Canadian Nuclear Safety Commission | Commission canadienne de sûreté nucléaire

CMD 21-H4.22

File / dossier : 6.01.07
Date: 2021-05-03
Edocs: 6553919

Oral Presentation

Exposé oral

Written submission from Jerry Cuttler

Mémoire de Jerry Cuttler

In the Matter of the

À l'égard de

Darlington New Nuclear Project

Projet de nouvelle centrale nucléaire de Darlington

Application to renew the nuclear power reactor site preparation licence for the Darlington New Nuclear Project

Demande de renouvellement du permis de préparation de l'emplacement d'une centrale nucléaire pour le projet de nouvelle centrale nucléaire de Darlington

Commission Public Hearing

Audience publique de la Commission

June 10, 2021

10 juin 2021

Canada

Intervenor Report for CNSC Public Hearing

by

Dr. Jerry M. Cuttler, D.Sc., P.Eng.

Vaughan, Ontario, Canada

regarding

Ontario Power Generation's Application

for renewal of its site preparation licence for the

Darlington New Nuclear Project

to be held June 10, 2021

Part A: **Review of the licence renewal documents**

Part B: **Evidence of beneficial effects of radiation and thresholds for detriment**

Objective

PFP contribution agreement *PFP 2020 DNNP01 Cuttler*, Section 2.2 requires:

1) participation in the proceedings of the Public Hearing on the OPG application to renew its site licence for the Darlington New Nuclear Project (DNNP),
2) review of the OPG licence renewal application and related documentation, including OPG and CNSC CMDs, and comment in its feasibility and safety aspects. The analysis must focus on OPG's proposed site preparation licence.
3) submission of a written report summarizing comments from the review,
4) a presentation at the June 10, 2021 virtual Public Hearing.

Executive Summary

This report is in two parts. Part A reviews the licence renewal documents, and it urges regulatory reform. Part B presents evidence that nuclear energy risks are very unlikely.

Part A recommends CNSC approval of the OPG application. The amount and detail of the information in the OPG licence application and the CMDs exceed the reviewer's expectations for the renewal of the site preparation licence for the DNNP. The material is familiar to the reviewer, who has more than 45 years experience in the design, procurement, construction, licensing, and operation of Canadian reactors. OPG is highly capable and will implement DNNP site preparation in compliance with all requirements. The CNSC Staff are very thorough and will carefully monitor OPG's performance.

The precautionary requirements being imposed to protect people and the environment from the effects of nuclear energy are far too onerous and costly. Part B of this report provides evidence that a credible event, at a nuclear facility today, would not expose employees, residents or the environment to doses or dose rates of radiation that exceed the thresholds for detrimental effects.

From the time that Pickering A was built until now, the prerequisites for constructing and operating nuclear facilities grew enormously. These changes were due to increasing perceptions of risk—health scares that are not based on actual radiation-induced harm. Nuclear plants have become too costly and fearful. Small modular reactors are being developed; however, the regulatory requirements will prevent them from being viable. Expansion of nuclear energy requires a review of the evidence that likely exposures to radiation will cause biopositive effects. New laws and regulations are needed that will allow a revival of nuclear energy (and vital low-dose medical therapies) in Canada.

Part B presents evidence of radiation dose and dose-rate thresholds for the onset of detrimental health effects. The evidence shows beneficial effects of exposures to low doses of radiation and lifelong exposures to low-level background. Consequences of the extreme radiation doses at Chernobyl are reported. The Fukushima population doses are assessed. It is essential to inform Canadians about these facts. It will diminish their extreme fear of radiation. The precautionary principle policy and ALARA for radiation are not appropriate because the effects of radiation on organisms are known well.

Table of Contents

1.0 Introduction

This document was produced to fulfill the requirement in Section 2.2 of Participant Funding Program agreement *PFP 2020 DNNP01 Cuttler*. The intervenor reviewed the OPG licence renewal application [1] against CNSC REGDOC-1.1.1 [2], the OPG Aggregate Assessment and Commitments Reports [3], the OPG submission CMD 21-H4.1 [4], and the CNSC Staff's submission and recommendation CMD 21-H4 [5].

Part A of this report contains the intervenor's comments on the OPG documents and the CNSC Staff document. It then goes on to discuss the importance of nuclear energy and how the unscientific radiation scare came about that led to overprotective government laws and regulations, worldwide.

Three fundamental concerns are raised by opponents of nuclear facilities: accidents that release radioactive materials, the problem of nuclear waste, and the risk of weapons proliferation. These political issues are shown to be invalid.

The information provided in this report needs to be communicated widely, to remove the barriers against building nuclear energy facilities. Governments should examine the biological evidence regarding the effects of radiation on organisms, especially the dose and the dose-rate thresholds for the onset of detrimental effects.

After this information is communicated to the public, in plain language, it will be possible to change the radiation protection laws, regulations, and standards. Currently, they are based on the invalid linear no-threshold model of radiation carcinogenesis, which was accepted in 1960, along with the precautionary principle policy. It requires enforcement of ALARA (as low as reasonably achievable). The changes are appropriate because the effects of radiation on organisms are known. Only after major regulatory changes are in place will nuclear energy become economically viable.

Part B of this report presents evidence of radiation dose and dose-rate thresholds for the onset of detrimental health effects and evidence of beneficial effects of exposures to low doses of radiation and lifelong exposures to elevated background radiation.

The effects, after 30 years, of the high doses received by the 106 emergency Chernobyl workers, who recovered from acute radiation syndrome, are surprising. The cumulative doses during the first year, in the areas around the 3 Fukushima reactors that melted down, are compared against the threshold dose rate (lifelong) for detrimental effects (reduction of life span). The emergency measure of evacuating the nearby residents did not reduce their risk. On the contrary, it induced enormous psychological stress that caused considerable harm.

Informing all Canadians about the actual effects of such very unlikely exposures will allay their concerns about credible events and fears of nuclear radiation and X-rays.

Part A – Review of the DNNP site preparation licence renewal documents

2.1. Comments on OPG Application for Renewal of Site Preparation Licence

The application submitted to the CNSC on June 29th, 2020 requested a 10-year licence renewal to prepare the DNNP site [1]. The document demonstrates that OPG meets the requirements of the Nuclear Safety and Control Act and the associated regulations, including REGDOC-1.1.1 [2], for the DNNP. Licensed activities will begin when OPG selects the SMR facilities that it would like to build and operate. Meanwhile, OPG's excellent record in operating the adjacent Darlington NGS since 1990 and the Pickering NGS since 1971 exudes confidence it will continue to manage DNNP site preparation in an exemplary manner, with safety being an overriding priority. This application assures the absence of risks to health and to the environment.

When evaluating a novel SMR design, a *graded approach* may be used in which the application of regulatory requirements and guidance will be commensurate with the risks posed and characteristics of the proposed reactor facility or activity. An applicant or licensee may put forward a case to demonstrate that the intent of a requirement is addressed by other means and demonstrated with supportable evidence.

The application mentions activities underway, including those related to commitments made during the Joint Review Panel process. Reports on licence renewal activity, site selection threat and risk assessment update, and an aggregate assessment report were prepared. The DNNP site continues to be suitable for the proposed new SMRs.

Of particular interest in this review is recommendation #55 in Table 12, directed to Health Canada and the CNSC: "continue to participate in international studies seeking to identify long-term health effects of low-level radiation exposures, and to identify if there is a need for revision of limits specified in the *Radiation Protection Regulations*." Part B of the intervenor's CMD discusses this subject and presents biological evidence.

Also of interest is recommendation #65 in Table 12, directed to the Government of Canada: "make it a priority to invest in developing solutions for long-term management of used nuclear fuel, including storage, disposal, reprocessing and re-use." This issue is also discussed in this CMD.

The abundant information in [1] demonstrates that OPG: meets all the requirements, is qualified to carry on the activity to be licensed, will protect the environment and the health and safety of persons, and will maintain national security and measures required to implement international obligations to which Canada has agreed. OPG commits to continued transparency and appropriate Indigenous and public consultations.

The site preparation licence is an important asset for OPG and the Province of Ontario, as it enables the option for additional nuclear generation capacity. This would ensure an ongoing, reliable supply of nuclear electricity within Ontario's energy supply mix.

2.2. Comments on the OPG Aggregate Assessment and Commitments Reports

These reports submitted on June 29th, 2020 [3], are in accord with Licence Condition 1.3 of the DNNP licence PRSL 18.00/2022 and support licence renewal. The Aggregate Assessment report provides the methodology and results of the assessment, identifying the areas for mitigating actions: updates to three existing commitments plus a new one. Attachment 1 in the package summarized the changes to the Commitments Report, which is to be updated as the licence renewal process and overall project advances.

Considering that the DNNP is located on the Darlington nuclear site and is adjacent to Darlington NGS, a licensed and operating facility, these documents are overly complex, overbearing and reflect costly requirements for SMRs that are intended to be affordable to construct and operate. There is no evidence that a *graded approach* is being applied, given that SMRs are to be low risk facilities. If the regulatory requirements and guidance are not commensurate with the risks and characteristics of the proposed reactor facility, then the DNNP will fail. The intervenor's CMD demonstrates that risks of well operated nuclear facilities, including SMRs, are likely to be negligible or nonexistent.

2.3. Comments on the OPG submission CMD 21-H4.1

This CMD [4] summarizes the evidence already presented that OPG meets all legal requirements of the NSCA and the associated regulations and assures that OPG will make adequate provisions to protect the health, safety and security of persons and the environment in the DNNP. It also commits to maintain national security and measures to implement the international obligations. The site remains suitable for a new nuclear facility because it would not pose an unreasonable risk to employees, the public or the environment.

This request is for a 10-year renewal of the site preparation licence, “as is”, with no increase in scope. The reactor technology to be selected will be within the bounds of the licensing basis, with detailed demonstration during licensing of the construction phase. No licensed activities have been initiated, so there is no change in scope since 2009.

OPG pointed to its strong safety and operational performance at two nuclear stations over 50 years and commits to uphold its standards of excellence. OPG's relationships with indigenous communities, the public and the stakeholders are good. It engages and communicates information updates with government, media, business leaders, schools and universities, interest groups, and community organizations.

The original site information and licence application were evaluated against REGDOC-1.1.1 requirements and guidance. Current codes, standards and practices that are referenced were examined. Baseline data were updated, and gaps addressed in the Aggregate Assessment report, mitigating actions added to the Commitments Report. The formal actions to mitigate a butternut tree (sapling) and bank swallow nests in the shoreline bluffs are overly prescriptive for an industrial project.

OPG completed an environmental risk assessment for the original licence, evaluating the risk posed by contaminants and physical stressors in the environment, associated with the facility, on human and ecological receptors. The assessment of effects of the DNNP on human health considers the physical, mental, and social well-being of workers and members of the public. The assessment concluded that no residual adverse effects on human health or non-human biota are expected over the lifecycle of the DNNP. The assessment fails to mention the mental stress that will be induced by the activities of the antinuclear organizations, who are expected to exploit the widespread radiophobia, to arouse social and political opposition against additional nuclear energy facilities. These activists can be expected to urge the construction of “renewable energy” facilities that supply electricity intermittently and require the provision of additional gas-fired power plants. The June 9-10, 2021 Public Hearing recognizes the health risk of these stressful encounters and will mitigate it.

2.4. Comments on CNSC Staff submission CMD 21-H4

This CMD [5] is thorough and of high quality. It identifies all the requirements. The CNSC staff assessed the OPG application and confirmed that the licensing basis and the Commitments Report remain valid. It recognizes that OPG is qualified and capable to fulfill all requirements of the licence to prepare this site. It points out that OPG has not initiated licensed activities but focused its efforts on addressing the recommendations of the Joint Review Panel (JRP) process that examined the Environmental Assessment of the new nuclear project on this site. Section E2 lists the 67 JRP recommendations and their status; 14 of them have been closed to date.

The CNSC staff recommend that the site preparation licence be renewed with specific amendments and that authority be delegated to specific CNSC staff members to administer the licence conditions. These are specified in the draft licence conditions handbook, also included in this CMD. The CMD provides a complete basis for the staff recommendation to renew OPG’s DNNP site preparation licence.

The environmental assessment is far too demanding for a nuclear energy facility, such as the DNNP, whose impact on the environment will be benign when compared with the impact of other electricity generating facilities and many industrial projects. Likewise, the CNSC licensing requirements for nuclear generating stations are much more stringent than really needed, based on a scientific evaluation of the actual hazards and risks as discussed in this intervenor’s submission.

2.5. The importance of nuclear energy

The welfare of humanity and the environment depends on the availability of energy. It is essential for the existence of all life. Humans exploit energy to increases the productivity of labour. Solar radiant energy is the ultimate source; it warms the planet and provides fresh water, photosynthesis, oxygen, and food. It drives the ocean and air currents that people have exploited for centuries. Humans improved their welfare immensely, when people began releasing energy by the combustion of coal, oil, and methane gas to power engines, heat homes and drive chemical processes.

The discovery of the nuclear fission reaction, which releases an enormous amount of energy, was first applied militarily to the manufacture the explosives that ended WWII. Some of the scientists who developed this technology, and many other people, became angry about the bombing of Hiroshima and Nagasaki and the subsequent activities by world powers to develop more powerful nuclear weapons and produce large quantities of them. An antinuclear movement arose that opposes nuclear weapons. One of its important strategies has been the creation of a radiation health scare [6] linking the smallest exposure to nuclear (ionizing) radiation to a risk of DNA mutations and cancer.

On December 8, 1953, U.S. President Eisenhower delivered his “Atoms for Peace” speech at the United Nations. Many civilian nuclear research programs started for the benefit of humanity. He proposed the creation of non-proliferation agreements to stop the use and spread of nuclear weapons, and he urged peaceful applications of nuclear energy, such as the generation of electricity. This led to the creation of the International Atomic Energy Agency.

The amount and immense concentration of nuclear energy can be appreciated when its energy release is compared with that from the combustion of common fuels. Burning a carbon atom releases 4.1 eV (electron volts) and burning a hydrogen molecule releases 3.0 eV. The fission of a uranium atom releases about 200 million eV, of which 170 MeV can be captured. The energy from this fuel is about 50 million times more concentrated than the energy from chemical fuels. The comparatively small volume of the used fuel allows it to be stored at the nuclear reactor site, initially in deep pools of water and years later in robust, sealed containers. Almost all nuclear plants fission only about 1% of the mined uranium, which is like burning the bark on a log of wood and discarding the rest of the log. More advanced nuclear plants are in operation that transform much more of the uranium-238 material into plutonium, making it economical to purify the used fuel and reuse it. Eventually, advanced reactors will enable Canada’s uranium to be almost fully utilized, including the slightly used CANDU fuel now stored at the nuclear sites. An enormous increase in energy supply and a reduction in the amount of radioactive waste to be stored can be expected. For the same amount of energy produced, the effect on the environment of storing used fuel and nuclear waste is astonishingly small, compared with the effects of burning coal, oil, or gas, or the effects of building thousands of wind turbines or many square kilometres of solar panels.

2.6. Origin of the fear of radiation that blocks the use of nuclear energy

During the early 1950s, testing of nuclear weapons led to increased worldwide exposure to various radionuclides prompting public health concerns. The Rockefeller Foundation (RF), an oil industry benefactor, which had been funding medical research for many years, began funding the U.S. National Academy of Science (NAS) to take on detailed assessment of the areas of concern [7]. In early 1955, after start of the Atoms for Peace initiative, which included use of nuclear energy to generate electricity, the RF began a study of radiation effects “with particular attention to the possible danger to the genetic heritage of man" [8] p56. The NAS Biological Effects of Atomic Radiation (BEAR) Genetics Panel first met in late November 1955.

The President of the Rockefeller Institute for Medical Research was also the President of the NAS. He selected a long-term scientific director of the RF to chair the NAS BEAR I Genetics Panel. The panel members, many who were being funded by the RF, began working in February. The recommendation, published in June 1956 in *Science* [9], is to use the linear no threshold (LNT) dose-response model to assess the risk of radiation-induced genetic mutations instead of the threshold model, which was the basis for the “tolerance dose” rate limit that radiologists had employed for their protection, for more than three decades [10]. This LNT recommendation was controversial because it was based on faulty fruit fly research. It was contradicted by a ten-year study of over 70,000 children of the survivors of the bombing at Hiroshima and Nagasaki, which continued to show no hereditary damage [11]. This essential human evidence was disregarded.

A deeply flawed study on the incidence of leukemia among the atomic bomb survivors was published in 1957 in *Science*. It tried to link radiation to a risk of cancer using the LNT model [12,13]. Scientists disagreed because there was no evidence that supported the LNT model, and there was evidence of radiation and leukemia that contradicted the LNT model. Nevertheless, during discussions in the National Committee on Radiation Protection and Measurement, a compromise was reached to adopt and recommend the “Precautionary Principle” for the general population and the policy of ALARA. This, in effect, meant that LNT would be adopted, based on fear and/or lack of knowledge [14]. This NCRP change was published in 1960 in *Science* [15]. Ongoing political activity by the scientists, who promoted fear of radiation, and by many other ethical people was successful in achieving the 1963 ban on above-ground testing of nuclear weapons [16].

“The *Science* publication restored, even though improperly, the scientific and moral initiatives of the Panel and led directly to multiple high level LNT recommendations for cancer risk assessment based on the Precautionary Principle, … and which remains in place today in essentially all countries” [14]. It was ideologically motivated and based on the deliberate falsification and fabrication of the research record. It had far-reaching influence, affecting cancer risk assessment, risk communication strategies, community public health, and numerous medical practices in the United States and worldwide [17].

2.7. The key concerns about nuclear energy facilities and the intervenor’s responses

The following are the key concerns that are raised by opponents of the construction or refurbishment of nuclear energy facilities:

- An accident or a failure could occur that releases radioactive materials, which would deliver a radiation dose or dose-rate to surrounding residents and the environment. Any exposure would increase the risk of detrimental effects (mutations and cancer).
- Nuclear facilities produce radioactive waste materials with long half-lives, and any exposure to radiation increases the risk of detrimental effects. They state, “There is no solution to the problem of nuclear wastes.”

- Used nuclear fuel contains plutonium, which presents a risk of weapons proliferation.

These three issues are not valid for the reasons given below. Communication of the following information by the Government of Canada to all Canadians would allow these concerns to be dismissed.

- The amounts of radioactive materials released in a credible accident or failure would not expose employees, residents or the environment to harmful doses or dose rates of radiation. Evidence is presented in Part B of this submission that supports the biphasic dose-response model, for both an acute dose and a lifelong dose-rate. The threshold radiation dose that must be exceeded in an acute exposure before there is a risk of inducing leukemia is about 1.1 Gy. The threshold radiation dose-rate before observing a reduction in longevity is about 600 mGy per year. Nearby residents have not received exposures that exceed the dose or dose rate thresholds, nor are they ever expected to, following credible events. Therefore, detrimental health effects will not occur.
- The radioactive materials at nuclear energy facilities are managed without harming employees, residents, or the environment. Unlike wastes from many other kinds of facilities, radioactive materials at nuclear energy facilities, including the wastes, are placed in sealed containment. The amounts are manageable. Used CANDU fuel is stored in robust, sealed containers that, eventually, will be opened to purify and recycle the stored material in advanced nuclear plants. Therefore, there is no need for a solution for the non problem of nuclear waste.
- The plutonium in fuel discharged from nuclear energy facilities does not present any risk of weapons proliferation. Weapons require plutonium that is at least 90% Pu-249 with less than 7% Pu-240; however, the plutonium in the fuel that is discharged from a LWR has a composition that is typically ~ 2% Pu-238, 56% Pu-239, 24% Pu-240, 13% Pu-241 and about 5% Pu-242. Furthermore, postulated scenarios about armed intruders or terrorists are not credible—that they could open used fuel containers or seize a fuel shipment, escape capture, transfer the fuel into hot cells, separate bomb grade plutonium and bring it to a bomb factory. Therefore, the issue of nuclear weapons proliferation is not valid.

2.8. The need for regulatory change

In 1987, the Engineering Centennial Board recognized the CANDU Nuclear Reactor System to be among the 10 outstanding Canadian achievements of the 20th century. It set Canada on the path towards establishing a sound electricity generating system and becoming a major player in medical and industrial applications of nuclear knowledge [18].

This vision is now in jeopardy because of extreme social fear of radiation. After 50 years of excellent service to the people of Ontario, the Pickering Nuclear Generating Station is facing shutdown and decommissioning in 2025, and there is no plan to replace the eight reactors with new CANDU-6 ones, like those that Canada supplied for Qinshan, China. The capital cost of nuclear reactors and the cost to operate them have increased many fold. Nuclear energy is no longer affordable. Most of the cost increase is likely due to the constantly escalating regulatory requirements that have been introduced since the late 1960s against postulated events that are very unlikely. They address the issues discussed in Sections 2.6 and 2.7, above. The evidence presented in this submission indicates there would be no adverse health effects due to the expected release of radioactive materials in credible nuclear events because the dose and the dose rate thresholds for onset of detrimental effects are relatively high. As for the environment, the radiation thresholds for lethal effects on birds, fish and other classes of organisms are higher than those for humans.

An evaluation of the impacts of Canadian regulatory requirements on the economics of nuclear energy should lead to major simplifications and removal of unnecessary ones. Nuclear facilities should be treated more like normal industrial facilities.

The requirements to protect people and the environment from radiation are based on the 1956 NAS recommendation to use the invalid LNT dose-response model instead of the threshold model to assess risk. Accepting it led to the policy of ALARA and the precautionary principle for exposures. It aggravated radiophobia and required the evacuation of residents, to minimize hypothetical risks, even for an event where the radiation level is beneficial, far below the dose-rate threshold for the onset of detrimental effects.

From the 1960s when Pickering A was constructed until the present, the requirements for constructing and operating nuclear facilities have exploded. Changing perceptions of acceptable risk caused these changes, not evidence of more radiation-induced harm. Precautionary measures have made nuclear plants too costly to build. Small modular reactors are now being developed because they are expected to be affordable; but they will not be viable due to the current regulatory requirements, which are severe.

Expansion of nuclear energy will require the review of 1) the observations over the past 120 years that radiation in small amounts caused biopositive effects, and 2) the lack of evidence of detrimental effects from small doses. It is essential to communicate these results to the public and then replace the radiation protection laws and regulations with new ones, which will allow the revival of nuclear energy in Canada and the acceptance of hugely important medical therapies (for cancer, inflammation, and for autoimmune and neurodegenerative diseases).

2.9. Conclusions

The OPG licence application and the CMDs are of high quality, detailed, and accurate.

The OPG application is satisfactory; it complies with all the requirements. The evidence presented demonstrate that OPG is qualified and capable of fulfilling the conditions of the revised licence to prepare the DNNP site. The CNSC Staff recommend approval of the OPG application to renew its licence for 10 years.

Nuclear energy is important for maintaining and increasing the welfare of humanity. It is concentrated and abundant. New nuclear fuel, slightly used fuel and nuclear wastes can be easily stored on nuclear sites. Technologies exists today and improved ones are being developed to purify the used fuel and reuse it repeatedly, to minimize the quantity of the waste and its radioactivity. Used fuel is safely stored in robust, sealed containers.

A false radiation scare was created and communicated in late 1950s by an antinuclear political movement. It was accepted by all governments and led to a flood of radiation protection laws, regulations, and standards, based on the Precautionary Principle policy of ALARA. They became more and more restrictive after three events at nuclear plants. Two were caused by human failures and one event was due to an enormous natural disaster.

To restore the viability of nuclear energy, it is essential to review and communicate the evidence about the effects of radiation—beneficial effects of low doses and low levels of radiation and the thresholds, of dose and dose-rate, for the onset of detrimental health effects that increase only when the dose or the dose rate exceeds the thresholds.

To enable nuclear facilities to continue operating and new ones to be constructed, all antinuclear issues and concerns must be challenged, and the invalid ones discredited and dismissed. The false basis for the 60-year-old radiation scare must be exposed and the unwarranted fears quashed to avoid expressions of outrage when events occur.

The present regulations are intended to protect humans and the environment; however, they are based on the precautionary principle and ALARA, which was recommended in 1960 [15]. The assumption that has been made, since then, is the information about the effects of radiation is inadequate for protection purposes. This assumption was incorrect four decades ago, when Lauriston Taylor twice stated in 1980, “Today, we know about all we need to know for adequate protection from ionizing radiation” [19]. The intervenor provided information in the June 2018 Public Hearing in Pickering [20], and additional factual information is presented in part B of this submission.

2.10. Recommendations

a) The reviewer recommends that the CNSC approve the application for a 10-year licence to prepare the DNNP site.

b) To restore viability of nuclear energy, the Government of Canada is urged to
   - review the history of the creation of the radiation scare,
   - examine the biological evidence of the effects of radiation on organisms,
   - inform Canadians about the beneficial and the detrimental effects of nuclear radiation and X-rays, and
   - change Canada’s radiation protection laws and regulations to be compatible with the evidence of dose thresholds and dose rate thresholds for the onset of detrimental effects.

c) The Canadian nuclear industry and the government are urged to assess the impact of the present laws, regulations, and standards on the viability of nuclear energy. Changes should be made that will allow nuclear energy facilities to be again affordable, while protecting humans and the environment from detrimental health and biological effects.

3.0 Part B – Evidence of radiation thresholds between beneficial and detrimental health effects: There are no risks from low doses

As pointed out in Section 2.6, a compromise was reached in an ad hoc committee of the U.S. NCRPM in 1959 to recommend adoption of the precautionary principle policy for protecting the general population. This meant accepting the LNT dose-response model due to fear and "lack of knowledge." The Canadian objective to restore nuclear energy as a welcome and viable non-polluting source of electricity is challenged by concerns about risks of detrimental health and environmental effects from exposures to radiation. It is time to change radiation protection policy from the precautionary principle that was recommended in 1960, to a strategy that is based on science and fact—on observed evidence of beneficial effects and thresholds for onset of detrimental effects. This would allow a change of laws, regulations, and standards that require minimizing exposures. It would permit low exposures that are in the beneficial range, well below harmful limits.

3.1. Early information about health effects of ionizing radiation

After the discoveries of X-rays in 1895 and nuclear radiation in 1896, medical doctors began applying these penetrating radiations to image internal injuries and assess many diseases. They soon found out that such exposures induced important changes in the patient's condition. A large X-ray dose produced a painful burn; but a small dose often resulted in beneficial health effects that were attributed to stimulation of the patient's innate protection systems. Thousands of articles began to appear in medical journals and other publications [21].

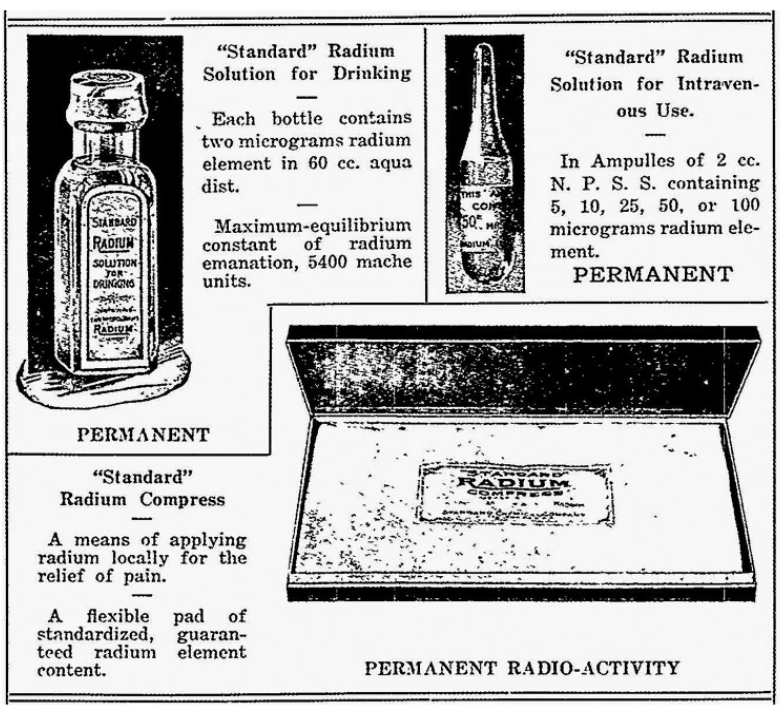


Fig. 1. Standard 2 µg radium solution for drinking [22].

Physicians treated patients, orally and intravenously, with a 10-µg dose of radium every week; the total dose ranged between 100 and 300 µg. Radium like calcium accumulates in bones. The best-known form, available to the public in the 1920s as an elixir, was a 60 cm^3 bottle containing 2 µg of radium in solution, Fig 1. From 1925 to 1930, ~ 400,000 bottles were sold at $1 per bottle. These sales ended in 1932 after a celebrity died from radium poisoning. He had consumed about 5,000 µg [22]. The threshold for the onset of radium-induced malignancy, an intake of about 100 µg, was determined from a study on many radium dial painters. There were 56 malignancies among 1468 cases Fig. 2 [23]. The cumulative dose threshold for bone sarcoma is 10 Gy, Fig. 3 [24].

Low doses of radiation were employed against cancers to reduce tumor size, slow their progression, and eliminate cancer metastases. Cancer cells, like foreign pathogens, are targeted by the patient's immune system. Physicians discovered that a low dose of radiation stimulates immunity, Fig. 4 [25,26]. A review of ultra-low dose whole-body radiotherapy of cancer, from 1930 until the end of the 20th century, demonstrates that this form of treatment can be equal or superior to other systemic anti-neoplastic modalities, in terms of the rates of remissions, toxicity, and side effects [27].

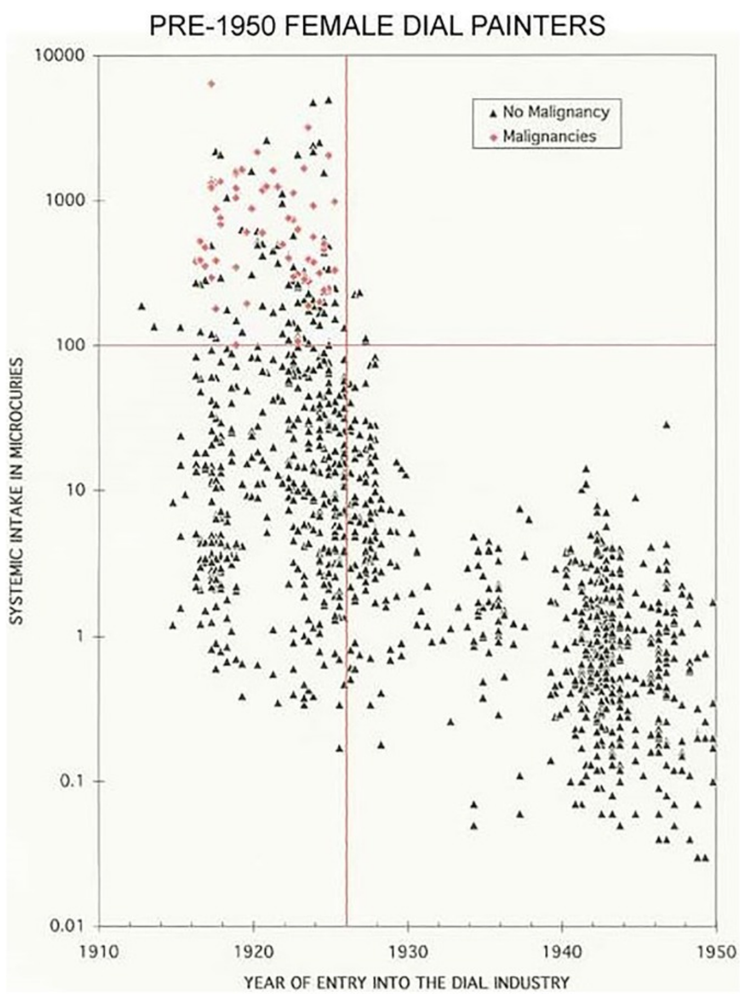


Fig. 2. Evidence of 100 µCi (µg) radium intake threshold for onset of malignancy [23].

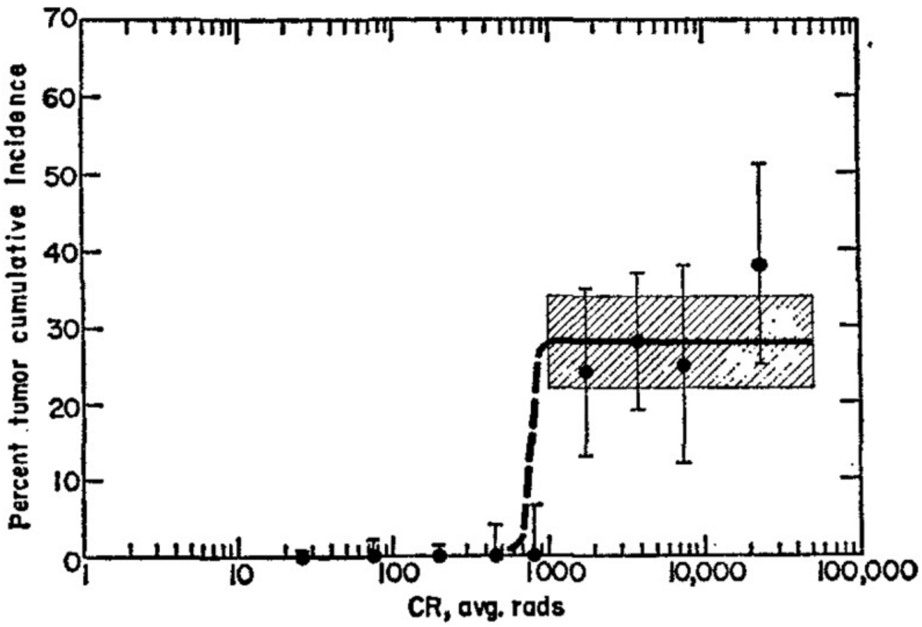


Fig. 3. Evidence of cumulative dose threshold of 10 Gy for onset of bone sarcoma [24].

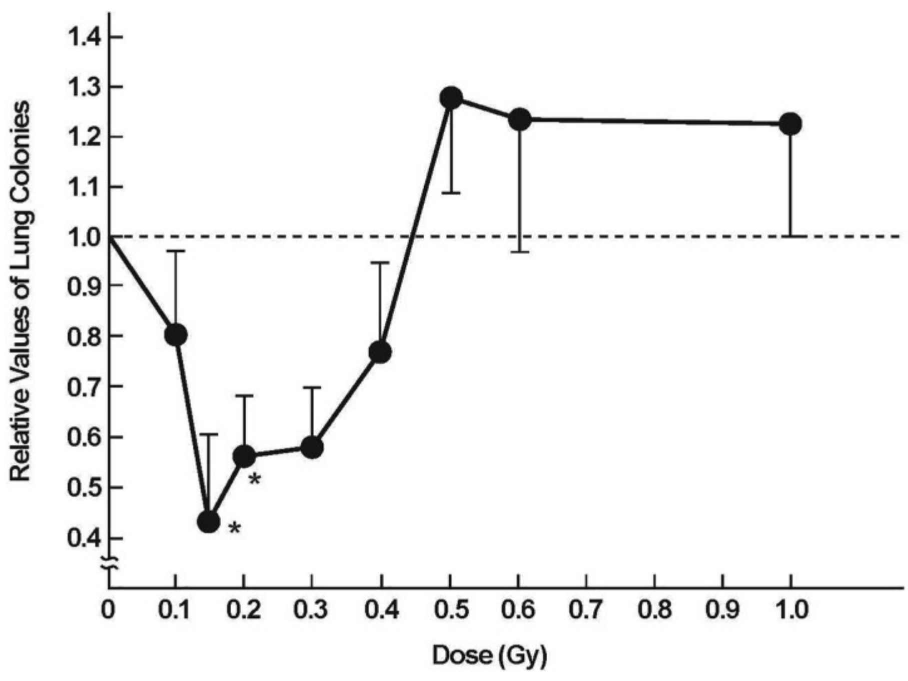


Fig. 4. Evidence of immune system stimulation by an X-ray dose below 0.45 Gy. A low, total-body dose to mice, 12 days after lung cancer cells were transplanted into their groin, depressed the metastases, which were counted 20 days after the irradiation [25].

Low doses were observed to stimulate a patient's innate protection systems, leading to a more rapid healing of wounds.

Low-dose treatments cured a variety of infections and inflammations, such as inner ear, sinus, pertussis, adenoids, pneumonia, gas gangrene, carbuncles, and boils. It was also effective against inflammatory and autoimmune diseases, such as asthma and arthritis. Table 1 is the result of a historical review of the treatment of more than 37,000 patients; optimal dose was 30-100 roentgen, with no reports of increased cancer incidence. The likely mechanism by which radiotherapy mitigates inflammation and facilitates healing is low dose polarization of macrophages to an anti-inflammatory (or M2) phenotype [28].

Table 1. Diseases that were treated with low doses of radiation [28].

	No. of Patients	Successful treatments %	Studies, N	References [28]
Arthritis	>5000	~85	Cumulative experience	Kahlmeter and Kuhns and Morrison
Bronchial asthma	~4000	75-80	57	Calabrese et al
Carbuncles	187	60-90	5	Calabrese
Cervical adenitis	893	75-90	11	Calabrese and Dhawan
Deafness	15 000	>95%; performed prior to age 15	Cumulative experience	Crowe and Baylor
Furuncles	420	75-95	5	Calabrese
Gas gangrene	365	Mortality rate decreased from 40% to 10%	13	Calabrese and Dhawan
Otitis media/mastoides	564	~90	16	Calabrese and Dhawan
Pertussis	~2400	~80	22	Calabrese et al
Pneumonia	863	80-85	18	Calabrese and Dhawan
Sinus infection	4492	75-90	16	Calabrese and Dhawan
Tendonitis/bursitis	3333	70-90	31	Calabrese and Dhawan
	37 517			

Nasopharyngeal radium irradiation therapy was employed widely from 1940 through 1970 on between 0.5 and 2.5 million U.S. children and at least 8000 military personnel to shrink swollen tissue in the nasopharyngeal cavity to remediate adenoid inflammation and ear dysfunction. The dose, locally and to nearby organs, is shown in Fig 5 (1 Gy = 100 rad). The many worldwide studies carried out on the U.S. patients and also those in other countries did not confirm a definite link between these treatments and any disease [29-31]. This robust evidence contradicts the widely held opinion that children are more sensitive to radiation.

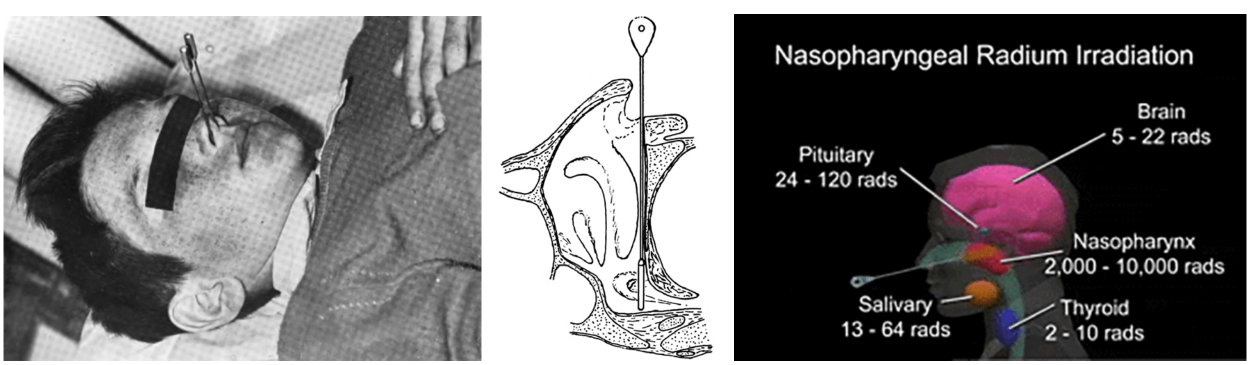


Fig. 5. Nasopharyngeal radium irradiation therapy and associated organ doses [29-31].

3.2. Change in medical applications of ionizing radiation after 1960

As mentioned, scientists have been studying the effects of radiation since the late 1890s and reporting the evidence of both beneficial and detrimental effects in internal documents and published journal articles and books. After the 1956 recommendation of the U.S. NAS BEAR Genetics Panel to use the LNT model to assess risk [8] and the 1960 paper by the NCRPM adopting the precautionary principle policy [15] and ALARA, an international consensus opinion formed to accept this [14]. Most scientists avoided studies on beneficial effects and tried to ignore such evidence when it appeared. For example, the first UNSCEAR report in 1958 tabulated the incidence of leukemia among 96,000 Hiroshima survivors; however, it did not comment on the obvious evidence of low-dose beneficial effects and the high threshold for radiation-induced cancer [32,6]. After much research on beneficial effects of radiation, in the 1980s, the UNSCEAR 1994 report appeared [33] with extensive evidence of beneficial effects in Annex B, "Adaptive responses to radiation in cells and organisms" (192 references). Unfortunately, these scientific facts have been disregarded ever since.

Treatments with low doses became controversial after 1960. Newly available and easily administered antibiotics were welcomed. Chemotherapy, often with severe side effects, is prescribed instead of low doses of radiation against cancer metastases. All doctors have been carefully taught that any exposure to radiation carries a cancer risk. They are constantly urged to avoid it or to minimize the dose in essential diagnostic imaging. The potential benefit is to be weighed against the risk, as calculated by the LNT model [21].

Without a supportive medical community, it is impossible for researchers to carry out clinical studies of radiation therapies that would stimulate a patient's protection systems. A noteworthy exception is the recent pilot clinical study on the treatment of Alzheimer's disease with low doses of ionizing radiation (CT scans of the brain) that was carried out in Toronto. It provided remarkable evidence of improved cognition and behaviour. This study was published in April 2021 in the Journal of Alzheimer's Disease [34].

3.3. Protection against radiation effects: Changing perceptions of risk

A 1995 Los Alamos article on radiation and risk [35] mentions that the earliest exposure limits were based on preventing the onset of obvious skin damage after a ~ 6 Gy or more dose, at a large dose rate, e.g., 0.3 Gy per minute. Later limits were based on preventing delayed effects such as cancer. At a 1924 American Roentgen Ray Society meeting, radiologists received a recommendation to keep exposures below a "tolerance dose" limit of 0.2 roentgen per day. Compliance with this limit decreased their incidence of neoplasms below that of other medical practitioners. (This daily limit amounts to a "cumulative dose" of about 70 rad or 700 mGy per year. Since almost all the radiation damage incurred during daytime work is repaired overnight, the effect of this cumulative dose would be smaller than that of a continuous exposure of 700 mGy per year.)

The politically driven recommendations to use the LNT dose-response model to assess risk and to adopt a "Precautionary Principle" policy to protect the general population led to changing attitudes toward acceptable risk. This is reflected in the stepwise decrease in annual occupational dose limit and the addition of a public limit, shown in Fig. 6 [35].

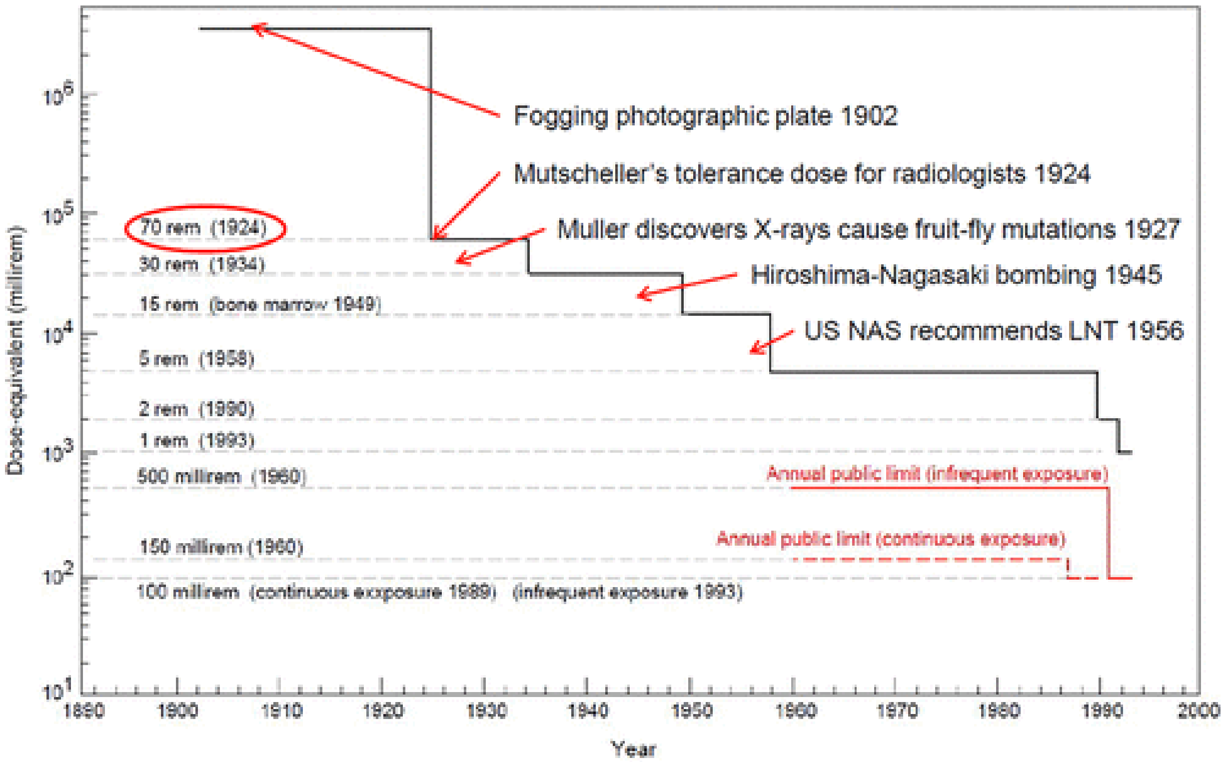


Fig. 6. Stepwise decrease in the annual occupational dose limit [35].

3.4. Acute radiation dose and a threshold for cancer incidence

There was strong human evidence in the late 1950s of the high threshold for radiation-induced cancer. This was pointed out in 2014-15 [36-38] and reviewed, more carefully, in 2018-19 [39,40]. Fig. 7 shows the below-normal incidence of leukemia among 32,692 Hiroshima atomic bomb survivors, who were in Zone D and received a low dose. The incidence rose above normal as the dose exceeded the 1.1 Gy threshold. Surprisingly, only about 50, or 0.5%, of the 10,051 survivors in Zones A and B had elevated leukemia incidence. Having survived the heat and the bomb blast, they were more resilient. The incidence would be greater for an exposure just to high radiation.

Blood forming stem cells in bone marrow are the most radiation sensitive cells in the body. Therefore, the dose threshold for acute radiation-induced cancer in other organs is likely higher, and the incidence likely lower. A more likely mechanism for radiation to induce cancer is high-dose impairment of the cancer-fighting immune system rather than induction of mutations. As explained later, DNA mutations are caused mostly by the normal endogenous production of reactive oxygen species (ROS) or free radicals for redox signaling.

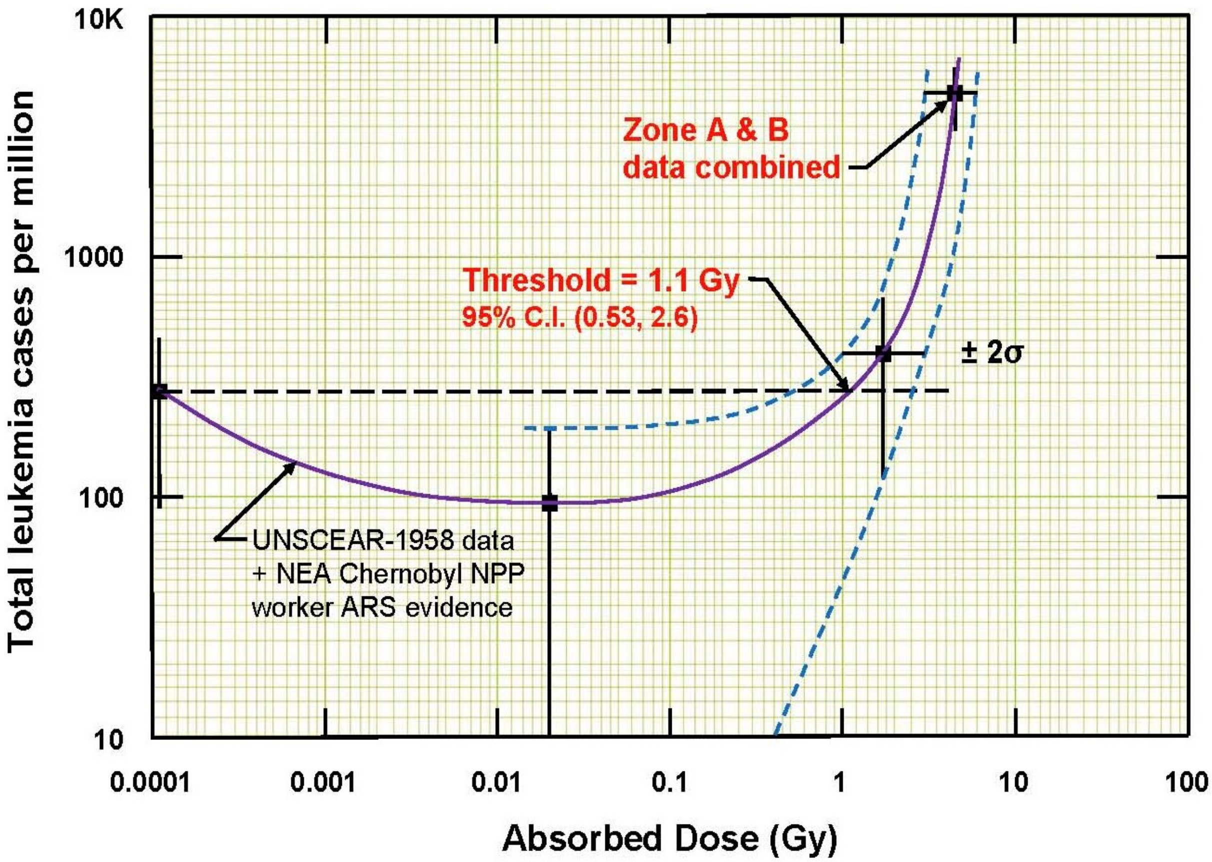


Fig. 7. Evidence of a threshold at 1.1 Gy for radiation-induced leukemia from analyses of the 1950 to 1957 data of 95,819 Hiroshima atomic bomb survivors [39,40].

A brief exposure to ionizing radiation damages biomolecules, including DNA, directly by "hits" on atoms and indirectly by the ROS from radiolysis of water. The burst of damage events triggers an adaptive protection (AP) system response that is biphasic, as shown in Fig. 8 [34]. A *high dose*, above the threshold of the onset of persistent detrimental effects, inhibits or damages the AP systems. Fig. 9 shows the thresholds for lethality of different classes of organisms in the environment. It is about 2 Gy for mammals [41].

A *low dose* of radiation, e.g., below 2 Gy, stimulates the AP systems to overrespond [21]. After a low dose, there is remediation not only of the radiation-induced damage but also of the damage resulting from both the endogenous and exogenous factors such as natural oxidative aging, pathogens, toxins, injuries, etc. There is an immediate response and a delayed response due to cellular signaling [42,43]. This is the mechanism for low-dose-induced beneficial effects.

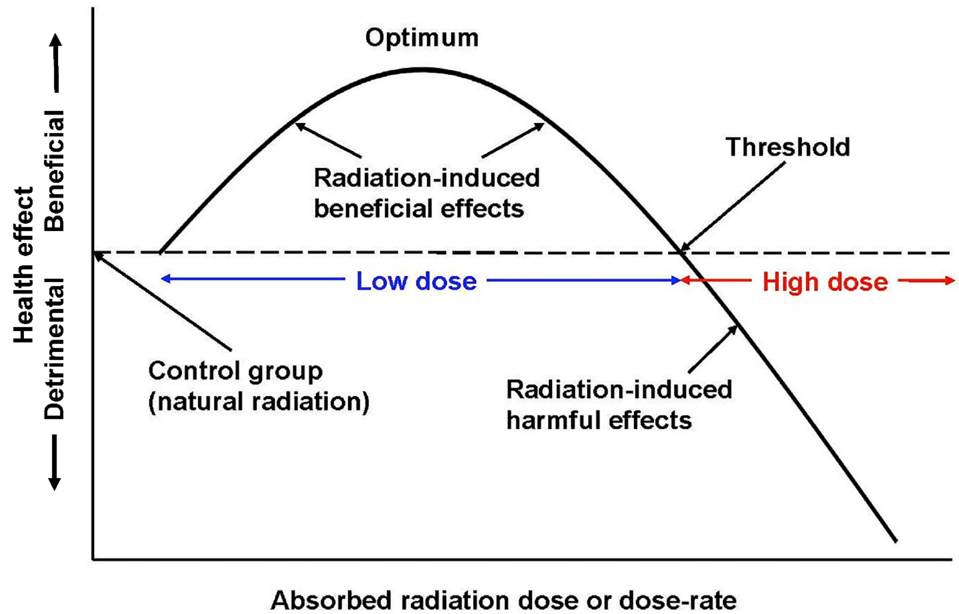


Fig. 8. Biphasic dose-response model and the definition of a *low dose* of radiation [34].

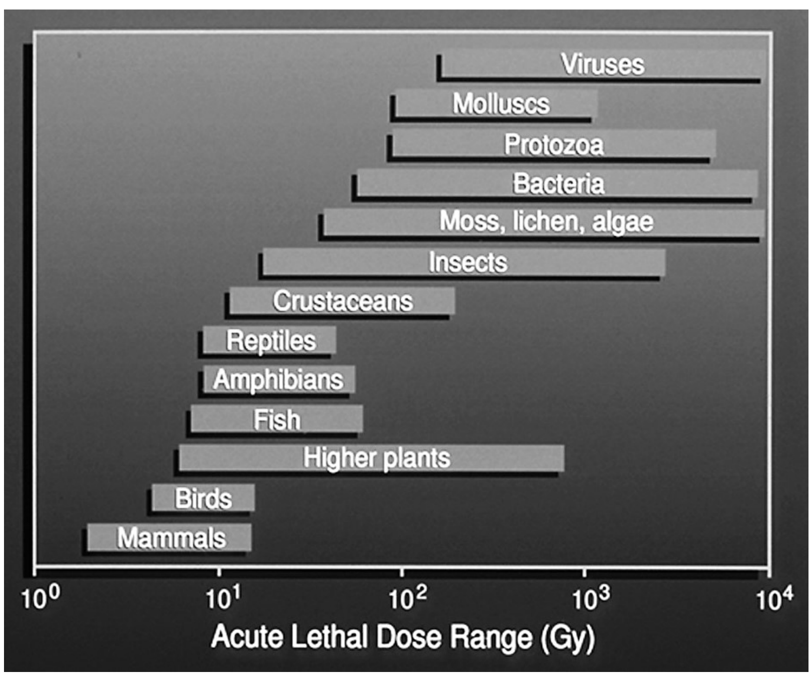


Fig. 9. Approximate acute dose ranges producing 100% lethality in organisms [41].

3.5. A low radiation dose remediates endogenous induction of DNA damage

People are unaware that the rate of DNA damage due to natural background radiation is negligible compared to the rate of DNA alterations caused by endogenous production of ROS [44]. Organisms require redox cell-signaling agents in order to function, and there are multiple sources of these vital agents [45-48]. To cope with oxidative and all other causes of damage, all organisms have enormously powerful innate AP systems, which produce antioxidant enzymes, repair DNA breaks and other molecular damage, kill and scavenge unrepaired cells, and restore good health, Fig. 10 [44]. However, potency of the AP systems progressively weakens with age, becoming less capable of remediating the damaging effects of ongoing oxidative distress [42].

As discussed earlier, a burst of low dose radiation triggers the AP systems to act faster. They overrespond, remediating not only the radiation-induced damage but also the damage produced by all the endogenous and exogenous causes [21,34].

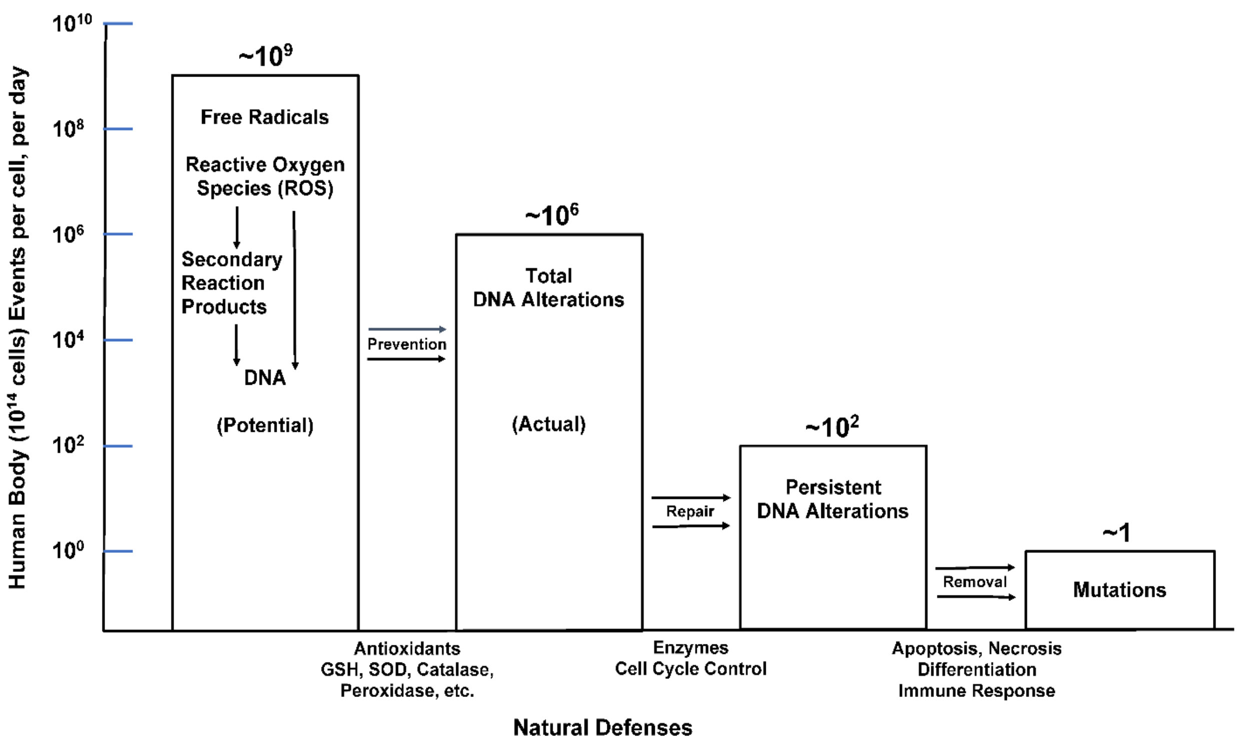


Fig. 10. Natural defenses act against endogenous DNA damage. A 100 kg person has about 10^{14} cells (avg. cell wt. ~ 10^{-9} g). Free radical production would cause about 10^{9} DNA alterations per cell per day; however, antioxidant production lowers the alteration rate to about 10^{6} per cell per day. The damage-repair defense lowers the incidence of persistent DNA alterations to about 10^{2} per cell per day, and the damaged-cell removal defence results in the natural occurrence of one mutation per cell per day. The ratio of metabolic DNA damage to the radiation-induced DNA damage caused by 0.1 cGy/year of natural background radiation is about 10 million [44].

3.6. Follow-up of Chernobyl workers hospitalized for acute radiation syndrome

Of the 237 who were hospitalized, 134 workers were heavily irradiated and 28 died after several weeks, Table 2 [49]. From among the 106 who recovered, 22 died during the following 19 years. This corresponds to a mortality rate of 109% per year, which is lower than the 1.4% average mortality rate in 2000 in Russia. Thirty years after the exposure, 26 of the 106 were deceased, a mortality rate of 0.82% per year. The number of cancer deaths is 27% of the 26 deaths. This is about the same fraction of cancer deaths among all mortality causes for Central Europe. This human evidence does not support the fear laden message that an acute dose of radiation increases the risk of delayed effects [21].

Table 2. Radiation doses (biological dosimetry) of the Chernobyl workers hospitalized for acute radiation syndrome [49]

	Number of patients	Estimated Dose (Gy)	Deaths
	21	6 - 16	20
	21	4 - 6	7
	55	2 - 4	1
	140	less than 2	0
Total	**237**		**28**

3.7. Long-term radiation exposure: Dose-rate threshold for shortened longevity

A nuclear event may cause acute radiation exposures, as discussed in Sections 3.4 and 3.6. This event may also release radioactive materials, radionuclides that would cause long term radiation exposures, depending on their half-lives and how long they remain in situ before being washed away by rainfall.

An acute exposure on organisms differs from a continuous exposure because radiation-induced effects on the organism change when the exposure ends. The AP systems can remediate damage more quickly [42]. Therefore, the effects of a continuous exposure differ from the effects of an acute exposure whose dose equals the “cumulative dose” of the continuous exposure. Fig. 8, shows the biphasic dose-rate-response model. The optimal dose rate confers the benefit of maximal life span. There is a threshold for the onset of the detriment of progressively shorter longevity with increasing dose rate.

It is not possible to measure the effect of continuous radiation on humans. They live for approximately eight decades, and it is not feasible to control, lifelong, all the key factors that affect their health. Also, it is not acceptable to expose groups of humans to a fixed radiation dose rate lifelong. However, such studies have been performed on dogs. They live for about 15 years and are a good model for humans.

Fig. 11 shows an analysis of life span vs. dose rate for dogs that were exposed lifelong to Co-60 gamma rays, and Fig. 12 shows an analysis of life span vs. initial lung burden for dogs that inhaled plutonium aerosols [50]. Analysis of the gamma ray study revealed a threshold at a dose rate of about 700 mGy per year for the onset of progressive life span reduction, as dose rate is increased. The analysis suggests the optimal dose rate is about 50 mGy per year. It is unfortunate that this study did not include a group of dogs that were exposed to this radiation level. Analysis of the plutonium study revealed a threshold at a lung burden of 0.2 kBq per kg of tissue and an optimal lung burden of

0.05 kBq per kg of tissue [50]. Note that the short-lived dogs (5% mortality) experienced a relatively greater boost in their longevity in the low dose rate range, below the threshold for detrimental effects.

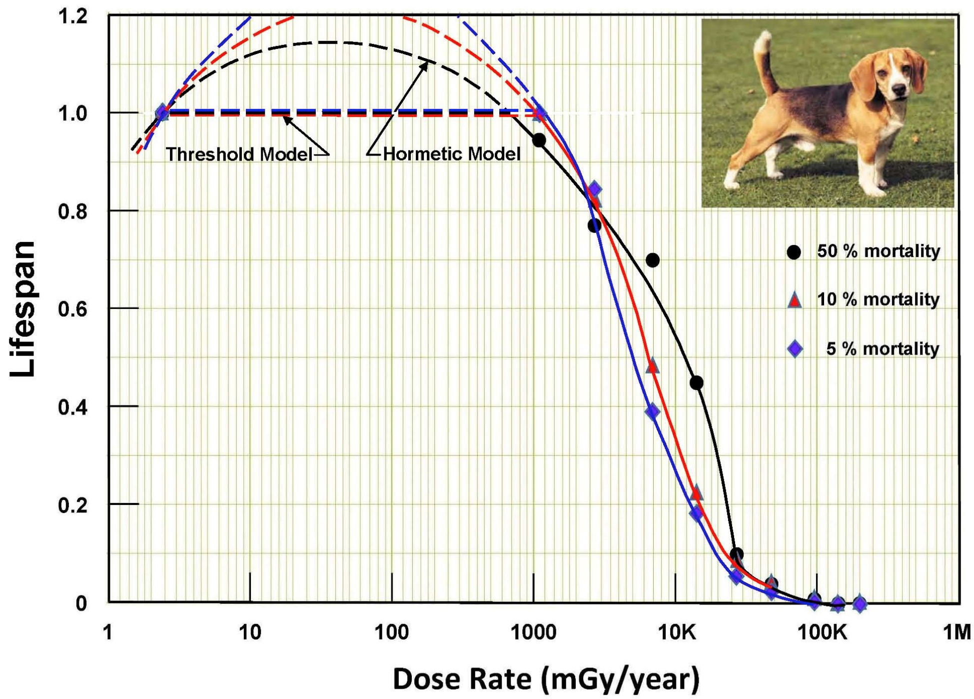


Figure 11. Gamma radiation threshold at 700 mGy per year for beagle dogs [50]

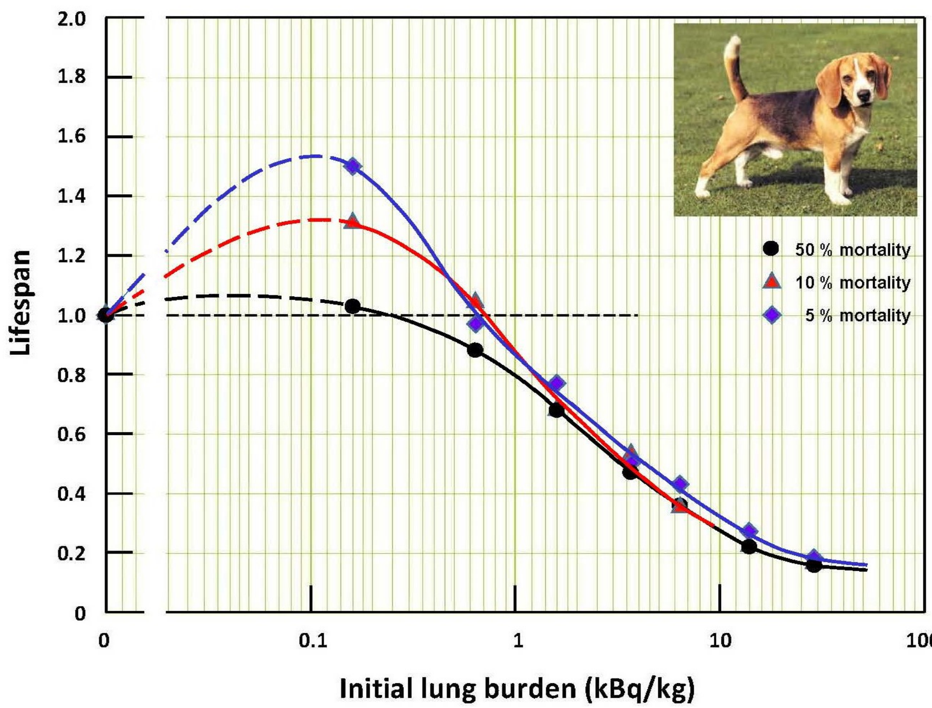


Figure 12. Inhaled plutonium threshold lung burden for beagle dogs [50]

Following comments on statistical uncertainties, additional analysis on the gamma ray study yielded a dose rate threshold in the range 0.5 to 1.1 Gy per year, Fig 13 [51].

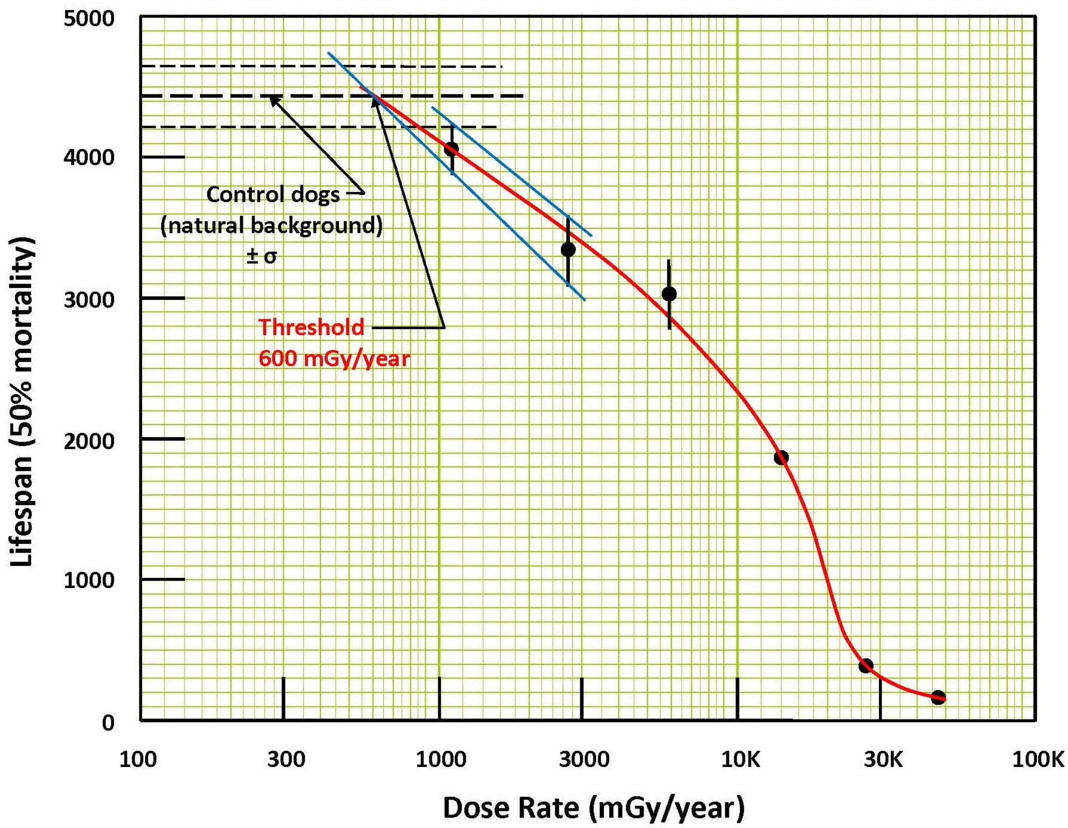


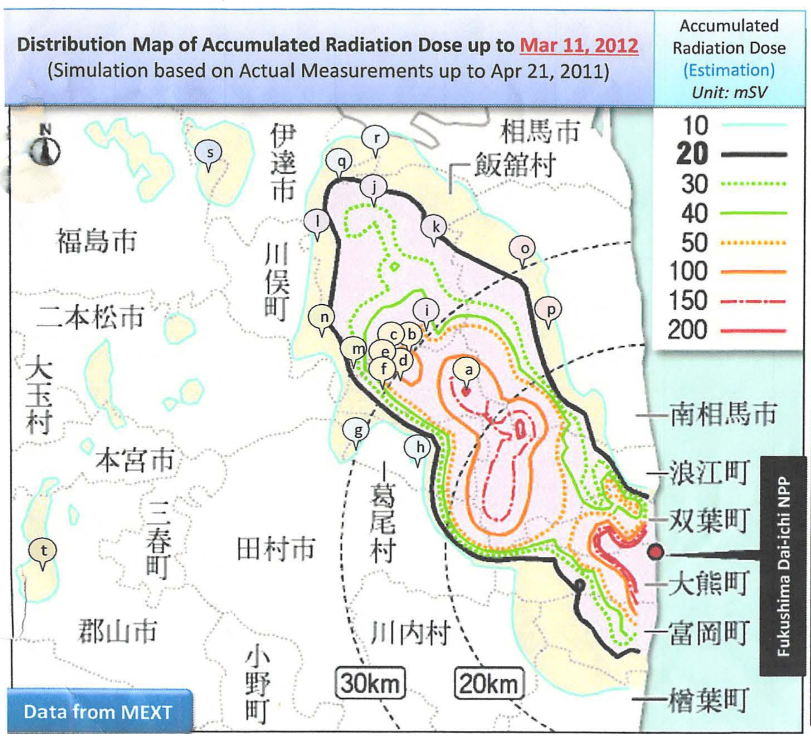
Fig. 13. Dose rate threshold, 0.5 to 1.1 Gy per year, for shortened longevity [51].

Elevating the ambient radiation level, above natural background, increases the normal rate of DNA damage, shown in Fig. 10. The natural defences adapt to the increased damage rate and increase their rate of remediation. The evidence in Fig. 11 and 12 indicates that the AP systems overrespond to an increase in the ambient radiation level, and remediate more oxidative damage (mutations) that is accumulating naturally, in addition to the damage occurring from the higher radiation level. Increased longevity occurs. However, when the radiation level exceeds the dose rate threshold, shown in Fig. 13, the protective systems are overwhelmed and cannot remediate all the damage that is occurring. As the ambient level rises, more and more above the threshold, life span progressively decreases.

3.8. Emergency evacuation of the surrounding residents is not conservative

This evidence demonstrates that the precautionary principle of ALARA is not the correct policy when radioactive materials have been released in a nuclear event. If the radiation levels are below the threshold for detrimental effects, they would be harmless (and likely beneficial). The emergency measure of evacuating the nearby residents, to comply with the ALARA requirement, would create traumatic fear and cause stress-related deaths, as occurred after the Fukushima disaster. Fig. 14 shows the cumulative dose during the first year, at each of the places monitored [52]. All doses were well below the threshold for detriment, so the deaths of 1632 people because of the evacuation policy [53] and the trauma to Japan, including the economic consequences might have been avoided if the precautionary principle had not been adopted by the NCRP in 1960. The Fukushima tragedy should be attributed to the ALARA policy that has been adopted by the radiation protection organizations. The 1959 ad hoc NCRP committee had medical evidence of a high threshold for radiation-induced cancer, and it disregarded this evidence [14].

Accumulated Radiation Dose around Fukushima Dai-ichi **Estimation**



MEXT has released a map showing how much radiation will be accumulated around Fukushima Dai-ichi Nuclear Power Plant.

Place		Distance from Fukushima Daiichi	Accumulated Radiation (Estimation) *unit:mSV*
Namie-machi	a	NW 24km	235.4
	b	NW 31km	188.6
	c	NW 31km	110.2
	d	WNW 29km	56.2
	e	WNW 30km	48.2
	f	WNW 30km	24.2
Katsurao-mura	g	WNW 32km	18
	h	NW 25km	11
Iitate-mura	i	NW 33km	61.7
	j	NW 39km	34.8
	k	NW 36km	26.3
	l	NW 44km	10
Kawamata-machi	m	WNW 34km	24.2
	n	WNW 40km	19.6
Minamisoma-shi	o	NNW 30km	15.6
	p	NNW 25km	11.9
Date-shi	q	NW 48km	21.2
	r	NW 46km	16
Fukushima-shi	s	NW 56km	10.6
Koriyama-shi	t	W 60km	10.1

Fig. 14. Accumulated radiation dose from April 21, 2011 until March 11, 2012 [50]

3.9. Low dose lung radiotherapy against COVID-19 acute respiratory distress

The COVID-19 viral pandemic began spreading rapidly in early 2020. Most of those who became infected had mild symptoms and recovered within two weeks. However, a small fraction, especially old people with pre-existing medical conditions, developed severe symptoms beginning with breathing impairment due to lung inflammation. Physicians proposed a variety of antiviral drugs, early on, to prevent infection. Most were rejected with great controversy as pharmaceutical companies raced to develop new vaccines. As mentioned in Section 3.1, low doses of X-rays were employed in the early 1900s to treat many diseases. Table 1 shows a cure rate of 80-85% for 863 cases of pneumonia, with no side effects.

A letter urging a clinical trial to confirm this efficacy “went viral.” The first trial started in late April 2020. More than 15 clinical trials are underway around the world. The early evidence of the efficacy of lung radiotherapy has been encouraging [54]. Unfortunately, there has been strong political resistance in the medical community against the use of a low dose (0.5 Gy) of radiation to provide this health benefit. More than 3 million people have died who could have been treated using X-ray devices that are in most hospitals.

A clinical trial has started in 2021 on inhalation of 6-hour ^{99m}Tc aerosols instead of external beam lung irradiation [55]. A paper on the mechanism for the benefit provided by low-dose radiotherapy for COVID-19 is available [56]. A remedy for inflammatory infections of the lungs, without side effects, would be especially important because the efficacy of vaccines against different variants of the COVID-19 virus or other pathogens is uncertain.

3.10. Conclusions

After X-rays were discovered, medical doctors began to image internal injuries and assess many diseases. Following observations of remarkable beneficial effects, they began to prescribed radiation treatments for diseases, such as cancers, infections, and inflammations. A safe dose limit was established in 1925 that protected radiologists for 35 years from the harmful effects of overexposures, such as neoplasms.

Studies on the radium dial painters revealed the threshold amount of radium intake, for the onset of malignancy, and an abrupt cumulative dose threshold for the onset bone sarcoma. A study on mice in the early 1990s gave evidence that a whole-body dose, in the range 0 to 0.45 Gy, stimulates the immune system against lung cancer metastases. A review of low-dose radiation treatments of infections and inflammations, in 37,517 patients, showed a high success rate (60 to 95%): optimal dose 30-100 roentgen, with no reports of increased cancer incidence. Nasopharyngeal radium irradiation therapy was employed widely on millions of children and thousands of adults. Doses to nearby organs ranged up to about 1 Gy, yet studies could not link these successful treatments to any late-occurring disease.

The 1960 NCRPM recommendation to adopt the precautionary principle for protecting the general population, using the LNT dose-response model, ended the treatments with low doses of radiation. Changing perceptions of acceptable risk resulted in a stepwise decrease in the annual occupational dose limit from 70 rad (700 mGy) to the present limit. Most medical scientists avoid low-dose studies on beneficial effects; they ignore such “controversial” evidence when observed or published. Pharmaceuticals are almost always employed instead of low-dose radiation.

A noteworthy exception is the recent pilot clinical study on the treatment of Alzheimer’s disease with low doses of ionizing radiation (CT scans of the brain) that was carried out in Toronto. It provided remarkable evidence of improved cognition and behaviour, with no side effects, and was published in April 2021 in the Journal of Alzheimer’s Disease.

Another exception—the ~15 clinical trials underway on low-dose lung radiotherapy to remediate acute respiratory distress syndrome in COVID-19 patients.

All doctors have been carefully taught that any exposure to radiation carries a risk of cancer and must be avoided or minimized. Radiotherapy is now limited to high-dose exposures, daily fractions of about 2 Gy for 3 to 6 weeks—a cumulative dose of 40 to 60 Gy, against cancer. After surgery or focused radiotherapy to remove a primary tumour, 40-60 Gy therapy is given to the adjacent area, to kill the remaining cancer cells. The risk of inducing cancer by this follow-up therapy is not significant.

Recent analyses of the 1950-57 Hiroshima leukemia data indicate that an acute dose below about 1.1 Gy is associated with a lower cancer incidence, i.e., a beneficial effect. A dose above 1.1 Gy is detrimental. This aligns with the biphasic dose-response model. For mammals, lethality ranges from about 2 to 15 Gy. The lethality dose range of other classes of organisms in the environment is higher.

The rate of DNA damaged caused by internally produced reactive oxygen species is enormous, but it is managed by natural protection systems that are extremely powerful. A small burst of radiation stresses these systems, and they overrespond by remediating not only the radiation-induced damage but also some of the damage due to internal and external causes. If the radiation dose exceeds a threshold, these protection systems are inhibited or damaged, resulting in detrimental effects. This explains the biphasic dose-response model and the threshold—the dose at which the beneficial effects end and the detrimental effects begin.

After 30 years of follow-up, the 106 heavily irradiated Chernobyl workers who recovered have a lower mortality rate than the average Russian. The fraction of worker deaths that were due to cancer is about the same. This human evidence contradicts predictions of risk, which are based on the LNT dose-response model.

The radiation levels after the Fukushima reactor meltdowns were all well below the dose rate threshold for detrimental effects. The threshold was determined in a recent analysis of a study on groups of dogs that were exposed lifelong to different levels of cobalt-60 radiation. These facts indicate that the precautionary evacuation was not appropriate.

3.11. Recommendations

The reviewer urges the CNSC to review all the evidence presented in this report, which supports the application of the biphasic dose-response model instead of the LNT model for assessing the risk of radiation-induced health effects. These facts indicate that risk of an elevated cancer incidence or a shortened life span occurs only after an exposure to a high dose or a high dose rate, above the evidence-based thresholds for detriment. Exposures below the thresholds likely result in beneficial effects, the amount depending upon the specific characteristics (genetics) of the exposed individuals.

This information should be communicated to Canadians in plain language. The government should explain that the 1960 precautionary principle of minimizing radiation exposures is not appropriate. Small amounts of nuclear radiation and X-rays are not harmful; they are likely healthful. Exposures should not exceed the known limits for the onset of detrimental effects.

The government should change its laws and regulations for protecting Canadians and the environment. They need to be guided by modern science and facts.

The Canadian nuclear industry and specialists in nuclear safety, medicine and biology are urged to assess the information and the proposed changes, and provide scientific and factual inputs.

References

1. OPG Letter, D. Townsend to M. Leblanc, Application for Renewal of OPG's Darlington New Nuclear Project (DNNP) Nuclear Power Reactor Site Preparation Licence (PRSL), June 29, 2020, CD# NK054-CORR-00531-10533.

2. CNSC Regulatory Document. Site Evaluation and Site Preparation for New Reactor Facilities. REGDOC-1.1.1. July 2018.

3. OPG letter, D. Townsend to C. Carrier, DNNP – Submission of Aggregate Assessment Report and CNSC Staff's Prior Written Notification of Document Change: Darlington New Nuclear Project Commitments Report R004, June 29, 2020. CD# NK054-CORR-00531-10530.

4. OPG written submission. In support of the renewal of Darlington's New Nuclear Project's Power Reactor Site Preparation Licence. CNSC Public Hearing June 9-10, 2021. CMD 21-H4.1. File: 6.01.07. Date: 2021-02-24. e-Doc: 6498753.

5. CNSC Staff submission. A licence renewal. OPG Darlington New Nuclear Project. Commission Public Hearing. June 9-10, 2021. CMD 21-H4. Date: 8 March 2021. e-Doc: 6479802.

6. Jaworowski Z. Radiation hormesis — A remedy for fear. *Human and Experimental Toxicology*. 2010; 29(4):263-270. https://doi.org/10.1177/0960327110363974

7. Calabrese EJ. The linear No-Threshold (LNT) dose response model: A comprehensive assessment of its historical and scientific foundations. *Chemico-Biological Interactions*. 2019; 301:6-25.

8. Divine RA. Blowing on the Wind: The Nuclear Test Ban Debate 1954-1960. New York: Oxford University Press, 1978. https://doi.org/10.1177/003232928000900306

9. National Academy of Sciences (NAS)/National Research Council (NRC). The biological effects of atomic radiation (BEAR): a report to the public. NAS/NRC, Washington. 1956. Published as, Genetic effects of atomic radiation. *Science*. 124:1157-1164; 1956.

10. Inkret WC, Meinhold CB, Taschner JC. Radiation and risk—a hard look at the data. A brief history of radiation protection standards. *Los Alamos Science*. 1995; 23:116-123. https://fas.org/sgp/othergov/doe/lanl/pubs/00326631.pdf

11. Neel JV, Schull WJ. The effects of exposure to the atomic bombs on pregnancy termination. In: Hiroshima and Nagasaki. Vol. 461. National Academies Press, Washington DC. https://doi.org/10.17226/18776

12. Lewis EB. Leukemia and ionizing radiation. *Science*. 1957; 125:963-972.

13. Calabrese EJ. LNT and cancer risk assessment: Its flawed foundations part 1: Radiation and leukemia: Where LNT began. *Environmental Research*. 2021; 197:111025. https://doi.org/10.1016/j.envres.2021.111025

14. Calabrese EJ. LNT and cancer risk assessment: Its flawed foundations part 2: How unsound LNT science became accepted. *Environmental Research*. 2021; 197:111041. https://doi.org/10.1016/j.envres.2021.111041

15. NCRPM. Somatic radiation dose for the general population. The report of the Ad Hoc Committee of the National Committee on Radiation Protection and Measurement, 6 May 1959. *Science*. 1960; 131:482-486.

16. Cuttler JM. What becomes of nuclear risk assessment in light of radiation hormesis? *Dose-Response*. 2007; 5(1):80-90. https://pubmed.ncbi.nlm.nih.gov/18648610/

17. Calabrese EJ. LNTgate: The ideological history of cancer risk assessment. *Toxicology Research and Application*. 2017; 1(1):1-3. https://doi.org/10.1177/2397847317694998

18. Ball NR. History of engineering. The Canadian Encyclopedia. May 30, 2007. Available at: http://www.thecanadianencyclopedia.ca/en/article/history-of-engineering/

19. Taylor LS. Some nonscientific influences on radiation protection standards and practice, The 1980 Sievert Lecture. *Health Phys*. 1980; 39:851-874.

20. Cuttler JM. Intervenor Report, submitted to June 2018 Public Hearing on the OPG application to renew operating licence for Pickering NGS. CNSC CMD: 18-H6-35, May 07, 2018. http://www.nuclearsafety.gc.ca/eng/the-commission/hearings/cmd/pdf/cmd18-h6/CMD18-H6-35B.pdf

21. Cuttler JM. Application of low doses of ionizing radiation in medical therapies. *Dose-Response*. 2020; 18(1):1-17. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6945458/

22. Rowland RE. Radium in humans: A review of U.S. studies. Argonne National Laboratory. ANL/ER-3 UC-408. 1994. US DOE OSTI.GOV. https://www.osti.gov/biblio/10114798

23. Rowland RE. Radium dial painters: what happened to them? http://www.rerowland.com/Dial_Painters.pdf

24. Evans RD. Radium in man. *Health Phys*. 1974; 27:497-510.

25. Sakamoto K, Myojin M, Hosoi Y, et al. Fundamental and clinical studies on cancer control with total or half body irradiation. *J Jpn Soc Ther Radiol*. 1997; 9:161-175.

26. Pollycove M. Radiobiological basis of low-dose irradiation in prevention and therapy of cancer. *Dose-Response*. 2007; 5(1):26-38.

27. Janiak MK, Pocięgiel M, Welsh JS. Time to rejuvenate ultra-low dose whole-body radiotherapy of cancer. *Critical Reviews in Oncology/Hematology*. 2021; 160:103286.

28. Calabrese EJ, Dhawan G, Kapoor R, Kozumbo WJ. Radiotherapy treatment of human inflammatory diseases and conditions: optimal dose. *Hum Exp Toxicol*. 2019; 38(8):888-898.

29. Proctor DF. *The Tonsils and Adenoids in Childhood*. Springfield, IL: Thomas; 1960. Ch 2 https://babel.hathitrust.org/cgi/pt?id=mdp.39015000794811&view=1up&seq=7

30. Centers for Disease Control and Prevention. Proceedings of 1995 workshop on the public health response to nasopharyngeal radium irradiation. *J Otolaryngology Head Neck Surg*. 1996; 115:388-446. https://www.sciencedirect.com/journal/otolaryngology-head-and-neck-surgery/vol/115/issue/5.

31. Centers for Disease Control and Prevention. Centers for Disease Control and Prevention Brochure. Nasopharyngeal radium irradiation (NRI). 2014. http://www.cdc.gov/nceh/radiation/brochure/profile_nri.htm

32. UNSCEAR 1958. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. United Nations General Assembly Official Records, Thirteenth Session, Supplement 17 (A/3838). New York. http://www.unscear.org/unscear/en/publications/1958.html

33. UNSCEAR 1994. Adaptive Responses to Radiation in Cells and Organisms Sources and Effects of Ionizing Radiation Report to the United Nations General Assembly, with Scientific Annexes. http://www.unscear.org/unscear/publications/1994.html

34. Cuttler JM, Abdellah E, Goldberg Y, Al-Shamaa S, Symons SP, Black SE, Freedman M. Low doses of ionizing radiation as a treatment for Alzheimer disease: a pilot study. *J Alzheimer’s Disease*. 2021; 80:1119-1128. DOI: 10.3233/JAD-200620 https://pubmed.ncbi.nlm.nih.gov/33646146/

35. Inkret WC, Meinhold CB, Taschner JC. Radiation and risk—a hard look at the data. *Los Alamos Sci*. 1995; 23:116-123. https://fas.org/sgp/othergov/doe/lanl/pubs/00326631.pdf.

36. Cuttler JM. Remedy for radiation fear—discard the politicized science. *Dose Response*. 2014; 12(2):170-184.

37. Cuttler JM. Leukemia incidence of 96,000 Hiroshima atomic bomb survivors is compelling evidence that the LNT model is wrong. *Arch Toxicol*. 2014; 88(3):847-848. https://pubmed.ncbi.nlm.nih.gov/24504164/

38. Cuttler JM, Welsh JS. Leukemia and ionizing radiation revisited. *J. Leukemia*. 2015; 3(4):1-2. https://www.longdom.org/open-access/leukemia-and-ionizing-radiation-revisited-2329-6917-1000202.pdf

39. Cuttler JM. Evidence of a dose threshold for radiation-induced leukemia. *Dose-Response*. 2018; 16(4):1-5.

40. Cuttler JM. Evidence of a dose threshold for radiation-induced leukemia: absorbed dose and uncertainty. *Dose-Response*. 2019;17(1):1-2

41. Whicker FW. Environmental radiation and life—A broad view. 41st Lauriston S. Taylor Lecture. *Health Phys*. 2018; 114(2):192-203.

42. Feinendegen LE, Cuttler JM. Biological effects from low doses and dose rates of ionizing radiation: Science in the service of protecting humans: A synopsis. *Health Physics*. 2018; 114(6):623-626.

43. Sies H, Feinendegen LE. Radiation hormesis: the link to nanomolar hydrogen peroxide. *Antioxidants & Redox Signaling*. 2017; 27(9):596-598.

44. Pollycove M, Feinendegen LE. Radiation-induced versus endogenous DNA damage: possible effect of inducible protective responses in mitigating endogenous damage. *Human & Experimental Toxicology*. 2003; 22:290-306.

45. Sies H, Jones DP. Reactive oxygen species (ROS) as pleiotropic physiological signalling agents. *Nat Rev Mol Cell Biol*. 2020; 21:363-383.

46. Go Y-M, Jones DP. Redox theory of aging: implications for health and disease. *Clinical Science*. 2017; 131:1669-1688.

47. Sies H, Berndt C, Jones DP. Oxidative stress. *Annual Review Biochem*. 2017; 86:715-748.

48. Mailloux RJ. An update on mitochondrial reactive oxygen species production. *Antioxidants*. 2020; 9:472.

49. OECD Nuclear Energy Agency. Chernobyl ten years on: radiological and health impact. 1995. https://www.oecd-nea.org/jcms/pl_13024

50. Cuttler JM. Feinendegen LE, Socol Y. Evidence that lifelong low dose rates of ionizing radiation increase lifespan in long- and short-lived dogs. *Dose-Response*. 2017; 15(1):1-6. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5347275/

51. Cuttler JM, Feinendegen LE, Socol Y. Evidence of a dose-rate threshold for lifespan reduction of dogs exposed lifelong to γ-radiation. *Dose-Response*. 2018;16(4):1-5. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6311660/

52. Government of Japan. Ministry of Education, Culture, Sport, Science and Technology (MEXT). Accumulated radiation dose around the Fukushima Dai-ichi NPS. 2012.

53. Ichiseki H. Features of disaster-related deaths after the Great East Japan Earthquake. *Lancet*. 2013; 381:204 https://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(13)60091-4.pdf

54. Cuttler JM, Calabrese EJ. A novel therapy for influenza-induced pneumonia. J *Radiat Cancer Res*. 2021; 12(1):36-38. DOI: 10.4103/jrcr.jrcr_49_20

55. Kaprin A. Inhalation low dose radionuclide therapy in treatment of COVID-19. *ClinicalTrials.gov* PRS. 2021. NCT04724538.

56. Calabrese EJ, Kozumbo WJ, Kapoor R, Dhawan G, Jimenez CL, Giordano J. NRF2 activation putatively mediates clinical benefits of low-dose radiotherapy in COVID-19 pneumonia and acute respiratory distress syndrome (ards): novel mechanistic considerations. *Radiotherapy and Oncology*. 2021. https://doi.org/10.1016/j.radonc.2021.04.015