# Drawing the Line: The Linear No-Threshold Model, and When are Doses Too Small to Matter?

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## Executive Summary

The Linear No-Threshold (LNT) model, which presumes that any dose of ionizing radiation carries a proportional risk of harm, has been the basis of radiation protection around the world for more than fifty years. This model underpins the regulatory frameworks of the U.S. Nuclear Regulatory Commission (NRC), the Department of Energy (DOE), and the Environmental Protection Agency (EPA). Amid a renewed push for deploying nuclear energy to meet rising global electricity demands, and following a Presidential Executive Order to evaluate radiation standards, a critical reassessment of these regulations is imperative.

This paper evaluates the scientific and policy landscape of radiation protection. While extensive research has expanded understanding of the effects of small radiation doses, significant uncertainty persists, particularly at doses below 100 mSv. Epidemiological studies in this range face significant limitations, as any potential increase in cancer risk is statistically indistinguishable from the normal background incidence of cancer and is confounded by a multitude of lifestyle and environmental factors. Consequently, the LNT model's assumption of a linear, proportional risk extending down to zero dose is not a proven scientific certainty but rather a conservative, simplifying assumption used for regulatory policy in the face of this ambiguity. The continued use of LNT is therefore not based on a fully validated scientific fact; it is a pragmatic, intentionally conservative policy choice. The paper argues that instead of an overhaul of the LNT model itself—a contentious change that would likely create greater disruption and still not achieve definitive scientific resolution—the focus should be on pragmatic policy and regulatory adjustments that leverage existing legal discretion.

**Key Policy Recommendations**:

- **Revising Risk Definitions**: The NRC should define a quantitative threshold for "adequate protection," aligning its practice with the statutory risk standards established by Congress in the Clean Air Act. Furthermore, the principle of ALARA ("as low as reasonably achievable") should be reframed to focus on dose optimization rather than dose minimization, a change that aligns with international wording and discourages the expenditure of resources to reduce already negligible exposures.

- **Implementing a Tiered System for Dose Limits**: A modernized, flexible system of dose and action limits is proposed:

    a. Tier 1 (Exempt or Clearance Limit): Establish a lower threshold of 1 mSv (100 mrem). Doses below this level, which are comparable to variations in natural background radiation, would be considered de minimis and exempt from ALARA and other regulatory requirements.

    b. Tier 2 (Public Dose Optimization): A public dose optimization threshold would be set at 10 mSv (1 rem). This matches the greatest variation in background exposure and then some moderate amount of anthropogenic exposure on top that can all be optimized but recognizes the impact of the many possible sources.

    c. Tier 3 (Occupational Action Limit): The occupational optimization threshold would be set at 20 mSv (2 rem), in line with DOE regulations and International Atomic Energy Agency recommendations. This could be further aligned with international standards to be 20 mSv (2 rem) averaged over a 5 year period.

    d. Tier 4 (Overall Dose Limit): Maintain the current occupational dose limit as 50 mSv (5 rem) and consider this joint public/occupational, with the action levels controlling to lower doses. This allows for safety based on current science, and for operational flexibility.

- **Recognition of Comparative Risks**: Regulations must contextualize radiation risk by comparing it to the risks associated with other energy sources, such as pollution from fossil fuels, and other societal risks. Improved risk communication strategies are essential to address disproportionate public fear and accurately convey scientific evidence, thereby fostering greater acceptance of beneficial nuclear technologies.

These recommendations are designed to allow a prudent evolution of radiation protection standards. By adopting them, the U.S. can reduce unnecessary economic burdens, foster innovation in advanced reactor design, and improve the cost-competitiveness of nuclear energy, all while maintaining a world-leading safety record appropriate for workers and the public.

# 1. Introduction: The Imperative for Radiation Protection Reform

The United States and numerous nations worldwide are anticipating, or already experiencing, an unprecedented surge in electricity demand, driven by the rapid expansion of artificial intelligence, data centers, industrial growth, and widespread electrification. In response to these pressing needs, there is a renewed and emphatic push for nuclear energy deployment. Recent executive orders from the U.S. President and a global commitment by over 30 nations to triple nuclear energy capacity by 2050 underscore nuclear power's renewed recognition.[1] This heightened prioritization of nuclear energy necessitates a critical assessment of all factors that might impede its deployment, with excessively conservative radiation protection requirements consistently identified as adding unnecessary costs.

For decades, radiation protection standards have been built upon the Linear No-Threshold (LNT) model, which posits that any radiation dose, no matter how small, carries a proportional risk of

[1] Donald J Trump, "Ordering the Reform of the Nuclear Regulatory Commission," Pub. L. No. Executive Order 14300, 90 FR 22587 FR (2025), https://www.federalregister.gov/documents/2025/05/29/2025-09798/ordering-the-reform-of-the-nuclear-regulatory-commission.

harm, with no threshold below which the risk is zero.[2] This model was adopted in the mid-20th century, an era when scientific data on low-dose radiation effects were limited, as a conservative, precautionary measure. But, the model has been reaffirmed numerous times since, with the NRC and National Council for Radiation Protection & Measurement (NCRP) recently upholding its utility.[3] Importantly, the NRC reaffirmed LNT in denying a petition for rulemaking, originally requested in 2015, raising the hurdle for its removal. The 2021 decision on the topic acknowledged the many faults in the model, but still supported it nonetheless.[4] While NCRP's recommendation is non-binding, it is the congressionally designated authority on radiation safety advice, and its publications carry significant weight with staff of federal agencies.

On May 23, 2025, President Trump issued Executive Order 14300: Ordering the Reform of the Nuclear Regulatory Agency. The NRC has been ordered to "adopt science-based radiation limits. In particular, the NRC shall reconsider reliance on the linear no-threshold model for radiation exposure and the "as low as reasonably achievable" standard, which is predicated on LNT."[5] The order specified that "in reconsidering those limits, the NRC shall specifically consider adopting determinate radiation limits, and in doing so shall consult with the Department of Defense (DOD), the Department of Energy (DOE), and the Environmental Protection Agency.

Yet, even for its detractors it would be hard to say that LNT is not grounded in science, despite disagreeing on which studies should be most pertinent. The central challenge confronting radiation protection today is that while low-dose data has become more readily available, it is nonetheless insufficient to make definitive statements of risk. While overloaded with information, Figure 1 provides a starting point for understanding this complex subject.

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[2] National Academy of Sciences, *Leveraging Advances in Modern Science to Revitalize Low-Dose Radiation Research in the United States* (Washington, D.C.: The National Academies Press), accessed June 23, 2025, https://doi.org/10.17226/26434.

[3] "Linear No-Threshold Model and Standards for Protection Against Radiation" (Federal Register, August 17, 2021), https://www.federalregister.gov/documents/2021/08/17/2021-17475/linear-no-threshold-model-and-standards-for-protection-against-radiation; R E Shore et al., "Implications of Recent Epidemiologic Studies for the Linear Nonthreshold Model and Radiation Protection," Commentary (Washington, D.C.: National Council on Radiation Protection and Measurement, September 2018), https://iopscience.iop.org/article/10.1088/1361-6498/aad348.

[4] "Linear No-Threshold Model and Standards for Protection Against Radiation."

[5] Trump, Ordering the Reform of the Nuclear Regulatory Commission.

Extensive epidemiological studies, radiobiological research, and analyses of populations with chronic elevated exposures have significantly expanded knowledge of radiation's health effects at low doses. However, the regulatory approach has remained largely unchanged, and at very low doses, knowledge of effects remains highly uncertain, with the most recent recommendations from the National Academies recommending substantial funding and decades of research to address the limitations.

The confluence of political will, economic pressure, and societal challenges creates a unique opportunity to review and reconsider radiation protection regulations. Effective and durable changes can be implemented for pragmatic policy and regulatory adjustments that align with current scientific understanding and balance safety with broader societal benefits.

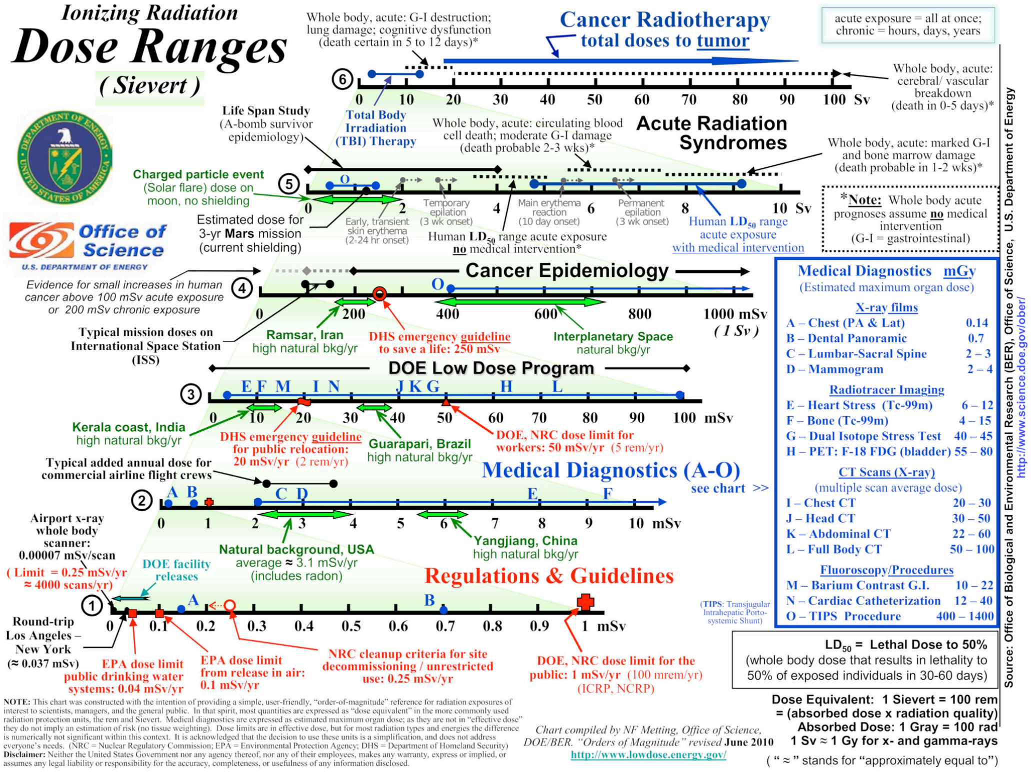


Figure 1: Both a very informative chart and lesson in when two many words make for an overwhelming image. [This high-resolution version](#) of the chart is easier to read. Courtesy of the DOE Office of Science.[6]

6 "The DOE Ionizing Radiation Dose Ranges Charts," Energy.gov, accessed July 9, 2025, https://www.energy.gov/ehss/articles/doe-ionizing-radiation-dose-ranges-charts.

# 2. The Linear No-Threshold Model: Foundations and Contentions

> A note about units: SI units will be the primary units in discussion as they are the international standard, and the most common in studies of radiation risk. US standards are still written in rem/rad and are included for readability. Sieverts (rems) include the biological effects of different types of radiation and are the most commonly used unit for risk evaluation, but they do include an inherent set of assumptions. Grays (rads) are a physical measurement of energy absorption per unit mass and are sometimes reported to accurately reflect variation in dosimetry. Grays are also used more frequently for deterministic effects, at doses significantly beyond the low dose range. The authors believe that SI units should be the sole values for nuclear phenomena to reduce confusion in communication and better harmonize standards.

The LNT model, which assumes a direct proportionality between radiation dose and risk with no lower dose limit, has its origins in the work of geneticists in the mid-1920s. Scientists like Hermann Muller and Edward Lewis investigated gene mutation under the hypothesis that natural and cosmic background radiation contributed to evolution, leading to the premise of a no-threshold dose response.[7] Much of the initial work in the field was conducted using fruit flies, investigating how spontaneous mutations affected biology. Notably, both men became Nobel laureates for their research. This work, conducted before modern understanding of the genome and gene repair, formed the basis for linear extrapolation from high-dose populations, with significant additional data and research following the atomic bombings of Hiroshima and Nagasaki.[8] ALARA, initially called "as low as practicable" (ALAP) was also created at this stage, with both topics the subject of Congressional hearings due to concerns over radioactive fallout from

[7] Hermann J Muller, "Hermann J. Muller — Nobel Lecture" (Nobel Prize Lecture, 1946 Nobel Awards, Stockholm, Sweden, December 13, 1946), https://www.nobelprize.org/prizes/medicine/1946/muller/lecture/; Jeremy Pearce, "Edward Lewis, Nobelist Who Studied Fly DNA, Dies at 86," *The New York Times*, July 26, 2004, sec. U.S., https://www.nytimes.com/2004/07/26/us/edward-lewis-nobelist-who-studied-fly-dna-dies-at-86.html.

[8] *The History of the Linear No-Threshold (LNT) Model*, Video, 22 vols., 2022, https://hps.org/hpspublications/historylnt/episodeguide/; Ronald L Kathren, "Historical Development of the Linear Nonthreshold Dose-Response Model as Applied to Radiation," *The University of New Hampshire Law Review* 1, no. 1 (December 2002).

atmospheric testing.[9] After these hearings in 1957, the Joint Committee on Atomic Energy (JCAE) began to pressure the AEC on managing concerns about population exposure. These discussions would shift after the Comprehensive Test-Ban Treaty to addressing other forms of radiation exposure, especially around nuclear power operations. ALAP was internationally recognized with ICRP's first recommendations publication in 1959.

The LNT model was formally defined in reports such as the 1972 Biological Effects of Ionizing Radiation (BEIR) I report and subsequently adopted by key international and national organizations.[10] This support was not unequivocal though, with the committee noting: "Although experimental evidence indicates that the dose-effect relationship for x rays and gamma rays may not be a linear function that is invariant with dose and dose rate, the use of a non-linear hypothesis for estimating risks in support of public policy on radiation would be impractical in the present state of knowledge. . ." That is, the LNT was more pragmatic due to its simplicity both mathematically and in regulatory application. This simple fact has been true since the model's inception and has been a key factor in its retention. ALARA was actually first codified in the United States that same year when the Atomic Energy Commission adopted 10 CFR Part 50, which would be inherited by the NRC after the Energy Reorganization Act of 1974.[11]

The basis for LNT is three assumptions,[12] 1) potential health risk is proportional to the dose received and that there is an incremental health risk associated with even very small doses, 2) the severity of a stochastic effect is independent of, the amount of radiation dose received, and 3) the LNT model only applies to stochastic effects, not deterministic health effects. The 1991 rule states the "assumptions are necessary because it is generally impossible to determine whether or not there are any increases in the incidence of disease at very low doses and low dose rates, particularly in the range of doses to members of the general public resulting from NRC-licensed activities."[13] Put together, assumptions 1 and 2 essentially say that risk increases with dose

[9] "The Nature of Radioactive Fallout and Its Effects on Man" (Washington, D.C.: National Archives, April 27, 1957).

[10] "Effects on Populations of Exposure to Low Levels of Ionizing Radiation," Report of the Advisory Committee on the Biological Effects of Ionizing Radiation (Washington, D.C.: National Research Council, 1972), https://doi.org/10.17226/18994.

[11] Chet D-CA-19 Rep. Holifield, "Energy Reorganization Act of 1974," Pub. L. No. 93—438, 88 Stat. 1233 (1974).

[12] "Standards for Protection Against Radiation,. 1991. 56 FR 23360.

[13] Id.

because as dose increases, there are more chances of a random (stochastic) effect (cancer) occurring.

Over time, radiation protection standards have become increasingly conservative, with annual occupational dose limits decreasing five-fold from approximately 250 mSv (25 rem)/year (based on early tolerance doses) to today's 50 mSv (5 rem)/year limit.[14] Further, some of the numerical ALARA limits are incredibly stringent. The liquid ingestion guidelines for the public are 3 mrem (0.03 mSv) per year.[15] Preventing public consumption of high levels of man-made radioactive materials is a good effort, but this limit would be hard to measure in the average member of the public, especially considering that naturally occurring isotopes could provide an order of magnitude higher dose that would make this level of exposure much more difficult to accurately determine. This is among the most stringent of all recommendations, but both the EPA and the NRC have other goals that require costly procedures for measurement and mitigation. However, even natural variation in naturally occurring radioactive isotopes could cause greater than a 3 mrem dose. Using an example of a gas, radon is part of the uranium decay chain, and there is a 5 mrem limit.[16] A strong rainstorm can cause further dispersion of radon, and if a plant is running its ventilation at a higher rate, is this an effluent if it comes from site grounds? This would normally be excluded as not from the operation of the plant, but these dose requirements are so low it would require substantial measurements to prove definitively that the emissions from the site were not from plant operations. Not only is this within natural variation but it is also less than many voluntary actions. A flight from Chicago to London, one-way with average conditions, delivers a dose of 4 mrem just from the increased altitude and reduced atmospheric protection.[17] This is not something that the average person notices or should notice, and should be wholesale exempt.

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[14] Kathren, "Historical Development of the Linear Nonthreshold Dose-Response Model as Applied to Radiation"; "Permissible Dose from External Sources of Ionizing Radiation," Handbook, September 24, 1954.

[15] Steven Schaffer, "RETS/REMP: NRC's Program for Keeping Nuclear Power Plant Offsite Doses As Low As Reasonably Achievable (ALARA)," https://www.nrc.gov/docs/ML1110/ML111050205.pdf.

[16] "Appendix I to Part 50—Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion 'As Low as Is Reasonably Achievable' for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents," Appendix (Rockville, MD, March 24, 2021), https://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-appi.html.

[17] Kyle Copeland and Wallace Friedberg, "Ionizing Radiation and Radiation Safety in Aerospace Environments" (Washington, D.C.: Federal Aviation Administration, March 2021).

LNT can be considered "trans-scientific" in that it is an amalgam of both scientific and policy decisions.[18] Even according to the International Atomic Energy Agency (IAEA) LNT is "probably not provable."[19] This means it cannot be definitively proven or disproven by science, especially at low doses. The inherent difficulties in acquiring sufficient data for low-probability events, like any single person getting cancer from chronic exposure, mean that achieving statistical confidence to predict risk at very low doses would require millions of data points and decades of research.[20] Consequently, LNT's continued use is a policy choice, not a fully validated scientific fact. The NRC's continued failure to adopt a quantitative threshold for "adequate protection" to align with Congressional standards represents a missed opportunity and a potential breach of its legal obligations. By regulating even negligible risks through the same procedures applied to higher-risk designs, the NRC imposes unnecessary burdens on developers, suppresses innovation, and delays the deployment of more advanced reactors.

## 3. Scientific Evidence on Low-Dose Radiation: Challenging the LNT Premise

Considering LNT's piecemeal historical development, frequent challenges, and numerous reports noting a lack of strong scientific consensus, what is the actual evidence that underlies the model? It is based on several overlapping sets of data that attempt to address the risk at various levels. Epidemiology data from exposed populations of individuals are the highest level, followed by animal studies, and then radiobiology, moving down from the individual to the cellular level. All of these studies should be considered simultaneously to get the greatest depth of understanding, and there is substantial literature. Focusing on individual studies in isolation is a common pitfall in examining research, and meta-analyses are conducted to look at large batches of studies at once. This is the general principle used by review bodies like the National Council on Radiation Protection and Measurements (NCRP) and other organizational reviews. However, even then, the

[18] Alvin M Weinberg, "Science and Trans-Science," *Science* 177, no. 4045 (July 21, 1972): 1, https://doi.org/177.4045.211.

[19] "ICRP Publication 103: 2007 Recommendations of the International Commission on Radiological Protection" (ICRP, 2007).

[20] *Radiation Dose Reconstruction for Epidemiologic Uses* (Washington, D.C.: National Academies Press, 1995), https://doi.org/10.17226/4760.

crux of the problem is that at low doses, the uncertainty in nearly all studies overwhelms the actual data on exposures below 50 mSv (5 rem), and especially below 100 mSv (10 rem).

## 3.1 Epidemiological Evidence

Epidemiological studies, which investigate health patterns in populations, face significant methodological challenges when examining low-dose radiation effects. These include limited statistical power, the influence of numerous confounding factors (such as socioeconomic status and lifestyle), uncertainties in historical dose reconstruction, and the "healthy worker effect" in occupational studies.

The statistical significance of observed effects at doses below 100 mSv (10 rem) is hard to determine. For these reasons, based on epidemiological evidence BEIR VII officially classified this as the low-dose range, internationally finalized in ICRP 147.[21] This is a frequent critique of its foundational use with the kinds of chronic low-dose exposures typically encountered by radiation workers or the public. Starting with ICRP Publication 60, applying a Dose-Rate Effectiveness Factor (DREF) of 1.5 – 2 is recommended when extrapolating from acute high-dose exposures to chronic low-dose scenarios.[22] This factor means that these long-term exposures might only cause half the of expected damage as compared to acute exposure. DREF is one of the tools available to make up for the inadequacies of the low-dose data.

DREF exists because the LNT model is explicitly not recommended for calculating effects across large populations. It is meant to be a tool in the analysis of individual doses. A particular egregious example of this was a recent paper published in JAMA, which attributed up to 5% of future US cancer cases to the current rate of CT scanning in medical imaging.[23] Studies that use low-dose risk in this manner fuel the fire against LNT, where utilizing the model with doses that

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[21] National Research Council, *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2* (Washington, D.C.: National Academies Press, 2006), https://doi.org/10.17226/11340; J.D. Harrison et al., "ICRP Publication 147: Use of Dose Quantities in Radiological Protection," *Annals of the ICRP* 50, no. 1 (February 1, 2021): 1, https://doi.org/10.1177/0146645320911864.

[22] ICRP, "ICRP Publication 60: 1990 Recommendations of the International Commission on Radiological Protection," *Annals of the ICRP* 21, no. 1—3 (1991): 60.

[23] Rebecca Smith-Bindman et al., "Projected Lifetime Cancer Risks From Current Computed Tomography Imaging," *JAMA Internal Medicine* 185, no. 6 (June 1, 2025): 710—19, https://doi.org/10.1001/jamainternmed.2025.0505.

are in the deepest part of the statistical uncertainty has the potential to fuel radiophobia about medical procedures. Medical radiation exposures offer valuable insights due to their well-characterized doses. CT scans have shown where lower doses are much more strongly suggestive of risk: children. Since children are underrepresented in most studies, doses in pediatric imaging are an important source of information about radiation effects. Crucially, they most poignantly illustrate the tradeoffs inherent in certain exposures; exposure to even high-risk populations can be warranted by the benefits, and both diagnostic and therapeutic doses are potentially life-saving.

The Life Span Study (LSS) has, to date, been the most important set of analyses for continuously monitoring the health effects of radiation due to its unique epidemiologic cohort. Initiated to advise the U.S. government on radiation and human health, the study includes approximately 120,000 survivors of the atomic bombings in Hiroshima and Nagasaki, Japan, in 1945. The LSS data is exceptionally valuable due to the cohort's large size, the inclusion of both sexes and all ages at exposure, and the wide range of estimated individual doses, which enables robust quantitative risk estimates for radiation exposure. Moreover, since the cohort experienced whole-body exposure, the LSS offers a unique opportunity to assess and compare risks for a large number of specific cancer sites, and it benefits from high-quality mortality and cancer incidence data derived from long-term follow-up (over 50 years) and established tumor registries in Japan. These combined strengths establish the LSS as the single most important source of data for evaluating low and moderate dose radiation risks and informing radiation safety standards globally.[24] However, a key limitation is the LSS cohort received the dose nearly instantaneously, instead of chronically over a long period of time.

Studies of nuclear industry workers, such as the International Nuclear Workers Study (INWORKS), have reported statistically significant excess risk for certain cancers at the upper end of the low-dose range, but not statistically significant and large confidence intervals at very low doses. The INWORKS study includes 309,932 workers from the nuclear industry in France, the United Kingdom, and the United States, representing some of the largest and most informative cohorts of nuclear workers globally. The study monitors data on individual worker external exposure to

[24] Eric J. Grant et al., "Solid Cancer Incidence among the Life Span Study of Atomic Bomb Survivors: 1958—2009," *Radiation Research* 187, no. 5 (May 2017): 513—37, https://doi.org/10.1667/RR14492.1.

ionizing radiation. The study encompassed a total of 10.7 million person-years, with the average worker followed to nearly 70 years of age. The cohort includes approximately 13% women.[25]

The Million Person Study (MPS) is an extensive, ongoing U.S. epidemiological program spearheaded by the NCRP, designed to furnish scientifically robust information on radiation risk when exposures are received gradually over time, contrasting with the acute exposures of the Japanese atomic bomb survivors. Its core objective is to estimate health effects, primarily cancer mortality (with an initial focus on leukemia and male breast cancer for atomic veterans), but also cardiovascular and cerebrovascular diseases, from low doses (less than 100 mGy delivered acutely) and low dose rates (less than 5 mGy/h) of ionizing radiation. The study encompasses a diverse array of U.S. occupational groups, including approximately 115,000 atomic veterans, 360,000 U.S. Department of Energy (DOE) workers, 430,000 nuclear power plant workers, 130,000 industrial radiographers, and 240,000 medical radiation workers.[26] The success of the MPS hinges on meticulous dose reconstruction to provide accurate and precise organ-specific absorbed dose estimates along with their associated uncertainties, leveraging millions of dosimetry measurements, archived records, and modeling for both external and internal radiation sources. Preliminary insights from MPS cohorts indicate a positive association between cumulative external radiation dose and solid cancer mortality. For U.S. nuclear workers within INWORKS, the ERR for solid cancer mortality was 0.19 per Gy, with this association appearing larger among workers first hired after 1960, possibly due to improved dosimetry over time. The large-scale and long-term individual dose monitoring in the MPS significantly enhances its statistical power for detecting small risks and its generalizability to societies outside of Japan (cancer rates can vary by race and culture), providing crucial information for radiation protection standards.[27]

Perhaps the most compelling real-world evidence comes from populations living in areas with high natural background radiation (HNBRAs). Investigations in Yangjiang, China, where background radiation averages 6.4 mSv (640 mrem), Kerala, India, with background radiation

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[25] David B. Richardson et al., "Cancer Mortality after Low Dose Exposure to Ionising Radiation in Workers in France, the United Kingdom, and the United States (INWORKS): Cohort Study," *BMJ* 382 (August 16, 2023): e074520, https://doi.org/10.1136/bmj-2022-074520.

[26] André Bouville et al., "Dose Reconstruction for the Million Worker Study: Status and Guidelines," *Health Physics* 108, no. 2 (February 2015): 206—20, https://doi.org/10.1097/HP.0000000000000231.

[27] John D. Boice Jr. et al., "The Million Person Study, Whence It Came and Why," *International Journal of Radiation Biology* 98, no. 4 (April 3, 2022): 537—50, https://doi.org/10.1080/09553002.2019.1589015.

reaching up to 70 mSv (7 rem) annually, and Ramsar, Iran, where levels can exceed 260 mSv (26 rem) annually, have not demonstrated conclusive evidence of increased cancer rates or other adverse health effects among residents. Studies of these regions are some of the strongest arguments in favor of an alternative to the LNT model, known as hormesis. This model theorizes that low doses of an otherwise harmful agent, such as radiation, may be beneficial by stimulating the body's natural defense and repair mechanisms. However, the existence of such a protective effect in humans remains a subject of significant scientific debate, as the lack of observed harm in these populations could be influenced by other genetic or environmental factors. Consequently, this lack of definitive proof is a primary reason why more conservative, precautionary models continue to form the basis for radiation protection standards.[28]

One of the most intriguing examples comes from a construction incident in Taiwan. Steel that had been exposed to neutron radiation (thus creating Co-60) was accidentally incorporated into an apartment complex. Average doses to residents were approximately 47 mSv. Importantly, a demographically varied population inhabited the tower, including children. The results showed that while leukemia did occur at slightly higher rates and that the children were potentially more sensitive to dose, overall cancer rates were actually lower among residents than the general population.

Collectively, these studies provide strong evidence to reject the assumptions that provide the basis for LNT. Put simply, if it is purely stochastic as assumed, the more interactions with radiation (higher dose), the more rolls of the figurative dice. That inherently makes it more likely for a random cancer to occur.

The lack of observed health risk due to variation in background radiation alone challenges the assumption of a purely stochastic relationship. Under that assumption, a clear increase in health outcomes is expected in higher background dose locations. That is not shown in the evidence. With stochastic effects, it is *possible* that more interactions in higher dose areas randomly do not result in more incidence, but the odds are essentially zero.

[28] If you are comfortable with scientific literature review, researching hormesis is the one of the quickest ways to understand how strongly scientific agreements can play out.

## 3.2 Radiobiological and Animal Studies

One of the largest methodological critiques of the LNT model is that it does not inherently incorporate measures for how responses to small radiation doses may differ in chronic vs acute exposure.[29] The ICRP has attempted to correct this with the Dose and Dose Rate Effectiveness Factor, first proposed in 1990.[30] This value has generally been set between 1.5 and 2, meaning that chronic low-dose exposure is between 66 and 50% as damaging when compared to acute doses.

At its core, cancer often originates from DNA damage and subsequent mutations, which alter the function of critical genes involved in cell signaling, growth regulation, and DNA repair. Cancer fundamentally occurs with at least two crucial mutations: one in tumor-suppressor genes (analogous to the brakes in a car for cell division) and another activating proto-oncogenes (hitting the gas on cell growth). Radiation-induced errors frequently cause loss-of-function mutations in DNA or even larger chromosomal abnormalities. The fundamental understanding that a single ionizing particle has the potential to damage a cell's DNA and that DNA repair mechanisms are not entirely error-free is why the broad assumptions inherent to LNT have not been invalidated.[31]

Radiobiological studies are crucial in informing the discussion on the LNT model, particularly for low-dose exposures where direct epidemiological data may be limited or statistically uncertain. These studies delve into molecular and cellular responses to radiation, exploring mechanisms such as DNA repair, radiation-induced genomic instability, adaptive responses, and bystander effects. While some studies explore potential non-linearities or beneficial effects (hormesis) at very low doses, the overall consensus from various scientific bodies is that no alternative dose-response relationship appears more plausible or prudent than the LNT model for radiation protection purposes based on current scientific knowledge. Research in this area continues to integrate biological insights with epidemiological findings to refine risk estimates, especially

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[29] Note however, that for the assumption underpinning LNT that all effects are stochastic to be valid, dose rates should not have an impact.

[30] ICRP, "ICRP 60."

[31] National Research Council, *BEIR VII*; C. H. Clement and K Nakamura, "TG91 Report for Public Consultation Final," ICRP Publication (International Commission on Radiological Protection, June 13, 2025).

through the use of biologically-based mechanistic models that can describe the complex interplay of cellular processes in carcinogenesis.[32]

Understanding how hazards like radiation affect the body requires understanding the levels of emergence. All of the components in your cell function in cohesion to keep the cell running, which in turn allows groups of cells to function as tissue, and then organs, and then the person. The differences in the gene expression among people means that epidemiology is necessary to tease out the average responses among people, since some might be more radiosensitive with less effective DNA repair, while others might have radioprotective ways of packaging or repairing DNA. Advocates of hormesis note that all cells have evolved over billions of years to respond to radiation, and some studies do indeed show that low-dose exposure can prompt protective actions. However, these effects can be hard to see due to confounding factors. If a cell suddenly needs to repair its DNA, it can release signals to other cells which might make them protect themselves, but could elicit an inflammatory response which could result in cascading immune events. The current ICRP task group 91 is attempting to overcome these challenges and is doing meta-analyses of different research areas (radiobiology, animal studies, epidemiology) and getting distinctive DREF for each section, which can then be pooled into a final DREF recommendation. This kind of analysis could eventually yield a true alternative to the LNT model, but given the wide range of values (the recommendation is for a DREF between 1 and 3, two whole factors different), in just determining overall low-dose response, this shows the challenge in developing science-based alternative models.[33] We struggle to modify a simple linear model to adjust for these kinds of exposures. How can we develop a more complicated fitting equation and justify it to a high degree?

## 3.3 Positions of Leading Professional and International Organizations

The Health Physics Society (HPS) has adopted one of the most explicit positions, stating unequivocally that "below levels of about 100 mSv (10 rem) above background from all sources

[32] Werner Rühm, Eidemüller ,Markus, and Jan Christian and Kaiser, "Biologically-Based Mechanistic Models of Radiation-Related Carcinogenesis Applied to Epidemiological Data," *International Journal of Radiation Biology* 93, no. 10 (October 3, 2017): 1093—1117, https://doi.org/10.1080/09553002.2017.1310405.

[33] Clement and Nakamura, "ICRP TG91 Final Report."

combined, the observed radiation effects in people are not statistically different from zero".[34] HPS explicitly calls the LNT model a "questionable premise" that "cannot provide reliable projections of future cancer incidence from low-level radiation exposures."

The International Commission on Radiological Protection (ICRP), while maintaining the LNT model as the basis for its recommendations, views it primarily as a "prudent basis" for practical radiological protection, rather than an established scientific fact.[35] This carefully worded statement suggests a precautionary policy choice that may exceed what is strictly required by scientific evidence. Several ICRP task groups have divided up the work of an ongoing review and revision of the System of Radiological Protection.[36]

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has expressed notable skepticism about applying the LNT model to very low doses. Its 2012 report explicitly states that the Committee "does not recommend multiplying very low doses by large numbers of individuals to estimate numbers of radiation-induced health effects within a population exposed to incremental doses at levels equivalent to or lower than natural background levels". This statement directly challenges a common regulatory practice based on the LNT model.[37]

The National Council on Radiation Protection and Measurements (NCRP) acknowledges that the dose-response relationship at low doses and/or low dose rates remains uncertain due to intrinsic uncertainties in epidemiological and radiobiological studies. While the council concludes that the LNT model "should continue to be used for radiation protection purposes" based on current

[34] "Radiation Risk in Perspective," Position Statement of the Health Physics Society (Health Physics Society, February 2019).

[35] "ICRP 103."

[36] C Clement et al., "Keeping the ICRP Recommendations Fit for Purpose," *Journal of Radiological Protection* 41, no. 4 (December 1, 2021): 1390—1409, https://doi.org/10.1088/1361-6498/ac1611.

[37] United Nations Scientific Committee on the Effects of Atomic Radiation, *Sources, Effects and Risks of Ionizing Radiation, UNSCEAR 2012 Report: Report to the General Assembly, with Scientific Annexes A and B*, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) Reports (UN, 2015), https://doi.org/10.18356/2ed43f39-en.

epidemiological data, it also notes that "the current data are not precise enough to exclude other models" and that the risk below 100 mSv (10 rem) is uncertain but small.[38]

For its part the American Nuclear Society has only called for expansion and funding of low-dose research, noted ICRP's recommendation that LNT not be used for large population extrapolation, and said that regulations should be harmonized and communicated effectively. It does explicitly call for ALARA to be a policy of dose optimization, not minimization.[39] As a representative group that focuses more on applied nuclear science rather than health physics, it is a less controversial statement to focus on ALARA practices rather than LNT overall.

As noted, all of these organizations connect policy recommendations to the science because of the uncertainty in the science. Policy recommendations vary relative to the organization's risk tolerance and not the underlying science.

## 3.4 Uncertainty: Insurmountable Scientific Mountain, Policy Molehill

Despite hundreds of studies and decades of research, the question remains why is there still so much argument and consternation on this topic? The HPS comment, "below. . .100 mSv. . . [risks] are not statistically different," provides an example of the usual balance between safety and scientific certainty. Safety should usually be precautionary, trying to prevent possible harm. Scientific discovery necessitates more and more information to confine these values to more reasonable windows. The variability in the data might be too, or the dataset too small, to result in a statistically significant result. Multiple methods are used to describe the range of variability in the results, including interquartile ranges, standard deviation, or confidence intervals in statistics. These confidence intervals, the more certain one wishes to be, require either a wider window or more data to confine the results. This is true of all analyses, but more so when the data shows high variability.

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[38]Shore RE, Beck HL, Boice JD, Caffrey EA, Davis S, Grogan HA, Mettler FA, Preston RJ, Till JE, Wakeford R, Walsh L, Dauer LT. Implications of recent epidemiologic studies for the linear nonthreshold model and radiation protection. J Radiol Prot. 2018 Sep;38(3):1217-1233. doi: 10.1088/1361-6498/aad348. Epub 2018 Jul 13. PMID: 30004025.

[39] "Risks of Exposure to Low-Level Ionizing Radiation," Position Statement (American Nuclear Society, November 2020).

Within radiation epidemiology, two values are often used to indicate risk and variance: excess relative risk (ERR) and excess absolute risk (EAR). Relative risk, such as seen in INWORKS, gives a proportion; at a certain exposure, you have a 50% greater chance of cancer (0.50 ERR), for instance. Government agencies, on the other hand, use EAR, the specific risk of 1 in a million for instance, to have cancer based on exposure. An important consideration in the change between these values is that a 50% increase in absolute risk might mean a 1.5 in a million chance of cancer. That is a large relative increase, but is that enough for the average person to noticeably change their internal calculation of risk? Is that enough at a population level? In the very low dose range effects are not usually statistically significant and the confidence interval is usually 2-10 times the range of the effect, and includes both zero and negative effect values. How should risks that are not statistically different from zero be considered in policy? These are open questions, and ones that science alone cannot answer.

What science can do is further constrain these calculations to get more accurate and more reliable models. The analysis of DREF values is an example; by pooling the different values between radiobiology, animal studies, and epidemiology, there is greater certainty in the result by constraining across multiple methodologies. Continuing analysis of the LSS data, especially by following individuals across the decades, gives greater validity to the use of low-dose data across a lifetime. New tools for analysis, including machine learning, could offer potentially new avenues of epidemiological analysis. Such inference could both draw new correlations out of the cohorts and could help fill in the informational gaps in the same manner as increasing the resolution of a photo (upscaling). Such opportunities will become more available and more efficacious in the near future and deserve consideration alongside traditional analyses.

# 4. The Economic and Societal Burden of Overly Conservative Regulations

The use of ALARA and dose optimization is objectively good when applied within reasonable dose ranges. It is fair to say that simple practices like reducing worker time near radiation sources and engineering spaces to give greater distance between radioactive materials and workers are good in practice. What is missing is a lower threshold below which these practices have minimal, if any, benefit.

Take for instance, the NRC's own data from 2019. It showed a total of 7,150 person-rem across 44,848 non-transient workers. This averages out to 2 mSv (200 mrem) per worker that year.[40] This is only twice the public dose limit, much less than the occupational dose limit, and less than the normal variation in background doses across the US.[41] However, according to the NRC's ALARA cost guidance, it is considered reasonable to have the nuclear industry spend ~$36 million in direct costs to mitigate these doses, without consideration of the potentially much larger indirect costs.[42] ALARA is typically practiced on a cost-basis for protective projects, but this illustrates the problem of no lower boundary.

This extreme disparity indicates that resources allocated to reducing already negligible radiation risks could yield far greater public health benefits if redirected to other areas, such as traffic safety or disease prevention, or even the construction of additional reactors. It represents a classic example of diminishing returns, where additional investment yields virtually no additional safety. If the uncertainty in the data is considered instead of assuming a direct linear relationship as is done in the LNT model, it is indeterminable if this policy achieves any additional safety, or not. The current regulatory approach, driven by LNT and ALARA's misapplication, is not just economically inefficient but potentially harmful from a societal perspective by misallocating finite resources, diverting safety focus and resources from more important targets. The financial impact extends across all nuclear industries. In nuclear power generation, current requirements, which combine the 50 mSv (5 rem)/year occupational limit with ALARA principles, lead to significant costs for specialized personnel, monitoring equipment, protective infrastructure, administrative compliance, worker rotation, and increased outage times. These requirements also significantly influence the cost of design and implementation for new advanced research and power reactors.

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[40] "Occupational Radiation Exposure at Commercial Nuclear Power Reactors and Other Facilities 2019," NUREG (Rockville, MD: Nuclear Regulatory Commission, April 2022).

[41] I.e., a worker could have received a higher additional dose simply by living in a different location.

[42] Nuclear Regulatory Commission, Washington, DC (United States). Div. of Regulatory Applications, "Reassessment of NRC`s Dollar per Person-Rem Conversion Factor Policy," NUREG (Rockville, MD, February 2022), https://doi.org/10.2172/197836.

The Institute of Nuclear Power Operations (INPO) serves as the U.S. nuclear industry's self-regulatory body, driving the implementation of the ALARA principle. Established by the industry in the aftermath of the Three Mile Island incident, INPO's influence is not based on legal authority but on its comprehensive evaluation process and its role as a hub for industry best practices. INPO regularly conducts intensive, performance-based evaluations of every nuclear plant, tracking key performance indicators, with collective radiation exposure being a critical metric.[43]

This system of evaluation and comparison creates a powerful dynamic of peer pressure, effectively fostering a "race to the bottom" in dose reports. When one plant achieves a new low in doses or develops a new dose-reduction technique, other plants are strongly motivated to adopt similar practices to maintain their standing within the INPO performance rankings. This competitive but collaborative environment ensures that the ALARA principle is not just a theoretical concept but a practical reality, leading to a continuous cycle of dose reductions, which would be fine if doses were near upper limits, but all nuclear plants maintain worker dose limits not much higher than the average dose for a member of the public. If plants stray from the average, they invite increased scrutiny from the INPO board, which is composed of nuclear industry executives. It can also impact a utility's insurance rates and standing within the industry. In extreme cases, a plant's INPO membership could be suspended, which would have severe operational and financial consequences.

For nuclear-waste disposal and cleanup, the costs are immense, greatly accentuated by limits that require cleanup to levels below even background. Environmental remediation at former U.S. nuclear-weapons development sites is projected to cost between $675 billion and $900 billion. A Government Accountability Office (GAO) report highlights that costs accelerate rapidly for more restrictive cleanup standards, with a 0.05 mSv (5 mrem)/year level costing over 28 times more than a 1 mSv (100 mrem)/year level for certain sites.[44]

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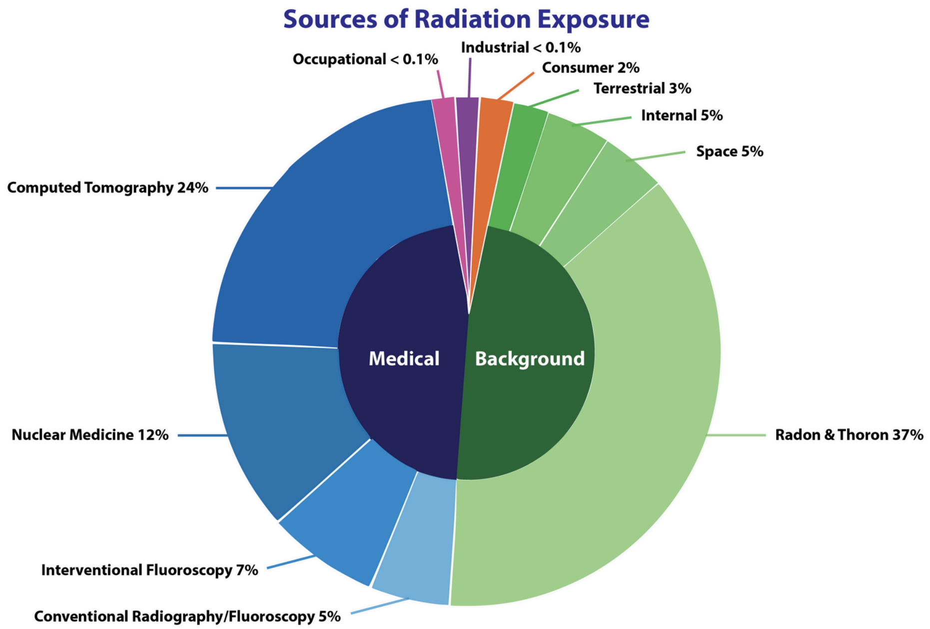
[43] "The Role of the Institute of Nuclear Power Operations in Supporting the United States Commercial Nuclear Power Industry's Focus on Nuclear Safety" (Washington, D.C., November 13, 2019).

[44] "Nuclear Waste Cleanup: Closer Alignment with Leading Practices Needed to Improve Department of Energy Program Management," GAO Report (Washington, D.C.: Government Accountability Office, June 2024).

All considered, despite its scientific intent as a conservative regulatory tool, LNT has significantly exacerbated radiophobia by inherently positing that every single increment of radiation exposure, regardless of how minute, carries an associated, non-zero risk of harm, most notably cancer. This foundational "no safe dose" principle, applied across the entire dose spectrum, instilled a pervasive public apprehension, transforming radiation into an abstract, uniquely insidious threat. By simplifying a nuanced biological reality into an easily misconstrued direct proportionality, the LNT model, in the public consciousness, transcended its role as a cautious regulatory assumption to become a direct proclamation of danger at even background levels, disproportionately amplifying fear and fostering widespread, often irrational, aversion to anything associated with radiation.




Average Annual Radiation Dose

| Sources | Radon & Thoron | Computed Tomography | Nuclear Medicine | Interventional Fluoroscopy | Space | Conventional Radiography/ Fluoroscopy | Internal | Terrestrial | Consumer | Occupational | Industrial |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Units<br>mrem (United States)<br>mSv (International) | 228 mrem<br>2.28 mSv | 147 mrem<br>1.47 mSv | 77 mrem<br>0.77 mSv | 43 mrem<br>0.43 mSv | 33 mrem<br>0.33 mSv | 33 mrem<br>0.33mSv | 29 mrem<br>0.29 mSv | 21 mrem<br>0.21 mSv | 13 mrem<br>0.13 mSv | 0.5 mrem<br>0.005 mSv | 0.3 mrem<br>0.003 mSv |

(Source: National Council on Radiation Protection & Measurements, Report No. 160)

Figure 2: An EPA pie chart illustrating the population-level sources of radiation doses for US residents based on

NRCR 160[45]

**Table 1: Sources of Average Annual Radiation Exposure in the United States**

| SOURCE CATEGORY | AVERAGE ANNUAL DOSE mSv (mrem) | PERCENTAGE OF TOTAL (%) |
|---|---|---|
| Natural Background | ~3.1 mSv (310 mrem) | ~50 |
| Medical Procedures | ~3.1 mSv (310 mrem) | ~50 |
| Consumer Products | Minor | Minor |
| Industrial/Occupational | Minor | Minor |
| Nuclear Power | Negligible | Negligible |

*Note: The average total U.S. annual radiation dose is approximately 6.2 mSv (620 mrem). Radon contributes about 68% of natural background radiation. Nuclear power exposures are often dwarfed by background and medical sources, frequently lumped into broader "industrial" categories due to their minimal contribution to population-level dose.*[46]

Doses are not uniformly distributed (Figure 3), with substantial variation across the United States, and some individuals getting regular doses above 20 mSv (2 rem).

[45] OAR US EPA, "Radiation Sources and Doses," Overviews and Factsheets, April 15, 2015, https://www.epa.gov/radiation/radiation-sources-and-doses.

[46] "Ionizing Radiation Exposure of the Population of the United States," NCRP Report 160 (National Council on Radiation Protection and Measurement, March 3, 2009).

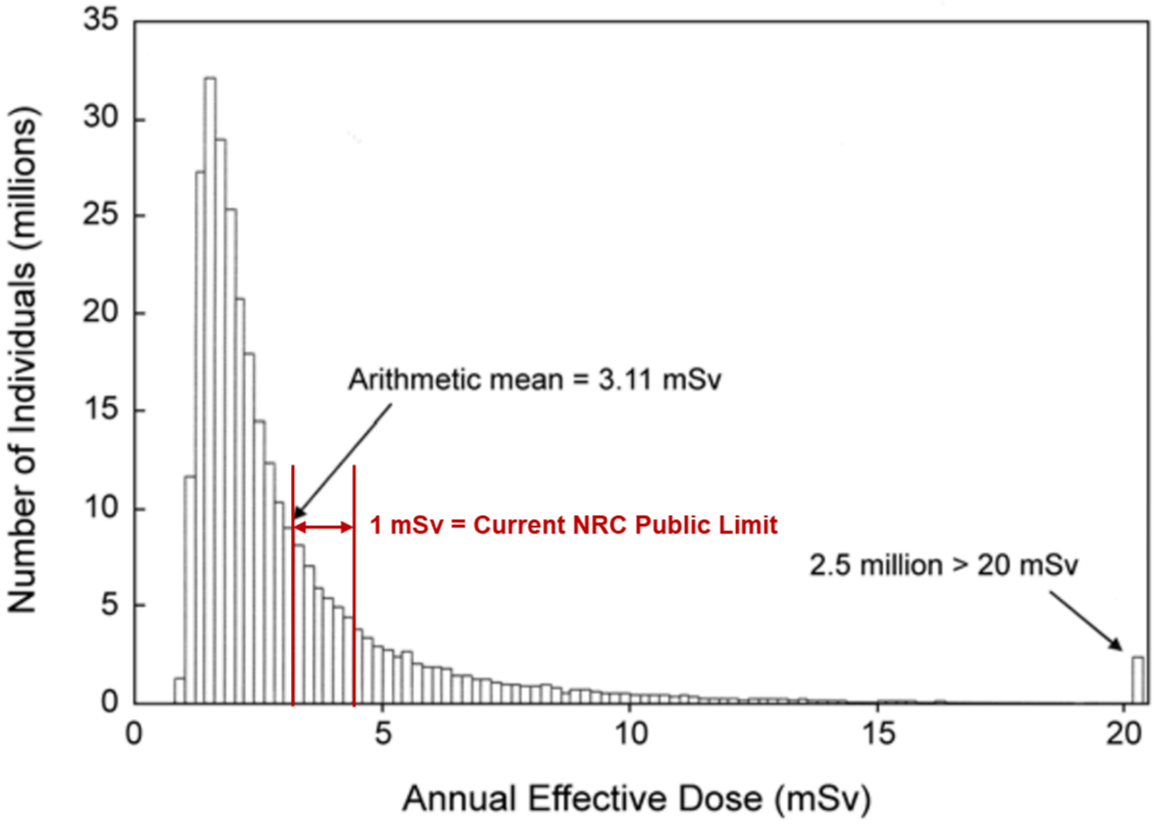



Figure 3: Histogram of background dose estimates to people in the United States. The current NRC public dose limit is overlaid beginning at the mean background dose. Adapted from[47]

The variation in naturally occurring background radiation is an order of magnitude larger than NRC public dose limits, and three orders of magnitude larger than limits for effluent releases.

[47] "NCRP Report 160," 160.

# 5. Quantifying Risk: Valuation of Mortality and Statistical Life

In the realm of public health and safety, federal agencies frequently employ economic valuation methods to quantify the benefits of risk reduction, particularly concerning mortality.[48] These methods do not attempt to place a monetary value on an individual life but rather estimate society's willingness to pay for small reductions in the risk of death. There is an alpha value that is used in a cost-benefit analysis to determine if the cost of implementing additional radiation protection measures is justified by the reduction in health detriment (monetized using the alpha value). For example, if a nuclear facility is considering installing a new shielding system that costs $500,000 and is expected to reduce the collective dose to workers by 10 person-rem, the monetized benefit of this dose reduction would be:

$$\textit{Benefit} = (10\ \textit{person-rem}) * \alpha$$

If the calculated benefit is greater than the $500,000 cost of the shielding, then the measure would be considered "reasonably achievable" under the ALARA principle. If the cost outweighs the monetized benefit, the additional protection may not be required. In essence, the Value of a Statistical Life (VSL) provides a quantitative basis for the "economic and social factors" that must be considered in ALARA determinations. The NRC's own analysis of VSL, prepared when the pre-inflation value of $5200 per person-rem was set, included a comparative analysis of other agencies and options in implementing the cost change.[49] Overall, valuation allows for a structured approach to deciding how much to invest in radiation safety, balancing radiation exposure with the practical realities of resource allocation. This application, like the broader use

[48] "Notice of Availability of Final Guidance for Estimating Value per Statistical Life," Final Guidance (Washington, D.C.: Federal Register, April 18, 2024), https://www.federalregister.gov/documents/2024/04/18/2024-08300/notice-of-availability-of-final-guidance-for-estimating-value-per-statistical-life.

[49] Nuclear Regulatory Commission, Washington, DC (United States). Div. of Regulatory Applications, "Reassessment of NRC`s Dollar per Person-Rem Conversion Factor Policy."

of the VSL, remains a subject of ongoing discussion and refinement within the scientific and regulatory communities.[50]

## 6. Radiation Safety can not be divorced from Societal Values

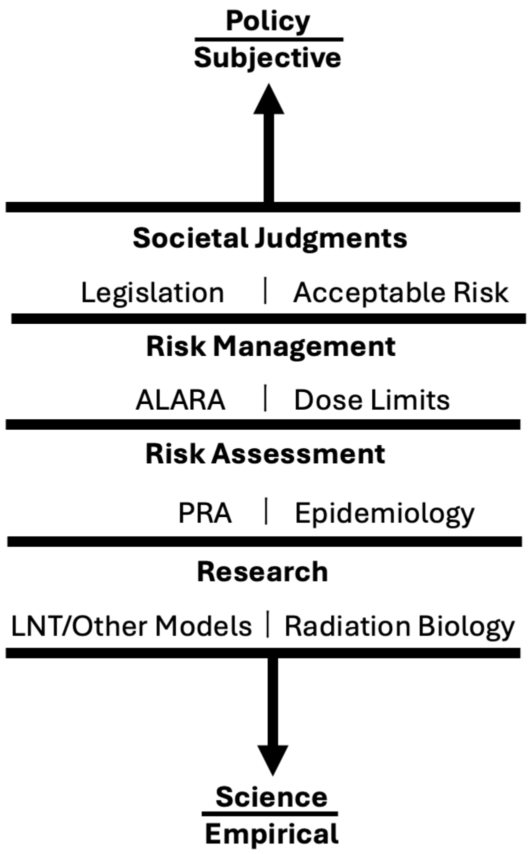



Figure 4: Illustrative continuum between research science and policy with examples[51]

[50] A Engström et al., "How Much Resources Are Reasonable to Spend on Radiological Protection?," *Journal of Radiological Protection* 44, no. 4 (January 2025): 041516, https://doi.org/10.1088/1361-6498/ad9f73.
[51] P J Seel and Adam Stein, "How to Regulate Radiation Exposure," *The Breakthrough Journal* (blog), January 29, 2025, https://www.breakthroughjournal.org/p/how-to-regulate-radiation-exposure.

For all of the progress that scientific discovery enables, it can rarely answer the questions that arise from its use; *what is truly acceptable and allowable when it is new or still unknown*? The ongoing debate surrounding the LNT model, and indeed many complex societal challenges, often highlights this fundamental distinction between the realms of science and policy. Science, at its core, is the systematic process of collecting, analyzing, and interpreting empirical data to build knowledge and understand natural phenomena. It seeks to describe what is through rigorous methodologies, striving for objectivity and testable hypotheses.

In the context of radiation, science provides insights into biological responses, dose-response relationships, and the mechanisms of harm or repair. Policy, conversely, is the process by which societal values, priorities, and ethical considerations are translated into concrete actions, regulations, and laws. It determines what should be done based on available scientific information, but also incorporates economic realities, social acceptance, risk tolerance, and political feasibility. While science should undeniably inform policy, providing the best available evidence for decision-making, it does not dictate policy. Policymakers must weigh scientific uncertainties against competing values and practical constraints, making judgments that extend beyond purely scientific conclusions. This inherent separation means that even when scientific consensus is elusive, policy decisions must still be made, often relying on conservative assumptions or adaptive frameworks to manage uncertainty in a manner consistent with public welfare and societal goals. Conversely, policy must not adjudicate or arbitrarily declare what is or is not science.

One of ICRP's lesser-known products is Publication 138, "Ethical Foundations of the System of Radiological Protection." This document highlights four core values defined as the underlying principles of radiation protection: beneficence/non-maleficence, prudence, justice, and dignity. While science provides the essential data on radiation effects and risk, these ethical values are the crucial second ingredient for making recommendations on how to behave wisely when faced with radiation exposure. As ICRP itself notes, "Scientific facts are essential to understanding, but, alone, are not enough to decide what to do. Ethical values are the other ingredients necessary for making recommendations on how to behave in light of our scientific knowledge." Protection recommendations inherently represent an ethical position, whether explicit or implied.[52]

Too often, discussions about acceptable risk are framed purely as scientific or technical problems, obscuring the fundamental ethical questions at their heart. Determining "how much risk is acceptable" or "how low is as reasonably achievable" (ALARA) for radiation exposure is not merely a calculation; it's a societal judgment that balances potential harm against the benefits of the activity. This involves complex trade-offs between protecting individuals and populations, enabling beneficial technologies (like medical imaging or nuclear energy), and considering the resources available for protection measures. The "reasonableness" of these decisions depends on relationships, rationale (including ethical considerations), and resources, underscoring the multi-faceted nature of the challenge.[53]

Therefore, for radiation safety standards to be truly legitimate and effective, they must openly acknowledge and grapple with these ethical dimensions. Rather than using scientific data to override ethical considerations, science should inform the ethical deliberation, providing the best available understanding of consequences. This necessitates inclusive, transparent, and accountable processes that engage diverse stakeholders — from experts and regulators to workers, patients, and the public — in a shared conversation about societal values and priorities. Only through such a balanced and collaborative approach can we set limits that genuinely protect all while still enabling the essential benefits that radiation technologies can provide.

For a tangible example, the origin of the 1-in-a-million chance value for dying from cancer appears to be “drawn from a hat” initially by some National Cancer Institute scientists looking to establish a trivial risk and setting it as 1 in 100 million. This would be finalized in a rule by the FDA in 1977. Superfund managers in the 1980s began to use one in a million for EPA decisions, and this definition of “acceptable risk” would be further strengthened by the Clean Air Act (CAA) explicitly noting the Benzene rule’s adoption of this threshold. U.S. Supreme Court Justice John Paul Stevens noted “that a reasonable person might regard a lifetime risk of 1 in 1,000 as

[52] K-W. Cho et al., “ICRP Publication 138: Ethical Foundations of the System of Radiological Protection,” *Annals of the ICRP* 47, no. 1 (February 1, 2018): 1—65, https://doi.org/10.1177/0146645317746010.
[53] Jessica S Wieder, Thierry Schneider, and Nicole E Martinez, “The Three R’s of Reasonable in Radiological Protection: Relationships, Rationale, and Resources,” *Journal of Radiological Protection* 42, no. 2 (June 1, 2022): 021513, https://doi.org/10.1088/1361-6498/ac563b.

significant but 1 in 1,000,000,000 as trivial."[54] Yet again, what is reasonable? Is this person weighing this probability on a daily basis? How much exposure through occupational practices can be considered the responsibility of the worker vs the institution? Can the benefits of an activity counteract the potential harm, or must they be weighed entirely separately?

Regardless of the historical origins or scientific basis of the various risk standards, Congress has provided a clear and pragmatic path forward by specifically acknowledging the CAA standards as an approved means of risk bounding, inclusive of nuclear power. As with LNT, knowing the history of risk measures provides useful context, but does not change the fundamental reality that these measures are currently implemented and usable. While future adjustments to these measures will undoubtedly be possible, perhaps when more revealing data is available, leveraging the existing CAA framework represents the most direct and legally sound approach for the present. Given the urgent need to create a stable and predictable regulatory landscape for the nuclear industry and the limited time available to do so, adopting this established set of values is the quickest and simplest path to achieving a modernized and effective radiation protection framework.[55]

## 7. Regulatory Flexibility: A Pragmatic Alternative to Model Overhaul

A definitive scientific refutation of LNT at low doses would be exceedingly difficult and resource-intensive, requiring decades of research and millions of data points to achieve statistical certainty. The most recent estimate from the National Academies of Science would have called for nearly $1.5 billion over 15 years to possibly find a more definitive answer.[56]

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[54] John D Graham, "The Legacy of One in a Million," *Harvard Center for Risk Analysis*, Risk In Perspective, 1, no. 1 (March 1993): 2.

[55] Executive Order 14300 set a 9-month window to review existing regulations and guidance, and a 18-month window to finalize changes. These windows close February 2026 and November 2026, respectively.

[56] National Academy of Sciences, *Leveraging Advances in Modern Science to Revitalize Low-Dose Radiation Research in the United States*.

Despite acknowledgement by NCRP that other models could not be excluded, the data also does not indicate that one is more dominant at low doses. Replacing LNT now would necessitate choosing an equally uncertain model, which would inevitably lead to years of litigation and continuous debate without a clear resolution. Furthermore, introducing additional uncertainty about scientific validity into the public discourse would only serve to perpetuate public concern about nuclear safety.

Some regulators, the EPA being the most prominent, use the precautionary principle: that harm should be presupposed until the science more definitively shows safety. For harms in which causality might be more easily proven, this can be a reasonable choice until such studies can be conducted. Yet, in low-dose radiation, decades of study have yielded only small gains. Now, if the precaution is not re-evaluated, it becomes just an easy shield to hide behind: any potential harm, even if not provable, is being addressed. However, precaution is still a regulatory choice, and by not reevaluating it in the face of persistent uncertainty, we are instead valuing the prevention of small unknowable and unobservable risk in an effort to drive doses down to zero.

An overhaul or selective curation of the scientific evidence is not necessary to leverage existing regulatory discretion. Regulators already possess the authority to define "acceptable risk" and "ample margin of safety," as affirmed by court decisions such as Union of Concerned Scientists v. NRC, which noted that "'adequate protection is not absolute protection".[57] Regulators should resume the role of policy and risk management, instead of the policy decisions embedded in the application of LNT, as acknowledged by scientific organizations.

A significant legal and strategic opening for reform is provided by the previously mentioned Clean Air Act Amendments of 1990, which codified a clear, scientifically supported risk standard for hazardous air pollutants, including radionuclides.[58] This standard established a lifetime cancer risk of 100-in-one million (10^-4) to the most exposed individual as an "acceptable risk" ceiling for public health, and a lower threshold of one-in-one million (10^-6) as an "ample margin of safety" for regulatory review. As analyzed in The Breakthrough Institute's white papers

[57] Union of Concerned Scientists, Petitioner, v. United States Nuclear Regulatory Commission and United States of America, Respondents,Nuclear Utility Backfitting and Reform Group, Intervenor, 880 F.2d 552 (D.C. Cir. 1989) (U.S. Supreme Court July 25, 1989).

[58] "CAA Section 112 Risk and Technology Reviews: Statutory Authority and Methodology" (Environmental Protection Agency, December 14, 2017).

*Clarifying the Limits of Regulatory Authority Under the Clean Air Act and Implications for NRC Comprehensive Risk Standards in Part 53 Post Loper Bright Decision*, congressional approval for these values has already been given, and both the EPA and NRC have the authority to make these changes. Based on the "acceptable risk" value and the NRC's risk calculations, the public dose could be as high as 1.7 mSv (0.17 rem) using current regulatory standards.[59] Using cohesive risk terminology and values could provide a solid foundation for more harmonized regulations on radiation protection.

Another driver for reconsideration is provided by the ADVANCE Act and the NRC's recently updated mission statement. The NRC's mission now explicitly emphasizes "enabling nuclear-energy deployment for the benefit of society and the environment".[60] This represents a substantial shift from a historically narrow focus solely on protection, providing a clear mandate for the NRC to actively balance safety with the societal benefits of nuclear technology. This means that proposals for regulatory flexibility are no longer merely industry requests but align directly with the agency's clarified purpose. This legal and strategic shift creates a powerful leverage point for advocating regulatory changes, reframing them not as a compromise on safety but as a necessary evolution to fulfill the NRC's broader, congressionally mandated mission. This makes the path to regulatory reform more viable and defensible against potential challenges.

A parallel can be drawn with the management of other hazards. For instance, benzene, a known human carcinogen, is managed using an LNT model, yet regulations set reasonable thresholds for exposure based on acceptable risk, rather than driving levels to near zero.[61] Nuclear safety should adopt a similar risk-informed approach, recognizing that the increase in cancer risk from low-dose radiation is dwarfed by cancer probabilities with other initiating causes.

[59] Adam Stein, Spencer Toohill, and Matthew L. Wald, "Clarifying the Limits of Regulatory Authority Under the Clean Air Act," White Paper (Washington, D.C.: The Breakthrough Institute, June 10, 2025), https://thebreakthrough.org/issues/energy/clarifying-the-limits-of-regulatory-authority-under-the-clean-air-act; Adam Stein and Kyle Danish, "Implications for NRC Comprehensive Risk Standards in Part 53 Post Loper Bright Decision," White Paper (Washington, D.C.: The Breakthrough Institute, February 20, 2025).

[60] "ADVANCE Act of 2024," Pub. L. No. 118—67, 138 Stat. 1447 (2024).

[61] EPA, "Benzene," CASRN, Chemical Assessment Summary (Washington, D.C.: National Center for Environmental Assessment, January 19, 2000), https://iris.epa.gov/static/pdfs/0276_summary.pdf.

Regulations must also consider comparative risks, including the risks of alternative energy sources, such as pollution from fossil fuels, when setting radiation standards. Notably, the NRC's quantitative health objective (QHO) for latent cancer risk from accidents, set at two in one million per year, is even more stringent than the EPA's acceptable risk for routine operations. This implies that the NRC effectively requires reactor designs to achieve risks on their 'worst conceivable day' that are still lower than what EPA tolerates from 'everyday operations' for other hazardous air pollutants. This stark contrast highlights that the NRC has substantial headroom to modify its regulations to meet reform mandates while continuing to provide the kind of health protection envisioned by Congress. As previously mentioned, despite a single international flight having a dose of 0.04 mSv (4 mrem), the same as the annual safety guidelines for certain effluents, Congress doesn't regulate air travel for its radiation exposure (although the NAS is evaluating the need for monitoring of airline staff).[62]

# 8. Policy and Regulatory Recommendations for Modernized Radiation Protection

As advocated in our article How to Regulate Radiation Exposure[63], we are seeking to make three primary recommendations:

## The Breakthrough Institute's Recommendations

1. Risk-informed regulation: Agencies could implement more flexible risk thresholds that better balance safety with other societal benefits, rather than adopting extremely conservative lifetime risk standards. Current implementation of ALARA principles heavily leans towards ambiguous definitions of "adequate protection" which assume risks should be near zero by default, instead of "ample margin of safety" which has quantitative definitions.

[62] "Assessing Radiation Exposure Health Outcomes and Mitigation Strategies for Flight Crewmembers National Academies,"accessed July 9, 2025, https://www.nationalacademies.org/en/our-work/assessing-radiation-exposure-health-outcomes-and-mitigation-strategies-for-flight-crewmembers.

[63] Seel and Stein, "How to Regulate Radiation Exposure."

2. Contextual dose limits: A tiered system of radiation thresholds would reflect a reasonable balance of safety without undue burden. This includes setting a higher limit when doses under natural variation are not regulated and a lower level when protective actions are required within the dose rates that show the highest likelihood of not being harmful. The first tier, up to the current public dose limit, would be exempt from regulation since it is less than the dose from someone moving from one house to another or from a low elevation to a high elevation. The second two tiers would progressively increase protection for the public and then workers. Beyond that would be an occupational limit within any one year. This both reduces regulatory burden and creates a more flexible but science-based safety regime.

3. Recognition of comparative risks: Despite the administration's normal defense of fossil fuels, even the executive acknowledges that "the reality that substitute forms of energy production also carry risk, such as pollution with potentially deleterious health effects." These other risks, like particulate matter (PM) are weighed against their ubiquity, relative risk, and their emissions from industries and technologies that are otherwise beneficial for society. Regulations must consider the impact of alternatives that will be used in place, or potentially result in increasing risk to the public from more harmful sources of energy.

## 8.1 Revising Risk Definitions

One of the greatest regulatory challenges is to set terms that can provide flexibility in interpretation for difficult-to-foresee use cases, while not being so prescriptive as to constrain utility. A core issue in nuclear regulation is the NRC's historical failure to define a quantitative threshold for "adequate protection." This mandate, originating from the Atomic Energy Act (AEA), directs the NRC to ensure civilian nuclear energy use does not pose an undue risk, but the AEA itself does not define what level of risk is "adequate".[64] In this void, the NRC has treated "adequate protection" as a qualitative concept rather than a measurable standard. This leads to a regulatory framework where any risk, no matter how negligible, can be cause for full regulatory intervention, creating an inconsistent and burdensome process untethered from science and law.

[64] "Atomic Energy Act of 1954," Pub. L. No. 83—703, 68 Stat. 919 (1954).

These frameworks encourage a "lower is always better" mentality, even when risks are orders of magnitude below established health standards. The result is a system that treats all reactors, regardless of their size, design, or actual risk profile, as equally hazardous. This not only stifles innovation but also delays the deployment of safer, advanced reactors by subjecting them to a licensing process designed for much larger, higher-risk facilities.

As defined in the previous section, aligning the definition of "adequate protection" with the CAA's quantitative thresholds would ground NRC practice in statutory law, enhance regulatory efficiency, and provide public confidence that safety standards are based on a long-standing legislative norm, not arbitrary agency discretion. Adopting this clear, congressionally defined risk standard is the necessary foundation for any meaningful modernization of nuclear regulation.

Further, ALARA as a set of principles should not be wholly removed. Rather, the NRC should align its rules with the international wording of dose justification, optimization (ALARA), and limitation. Optimization does not provide the same rhetorical drive to minimize doses except where warranted. It makes sense to do actions, especially when cost and effort are low, to reduce doses because precautionary measures can give greater flexibility when exposures have to happen.

## 8.2 A New Tiered System for Dose and Action Limits

This proposed system for managing radiation dose limits aims to strike a balance between ensuring safety and avoiding unnecessary regulatory burdens. It's built on the understanding that not all radiation exposures carry the same level of risk or require the same level of oversight.

The tiered levels are proposed as:

- **Tier 1:** Background Variation or Clearance Dose (De Minimus: Up to 1 mSv)
    - This first tier would cover very low radiation doses, specifically up to the current public limit of 1 millisievert (mSv) per year.
    - Why exempt this? Doses within this range are comparable to the natural variations in background radiation that people experience every day. For example, simply moving from a low-elevation home to a high-elevation one, or from one

geographical region to another, can result in a change in natural background radiation exposure that falls within this 1 mSv range. Research has not shown strong evidence of observable effects in this range.

  - Benefit: By exempting these naturally varying, negligible doses from stringent regulation, resources can be redirected to focus on more significant exposures, making the overall safety system more efficient.

- **Tier 2:** Public Action Limit (Up to 10 mSv)
  - This tier would establish a threshold for the general public, where doses should be optimized from 1-10 mSv per year.
  - What it means: Controlling doses between 1-10 mSv (0.1-1 rem) would ensure more deliberate protective actions and heightened scrutiny, thus minimizing risk to the broader population. An action limit provides for the natural flexibility of dose rates in different regions, variability in other types of environmental factors, and the lack of statistically valid data showing risk in this dose range.
- **Tier 3:** Occupational Action Limit and Average for Workers (Up to 20 mSv)
  - The third tier would focus on occupational limits for workers who may be routinely exposed to radiation as part of their jobs. A control threshold of around 20 mSv per year averaged across 5 years would be set.
  - Rationale: This acknowledges the managed risks inherent in specific occupations involving radiation, while still providing a clear boundary for safe practice. Per ICRP recommendation over 5 years, the average dose for a worker should be less than 20 mSv
- **Tier 4:** Overall Dose Limit (50 mSv/year)
  - Beyond these tiers, an overarching occupational limit of 50 mSv per year would serve as an upper boundary for workers in any single year, ensuring operational consistency.
- **Optional Public Dose Limit** (5 mSv/year)
  - If it is deemed unacceptable to combine public and occupational dose limits by instead using optimization action limits, a new public dose limit of 5 mSv would be suggested to account for the high end of the public background exposure rate, and be a simple 10% of the maximum limit. 5 mSv is already an allowable exemption that NRC licensees can request for public exposure, showing it is

sufficiently safe for current use.

- **Exceptional Cases**
  - Sensitive populations (including children, pregnant women, certain individuals with genetic disorders, etc.) should continue having different limits. Ideally action limits control automatically since doses below 10 mSv should still be wholly protective.
  - Medical doses above 50 mSv should be specifically highlighted as being justified by the diagnostic and therapeutic potential of treatment
  - Emergency procedures should be adjusted in relevant documents, such as the EPA's Protective Action Guidance (PAG), to exceed these limits and to have more stringent requirements for mandatory evacuations based on modern research into comparative risks.

This tiered approach offers a more flexible and scientifically grounded safety regime. It aims to reduce regulatory complexity where the risk is negligible, allowing efforts to be concentrated where they provide the most significant benefit in protecting both the public and workers. Importantly, these limits maintain the international dose limitation framework. This means that in a very competitive and internationalized nuclear industry, changes to US standards should not disadvantage American companies. This gives flexibility within the US regulatory environment, and as one of the largest voices in the world, this is a reasoned push for change. If, as some have suggested, the US were to pick a limit like 100 mSv (10 rem), at the statistical limit of detection for health effects, all current regulations would be useless, which is the goal, but no other country in the world would accept such an immense deviation from the rest of the globe. The point of this framework is reasonable change. While some of these thresholds could, in all likelihood, be raised even higher, this plan would be demonstrably safe, adhere to the limitation values currently in place, and provide regulatory reprieve justified by science in numerous areas, most especially in the clean-up and decommissioning of reactors, and certain planning procedures for new reactors.

Having a joint public and occupational limit with differential action limits is the most distinctive aspect of these suggestions. The intention behind this is that the action limits should provide sufficient controls to maintain the health and safety of members of the public who are involuntarily exposed, with the greater agency that workers have in choosing their roles, but are also constrained by the needs of their particular work. Further, this could help reduce the sense of imminent danger that many members of the public have related to radiation exposure, especially to medical treatments. Optimizing doses should keep levels below these limits anyway, but it provides a more reasonable set of guidelines that keeps risk low while acknowledging the various ways one might be exposed to radiation through life circumstances, location choices, and occupational choices.

## 8.3 Comparative Risk and Risk Communication

When discussing energy production and its safety, it's crucial to acknowledge the concept of comparative risks. As is often highlighted, even with a strong focus on traditional energy sources, it's recognized that "the reality that substitute forms of energy production also carry risk, such as pollution with potentially deleterious health effects."[65] This statement underscores a fundamental truth: no energy source is entirely risk-free. Whether it's particulate matter (PM) from fossil fuels, high-level spent fuel associated with nuclear power, or the manufacturing footprint of renewables: each option presents its own set of challenges that must be weighed carefully. These other risks, like PM emissions, must be considered in light of their ubiquity, relative risk compared to alternatives, and their origins from industries and technologies that provide significant benefits to society. Fossil fuel PM emissions alone might contribute to 10 million premature deaths per year, but societies facing a lack of energy to produce food, clean water, and life-saving goods could lose many more.[66]

This recognition leads to a vital point: regulations and public discourse must proactively consider the relative benefits alongside the risks. A technology or industry might pose certain risks, but its contribution to societal well-being—such as providing reliable power for hospitals, enabling economic stability, or supporting medical advancements that rely on related technologies—can be immense. Restricting one energy source without fully accounting for the risks and benefits of its alternatives can lead to unintended consequences, potentially forcing

[65] Trump, Ordering the Reform of the Nuclear Regulatory Commission.
[66] Karn Vohra et al., "Global Mortality from Outdoor Fine Particle Pollution Generated by Fossil Fuel Combustion: Results from GEOS-Chem," *Environmental Research* 195 (April 1, 2021): 110754, https://doi.org/10.1016/j.envres.2021.110754.

reliance on more harmful or less reliable energy sources. A balanced regulatory framework, therefore, should not only aim to reduce risks but also to optimize the overall societal outcome, including the benefits derived from the energy supplied.

Ultimately, effectively navigating these complex trade-offs requires a significant improvement in risk communication. Simply presenting raw risk numbers (like "1 in a million") often fails to convey the full picture or resonate with public understanding. Instead, communication needs to focus on helping the public grasp the comparative nature of risks—how the risk of one energy source stacks up against others, including the status quo or less desirable alternatives. This involves contextualizing risks, explaining the benefits that accrue from accepting certain levels of risk, and fostering a public dialogue that moves beyond fear-based reactions to informed decision-making. By transparently explaining the risks and benefits of all options, we can empower individuals and communities to participate more effectively in shaping energy policies that truly serve the common good.

Improved strategies are needed to accurately convey the scientific evidence regarding the risks and benefits of low-dose radiation to both workers and the public, as well as the benefits of nuclear energy. This is essential to address the disproportionate fear of radiation that often reduces the adoption of beneficial nuclear technologies. Guidance documents should be updated to reflect current scientific understanding and provide context about natural background radiation, moving away from language that suggests quantifiable risk at all dose levels. Clear and open communication around nuclear topics has been a challenge since the inception of the atomic age, and governments have often failed in their role to adequately inform the public[67] With the modern public support for new nuclear technologies, transparency and proactive outreach will continue to be essential.

## 8.4 Targeted Research and Development

[67] United States. Congress. Joint Committee on Atomic Energy, *The Nature of Radioactive Fallout and Its Effects on Man : Hearings before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, Congress of the United States, Eighty-Fifth Congress, First Session on the Nature of Radioactive Fallout and Its Effects on Man May 27, 28, 29, and June 3, 1957* (Washington : Govt. Print. Off, 1957), http://archive.org/details/b32177148_0001.

As previously mentioned, the National Academies estimate that achieving greater certainty regarding low-dose responses will require an additional 10-15 years and $1.5 billion of research. The LSS, INWORKS, and MPS studies will all continue collecting information (although in the next few decades, we will lose the last survivors of the atomic bombings). However, there is no guarantee that even these substantial cohorts will provide data that provides substantial reductions in uncertainty. Given the current substantial population sizes, and the general benefits of maintaining substantial reference populations for data, these projects should all continue.

The current focus in radiobiology should be better ascertaining DNA repair mechanisms and how they respond to external hazards, such as ionizing radiation. This is basic research that can inform many other potential discoveries, including cancer prevention and life extension. This work could be further enabled by the new advancements being pioneered with FDA support into "organ on a chip" technology, where local tissue and organ effects can be mimicked in controlled environments. These kinds of studies are cross-cutting and will reduce some of the uncertainty at the microscopic level.

## 8.5 Gold Standard Science

The White House Office of Science and Technology Policy (OSTP) recently released guidance on "Gold Standard Science," outlining a commitment to scientific integrity. These standards are defined as:

> *Gold Standard Science represents a commitment to the highest standards of scientific integrity, defined by nine core tenets: reproducible; transparent; communicative of error and uncertainty; collaborative and interdisciplinary; skeptical of its findings and assumptions; structured for falsifiability of hypotheses; subject to unbiased peer review; accepting of negative results as positive outcomes; and without conflicts of interest. These tenets ensure that federally-supported research, and research used in Federal decision-making, is transparent, rigorous, and impactful, enabling Federal decisions to*

*be informed by the most credible, reliable, and impartial scientific evidence available.*[68]

This guidance was released in response to an executive order on the topic, and especially from an administration that might, at times, appear skeptical of certain modern scientific conclusions, also provides reasonable assurance of scientific integrity. These definitions are directly applicable to the ongoing research into LNT.

Further scientific evaluation of the LNT model, in particular, can find a political and scientific balance by engaging with these Gold Standard Science tenets. Despite its many detractors, the LNT model continues to be supported by prominent institutions, such as the NRC, EPA, and NCRP. The NRC has only been asked to "reconsider" the LNT model, not commanded to throw it out.[69] Future research, by embracing reproducibility, transparently communicating uncertainties, and maintaining skepticism of even long-held assumptions, can provide clearer insights into low-dose radiation effects. This rigorous, collaborative, and peer-reviewed approach ensures that advancements in understanding, whether they reinforce, refine, or eventually challenge existing models, are built on the most credible scientific foundation, ultimately leading to more robust and ethically sound radiation protection policies.

## 8.6 Harmonization of Radiation Protection Standards

Executive Order 14300 asked the NRC to "specifically consider adopting determinate radiation limits, and in doing so shall consult with the Department of Defense (DOD), the Department of Energy (DOE), and the Environmental Protection Agency."[70] This is a long-overdue action. Part of the reason the Clean Air Act amendments occurred as they did was due to frustration with the NRC's processes, as well as the complex mixture of responsibilities spread among federal agencies for nuclear topics. This should be addressed more comprehensively in the scale of regulatory change, but the executive order offers a new set of impetus. Pursuant to both the Clean Air Act and Reorganization Plan No. 3, which founded the EPA, it was to assume primary responsibility

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[68] Michael J Kratsios, "Agency Guidance for Implementing Gold Standard Science in the Conduct & Management of Scientific Activities," Memorandum, June 23, 2025.

[69] Trump, Ordering the Reform of the Nuclear Regulatory Commission.

[70] Trump.

for control of radiological hazards.[71] In some ways, the EPA has fulfilled this role in its comprehensive environmental standards and all of the subcommittees of the Interagency Steering Committee on Radiation Standards (ISCORS) are run by their staff. However, as evidenced by the restrictive policies, with dose limits among the lowest of any agency, they have a strong conservative manner of regulating exposure. The NRC had to prove that its 25 mrem exposure met EPA standards by stating that ALARA practice brought them below the 15 mrem standard of the Agency, at levels that were at most six times below the average background rate. The executive order and the expertise the NRC has in dose assessment and its role as a safety regulator make it the ideal organization to lead a renewed effort at harmonization. Radiation is a physical hazard; there should not be such variation between regulatory bodies. Either ISCORS or some other federally mandated collaboration, with the renewed NRC at the fore, should standardize radiation safety standards and limits, with provisions to ensure fragmentation does not happen in the future.

## 9. Conclusion: Realizing the Full Potential of Nuclear Technologies

This report advocates for a balanced, science-informed approach to radiation protection, moving away from an overly conservative interpretation of the LNT model towards pragmatic regulation. One does not need to throw away the LNT model to change the manner in which it is applied. Dose optimization remains a prudent approach, made all the more useful by having a definitive point at which to stop. The preponderance of scientific evidence indicates that an annual dose limit of 50 mSv (5 rem) or less does not result in detectable increases in adverse health outcomes across diverse human populations and exposure scenarios. Furthermore, substantial evidence supports the conclusion that even 100 mSv (10 rem)/year would maintain a reasonable safety margin based on available epidemiological and radiobiological data, but limits should provide a reasonable margin from when risk definitively begins.

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71 "Reorganization Plan No. 3 of 1970," Federal Register §, accessed March 19, 2025, https://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title5a-node35-leaf129&num=0&edition=prelim.

Radiation protection frameworks, as currently practiced, will only reinforce an overly protective regime that inspires greater concern about nuclear technology than science would ever suggest. Regulatory reform is a strategic imperative, not just a deregulatory measure. The proposed changes are poised to transform the landscape for nuclear applications, improving the cost-competitiveness of nuclear energy, reducing waste management and cleanup costs, expanding access to life-saving nuclear medicine procedures, and enhancing industrial applications. This framing works within scientifically-supported safety and elevates the discussion beyond mere cost-cutting to unlock the full potential of a critical technology for national and global benefit.

The recommended changes outlined in this review represent a prudent evolution of radiation protection standards. By aligning them with current scientific understanding, the United States can realize the full potential of nuclear technologies while maintaining appropriate safety margins for workers and the public. This balanced approach will ensure that America's world-leading safety record is preserved, even as unnecessary burdens are eliminated where science indicates minimal concern, ultimately benefiting the nation's energy, healthcare, and industrial needs. If we are to realize the promise of nuclear energy, this is where we must begin.

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# Appendix A

**Table of Current and Proposed Dose Limits**

Table 2 provides a concise overview of the current and proposed radiation dose limits across these U.S. agencies.

**Table 2: Current vs. Proposed Radiation Dose Limits (Occupational and Public) by U.S. Agency**

| Agency | Current Occupational Limit (mSv (rem)/year) | Proposed Occupational Limit (mSv (rem)) | Current Public Limit (mSv (mrem)/year) | Proposed Public Limit (mSv (rem)) | Key Regulatory Citations (Example) |
|---|---|---|---|---|---|
| NRC | 50 mSv (5 rem) | 20 mSv action limit (2 rem) averaged over 5 years, 50 mSv (5 rem) in any one year (with 1 mSv (100 mrem) de minimus) | 1 mSv (100 mrem) | 10 mSv action limit (1 rem), 50 mSv (5 rem) in any one year (with 1 mSv (100 mrem) de minimus) | 10 CFR Part 20 |
| DOE | 50 mSv (5 rem) (Administrative control limit of 20 mSv (2 rem)) | 20 mSv action limit (2 rem) averaged over 5 years, 50 mSv (5 rem) in any one year (with 1 mSv (100 mrem) de minimus) | 1 mSv (100 mrem) | Should refer to NRC guidance | 10 CFR Part 835 |

| | | | | | |
|---|---|---|---|---|---|
| EPA | Defers to NRC/DOE | – | 0.1-0.25 mSv (10-25 mrem) (facility/pathway specific) | May include specific environmental standards, but should be based on NRC dose limits | 40 CFR Parts 61, 141, 190, 197 |

Note: Proposed occupational and public limits include establishing a *de minimus* dose of 1 mSv (100 mrem) below which no regulatory action or ALARA requirements apply. Specific pathway limits (e.g., airborne, drinking water) for EPA would be adjusted proportionally to the new public dose framework.

# Appendix B

List of Federal Codes that Require Harmonization

To implement these revised limits and foster a more risk-informed approach, specific modifications to the regulatory frameworks of the EPA, NRC, and DOE are necessary.

**U.S. Environmental Protection Agency (EPA)**

The EPA's complex, multilayered framework of radiation protection standards often exceeds the stringency of NRC and DOE requirements, particularly for public exposures. Harmonizing these standards with scientific evidence and proposed NRC/DOE changes would provide significant regulatory relief and align with the risk thresholds established in the Clean Air Act.

- **40 CFR Part 190—Environmental Radiation Protection Standards for Nuclear Power Operations (40 CFR 190.10—Standards for Normal Operations)**: Harmonize with the revised public dose limits of 20 mSv (2 rem) averaged over five years, with a limit of 50 mSv (5 rem) in any one year, and a *de minimus* dose of 1 mSv (100 mrem). Adopt the TEDE methodology and set a single consistent limit.
- **40 CFR Part 61—National Emission Standards for Hazardous Air Pollutants (NESHAP) (40 CFR 61.92—Standard)**: Increase the limit for airborne emissions of radionuclides to align proportionally with the revised public dose framework, with doses below 1 mSv (100 mrem) being *de minimus*.
- **40 CFR Part 141—National Primary Drinking Water Regulations (40 CFR 141.66—Maximum Contaminant Levels for Radionuclides)**: Increase the limit for beta particle and photon radioactivity in drinking water proportionally with the revised public dose framework, with doses below 1 mSv (100 mrem) being *de minimus*.
- **40 CFR Part 197 - Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada (40 CFR 197.20/25/30)**: Increase the limit of exposure within 10,000 years to align with the revised public dose framework, especially noting that doses to the maximally exposed individual below 1 mSv (100 mrem) are de minimus. If this position is not updated, it should be struck before analysis of another geologic repository to not affect

the preparation of new regulatory guidance.

**Nuclear Regulatory Commission (NRC)**

For **10 CFR Part 20—Standards for Protection Against Radiation**, specific modifications are proposed:

- **10 CFR 20.1201—Occupational Dose Limits for Adults**: Establish a *de minimus* dose of 1 mSv (100 mrem) below which no regulatory action or ALARA requirements apply. For occupational exposures, establish a joint maximum dose of 20 mSv (2 rem) averaged over five years, with a limit of 50 mSv (5 rem) in any one year. Tissue-specific limits should be proportionally adjusted.
- **10 CFR 20.1101—Radiation Protection Programs**: Modify this section to exempt doses below 1 mSv (100 mrem) from all ALARA requirements. For exposures that could reasonably be expected to exceed 1 mSv (100 mrem) but remain below the occupational limits, licensees shall apply ALARA principles to reduce doses to the extent practicable, focusing on preventing exposures above scientifically justified limits.
- **10 CFR 20.1301—Dose Limits for Individual Members of the Public**: Establish a *de minimus* dose of 1 mSv (100 mrem) for individual members of the public, below which no regulatory action or ALARA requirements apply. For exposures above this *de minimus* level, the public dose limit should be set at a joint maximum dose of 20 mSv (2 rem) averaged over five years, with a limit of 50 mSv (5 rem) in any one year.
- **10 CFR 20.1302—Compliance with Dose Limits for Individual Members of the Public**: Adjust methodologies to align with the revised public dose limits of 20 mSv (2 rem) averaged over five years and 50 mSv (5 rem) in any one year, including proportionally increasing concentration values in Appendix B to Part 20 and streamlining compliance-demonstration methods. Doses below 1 mSv (100 mrem) should be exempt from compliance demonstration.
- **10 CFR 20.2104—Determination of Prior Occupational Dose**: Strengthen requirements for tracking cumulative dose over 5-year periods to ensure compliance with the 20 mSv (2 rem) averaged over five years, and 50 mSv (5 rem) in any one year limits.

NRC Regulatory Guides would also require revision. **Regulatory Guide 8.8** and **8.10** should be revised to encourage ALARA principles only for activities where exposures could reasonably approach or exceed the occupational limit, restructuring guidance around a graded approach to radiation protection.

**Regulatory Guide 8.29** should be updated to reflect current scientific evidence regarding thresholds for observable health effects, providing a balanced view of epidemiological evidence and context about natural background radiation, eliminating language suggesting quantifiable risk at all dose levels.

**U.S. Department of Energy (DOE)**

For **10 CFR Part 835—Occupational Radiation Protection**:

- **10 CFR 835.202—Occupational Dose Limits for General Employees**: Align with NRC, establishing a *de minimus* dose of 1 mSv (100 mrem) below which no regulatory action or ALARA requirements apply. For occupational exposures, establish a joint maximum dose of 20 mSv (2 rem) averaged over five years, with a limit of 50 mSv (5 rem) in any one year.
- **10 CFR 835.101—Radiation Protection Programs**: Modify to exempt doses below 1 mSv (100 mrem) from ALARA requirements. For exposures that could reasonably be expected to exceed 1 mSv (100 mrem) but remain below the occupational limits, radiation protection programs should focus on compliance with dose limits, managing higher-risk activities, and providing appropriate training and monitoring.
- **10 CFR 835.1001—Design and Control**: Revise to focus design requirements on preventing exposures above the regulatory limit, providing flexibility for low-dose areas.
- **DOE Order 458.1—Radiation Protection of the Public and the Environment**: Increase public-dose limit to align with the proposed framework of 20 mSv (2 rem) averaged over five years, with a limit of 50 mSv (5 rem) in any one year, and a *de minimus* dose of 1 mSv (100 mrem).

DOE Technical Standards and Guidance Documents, such as **DOE-STD-1098-2017, Radiological Control**, and **DOE G 441.1-1C, Radiation Protection Programs Guide**, should be revised to align with the modified regulatory approach, eliminating requirements for continuous dose reduction below regulatory limits and focusing on prudent radiological practices.