended time will have radiation sickness and should be placed under medical care. People who receive more than 1 Gy/h will have serious radiation sickness. People exposed to more than 10 Gy/h should be placed in a hospice with care and a blessing.

The combined data from Hiroshima and Nagasaki[17] indicate that people exposed to less than 1,000 mSv acute radiation should be recruited to help those who are disabled and sick. People exposed to 1,000-2,000 mSv acute radiation may require treatment for radiation sickness. People exposed to 2,000-6,000 mSv need immediate hospitalization. People with more than 6,000 mSv should be placed in a hospice with care and a blessing. The quality factor (Q) of nuclear explosions needs to be re-examined.[13]

Sir Samurai T.D. Luckey, Ph.D., is honorary professor, Free University of Herborn, Germany, and retired professor, University of Missouri, Columbia. In 1984 he was knighted in Germany for two decades of world leadership in intestinal microecology. In 2003 he was awarded an honorary Samurai for his work in radiation hormesis. Contact: tdl108@sunflower.com.

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STANDARD FOR CHRONIC EXPOSURE TO IONIZING RADIATION

TD Luckey (March 2012)

Radiation Level mGy/year	Place and/or Event
1,000	THRESHOLD, the dose rate separating safe from harm
900	Miners in Austria, Germany, and China; high radiation homes in Ramsar, Iran
400	Some homes in Dolon, Kazakhstan; Guarapari Beach, Brazil; some homes in Ramsar, Iran; workers at Bad Gastein, Austria; astronauts in space
200	British radiologists; 200,000 people exposed at the atom bomb plant at Mayak, Russia; radon in Finland; British and USA radium dial painters; high area of Ramsar, Iran
100	Miners in Malaysia, Nigeria and Thailand; homes in Telesh Magalleh, Iran; streets of Guarapari, Brazil; radon in Sweden; spa attendants in Boulder, MT, USA and Bad Gastein, Austria; Canadian air crews; atomic plant workers in England; 8,000 villagers in the dust of an exploding tank at Mayak, Russia; many homes in Ramsar, Iran; radon in some Italian villages; German air crews
50	OPTIMUM. Kanyakumari, India; supersonic flight (average of 0.03 mGy each flight); radon in Missouri, USA; Canadian and British nuclear workers; Schneeberg, Germany; southwest France; mountains of Kerala, India; contaminated apartments in Taipei, Taiwan
40	Mt. Everest peak; USA radiologists; Austrian mine workers; popular beaches at Guarapari, Brazil
20	Niska Banja, Balkins; homes in Finland; Kerala beach, India; Araxa-Tapira beach, Brazil; British men in nuclear bomb tests; radon in parts of USA, Sweden and Canada; Meaipe Beach, Brazil; radon in Romania; China cave dwellers; attendants at Ikaria spa, Greece; 270,000 residents who stayed in Chernobyl; radon in southwest England; much of Japan
10	English nuclear workers; beach of Managalore, India; Gornja, Bosnia; Stubla, Serbia; geophagia in Kosovo, Serbia; French, Australian, and USA nuclear workers; average for the Rocky Mountain states, USA; average for Ramsar, Iran; Nile Valley, Egypt; French nuclear power workers; Korean nuclear power workers; spa workers in Montana, USA; streets of Guarapari, Brazil; the small radioactive plume northwest of Fukushima, Japan; 48,000 USA nuclear shipyard workers
5	Himalayan Mountains; supersonic flight crews; Kowary, Poland; Tamil Nadu and Chatrapur, India; Darling Scarp, Australia; the large prong from Fukushima, Japan; Kanyakumari, India; radon level in Moscow; homes in Guarapari, Brazil; British atom bomb observers; cancer (8 studies) in contaminated nuclear workers was 52% that of strict controls; coastal cities in Kerala, India
4	Many mountains above 9,000 feet
3	WORLD AVERAGE TODAY. Low cancer mortality rates and long life spans typify workers at nuclear weapons Laboratories, USA; spa areas of Turkey; mid-Honshu, Japan (after the Fukushima earthquake and explosion)
2.4	WORLD AVERAGE, 1980 (before Chernobyl and satellite explosions). High radiation cohort in Yangjiang, China; certain mountain caves; health spa in Misasa, Japan; Gulf Coast cities, USA
0.3	Nuclear submariners (film badge data)
0.2	Radioactive potassium in the body
0.01	Radiation from Three Mile Island to the nearby population
0.01	Fukushima's contribution to atmospheric radiation

Ionizing Radiation **Dose Ranges** *(Sievert)*

Office of Science
U.S. DEPARTMENT OF ENERGY

acute exposure = all at once; chronic = hours, days, years

Cancer Radiotherapy total doses to tumor

⑥ 0 10 20 30 40 50 60 70 80 90 100 Sv

Whole body, acute: G-I destruction; lung damage; cognitive dysfunction (death certain in 5 to 12 days)*

Total Body Irradiation (TBI) Therapy

Whole body, acute: cerebral/ vascular breakdown (death in 0-5 days)*

Acute Radiation Syndromes

Life Span Study (A-bomb survivor epidemiology)

Whole body, acute: circulating blood cell death; moderate G-I damage (death probable 2-3 wks)*

Whole body, acute: marked G-I and bone marrow damage (death probable in 1-2 wks)*

Charged particle event (Solar flare) dose on moon, no shielding

⑤ 0 2 4 6 8 10 Sv

Estimated dose for 3-yr **Mars** mission (current shielding)

Early, transient skin erythema (2-24 hr onset)

Temporary epilation (3 wk onset)

Main erythema reaction (10 day onset)

Permanent epilation (3 wk onset)

Human LD_{50} range acute exposure **no** medical intervention*

Human LD_{50} range acute exposure with medical intervention

***Note:** Whole body acute prognoses assume **no** medical intervention (G-I = gastrointestinal)

Cancer Epidemiology

Evidence for small increases in human cancer above 100 mSv acute exposure or 200 mSv chronic exposure

④ 0 200 400 600 800 1000 mSv *(1 Sv)*

Typical mission doses on International Space Station (ISS)

Ramsar, Iran high natural bkg/yr

DHS emergency guideline to save a life: 250 mSv

Interplanetary Space natural bkg/yr

DOE Low Dose Program

③ 0 10 20 30 40 50 60 70 80 90 100 mSv

Kerala coast, India high natural bkg/yr

DHS emergency guideline for public relocation: 20 mSv/yr (2 rem/yr)

Guarapari, Brazil high natural bkg/yr

DOE, NRC dose limit for workers: 50 mSv/yr (5 rem/yr)

Typical added annual dose for commercial airline flight crews

Medical Diagnostics (A-O)

see chart >>

② 0 1 2 3 4 5 6 7 8 9 10 mSv

Airport x-ray whole body scanner: 0.00007 mSv/scan

(Limit = 0.25 mSv/yr ≈ 4000 scans/yr)

Natural background, USA average ≈ 3.1 mSv/yr (includes radon)

Yangjiang, China high natural bkg/yr

DOE facility releases

Regulations & Guidelines

① 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 mSv

Round-trip Los Angeles – New York (≈ 0.037 mSv)

EPA dose limit public drinking water systems: 0.04 mSv/yr

EPA dose limit from release in air: 0.1 mSv/yr

NRC cleanup criteria for site decommissioning / unrestricted use: 0.25 mSv/yr

DOE, NRC dose limit for the public: 1 mSv/yr (100 mrem/yr) (ICRP, NCRP)

(TIPS: Transjugular Intrahepatic Porto-systemic Shunt)

Medical Diagnostics mGy
(Estimated maximum organ dose)

X-ray films	
A – Chest (PA & Lat)	0.14
B – Dental Panoramic	0.7
C – Lumbar-Sacral Spine	2 – 3
D – Mammogram	2 – 4
Radiotracer Imaging	
E – Heart Stress (Tc-99m)	6 – 12
F – Bone (Tc-99m)	4 – 15
G – Dual Isotope Stress Test	40 – 45
H – PET: F-18 FDG (bladder)	55 – 80
CT Scans (X-ray) (multiple scan average dose)	
I – Chest CT	20 – 30
J – Head CT	30 – 50
K – Abdominal CT	22 – 60
L – Full Body CT	50 – 100
Fluoroscopy/Procedures	
M – Barium Contrast G.I.	10 – 22
N – Cardiac Catheterization	12 – 40
O – TIPS Procedure	400 – 1400

LD_{50} = Lethal Dose to 50% (whole body dose that results in lethality to 50% of exposed individuals in 30-60 days)

Dose Equivalent: 1 Sievert = 100 rem = (absorbed dose x radiation quality)
Absorbed Dose: 1 Gray = 100 rad
1 Sv ≈ 1 Gy for x- and gamma-rays
(" ≈ " stands for "approximately equal to")

NOTE: This chart was constructed with the intention of providing a simple, user-friendly, "order-of-magnitude" reference for radiation exposures of interest to scientists, managers, and the general public. In that spirit, most quantities are expressed as "dose equivalent" in the more commonly used radiation protection units, the rem and Sievert. Medical diagnostics are expressed as estimated maximum organ dose; as they are not in "effective dose" they do not imply an estimation of risk (no tissue weighting). Dose limits are in effective dose, but for most radiation types and energies the difference is numerically not significant within this context. It is acknowledged that the decision to use these units is a simplification, and does not address everyone's needs. (NRC = Nuclear Regulatory Commission; EPA = Environmental Protection Agency; DHS = Department of Homeland Security)
Disclaimer: Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information disclosed.

Chart compiled by NF Metting, Office of Science, DOE/BER. "Orders of Magnitude" revised **June 2010**
http://www.lowdose.energy.gov/

Source: Office of Biological and Environmental Research (BER), Office of Science, U.S. Department of Energy
http://www.science.doe.gov/ober/

Dose-Response, 5:1–10, 2007
Formerly Nonlinearity in Biology, Toxicology, and Medicine

ISSN: 1559-3258
DOI: 10.2203/dose-response.06-109.Mitchel

International Hormesis Society
www.HormesisSociety.org

LOW DOSES OF RADIATION REDUCE RISK *IN VIVO*

R. E. J. Mitchel □ Radiation Biology and Health Physics Branch, AECL, Chalk River Laboratories, Chalk River, ON, Canada

□ The "Linear No Threshold" hypothesis, used in all radiation protection practices, assumes that all doses, no matter how low, increase the risk of cancer, birth defects and heritable mutations. In vitro cell based experiments show adaptive processes in response to low doses and dose rates of low LET radiation, and do not support the hypothesis. This talk will present cellular data and data from animal experiments that test the hypothesis in vivo for cancer risk. The data show that a single, low, whole body dose (less than about 100 mGy) of low LET radiation, given at low dose rate, increased cancer latency and consequently reduced both spontaneous and radiation-induced cancer risk in both genetically normal and cancer-prone mice. This adaptive response lasted for the entire lifespan of all the animals that developed these tumors, and effectively restored a portion of the life that would have been lost due to the cancer in the absence of the low dose. Overall, the results demonstrate that the assumption of a linear increase in risk with increasing dose in vivo is not warranted, and that low doses actually reduce risk.

I. INTRODUCTION

All current radiation risk estimates and all radiation-protection standards and practices are based on the so-called "Linear No-Threshold Hypothesis". This LNT hypothesis is in turn, based mainly on epidemiological data of humans exposed to high doses and dose rates but is considered to also apply at low doses and dose rates, with a two-fold reduction in risk. The hypothesis states that:

1. Risk per unit dose is constant without a threshold.
2. Risk is additive.
3. Biological variables are insignificant compared to dose.

These assumptions allow radiation dose to be used as a surrogate for radiation risk. However, at low doses the LNT hypothesis is acknowledged to be an assumption, and other dose responses are also possible, including supralinear, sublinear or threshold/hormetic responses. This paper presents data testing the validity of low dose risk estimates that are based on the LNT hypothesis, and will focus on cancer risk, considered to be the most important measure of risk. However, other papers presented at this meeting will focus on teratogenic effects and heritable mutations, also important measures of risk.

Address correspondence to R. E. J. Mitchel, Radiation Biology and Health Physics Branch, AECL, Chalk River Laboratories, Chalk River ON. Canada, K0J 1J0. E-mail: mitchelr@aecl.ca

While ultimately the influence of low doses on the risk of carcinogenesis must be measured *in vivo*, it is important to understand the mechanisms underlying any such effects. Experiments conducted in other organisms, or based on human and other cells grown in issue culture can provide such information. Therefore, in addition to *in vivo* data, this paper also presents the results of cellular experiments that indicate the mechanisms that may be involved.

If we consider the potential biological consequences of a radiation exposure to a normal cell, there are three general biological outcomes of DNA damage[1] as shown in Figure 1. When DNA damage is created as a result of one or more tracks of radiation through a normal cell, the cell will attempt to repair that damage. If the repair is successful and the DNA restored to its original state, i.e., an error-free repair, then the cell is also restored to normal. In this case, there is no resulting consequence to the cell and hence no resulting risk. Another possibility is that the cell recognizes that it cannot properly repair the damage, and as a consequence activates its genetically encoded cell death process, called apoptosis. Again, in this case, no risk of carcinogenesis results since dead cells do not produce cancer. The third possible outcome of the DNA damage is repair that avoids cell death but which is error-prone, resulting in a mistake that creates a mutation. At this point, the cell may still activate its apoptotic cell death program but could also simply resume dividing. Creation of these errors is part of a process called genomic instability, which can ultimately lead to cancer. Of the three possible outcomes, therefore, only one creates a risk of carcinogenesis. It is useful to remember that the LNT hypothesis implies that risk is influenced only by dose, and hence predicts that the relative proportions of these three biological possibilities must be constant. If they were not constant, then risk would vary with their relative proportions, and not strictly as a function of dose.

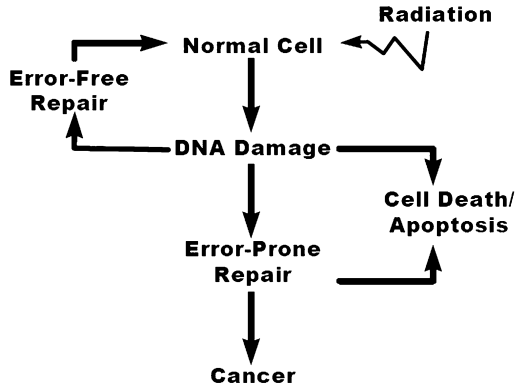

FIGURE 1. Possible outcomes of a cellular radiation exposure in a normal cell

II. EXPERIMENTAL RESULTS AND DISCUSSION

Cellular Studies

A common result of a radiation exposure in cells, particularly a high dose exposure, is a break in one or more chromosomes, which indicate DNA double strand breaks. If cells divide before repairing those breaks, the remaining pieces of chromosomes are packaged into micronuclei (MN). Measuring the frequency of MN in cells that have been exposed and allowed to repair therefore represents a measure of the competence of the cells at repairing such chromosomal breaks (and therefore DNA double strand breaks) in response to radiation damage. We have tested the influence of low doses and low dose rate exposures on the ability of human skin cells to repair radiation breaks in chromosomes[2]. Figure 2 shows the MN frequency in cells exposed to a variety of doses (1-500 mGy) delivered at a low dose rate (3 mGy/min) 3h before exposure to a high dose (4 Gy) delivered at a high dose rate (1.8 Gy/min). The LNT hypothesis predicts that the consequences of the two doses would be additive and yet the experiment shows that they are not. The combined exposure resulted in fewer broken chromosomes than the single acute 4 Gy exposure alone. The figure also shows that enhanced repair occurs after 1 mGy, the lowest γ dose possible in a single cell since it represents, on average, a single track per cell. The figure also shows that higher doses, representing multiple

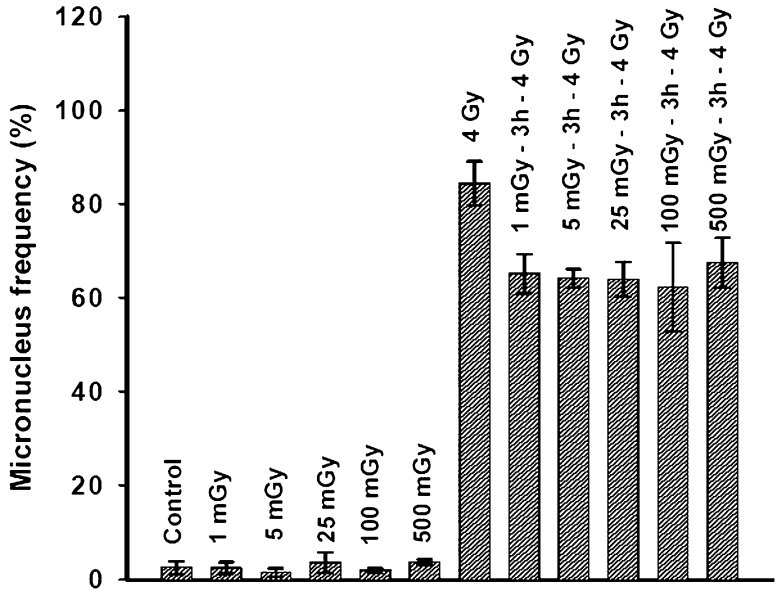

FIGURE 2. Low doses enhance the repair of broken chromosomes in human cells.

tracks/cell, produce the same result as one track/cell when those tracks from the higher doses are spaced out in time (3 mGy/min). This type of analysis can be applied to *in vivo* situations that have particular importance in the environmental assessment and licensing of nuclear installations. For example we have shown[3] that this adaptive response also occurs in fibroblasts taken from wild white tailed deer, and therefore the consequences of radioactive contamination in the environment may not be as predicted by the conventional LNT assumptions.

A direct test of this idea is shown in Figure 3, which gives some preliminary data[4] obtained from leopard frogs living in either a radiologically clean pond or in a pond contaminated with tritium and ^{14}C that gave an annual dose of about 1 mGy. Liver cells from the frogs living in the clean pond showed a normal adaptive response to low doses, as was seen in the human cells in Figure 2. However, exposure of the frogs from the contaminated pond to a large dose produced comparatively little increase in chromosomal breakage in their liver cells, and this was only slightly reduced if the frogs were given a prior low adapting dose.

This lack of chromosomal damage after a high dose indicates that the frogs were already adapted to radiation by their environmental exposure. This *in vivo* measure of the consequences of environmental radiation exposure indicates that low levels of radioactivity in the environment may not be harmful to organisms, and may only serve to enhance cellular defence mechanisms. Evidence that improvement of cellular defence mechanisms after low dose exposures is actually reducing cancer risk is

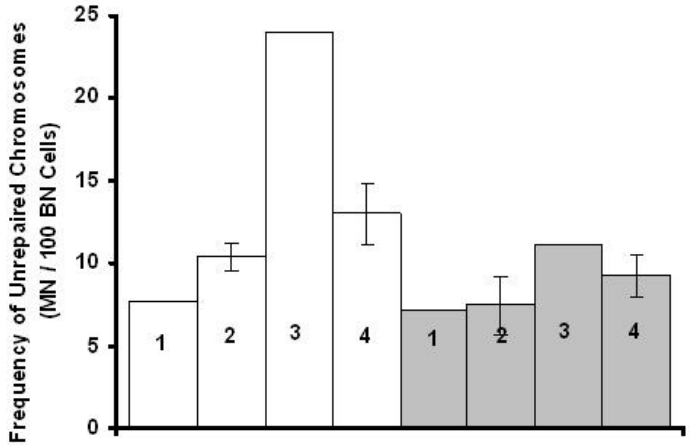

FIGURE 3. Repair of chromosome breaks in liver cells taken from frogs living in an uncontaminated pond (open bars) or a pond contaminated with ^{3}H and ^{14}C (shaded bars) delivering about 1 mGy/y to the frogs. 1. No further radiation exposure. 2. Frogs receiving 1-100 mGy of ^{60}Co gamma radiation at low dose rate. 3. Frogs receiving 4 Gy of ^{60}Co gamma radiation at high dose rate. 4. Frogs receiving 1-100 mGy at low dose rate 3h before 4 Gy at high dose rate.

TABLE 1.

Treatment	Transformation Frequency ($\times 10^{-4}$)
Control	3.7
4 Gy (high dose rate)	41
100 mGy (low dose rate) + 24h + 4 Gy (high dose rate)	16

shown in Tables 1 and 2. Table 1 shows the results of an experiment[5] using rodent cells and examining the influence of a prior low dose, given at low dose rate, on the risk of malignant transformation resulting from a subsequent high radiation dose. The risk associated with the high radiation dose was reduced by a factor of 2-3 by the prior low dose, a result that parallels the evidence for improved repair of radiation damage shown in Figure. 2.

The ability of a low dose to reduce the risk of a subsequent high dose has importance for medical types of exposures, such as those used in cancer therapy, and for estimates of environmental impact for the nuclear industry. However, the effect of the low dose alone is of more importance for human exposures in the nuclear industry. Table 2 shows the experiment testing the effects of low doses alone on malignant transformation in rodent cells[6]. All the doses tested, between 1 and 100 mGy, given at low dose rate, reduced the risk of spontaneous malignant transformation, and all doses were equally effective. The lowest dose tested, 1 mGy of ^{60}Co γ radiation, represents an average of 1 ionization track per cell, the lowest dose physically possible in one cell. Since radiation tracks are random, not all cells actually receive one track, but all respond to the same extent as they did when they certainly received one or more tracks at the higher doses. This is evidence therefore, that not all cells are actually required to be exposed (hit) by radiation in order to enhance their defences and reduce their risk. Such distributed effects are known as bystander effects and result from inter-cell signalling.

Cancer Risk in Animals

While experiments in cells provide important supporting information about the actual molecular and cellular responses to low doses, ultimate-

TABLE 2.

Treatment	Transformation Frequency ($\times 10^{-3}$)
Control	1.8
1 mGy	0.53
10 mGy	0.42
100 mGy	0.53

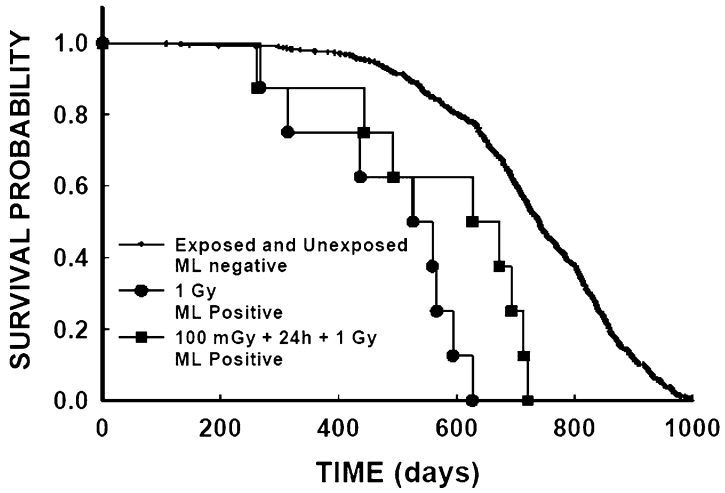

FIGURE 4. Delayed appearance ($P < 0.001$) of radiation-induced myeloid leukemia (ML) in genetically normal mice by exposure to 100 mGy at low dose rate 24h before the carcinogenic 1 Gy exposure.

ly experiments testing the effect of low doses on measures of risk such as cancer must be conducted in whole mammals. Figure 4 show a test[7] of the influence of a low dose exposure on radiation-induced myeloid leukemia in genetically normal mice. The figure shows that exposure to a high dose of 1 Gy induces myeloid leukemia in mice, and as a result, those mice with the disease lose a substantial portion of their normal lifespan. However, increasing the total exposure, by exposing the mice to 100 mGy, at low dose rate, the day before the 1 Gy exposure delayed the onset of those cancers ($P<10^{-3}$), effectively restoring a portion of the lifespan that would otherwise have been lost in those mice that developed the disease. It is important to note that the low "adapting" exposure did not affect the frequency of the disease induced by the high radiation dose, only the latency. The carcinogenic process is thought to involve an initiating event, which subsequently triggers an accelerating process of genomic instability leading to multiple genomic rearrangements, ultimately producing a cancer cell. The frequency of cancer is thought to reflect the number of initiating events while the latency of the disease reflects the rate at which the genomic instability process proceeds. The results shown in Figure 4 indicate that low doses delivered at low dose rates slows the rate of progression of the genomic instability process but does not change the frequency of the cancer initiating events[7].

Radiation protection standards and practices applied to humans must consider the possibility that some individuals may be radiation-sensitive and cancer-prone for genetic reasons. This raises the possibility that low doses may produce effects in such individuals that are different, and potentially more harmful, than those seen in genetically normal individu-

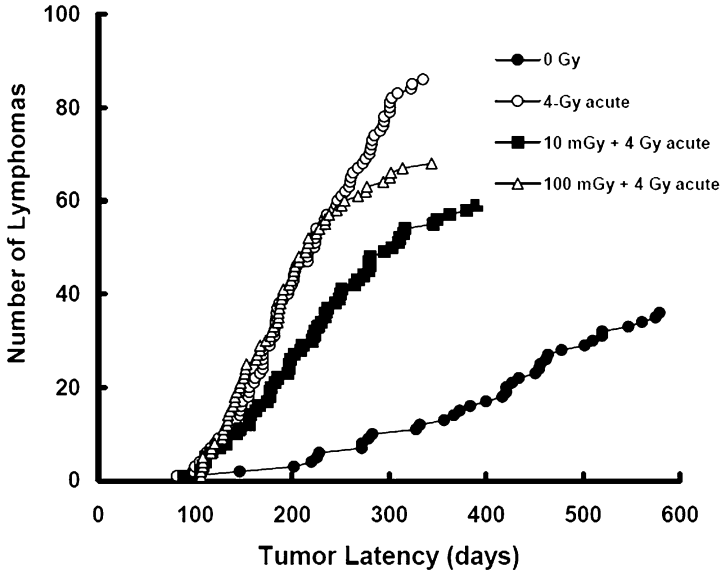

FIGURE 5. Appearance of lymphomas in unexposed cancer prone mice (Trp53 +/-) and in mice exposed to 4 Gy with or without a prior low dose and dose rate exposure.

als. Figure 5 shows a test[8] of this "worst case scenario". Mice that are heterozygous for the p53 gene (Trp53 +/-) are compromised in their ability to repair DNA damage and in their ability to initiate cell death in improperly repaired cells (Figure 1). Consequently, such mice are both cancer prone and radiation sensitive. Figure 5 shows that these mice spontaneously develop lymphomas, and a high 4 Gy dose of radiation increases the frequency and dramatically accelerates the appearance of these tumours. A dose of 10 mGy, given at a low dose rate the day before the 4 Gy exposure, delayed the onset of these lymphomas ($P<10^{-4}$), but did not significantly change the frequency. Correcting for competing causes of death did not change this conclusion. This effect of increasing latency was also seen in the genetically normal mice in Figure 4. Increasing the low adapting dose to 100 mGy caused this protective effect to disappear. While not increasing harm, 100 mGy apparently represents an upper threshold for doses that are protective against radiation-induced lymphomas.

Experiments testing the *in vivo* effect of low doses on cancer risk produced by high dose exposure are important for improving our understanding of the dominant biological outcome of such exposures, and are potentially useful concepts for medical radiotherapy procedures. However, for radiation protection standards and practices in the nuclear industry, it is more important to understand the influence of low doses on spontaneous cancer risk. Figure 6 shows the results of such a test[9] in

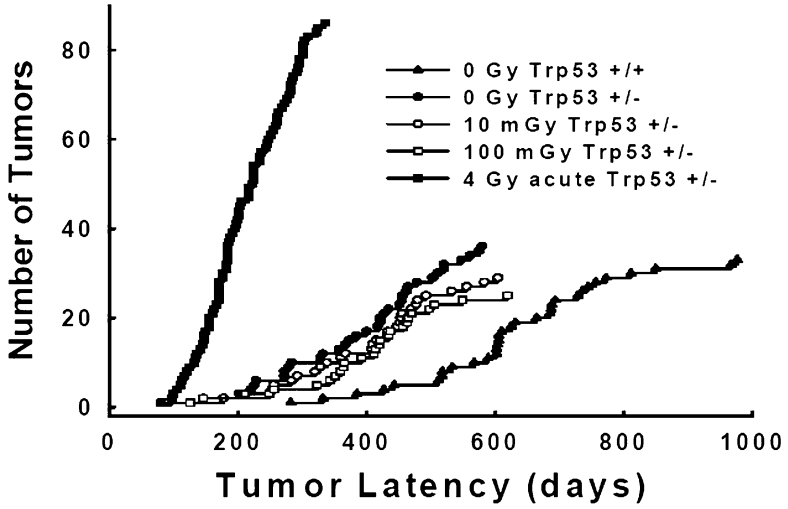

FIGURE 6. The appearance of lymphomas in unexposed or radiation exposed genetically normal (Trp53 +/+) or cancer prone (Trp53 +/-) mice.

the cancer prone p53 heterozygous mice that represent the "worst case scenario". The figure shows that unexposed, genetically normal mice (Trp53 +/+) of this strain also spontaneously develop lymphomas but that these cancers appear much earlier in the unexposed, cancer prone (Trp53 +/-) mice. Exposure to an acute 4 Gy dose of radiation dramatically accelerated this appearance. The figure also shows that a single exposure of either 10 or 100 mGy, given at low dose rate to young mice, restores a portion of the lifespan lost due to the disease in the unexposed, cancer-prone mice ($P<10^{-4}$). Unlike the result in Figure 5, where the lymphomas developed in mice that had subsequently received a high dose, the protective effect against these spontaneously appearing cancers was not lost when the dose was increased to 100 mGy. This result suggests that the upper dose threshold for protective effects varies with the severity or nature of the cancer-inducing event, with the threshold being higher for less severe inducing events such as spontaneous occurrences.

Other tumours also appear spontaneously in these cancer-prone mice. Osteosarcomas develop in the spine and grow to the point where they create paralysis in the mice. Figure 7 shows the time that these spontaneous cancers create paralysis in the mice, with and without a single exposure to 10 mGy given at low dose rate when the mice were 8 weeks old[8]. Compared to the mice not receiving the low dose, the appearance of the first spinal osteosarcoma was delayed by more than 100 days, and that delay persisted for all of the tumours that appeared, i.e. for the entire lifespan of the mice (P=0.005). This lifetime protection was also apparent

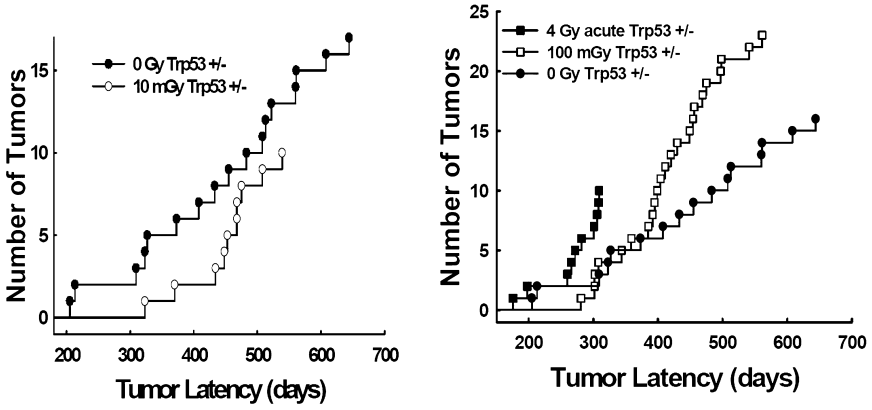

FIGURE 7. The appearance of spontaneous osteosarcomas in unexposed cancer prone mice (Trp53 +/-), or exposed to 10 or 100 mGy at low dose rate. Exposure to 4 Gy is shown for comparison.

for the spontaneous lymphomas shown in Figure 6. However, unlike the case for spontaneous lymphomas (Figure 6), increasing the low dose to 100 mGy resulted in a general acceleration of the appearance of the spontaneous spinal osteosarcomas ($P<0.04$, Figure 7). This decrease in cancer latency clearly represents an increase in risk, rather than the risk decrease seen at 10 mGy. For this tissue type therefore, the upper threshold for protective effects of a low dose must lie between 10 and 100 mGy. Since, in the same animals, the upper dose threshold for protection against lymphomas exceeded 100 mGy, we conclude that the dose threshold, where protective effects give way to detrimental effects, is tissue-type specific.

III. CONCLUSIONS

This paper has described experimental tests, at the molecular, cellular and whole animal levels, of the validity of the Linear No-Threshold Hypothesis at low doses and dose rates. Using a variety of endpoints, some surrogate for risk estimates and others direct measures of cancer risk *in vivo*, the hypothesis has failed at all levels. The LNT hypothesis states that risk per unit dose is constant without a threshold; i.e. that risk is additive and can only increase. The results in cells and *in vivo* show that risk decreases, rather than increases with increasing dose. This reduction in risk below the spontaneous risk level is also not linear with dose. The decrease appears to reach a maximum with the first track of radiation through the cells, i.e. at the lowest dose physically possible in a cell, and stays at that level until the dose reaches about 100 mGy where risk then rises above the spontaneous level. These results indicate that at low dose rate, the assumption of linearity may be valid only at doses above about 100 mGy (with some variation in different tissue types), and below this

level radiation-induced protective effects dominate risk. The results in human and other mammalian cells, and in whole animals, described here parallel earlier observations in lower organisms, indicating that these adaptive responses to low doses are not unique to mammals but are part of an evolutionarily conserved response. These protective responses appear to dominate even in individuals that are radiation sensitive and cancer prone for genetic reasons.

Since radiation exposures in the nuclear industry are overwhelmingly in this low dose and low dose rate region, these results should be considered for their implications for radiation protection and industry practices. In particular, the use of the LNT hypothesis for risk estimation at low doses should be reviewed.

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CANCER AND LOW DOSE RESPONSES *IN VIVO*: IMPLICATIONS FOR RADIATION PROTECTION

R. E. J. Mitchel □ Radiation Biology and Health Physics Branch, Atomic Energy of Canada Limited, Chalk River, Ontario, K0J1J0, Canada

□ The Linear No Threshold (LNT) hypothesis states that ionizing radiation risk is directly proportional to dose, without a threshold. This hypothesis, along with a number of additional derived or auxiliary concepts such as radiation and tissue type weighting factors, and dose rate reduction factors, are used to calculate radiation risk estimates for humans, and are therefore fundamental for radiation protection practices. This system is based mainly on epidemiological data of cancer risk in human populations exposed to relatively high doses (above 100 mSv), with the results linearly extrapolated back to the low doses typical of current exposures. The system therefore uses dose as a surrogate for risk. There is now a large body of information indicating that, at low doses, the LNT hypothesis, along with most of the derived and auxiliary concepts, is incorrect. The use of dose as a predictor of risk needs to be re-examined and the use of dose limits, as a means of limiting risk needs to be re-evaluated. This re-evaluation could lead to large changes in radiation protection practices.

Keywords: risk, adaptive response, radiation protection, low dose, cancer

1. THE LNT HYPOTHESIS, RISK PREDICTION AND RADIATION PROTECTION

The linear no-threshold (LNT) hypothesis is the fundamental basis for the prediction of risk from radiation exposure, and forms the basis for radiation protection practices (ICRP 1991). Dose limits for human exposure reflect this assumption that risk is proportional to total dose, without a threshold. However, radiation protection practices also utilize a number of additional concepts, derived from or auxiliary to the hypothesis, to predict the risk of a radiation exposure. The most basic concept presumes that since risk is proportional to dose, then dose (normalized as Sieverts using radiation weighting factors, W_R) can be used as a surrogate for risk. Additionally, since each dose is assumed to create some risk, those doses, and hence risks, are treated as additive. Therefore, with the absence of a threshold, risk can only increase with each dose, and this assumption applies to low as well as high doses. Importantly however, radiation protection practices (ICRP 1991) recognize the observation that different tissues respond differently to radiation, and, based only on the tissues actu-

Address correspondence to R. E. J. Mitchel, Radiation Biology and Health Physics Branch, Atomic Energy of Canada Limited, Chalk River, Ontario, K0J1J0, Canada. Phone 613-584-8811 X4721; Fax 613-584-8217; email mitchelr@aecl.ca

ally exposed, individually contribute different fractions to the total risk of radiation. In practice, different tissue types are assigned tissue weighting factors (W_T) that reflect their relative fractional contribution to the total cancer and non-cancer radiation risk. The W_T for each tissue is held to be constant, independent of dose, since every tissue is assumed to obey a linear no threshold response. Another concept, also derived from observation and not the LNT hypothesis, is an assumed 2-fold reduction in the risk of a high dose/high dose rate exposure, if that exposure is received at low dose or low dose rate (ICRP 1991). Recently, serious concerns have been raised about the appropriateness of many of these assumptions (Tubiana et al. 2005, 2006).

2. EPIDEMIOLOGICAL BASIS FOR RADIATION PROTECTION PRACTICES

In the development of the current radiation protection system, the main source of information on radiation-induced human cancer risk has come from epidemiological data on exposed populations. However, these data are mainly from medium to large doses, and for low LET radiation epidemiological studies do not show an increased cancer risk in adult humans below about 100 mSv for an acute exposure (Tubiana et al 2005). A linear extrapolation has therefore been used to estimate the cancer risk at the lower doses relevant to the general population and radiation workers. Uncertainties in dosimetry of epidemiological studies make it more difficult to observe a dose response, which in turn tends to lead to lower risk estimates. Other problems associated with the epidemiological studies include the comparison of the results obtained for different exposure patterns (for example, acute external irradiation versus protracted internal irradiation) and/or for different types of radiation (for example, γ rays versus α particles) and/or for exposures of mixed LET.

3. ADAPTIVE RESPONSE AND CARCINOGENESIS

The term adaptive response refers to biological responses whereby the exposure of cells or animals to a low dose of radiation induces mechanisms that protect the cell or animal against the detrimental effects of other events or agents, including spontaneous events or subsequent radiation exposure (Mitchel 1995). Adaptive responses occur in situations where all cells receive one or more radiation tracks at low dose rate, but also where the dose is too low for all cells to be hit. In the latter instance, the protective effect is amplified by chemical signals sent to other "bystander" cells (Broome et al. 2002; Mitchel 2004). For low LET radiation, the first ionisation track through the cell (a dose of about 1 mGy) appears to produce the maximum increase in DNA repair capacity and protective effects, and further tracks, if delivered at low dose rate, neither increase nor decrease that maximum response (Broome et al. 2002; Ulsh

et al. 2004). For malignant transformation in human and rodent cells, the protective effect of low doses is dose *independent* for all doses up to about 100 mGy, when given at low dose rate. Above about 300 mGy, these protective effects give way to an increased risk of malignant transformation, suggesting detrimental effects outweigh protective effects at this point (Azzam et al. 1996; Redpath and Antoniono 1998). The (unknown) signal(s) for adaptation can be transmitted through the medium that surrounds the cells. In human cells, there was no difference between gamma rays and tritium beta particles for the induction of the adaptive response (Broome et al. 2002), and low doses of low LET radiation protect against the detrimental effects, including detrimental effects of high LET exposure. At least some types of high LET radiation are also able to induce the adaptive response in mammalian cells (Gajendiran et al. 2001; Iyer and Lehnert 2002).

For low doses to induce an adaptive response, cells or animals require a functional copy of the *TP53* gene, responsible for the control of several processes critical to the risk of carcinogenesis. In animals with full *TP53* function, and in cancer-prone animals with partial *TP53* function a single low, whole body dose of low LET radiation, increased cancer latency and restored a portion of the life that would have been lost due to either spontaneous or radiation-induced cancer in the absence of the low dose (Mitchel et al. 1999; Mitchel et al. 2003; Mitchel et al. 2004; Mitchel 2005). An increase in tumor latency but not frequency, suggests that adaption to radiation *in vivo* acts primarily by slowing the multi-step process of carcinogenesis.

In *TP53* normal mice, protective effects against radiation-induced cancer occur up to at least 100 mGy (Mitchel et al. 1999). In the cancer prone mice protective effects give way to increased risk between about 10 and 100 mGy (Mitchel et al. 2004). However, different tissues appear to have different thresholds at which protection turns to detriment (Mitchel et al. 2003). The results suggest that protective adaptive responses may predominate at typical public and occupational exposure levels, but that at doses around 100 mGy detrimental effects may overcome the protection. High doses at high dose rates do not induce the protective response, although relatively high total doses received at low dose rates may be effective.

Adaptive responses to low doses (typically 1-100 mGy) have been shown to increase cellular DNA double-strand break repair capacity, reduce the risk of cell death, reduce radiation or chemically-induced chromosomal aberrations and mutations, and reduce spontaneous or radiation-induced malignant transformation *in vitro*. Elevated DNA repair capacity after low dose exposure is a response that has been tightly conserved throughout evolution, appearing in single-cell eukaryotes, simple eukaryotes, insects, plants, amphibians, and mammals including human cells, suggesting that it is a basic response critical to life (Mitchel 2006).

4. IMPLICATIONS FOR RADIATION PROTECTION

4.1 Dose additivity

Cancer is considered to be the most important risk associated with radiation exposure. If the LNT hypothesis is correct, sequential exposures to radiation should increase cancer risk for all types of exposures. However, cell and animal experiments indicate that adaptive responses occur after low dose exposures, and that, as a consequence, responses to radiation are not linear.

A fundamental principle of radiation protection is the assumption of a linear dose response and dose additivity. The universally observed phenomenon of the adaptive response, as exemplified by the cell and animal experiments described above, indicate that for low LET radiation, the risk of cancer is not linear with dose. In fact, increasing dose by adding low doses to high doses decreases risk. The concept of dose additivity, when at least one exposure is to a low dose at low dose rate, did not hold. These data indicate that at the low doses and dose rates typical of public and occupational exposures, the radiation protection principle of dose additivity, and the concept that risk can only increase as dose increases are not justified. In general, the use of dose as a surrogate for risk needs re-evaluation. However, once past the upper dose threshold, increased dose could increase risk, as currently assumed. It is also apparent, however, that genetic variations in cancer proneness can influence these thresholds.

If different exposures (e.g. internal / external, chronic / acute, low/high, low LET / high LET, etc.) can not be summed to estimate an individual's total detriment / risk, or even if, more simply, several specific types of exposure can not be summed, then we may need to develop a new approach to radiation protection, in order to protect against each specific type of exposure separately (Mitchel and Boreham 2000). Ultimately, that approach may need to be tailored to individual genetics.

4.2 Tissue weighting factors

At high doses, different tissues are known to respond differently to radiation and are assigned constant, dose independent tissue weighting factors (W_T) that reflect their relative fractional contribution to the total risk. However, experiments at low dose indicate that individual tissue risk is not a constant with dose, and exhibits a dose threshold below which risk is less than spontaneous risk. Different tissues appear to have different dose thresholds below which detriment turns to protection, indicating that individual tissue weighting factors (W_T) vary from zero to positive values as dose increases. These observations indicate that tissue weighting factors are neither constant nor dose independent, and the current assumptions used for radiation protection are not appropriate.

4.3 Radiation weighting factors and Sieverts

The currently accepted W_R factors have been determined by comparisons of Relative Biological Effect (RBE) at high doses, where all cells are hit by radiation and each cell receives multiple tracks of radiation. However, current animal and mammalian cell research is assessing the risk of low doses of low LET radiation down to and below a dose that represents an average of one track per cell. This is important as at these radiation levels epidemiological studies do not have sufficient power to provide risk data. Since the dose to a single cell from a single high LET track is much higher than the dose from a single low LET track, these measurements of RBE (and therefore W_R) are valid only when there are sufficient tracks of low LET per cell to provide enough physical dose to match the effect, at a minimum, of one high LET track per cell. At lower doses, however, these concepts break down. At lower doses of high LET most cells are not hit, yet those that are hit still receive the high dose delivered by one track. At similar doses of low LET radiation all cells may still receive multiple tracks. At even lower doses, low LET radiation, like high LET radiation, will not hit all cells. At these levels, typical of public and occupational exposures, the use of W_R derived from high dose exposure assumes that the biological mechanisms responsible for the observed difference in biological response to different radiation types are the same mechanisms that operate at low doses. This has clearly been shown to be incorrect, since low doses induce protective effects. Even at the level of the response of individual genes, different genes are activated at high versus low doses. These results therefore call into question the use of current W_R factors at low doses.

Animal and cell based experiments show that low doses reduce cancer risk below the level observed in the unexposed cells or animals; i.e. below the spontaneous risk. If the radiation weighting factor (W_R) for high doses of low LET radiation is taken as 1, then these data suggest that the W_R is a variable with dose, and can be zero at low doses. Since the W_r for high LET radiation is based on a reference to the same level of effects at low LET, the W_R for high LET also cannot be a constant. This, together with the physical impossibility of delivering the same dose per cell at low doses and the mechanistically different cellular response to high and low doses, suggests that the use of normalised dose (Sievert) at low doses is inappropriate, and that the risk or benefit of exposure to radiations of different quality needs to be understood and assessed independently, on the basis of physical dose.

The realities of human radiation exposures present an additional problem. Current cell based research indicates that a prior or concurrent exposure to low LET radiation is able to induce adaptive responses which mitigate much or all of the detrimental effect of exposure to high LET

radiation (Wolff et al. 1991). Since virtually all public (and much occupational) exposure to high LET radiation is accompanied by exposure to low LET radiation, and if the cell based studies apply to organs and whole organisms, then radiation protection policies and risk assessments also need to consider the effect of combined exposures to these different radiation types.

4.4 DDREF

It is widely accepted that a radiation dose delivered at a low dose rate produces fewer late effects than the same dose delivered at a high dose rate. This is in a large part due to the fact that dose protraction facilitates a more effective repair of cells, including DNA damage. The ICRP therefore defines a Dose and Dose Rate Effectiveness Factor (DDREF) to allow for the reduced effectiveness of low dose rate radiation doses. The DDREF factor represents the ratio of the slope of the linear no threshold fit of high dose, high dose-rate data to the slope of the linear no threshold fit of high dose, low dose-rate data. For radiological protection the ICRP recommend a DDREF factor of 2. The utility of the DDREF coefficient depends upon the assumption that, for exposure to low doses at low dose-rate, the dose-response is linear, continuous with the slope of the high dose, low dose rate response and has a slope that is less than the corresponding slope of a linear high dose, high dose rate response.

However, low dose and low dose rate studies using low LET radiation in cells and in adult animals have shown that below a threshold dose (about 100 mGy in human cells, rodent cells and normal mice) the detrimental effects of a radiation exposure disappear and are replaced by protective effects, manifested in cells by decreases in transformation frequency and in animals by increases in cancer latency. These observations show that low dose responses are non linear and that the biological processes occurring in cells in response to low doses and dose rates can be fundamentally different from those that result from exposure to high doses, These observations undermine the concept of DDREF and indicate that at low doses DDREF becomes infinite.

These experiments indicate that the linear no threshold hypothesis, and the associated dose and dose rate reduction factors derived from high dose experiments are inappropriate for use at low doses and low dose rates. There may be no constant and appropriate value of DDREF for use in radiological protection.

4.5 ALARA

Cell and animal based experiments indicate that low doses of low LET radiation induce a protective effect that reduces the risk from spontaneous cancer and the risk of cancer from further exposure. If this is also

true for humans, then radiation protection policies that endeavour to reduce exposures to the lowest possible dose (As Low As Reasonably Achievable, the ALARA principle), or entirely eliminate the exposure, may need to be reconsidered since they may prevent the induction of this protective response. For a public exposure, this could result in the otherwise reduced risk rising to the spontaneous level of the unexposed population. Such radiation protection policies could then be viewed as "withholding benefit". For persons who may be occupationally exposed, prevention of the induction of protective responses would result in a higher than necessary risk if that person were then accidentally exposed to a high dose. In this circumstance, such a radiation protection policy could be viewed as increasing occupational risk.

5. SUMMARY IMPLICATIONS FOR THE RADIATION PROTECTION SYSTEM

At low doses,

- The conceptual basis of the present system appears to be incorrect
- The belief that the current system embodies the precautionary principle and that the LNT assumption is cautious appears incorrect
- The concept of dose additivity appears incorrect
- Effective dose (Sieverts) and the weighting factors on which it is based appear to be invalid
- There may be no constant and appropriate value of DDREF for radiological protection dosimetry.
- The use of dose as a predictor of risk needs to be re-examined
- The use of dose limits as a means of limiting risk need to be re-evaluated

6. ACKNOWLEDGEMENTS

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RADIOBIOLOGICAL BASIS OF LOW-DOSE IRRADIATION IN PREVENTION AND THERAPY OF CANCER

Myron Pollycove □ North Bethesda, MD

□ Antimutagenic DNA damage-control is the central component of the homeostatic control essential for survival. Over eons of time, this complex DNA damage-control system evolved to control the vast number of DNA alterations produced by reactive oxygen species (ROS), generated principally by leakage of free radicals from mitochondrial metabolism of oxygen. Aging, mortality and cancer mortality are generally accepted to be associated with stem cell accumulation of permanent alterations of DNA, i.e., the accumulation of mutations. 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. As mutations accumulate and gradually degrade the antimutagenic system, aging progresses at an increasing rate, mortality increases correspondingly, and cancer increases at about the fourth power of age. During the past three decades, genomic, cellular, animal and human data have shown that low-dose ionizing radiation, including acute doses up to 30 cGy, stimulates each component of the homeostatic antimutagenic control system of antioxidant prevention, enzymatic repair, and immunologic and apoptotic removal of DNA alterations. On the other hand, high-dose ionizing radiation suppresses each of these antimutagenic protective components. Populations living in high background radiation areas and nuclear workers with increased radiation exposure show lower mortality and decreased cancer mortality than the corresponding populations living in low background radiation areas and nuclear workers without increased radiation exposure. Both studies of cancer in animals and clinical trials of patients with cancer also show, with high statistical confidence, the beneficial effects of low-dose radiation.

I. INTRODUCTION

Four decades of genomic, cellular, animal and human data have shown that low-dose ionizing radiation stimulates positive genomic and cellular responses associated with effective cancer prevention and therapy and increases the life span of mammals and humans.[1-8] Nevertheless, this data is questioned because it seems to contradict the unquestioned linear relation between ionizing radiation dose and damage to DNA without providing a clear mechanistic explanation of how low-dose radiation could produce such beneficial effects. Acknowledgment of the validity of this contradictory data would destroy the basis of a very expensive system of regulation and remediation.

A quantitative understanding of the antimutagenic DNA damage-control system essential for survival was recently developed[9] and is illustrated

Address correspondence to Myron Pollycove, 11441 Hollowstone Drive, North Bethesda, MD 20852. E-mail: pollycove@comcast.net

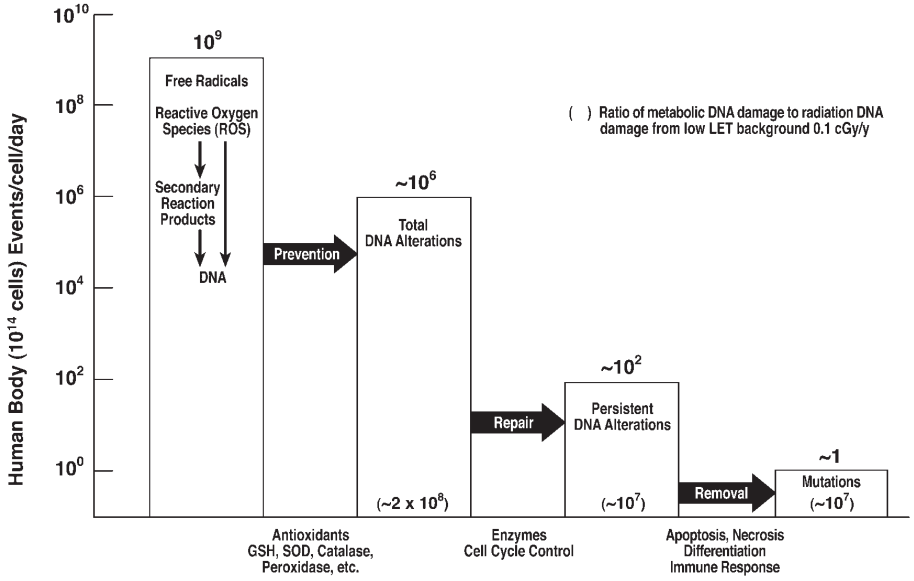

FIGURE 1. The antimutagenic DNA damage-control biosystem. Estimates are based on data in the literature.[9]

in Figure 1. This complex system evolved in aerobic organisms over eons of time in order to control an enormous, relentless burden of DNA alterations produced by reactive oxygen species (ROS), generated principally by free radicals leaked from mitochondrial oxygen metabolism. This antimutagenic system also operates against the DNA damage generated by ionizing radiation ROS and by chemicals. The enhanced response of the antimutagenic system to low-dose radiation provides a clear mechanistic explanation of the beneficial effects seen in cells, mammals and humans.

II. THE ANTIMUTAGENIC DNA DAMAGE-CONTROL SYSTEM

The immune system is an essential component of antimutagenic control of cumulative DNA damage and metabolic damage generated by a relentless burden of DNA alterations produced by ROS leaked from mitochondria.[10] In addition to removal of persistent DNA alterations by the immune system and cellular programmed self-destruction (apoptosis), the human antimutagenic system includes antioxidant prevention and enzymatic repair of DNA damage. This complex biosystem of prevention, repair and removal sequentially reduces DNA damage from about one million DNA alterations/cell/day to about one "mutation"/cell/day (Figure 1). In contrast, low LET background radiation of 1 mGy/year produces 1 DNA alteration/500 cells/day. Double-strand breaks/cell/day generated by oxygen metabolism is 1000 times greater than the double-strand breaks produced by this background radiation. The UNSCEAR 1994 Report[11] and recent studies[12, 13] furnish extensive documentation

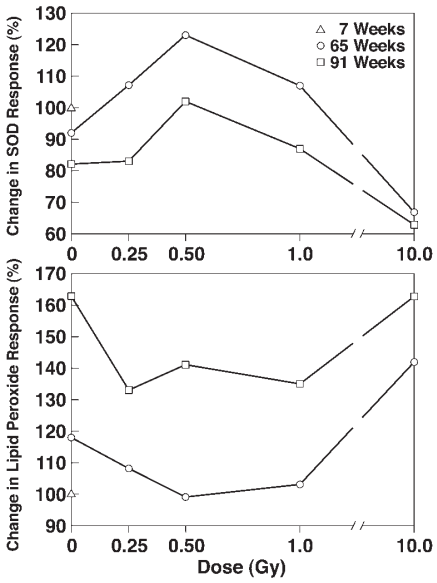

FIGURE 2. Antioxidant SOD and lipid peroxide response to age and radiation of rat brain cortex[14]

of low-dose stimulation of many cellular functions including: antioxidant prevention (Figure 2)[14], enzymatic repair (Figures 3 and 4)[15, 16], and immunologic and apoptotic removal (Figure 5)[17] of DNA damage. This stimulation of each of these antimutagenic responses by low-dose radiation, in contrast to their suppression by high-dose radiation, predictably precludes a linear dose-response relation of radiation and health effects.[18] Enhanced prevention of gene mutations by increased low-dose radiation (Figure 6) is associated with decreased mortality and decreased cancer mortality observed in human populations exposed to low-dose

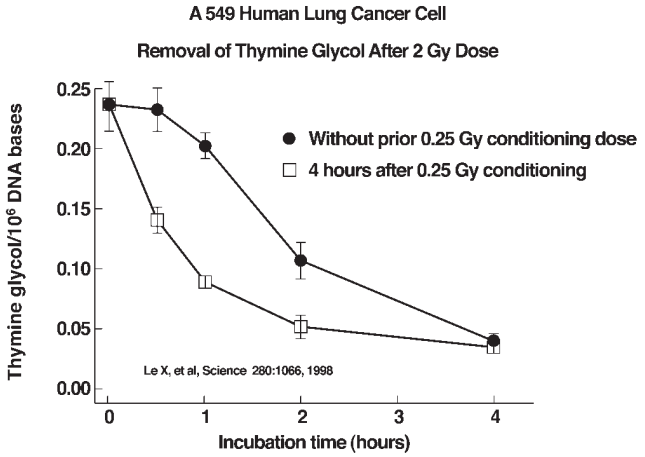

FIGURE 3. Low dose induced DNA repair[15]

	1 r/y HBRA ± SE	0.1 r/y NBRA ± SE	P-value
MCAPC (0 Gy)	0.013 ± 0.003	0.016 ± 0.004	Not Significant
MCAPC (1.5 Gy)	0.098 ± 0.012	0.176 ± 0.017	P < 0.001

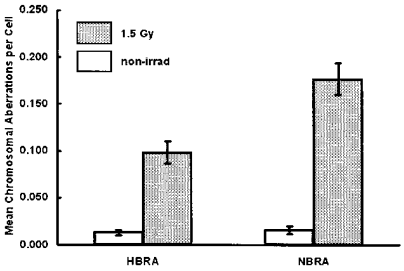

FIGURE 4. Mean chromosomal aberrations per cell in lymphocytes before and after exposure to 150 r. Lymphocytes were obtained from Ramsar residents in a high background γ radiation area of about 10 mGy/y and residents in a normal background γ radiation area of about 1 mGy/y.[16]

radiation.[19-21] Stimulation of the immune system by low-dose radiation prevents and removes cancer metastases in rodents and humans.

III. IMMUNE SYSTEM RESPONSE TO RADIATION

Low-dose total body irradiation (TBI) and chronic TBI (LDR) stimulate immune system prevention and removal of cancer metastases. This has been observed in mice for about 40 years[16, 22, 23] and more recently in rats[24] and humans.[3-6, 8, 25-29]

The maximal immune response of mouse spleen T lymphocytes to sheep red blood cells, both *in vitro* and *in vivo*, occurs after a single dose of 0.25 Gy or 25 r (Figure 7).[23] The maximal *in vitro* response is 180% with suppression to 50% of control after 100 r. The maximal *in vivo* response is 145%, but more than 260 r is needed for suppression to 50% of control.

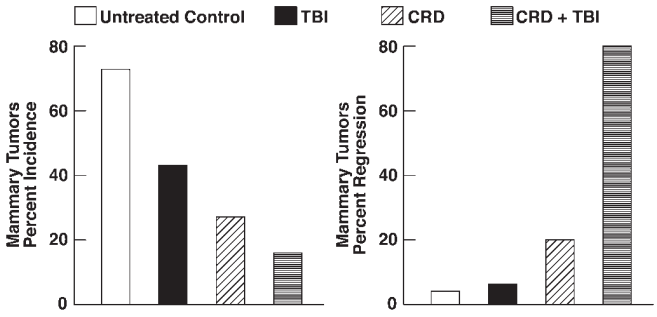

FIGURE 5. Eight month old, mammary tumor-susceptible, female C3H/He mice were first adjusted in a stepwise manner to chronically restricted diet (calorically 70% of ad libitum diet) over a period of 3 weeks. The mice were maintained on CRD until completion of the study. After their diet was adjusted, the mice were exposed to TBI (0.04 Gy, 3 alternating days/week, 4 weeks) and were observed for 35 weeks. Tumor regression of the CRD + TBI group was very rapid and large numbers of CD8+ T cells were found infiltrating the regressing tumors, which were not seen in mice of the untreated control, LDR and CRD groups.[17]

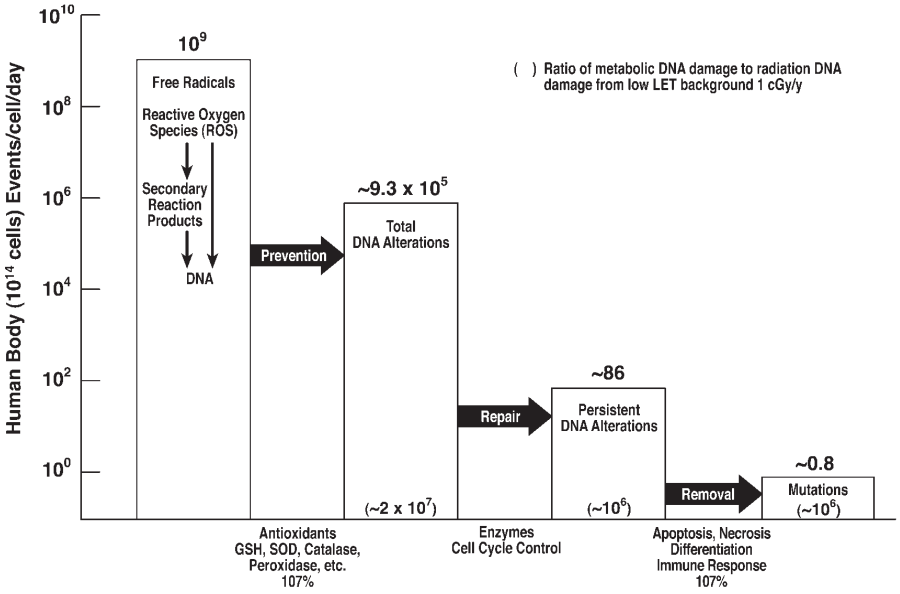

FIGURE 6. The antimutagenic DNA damage-control biosystem response to high background radiation = 120%. Estimates based on data in the literature.[9]

TBI given with subimmunogenic tumor antigen induces tumor immunization. Subcutaneous inoculation of sham irradiated controls with 100 non-viable tumor cells does not suppress growth of 10,000 viable tumor cells inoculated subcutaneously 21 days later. Strikingly, 15 r of TBI given simultaneously with inoculation of 100 non-viable tumor cells does induce marked suppression of tumor cell growth, exceeding that induced by 100,000 non-viable tumor cells without TBI (Figure 8).[22]

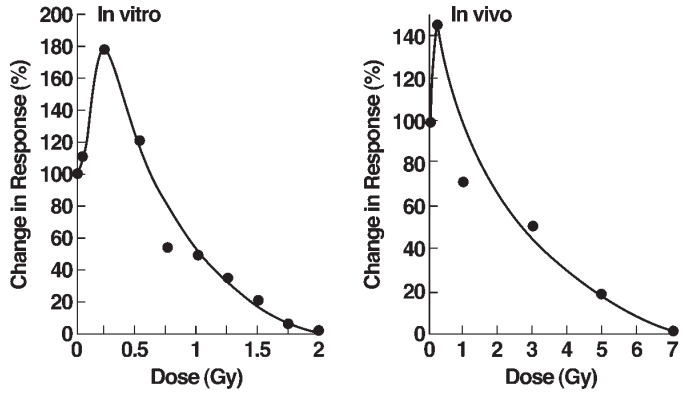

FIGURE 7. Immune system response to radiation. Mouse splenic cells primed with antigenic sheep red blood cells.[23]

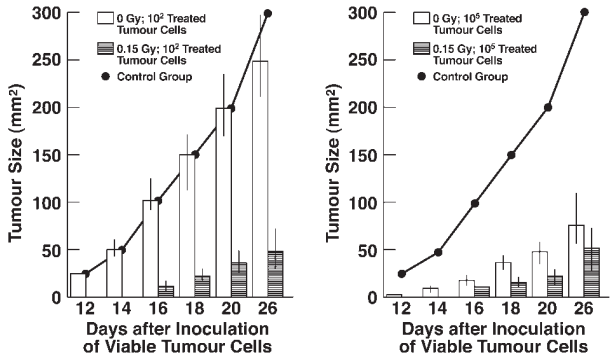

FIGURE 8. Effect of 0.15 Gy upon response of A/J mice to subimmuno-genic and immunogenic numbers of non-viable mitomycin-treated fibrosarcoma (SaI) tumor cells. Groups of 60 mice were exposed to whole-body irradiation or sham-irradiated and inoculated subcutaneously with the indicated numbers of mitomycin-treated tumor cells. Twenty-one days later, all animals received 10^4 untreated SaI cells and were followed for tumor size. A control group did not receive mitomycin-treated cells.[22]

TBI stimulates immune suppression of tumor metastases to the lung (Figure 9).[8] Lung colonies, counted 20 days after TBI given 12 days after tumor cell transplantation into the axilla of mice, were decreased by TBI doses less than 50 r; 15 r induced the maximal decrease of 60%. However, high doses in the 50-100 r range suppressed the immune system, with increased metastases to lung.

Chronic TBI (LDR) stimulates immune response of spleen T lymphocyte proliferation in mice (Figure 10).[23] Mice irradiated 5 days/week for 4 weeks with LDR courses of 10 r (0.5 r/d), 20 r (1.0 r/d) and 80 r (4.0 r/d) showed lymphocyte responses of 115%, 140%, and 160%, respectively, relative to 100% proliferation in the unirradiated control group.

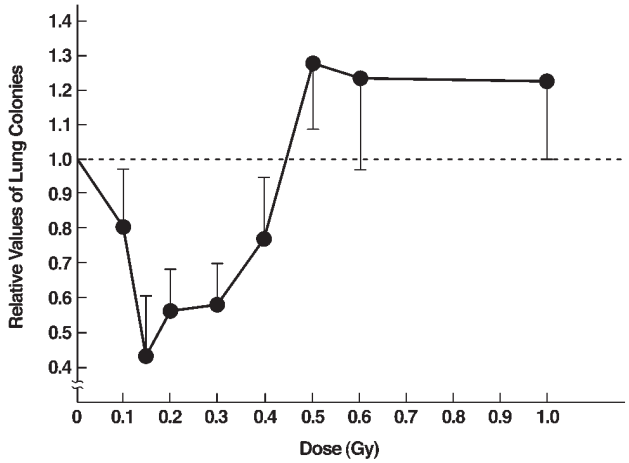

FIGURE 9. TBI given 12 days after tumor cell transplantation into axilla. Lung colonies counted 20 days after TBI. Low dose TBI ineffective with spleen blocked. Low dose splenic irradiation, half-body irradiation (HBI) and TBI equally effective.[8]

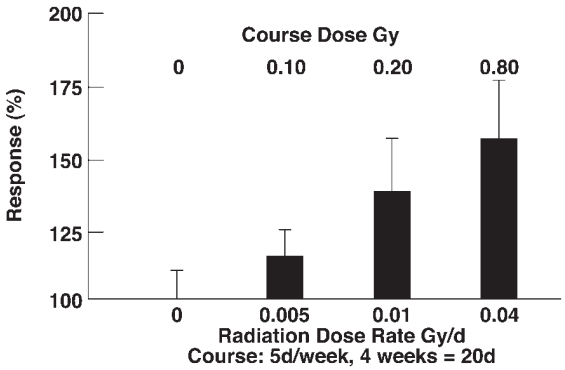

FIGURE 10. Dose-response analysis of splenic T cell proliferative response 3-5 days after the last radiation exposure of immunologically normal, long-lived C57B1/6J+/+ mice. Results are expressed as the mean percent increase in ^{3}H-thymidine uptake relative to 0 Gy control group as 100%. The vertical bars = 1 SEM.[23]

LDR with a calorically-restricted diet, of 70% ad libitum diet calories, prevents and removes spontaneous breast cancer tumors in mice (Figure 5).[17] Eight-month-old breast tumor susceptible female mice, after 3-week adjustment to CRD, were exposed to a 48 r, 4-week course of LDR (4 r 3d/week) and then observed for 35 weeks. While 73% of the ad libitum diet mice and 27% of the CRD mice developed breast cancer, only 16% of CRD + LDR mice developed breast cancer. Most impressive was the very rapid 80% tumor regression of CRD + LDR mice compared to the 20% and 4% regression in CRD and control mice, respectively. Large numbers of "killer" cytotoxic CD8+ T lymphocytes were observed infiltrating regressing tumors of CRD+LDR mice, but not in the control and CRD mice. Half-body LDR of women given 5-30 r by 25 to 150 fluoroscopic lung examinations similarly decreased breast

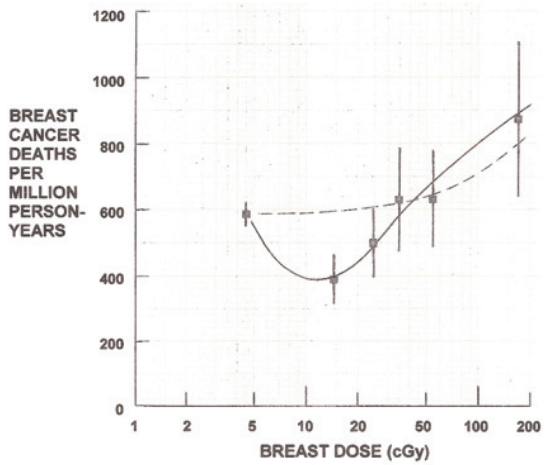

FIGURE 11. Reduced breast cancer mortality of tuberculosis patients who received LDI during fluoroscopy[24, 25]

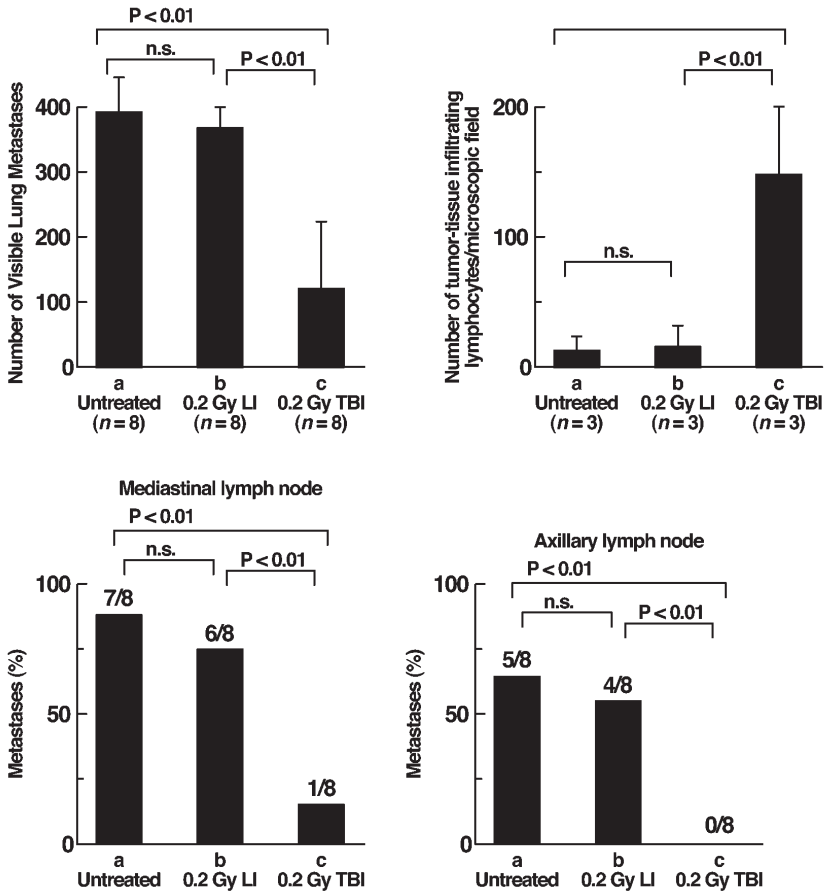

FIGURE 12. The number and incidence of metastases in lung and lymph nodes of mediastinum and axilla 50 days after intramuscular (leg) tumor implantation in rats, and the number of tumor infiltrating lymphocytes 21 days after implantation. Total body or localized tumor irradiation with 0.2 Gy was given 14 days after implantation of 5 x 10^5 allogenic hepatoma cells.[26]

cancer mortality. Breast cancer mortality of those receiving doses between 10-20 r was reduced to 66% of controls without LDR (Figure 11).[24,25]

Metastasis is also suppressed by TBI of tumor-bearing rats (Figure 12).[26] TBI or irradiation localized to tumor implanted into the leg or control sham-irradiation were given 14 days after tumor implantation. The number of visible metastases in the lung and the incidence of metastases in mediastinal and axillary lymph nodes were obtained 50 days after implantation. The number of tumor infiltrating lymphocytes/microscopic field was observed 21 days after implantation. Metastases to the lung, mediastinum and axillary lymph nodes in TBI rats were reduced by more than 70% of that in control and locally irradiated rats. Tumor infiltration by lymphocytes in TBI rats was more than 900% of that in control and locally irradiated rats. Cytotoxic CD8+ T lymphocytes in the spleen of TBI rats were increased to 176% of those in control and locally irradiated rats.

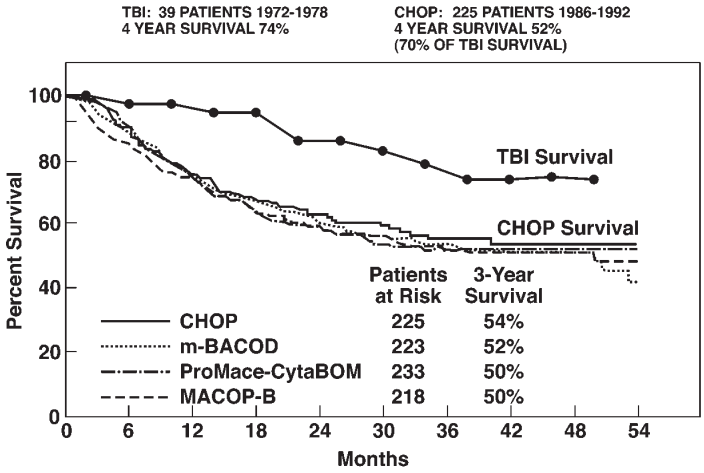

FIGURE 13. Comparison of TBI with CHOP chemotherapy. CHOP remains the best available chemotherapy treatment for patients with advanced-stage intermediate-grade or high-grade non-Hodgkin's lymphoma.[28]

IV. HUMAN LOW DOSE RADIATION (LDR) CANCER IMMUNOTHERAPY

Two Harvard University clinical trials of LDR therapy in patients with non-Hodgkin's lymphoma were published in 1976[27] and in 1979 (Figure 13).[28] The protocols were very similar. The Chaffey, et al. 1976 trial used a 150 r LDR course with TBI doses of 15 r 2x/week for 5 weeks. The Choi, et al. 1979 trial also used a 150 r LDR course with TBI doses of either 15 r 2x/week or 10 r 3x/week for 5 weeks. In both studies transient low platelets requiring interruption of scheduled therapy occurred in 35-40% of patients, irrespective of 10 r or 15 r dose schedule. Both chemotherapy and LDR patients had previously received chemotherapy and localized tumor high-dose radiation. Histologic tumor grades of LDR and chemotherapy patients were similar. COP chemotherapy used in the 1976 trial was replaced by the more effective CHOP chemotherapy still in current use. Both trials furnish 4-year survival data. Four-year survival in the 1976 study of 25 LDR patients is 70% compared with 40% survival of 24 matched patients treated with COP.[26] The 1979 trial shows a similar 74% survival of 39 LDR patients compared with improved 52% survival of 225 patients treated with CHOP (Figure 13).[28]

Sakamoto, et al., Tohoku University, Sendai, Japan, published a 1997 review of their experimental studies in mice and a clinical trial of LDR. In mice, 15 r TBI induced maximal suppression of tumor metastasis (Figure 9).[8] TBI given 6-12 hours before localized high-dose tumor therapy increases the effectiveness of tumor therapy. TBI, upper half body irradiation (HBI), and localized irradiation of the spleen were equally effective in stimulating the immune system of mice.

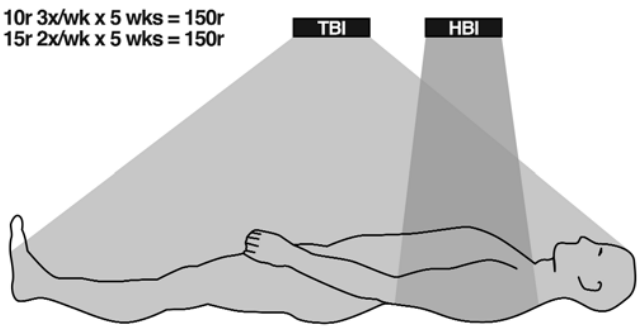

FIGURE 14. Treatment of patients with non-Hodgkin's lymphoma with half (HBI) or total (TBI) body irradiation. Adapted from Sakamoto et al[8]

The protocol used by Sakamoto, et al. in their clinical trial of LDR therapy of patients with non-Hodgkin's lymphoma is similar to that used by Choi, et al. Both used a 150 r LDR course with equally effective TBI doses of either 15 r 2x/week or 10 r 3x/week for 5 weeks in patients with previous CHOP chemotherapy and localized high-dose tumor irradiation. Choi, et al. used TBI, while Sakamoto, et al. used TBI or HBI (Figure 14) with equal effectiveness without interruption of scheduled therapy by low platelets.

Sakamoto, et al. report 9-year survival of 23 LDR patients and 94 CHOP chemotherapy patients with similar histologic tumor grades, approximately 75% of each group having intermediate or high grade lymphoma (Figure 15).[8] Tumors outside the HBI field regressed completely in response to LDR (Figure 16).[29] Nine-year survival of patients

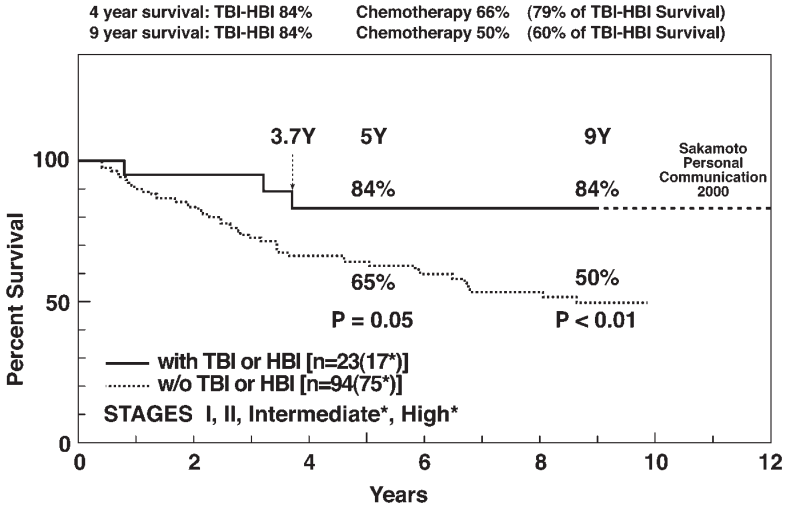

FIGURE 15. Utility of low-dose irradiation of HBI or TBI for patients with non-Hodgkin's lymphoma. Patients in both groups received chemothera-py and localized tumor high-dose radiation.[8]

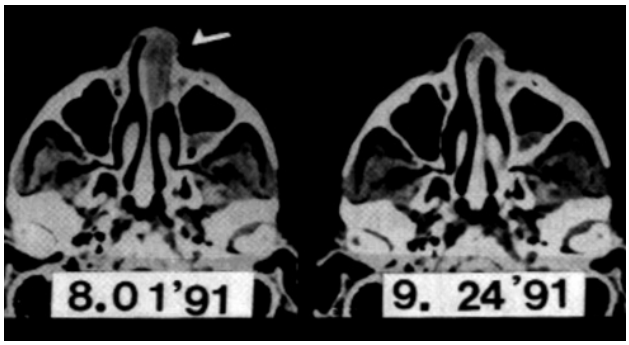

FIGURE 16. CT scans of upper nasal cavity before and after HBI therapy. Though entirely outside the HBI field, the nasal tumor completely disappeared.[29]

treated with LDR is 84%, unchanged from their 3½-year survival. Survival of these LDR patients at 12 years remains 84% (personal communication). In comparison, the 9-year survival of CHOP chemotherapy patients is 50% (Figure 15).[8]

Comparison of 4-year survival in the Harvard and Tohoku LDR *vs* CHOP trials are consistent in both showing about a 20% better survival of LDR patients compared with CHOP patients. In the Japanese trial, however, moderate decreases of platelets did not require schedule interruption, and the 4-year survival of both LDR and CHOP patients was increased about 10% above those of the United States trial. This may be related to the well-established benefits of lower caloric intake and more exercise in the Japanese population. Though racial differences may be a factor, this has not been demonstrated in Japanese living in the United States. As shown by Makinodan (Figure 5)[17], LDR therapy is more effective when administered to mice with optimal caloric intake and better initial immune system activity.

V. NEED FOR CLINICAL TRIALS OF LDR IMMUNOTHERAPY OF BREAST, PROSTATE AND COLORECTAL CANCER

Despite many hundreds of clinical trials of chemotherapy during the past 40 years, breast cancer mortality has not decreased significantly while prostate cancer mortality has risen steadily; colon and rectum cancer mortality also remains high.[30] Chemotherapy is not winning the war against cancer. In contrast, during this same period, research in mice, and more recently in rats and humans, LDR was shown with high statistical confidence to be very effective in preventing and treating cancer. Human clinical trials have shown this immunotherapy to be much more effective in treating intermediate and high-grade stages of non-Hodgkin's lymphoma. Intensive further research during clinical trials is needed to optimize course protocols of LDR immunotherapy and, when indicated,

the optimal interval between courses of LDR immunotherapy. LDR, in contrast to chemotherapy, stimulates rather than depresses all components of the antimutagenic biosystem and is asymptomatic without significant side effects. Published results of LDR immunotherapy justify current initiation of clinical trials in patients with breast, prostate and colorectal cancer.

VI. CONCLUSION

Recent research has led to recognition of the importance of the immune system in controlling cancer as well as infectious disease. LDR cancer immunotherapy has been shown to be effective in rodents and humans. Optimal protocols need to be developed by determining the mechanisms, magnitude and duration of immune response, and the optimal body localization of LDR needed to minimize marrow irradiation while maintaining maximal immune stimulation. Published results justify current support of well-designed clinical trials of LDR therapy in patients with breast, prostate, colorectal, ovarian cancer, and lymphomas. Clinical trials are also indicated to determine the effectiveness of LDR immune stimulation in patients with early HIV and other infectious diseases, and of LDR potentiation of vaccines to prevent HIV and other infectious diseases. LDR of patients is asymptomatic with minimal side effects, a rational and very promising way of using our antimutagenic system to control cancer and infection.

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Authors' Misrepresentations of their Data in Attempts to Support The Linear No Threshold Hypothesis

Myron Pollycove*

School of Medicine, University of San Francisco, San Francisco, CA USA

The current status of LNT theory is summarized in National Council on Radiation Protection and Measurements Report 121 on Collective Dose[1]:

> `..essentially no human data can be said to prove or even to provide direct support for the concept of collective dose with its implicit uncertainties of nonthreshold, linearity and dose-rate independence with respect to risk. The best that can be said is that most [sic] studies do not provide quantitative data that, with statistical significance, contradict the concept of collective dose.
>
> Ultimately, confidence in the linear no threshold dose-response relationship at low doses is based on our understanding of the basic mechanisms involved.. [Cancer] could result from the passage of a single charged particle, causing damage to DNA that could be expressed as a mutation or small deletion. It is a result of this type of reasoning that a linear nonthreshold doseresponse relationship cannot be excluded. It is this presumption, based on biophysical concepts, which provides a basis for the use of collective dose in radiation protection activities."

The LNT hypothesis was proposed tentatively more than 40 years ago and has since become firmly established, though still without any supporting low-dose data and contradicted by statistically significant epidemiologic and biologic data. Nevertheless, a *biophysical* presumption is considered sufficient justification for using LNT as the basis for current policy of protecting against levels of radiation far below the *variations* of natural background. Studies initiated with the expectation of demonstrating statistically significant increased risk of cancer at low doses of radiation have failed to do so; some even have shown statistically significant *decreased* risks. Consequent efforts to support the LNT have led to suppression and misrepresentation of their own contradictory data by authors of several studies:

Nuclear Shipyard Worker Study

This thirteen-year occupational study of the health effects of low-dose radiation was performed by the Johns Hopkins Department of Epidemiology, School of Public Health and Hygiene, reported to the Department of Energy in 1991[2] and in UNSCEAR 1994.[3] Professor Arthur C. Upton, who concurrently chaired the NAS BEIR V 1990 Committee on "Health Effects of Exposure to Low Levels of Ionizing Radiation," chaired the Technical Advisory Panel that advised on the research and reviewed results.

*Correspondence: Myron Pollycove
E-mail: pollycove@comcast.net

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ENHANCEMENT OF BIO-PROTECTIVE FUNCTIONS BY LOW DOSE/DOSE-RATE RADIATION

Kazuo Sakai □ Research Center for Radiation Protection, National Institute of Radiological Sciences

Takaharu Nomura, Yasuhiro Ina □ Low Dose Radiation Research Center, Central Research Institute of Electric Power Industry

□ Effects of low-dose-rate gamma-irradiation on the process of tumorigenesis were investigated in mice treated with a carcinogenic agent or irradiated with high dose X-rays at a high dose rate. A prolonged gamma irradiation at approximately 1 mGy/hr suppressed the appearance of skin tumors induced by methylcholanthrene and delayed the appearance of radiation-induced thymic lymphomas in C57BL/6 mice. We also investigated the effects of low-dose-rate irradiation on disease model mice. In Type II diabetic C57BL/KsJ-db/db (db) mice, the urine glucose level was improved in some of the mice irradiated at 0.70 mGy/hr, but not in non-irradiated control mice. In MRL-lpr/lpr (lpr) mice with severe autoimmune diseases, immunological status was kept better in the mice irradiated at 0.35 or 1.2 mGy/hr. The incidence of a number of symptoms, including lymphadenopathy, splenomegaly and proteinuria, was suppressed by the irradiation. Furthermore, in both of the strains, the low-dose-rate irradiation prolonged the life span of the irradiated mice.

I. INTRODUCTION

Low doses of ionizing radiation stimulate various biological functions: anti-oxidative capacity[1], DNA repair capability[2], apoptosis[3, 4], and immune functions[5, 6]. Each of these functions may work in a suppressive manner in the process of carcinogenesis, which would be initiated with DNA damage induced directly by radiation or through reactive oxygen species production. We have previously demonstrated that a low-dose-rate irradiation at around 1 mGy/hr suppressed the incidence of methylcholanthrene-induced skin tumors in ICR mice[7]. We also found some of biological protective functions, including anti-oxidative capacity and immune functions, were enhanced. To examine the possibility that the augmented protective capacity may have some other effects in addition to the tumor suppression, we investigated the effects of low dose irradiation on disease model mice.

Address correspondence to Kazuo Sakai, Research Center for Radiation Protection, National Institute of Radiological Sciences, 4-9-1 Anagawa, Inage-ku, Chiba 263-8555, Japan. E-mail: kazsakai@nirs.go.jp

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RADIOBIOLOGICAL BASIS FOR CANCER THERAPY BY TOTAL OR HALF-BODY IRRADIATION

Kiyohiko Sakamoto □ Tohoku Radiological Science Center, Sendai, Miyagi 980-0811, Japan

□ *The tumor control effects by total-body irradiation (TBI) or half-body irradiation (HBI) on tumor-bearing mice and human cancer were investigated. In fundamental studies using a murine experimental system, mice that received 10 or 15 cGy of TBI showed a high value of TD_{50} (number of tumor cells required for successful transplantation to a half group of injected sites) compared with nonirradiated control mice. The combination of low doses of TBI and local irradiation on tumor-bearing mice demonstrated enhanced tumor cell killing compared with only local irradiation, but this tumor-cell killing effect was not observed following 10 or 15 cGy of TBI alone. However, the suppression of distant metastasis of tumor cells was observed following low doses of TBI alone. Immunological studies on these effects suggested that TBI or HBI caused immunopotentiating effects. In clinical studies, malignant lymphoma (non-Hodgkin's lymphoma) was selected as the first disease for clinical trial. The results were promising for tumor control applications, except for advanced cases and very aged patients.*

Keywords. total-body irradiation, tumor immunology, murine squamous carcinoma, TD50, non-Hodgkin's lymphoma

INTRODUCTION

Total-body irradiation (TBI) with X-rays is generally considered to be a method of suppressing immunological responses in organisms and has been used to eliminate immunological ability from experimental animals. The immunological study group asked us, from time to time, to irradiate mice to suppress their immunological ability. We irradiated sublethal; however, the smallest dose required to suppress immunological responses was not clear (Hellstrom and Hellstrom, 1978; Tilkin *et al.*, 1981; Anderson *et al.*, 1982). The experiments described here were started about 25 years ago to determine the smallest dose. And then we investigated whether tumor cell transplantation could be accomplished with a small number of cells after TBI. On the contrary, it became clear that TBI of 10 or 15 cGy caused a rejection

The study introduced in this review paper was performed in cooperation with Drs. M. Myojin, Y. Hosoi, Y. Takai, and my colleagues belonging to the Radiotherapy Department of the Tohoku University. I am indebted to all of them, and I am very grateful for the assistance from Dr. Jerry M. Cuttler in the preparation of the manuscript. The study was supported by grants provided by the Ministry of Education, Culture, Sports, Science and Technology, Japan, and Tohoku Electric Power Co. Ltd.

Address correspondence to Kiyohiko Sakamoto, Tohoku Radiological Science Center, 1-1-30 Ichibancho, Aoba Sendai, Miyagi 980-0811, Japan. Tel: 81-22-266-8288. Fax: 81-22-224-8163. E-mail: sakamotokiyo@m1.bstream.jp

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CT Scans May Reduce Rather than Increase the Risk of Cancer

Bobby R. Scott, Ph.D.
Charles L. Sanders, Ph.D.
Ron E. J. Mitchel, Ph.D.
Douglas R. Boreham, Ph.D.

ABSTRACT

Extrapolating from data on atomic bomb survivors on the basis of the linear no-threshold (LNT) model as applied to radiation exposure, a recent paper concludes that within a few decades 1.5–2 percent of all cancers in the U.S. population could be caused by current rates of use of computed tomography (CT). This paper ignores the other war-related exposures of the Japanese population, which would be expected to shift the dose-response relationship for cancer induction to the left. Moreover, the LNT model is shown to fail in four tests involving low-dose radiation exposures. Considering the available information, we conclude that CT scans may reduce rather than increase lifetime cancer risk.

Introduction

In a Nov 29, 2007, article in the *New England Journal of Medicine*[1] Brenner and Hall argue that the potential carcinogenic effects from using computed tomography (CT) may be underestimated and that one-third of all CT scans performed in the United States may not be medically necessary. They estimated that more than 62 million CT scans per year are currently done in the United States as compared to 3 million in 1980.[1] With such an increased rate Brenner and Hall speculate, based on extrapolations from cancer data derived from survivors of the atomic bombings in Hiroshima and Nagasaki, that in a few decades about 1.5–2 percent of all cancers in the United States may be the result of current CT scan usage. Their calculation uses the linear-no-threshold (LNT) method of adding up small, hypothetical individual risks (none of which may be real) over a large irradiated population.

Such speculation aggravates the widespread worry about undergoing routine CT scans, which is unfortunate given that many lives have been saved because of medical problems revealed by these scans.

Brenner and Hall[1] correctly point out that x-ray doses from CT scans are much higher than those from dental and chest radiography. In discussing the biologic effects of low doses of ionizing radiation, the authors, while mentioning the potential cancer-inducing implications of DNA double-strand breaks and their misrepair, do not consider the adaptive response of humans to ionizing radiation. Low doses and low dose-rates of some forms of radiation (e.g., x-rays and gamma rays) stimulate the body's natural defenses. This effect has been called radiation activated natural protection (ANP).[2] Radiation ANP includes selective removal of aberrant cells (e.g., precancerous cells) via apoptosis and stimulated immunity against cancer cells. Thus, radiation ANP can prevent some cancers (sporadic and hereditary) that would otherwise occur in the absence of radiation exposure.[3]

Recent papers by Bauer[4] and by Portess et al.[5] describe how low-dose radiation activates the selective removal of precancerous cells via apoptosis. The selective removal is mediated via intercellular signaling involving reactive oxygen and nitrogen species and specific cytokines (e.g., transforming growth factor ß).

Numerous papers have been published related to low-dose radiation stimulating immunity against cancer cells.[6-8] Because of radiation ANP, low doses and low dose-rates of x-rays and gamma rays can actually reduce rather than increase cancer occurrences.[3] Conversely, high radiation doses suppress immunity and inhibit selective removal of aberrant cells via apoptosis, leading to an increase in the number of cancer cases to a rate greater than the spontaneous level.[3,6-8]

Extrapolating Observed Radiation Effects from High to Low Doses

In order to obtain lifetime cancer risk predictions from small radiation doses such as those received from CT scans, many researchers extrapolate the risk from observed effects after moderate and high radiation doses using the LNT model. With this model, any amount of radiation is considered to cause some cancer fatalities in any large irradiated population. Doubling the radiation dose doubles the number of cancer fatalities.

When the lifetime attributable risk estimates of radiation-induced cancer after high doses fall around an LNT function with slope α, a hypothetical risk R at a low dose D can be calculated with the LNT model as:

$$R = \alpha D.$$

Only the radiation-associated risk (i.e., attributable risk) is counted in this equation, which can be applied to both cancer incidence and cancer mortality. To obtain the total risk, the spontaneous risk R_0 must also be accounted for. Here, the focus is on attributable risk as defined by the equation above, which differs from attributable risk as used in addressing multiple risk factors. Brenner and Hall[1] evaluated what corresponds to R by using age-specific values for cancer mortality based on A-bomb survivor data.

To assess risk, Brenner and Hall used special dose units (valid only for LNT-type responses and based on dose weighting for different radiation types) that supposedly allow for converting the

effects of mixed neutron and gamma irradiation (as occurred for the A-bomb survivors) to equivalent harm from x-rays from CT scans. One such unit is the millisievert (mSv).[1] For radiation such as x-rays and gamma rays, a mSv is the same as a milligray (mGy). Further, 1 mSv received from combined exposure to neutrons and gamma rays can be hypothetically equated to 1 mSv of x-ray exposure from CT scans.

Brenner and Hall first extrapolated from A-bomb survivor data based on dose in mSv for combined neutron and gamma irradiation. The dose in mSv was then equated to the dose in mGy of CT scan x-rays. This is how they arrived at their Figure 4, which presents hypothetical lifetime attributable risk of death from lung or colon cancer per million patients exposed to 10 mGy of x-rays from a CT scan. Hypothetical results are presented for exposure at different ages from birth to 80 years.

No adjustments were made by Brenner and Hall[1] to account for the influences of combined injuries suffered by survivors in Hiroshima and Nagasaki or for differing genetic susceptibilities to radiation in the Japanese and U.S. populations. When an atomic bomb is detonated on a city, there are blast-propelled projectiles and thermal waves in addition to radiation. The mode of damage is one of combined injuries (radiation + toxins + wounds + burns + infection) to those people in demolished cities (a highly stressful and unsanitary environment). Such combined injuries are known to shift the radiation effect dose-response curve to the left, with higher risks coming from combined injuries than from radiation exposure alone.[9-11] Further, some genetic risk factors, such as defects in DNA repair mechanisms, are known to influence susceptibility to cancer.[12-16] The LNT model does not address combined injuries under stressful environments or population variability in genetic risk factors. These issues were also not addressed by Brenner and Hall[1] in their extrapolation of cancer risk from A-bomb victims in Japan (moderate- and high-dose data) to CT scan exposures (low doses) in clinical settings in the United States.

Brenner and Hall[1] recognized that radiation dose distribution over the body is quite different for A-bomb survivors, who received total-body irradiation, than for persons receiving CT scans. They simply assert, without evidence, that the cancer risk for one organ is not substantially influenced by the radiation exposure to other organs. Significant damage to the immune system is known to increase the risk of cancer.[7] Wounds and thermal (or radiation) burns would be expected to adversely affect the immune system.

Tests of the LNT Model

Four plausible tests of the LNT model are summarized below. They are based on recent studies of brief exposures to low doses ($\leq$100 mGy) of x-rays or gamma rays, or of protracted exposures to similar or higher doses of gamma rays over extended periods at low rates. Chemical carcinogen exposure in combination with low-rate gamma-ray exposure is also considered. Endpoints are neoplastic transformations and cancer. For the brief exposures, the dose can be presumed to be essentially instantaneous. For the protracted exposures, a small dose was added each hour or each day. With the LNT model any small dose increases the hypothetical risk of cancer. Each hourly or daily additional dose increases the hypothetical risk so that the risk of cancer is postulated to continue to increase under conditions of chronic, low-rate exposure.

Neoplastic Transformation and Low Doses

According to the LNT model, a low dose of x-rays or gamma rays is predicted to increase the risk of neoplastic transformation. The predicted increase was not supported by studies conducted by Redpath et al.[17] and by Azzam et al.,[18] who showed that for doses $\leq$ 100 mGy (100 mGy being the equivalent of several CT scans), the frequency of neoplastic transformation was reduced below the spontaneous level, presumably because of gamma-ray ANP with selective removal of aberrant cells via apoptosis.[3-5] Recall that high doses and high dose rates are considered to inhibit ANP.[3, 7] Redpath et al.,[17] when expressing their transformation frequency data as relative risk (RR), found the dose-response curves for neoplastic transformation were similar to and overlapped those for breast cancer and leukemia induction in humans, supporting the occurrence of radiation ANP against human cancers.

Neoplastic Transformation and Protracted Exposure

According to the LNT model, each small increment in radiation dose increases the risk of neoplastic transformation under circumstances of protracted exposure at a low rate. The predicted increase was, however, not supported by studies conducted by Elmore et al.[19] Low-rate exposure for doses up to at least 1,000 mGy (equivalent to multiple CT scans separated in time) suppresses rather than increases neoplastic transformation risk. The indicated suppression and extension of the protective dose range is considered to relate to the repeated activation of transient gamma-ray ANP during protracted exposure.[3] Similar gamma-ray ANP has also been reported against lymphomas in cancer-prone mice.[20] Low, single gamma doses of 10 or 100 mGy administered at a low rate extended the lifespan of the cancer-prone mice and reduced the cancer incidence at given follow-up times.[20] Similar studies with repeated exposures to low-dose x-rays, now being carried out by Boreham, will have implications for assessing risk from multiple CT scans. Because the biological processes that contribute to radiation ANP are transient, appropriate time intervals between exposures should also be determined.

Combined Exposure of Lung to Low-dose-rate Alpha and Gamma Radiation

According to the LNT model, adding a low-rate, low-dose gamma-ray exposure on top of a low-rate alpha-radiation exposure increases the risk of lung cancer. The predicted increase was not supported by the study by Sanders.[21] Adding a very small (1-2 mGy) gamma-ray dose to the protracted alpha radiation dose prevented alpha-radiation-induced lung cancers in rats that inhaled the alpha-emitting radionuclide plutonium-239 in an insoluble dioxide form,

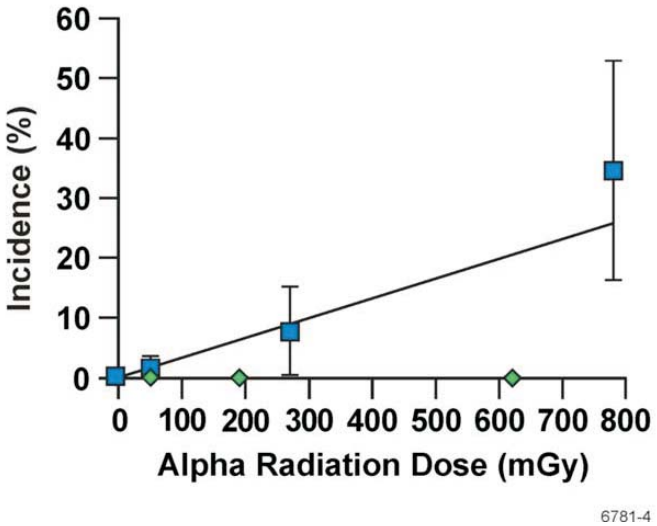

Figure 1. Lung Cancer Incidence in Wistar Rats: after inhalation exposure to the alpha radiation source $^{239}PuO_2$ (squares) or $^{239}PuO_2$ labeled with a ytterbium-169 gamma-emitting tag (diamonds). The added gamma exposure (1-2 mGy) prevented alpha-radiation-induced lung cancers, presumably via gamma-ray ANP. None of the 1877 animals receiving gamma rays (diamonds) in addition to their alpha radiation exposure developed lung cancer for the indicated dose range. The data are from Sanders,[21] and for the indicated dose range a total of 3793 animals were used. Error bars are 95% CI, assuming a binomial distribution of cancer cases.

$^{239}PuO_2$ (Figure 1). The plutonium aerosols were labeled with a gamma-emitting ytterbium-169 tag. Complete cancer prevention occurred even for alpha radiation doses up to about 600 mGy. The prevention is thought to relate to gamma-ray ANP, which includes selective apoptosis of precancerous cells[3-5] and enhanced immunity to cancer cells.[6-8] Gamma-ray ANP against ^{239}Pu alpha-radiation-induced lung cancer has also been reported for humans.[3] An average of 86 percent of lung cancer cases were estimated to be avoided by chronic-gamma-irradiation ANP.[3]

Combined Exposure to Chemical Carcinogens and Low-dose-rate Gamma Rays

According to the LNT model, adding low-rate gamma rays to a chemical carcinogen exposure increases the cancer risk as the radiation dose increases. The predicted increase was not supported in the study by Sakai et al.[22] The protracted low-dose-rate gamma-ray exposure reduced rather than increased the risk of skin cancers from methylcholanthrene injected into mice.[22]

In many additional published tests of the LNT model, reduced rather than increased harm was found to be associated with doses similar to those from CT scans.[3,23]

Failure to Report Radiation-ANP-related Suppression of Cancer

Most epidemiologic studies of radiation-induced cancer do not report radiation-related ANP. The designs of epidemiologic studies of radiation-induced cancer are largely influenced by the presumption that the LNT model is valid. Some approaches used in such epidemiologic studies that make it difficult to demonstrate or recognize radiation adaptive response and thresholds for excess cancers are as follows:

1. Dose lagging (ignoring some of the radiation dose), which shifts the dose-response curve to the left,[24] as was done in the analyses of Cardis and colleagues discussed by Brenner and Hall[1] as supporting evidence for increased cancer risk at low doses;

2. Averaging risk over wide dose intervals in cohort studies,[24,25] as was done for A-bomb survivor cancer data cited by Brenner and Hall[1] to infer increased risk for the entire weighted dose interval 10–150 mSv;

3. Averaging odds of cancer over very wide dose intervals before calculating the odds ratio in case-control studies;[24]

4. Including individuals who received low-dose radiation in the unexposed group in cohort and case-control studies;[24]

5. Employing linear extrapolation from high to low doses after dose lagging and risk or odds averaging over wide dose intervals;

6. Not adjusting for the impact of combined injuries and differences in genetic susceptibilities when using A-bomb survivor data to assess cancer risk for another population; and

7. Ignoring radiation ANP (which is supported by low-dose data) for no apparent reasons other than it does not fit the LNT model.

Employing such approaches can cause one to conclude that an LNT-type dose-response curve is real when actually there is a reduced risk at low doses and dose rates and/or a threshold dose for excess risk.[26,27]

Dose lagging, a potential flaw in epidemiologic study design, is based on the assumption that some radiation dose is wasted. Assuming an LNT dose-response curve and using dose lagging is a contradiction because with the LNT model each unit-dose increment (e.g., each 1 mGy increment) is presumed equally effective in adding to the cancer risk. Actually, no wasting occurs when each fixed increment in dose (e.g., each 100 mGy increment) shortens the latency period for cancer occurrence as is implied by existing data for the cumulative incidence of cancer vs. time for different radiation dose groups.[20] Additionally, no dose is wasted when added dose increments contribute to suppression of neoplastic transformation and cancer as was demonstrated for extended low-rate protracted exposure.[19,22] No evidence of dose wasting has been reported for inducing DNA double-strand breaks, mutations, or neoplastic transformations. Discarding radiation dose under the presumption of dose wasting could mistakenly support an LNT-type dose response for cancer induction with a corresponding slope parameter (α in the equation above).

Influence of Age at Exposure

Brenner and Hall[1] point out that children are at higher risk than are adults for cancer induction by radiation. Based on the published data of Nyström et al.[28] from Swedish randomized controlled trials of breast cancer mortality after multiple mammography-related x-

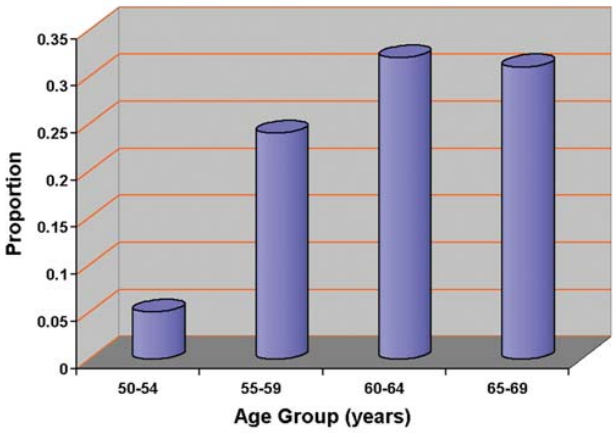

Figure 2. Radiation ANP and Age. Bars show upper-bound estimates of the proportion of breast cancer cases prevented by radiation ANP as a function of age at exposure to diagnostic x-rays (multiple mammograms), based on breast cancer mortality data of Nyström et al.[26]

rays, the level of x-ray ANP appears to be age dependent (Figure 2). Figure 2 presents upper-bound estimates of the proportions of breast cancer cases among those that would occur normally that are calculated *not* to occur as a result of radiation ANP. With such age dependencies, children may benefit much less from low-dose x-ray ANP than adults. However, radiation ANP benefits are known to vary for different body organs; thus, age dependencies for radiation ANP may vary with cancer sites.[20] New adaptive-response research is needed to address such issues.

Conclusions

There is no credible evidence to support the contention that current routine usage of CT scans in clinical settings in the United States will cause future cancers. Rather, the available data indicate that occasional exposure to diagnostic x-rays could possibly reduce the risk of future cancers among irradiated adults. The impact of CT scans on future cancers among persons irradiated as children is less clear. However, LNT-model-based risk estimates derived for children by extrapolating from A-bomb survivors cannot be considered valid, especially when no adjustment is made to remove the influence of combined injuries or to account for differing genetic susceptibilities of Japanese and U.S. populations, or when radiation adaptive response is not addressed.

Bobby R. Scott, Ph.D., is a senior scientist at Lovelace Respiratory Research Institute, 2425 Ridgecrest Drive SE, Albuquerque, NM 87108, Tel. (505) 348-9470, Fax (505) 348-8567, e-mail bscott@LRRI.org. **Charles L. Sanders, Ph.D.,** is a visiting professor in the Department of Nuclear and Quantum Engineering at the Korean Advanced Institute of Science and Technology (KAIST), Daejeon, Republic of Korea. **Ron E.J. Mitchel, Ph.D.,** is a consulting scientist for Atomic Energy of Canada, Ltd., Chalk River Laboratories, Chalk River, Canada. **Douglas R. Boreham, Ph.D.,** is an associate professor in the Department of Medical Physics and Applied Radiation Sciences, McMaster University, Hamilton, Ontario, Canada.

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Nuclear shipyard worker study (1980–1988): a large cohort exposed to low-dose-rate gamma radiation

Ruth Sponsler*

P.O. Box 553, Burnsville, NC 28714, USA
E-mail: jk5554@yahoo.com
*Corresponding author

John R. Cameron#

Departments of Medical Physics, Radiology and Physics,
University of Wisconsin-Madison
#Deceased 2005

Abstract: This paper is a summary of the 1991 Final Report of the Nuclear Shipyard Worker Study (NSWS), a very comprehensive study of occupational radiation exposure in the US. The NSWS compared three cohorts: a high-dose cohort of 27,872 nuclear workers, a low dose cohort of 10,348 workers, and a control cohort of 32,510 unexposed shipyard workers. The cohorts were matched by ages and job categories. Although the NSWS was designed to search for adverse effects of occupational low dose-rate gamma radiation, few risks were found. The high-dose workers demonstrated significantly lower circulatory, respiratory, and all-cause mortality than did unexposed workers. Mortality from all cancers combined was also lower in the exposed cohort. The NSWS results are compared to a study of British radiologists. We recommend extension of NSWS data from 1981 to 2001 to get a more complete picture of the health effects of ^{60}Co radiation to the high-dose cohort compared to the controls.

Keywords: low-dose-rate gamma radiation; nuclear shipyard workers; cohort; cardiovascular disease; cancer; mortality.

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Biographical notes: Professor John R. Cameron was trained in nuclear physics but spent most of his career applying physics to medicine. In the 1960s, he and his graduate students developed thermoluminescent dosimetry (TLD) and invented bone densitometry for detection of osteoporosis. In 1981, he was the founding chair of the Medical Physics Department at the University of Wisconsin. From 1980–1988, he was a member of the external panel that advised scientists doing the US nuclear shipyard worker study. He was disappointed that the scientists who did the research chose not to publish the details of this excellent study.

Ruth Sponsler has an MS in Entomology from Auburn University and is interested in biostatistics. She also has active hobby interests in geology.


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