Estimation of Cost Reduction From Risk-Informed Radiation Standards

12/18/2025

Executive Summary

This analysis provides an initial estimation of the potential cost savings associated with increasing the U.S. public radiation dose limit from 100 mrem/year to 500 mrem/year and modifying or removing the As Low As Reasonably Achievable (ALARA) requirement from NRC regulations and related guidance or limiting the application of ALARA to only doses above 100 mrem/year. The analysis develops a bounding range for potential cost reductions using the best publicly available information.

A range of deployment and cost scenarios was evaluated to capture uncertainty in technology readiness, regulatory implementation, and industry response. Results vary significantly by reactor type, degree of redesign effort undertaken, and the extent to which associated regulations are modified or clarified.

Across the evaluated scenarios, total estimated savings range from $200 million—$40 billion for new construction, with approximately 0-20% derived from reduced plant capital and operational costs, and 0-10% from reduced regulatory compliance and oversight costs. Combined with the savings from the current fleet, total estimated savings range from $4 billion to $70 billion.

Realized savings are not guaranteed and will depend on many factors, especially industry implementation. A stable policy environment is necessary to encourage implementation. Potential savings are further limited by other regulations that separately set lower limits.

Introduction

The purpose of this analysis is to explore the potential economic impacts of risk-informed U.S. radiation protection standards. Facilities that possess or utilize special nuclear material are regulated by several federal agencies, primarily the Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC).[1] These agencies issue operating licences for research, industrial, or commercial purposes and enforce radiation protection standards that influence plant design, operations, and regulatory compliance.

The NRC and DOE use a dose-based framework. Protection relies on dose limits intended to provide adequate protection. Operational decisions are guided by ALARA, which uses a cost-benefit framework to optimize exposures.

The regulations include worker and public annual exposure limits and requirements to reduce exposure As Low As Reasonably Achievable (ALARA). Despite regulatory limits of 5,000 mrem/year for workers, actual exposures have been driven substantially lower due to current ALARA requirements. Most of the closely monitored nuclear workers receive no measurable annual dose, and those who do receive a dose average only 2% of the occupational limit (See Figure 1). The average measurable dose has remained consistent over the last 20 years.

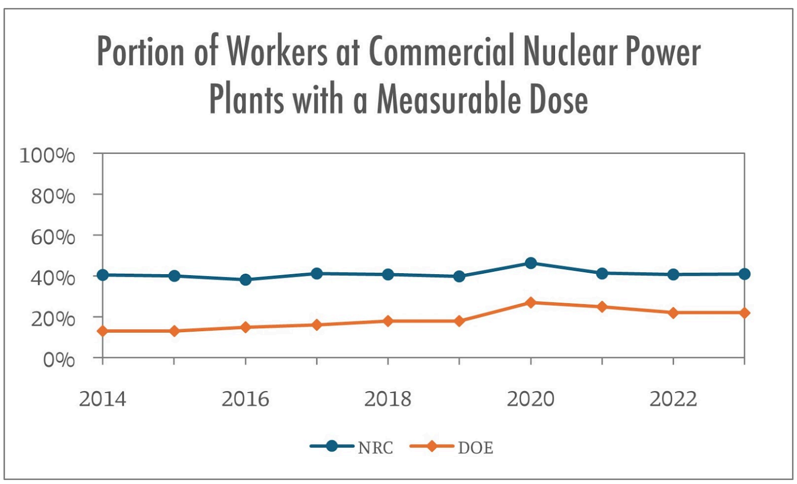

Figure 1. *Portion of monitored commercial power plant workers and monitored DOE workers who receive any measurable dose in a year. The value is consistently around 40% of workers for NRC facilities and 20% for DOE facilities.*[2]

[1] P.J. Seel and Adam Stein, The Breakthrough Institute, *The Current State of Radiation Protection in the United States*, 2025, https://thebreakthrough.org/issues/nuclear-energy-innovation/the-current-state-of-radiation-protection-in-the-united-states.

[2] Values calculated from data in Table 3-1, U.S. Nuclear Regulatory Commission, *Occupational Radiation Exposure at Commercial Nuclear Power Reactors and Other Facilities 2023*, NUREG-0713 Volume 45, 2025,

The public, at a greater distance, behind barriers, with environmental dilution, cannot receive more than the workers themselves. The average American receives about 620 mrem (6.2 mSv) per year from natural background and medical imaging.[3] Living near a nuclear power plant typically adds less than 1 mrem (0.01 mSv) per year, which is comparable to the radiation exposure one receives from a few hours of air travel.

While many previous studies have addressed the scientific basis of low-dose radiation protection, relatively few have quantified the operational and economic consequences of current standards. This analysis aims to provide a high-level, first-order estimate of potential cost savings to industry, regulators, and ultimately electricity consumers.

The Breakthrough Institute has previously recommended a tiered action and dose limit system to improve the implementation of radiation protection, with risk-informed limits based on reasonable windows of limitation for ALARA given uncertain risks at low doses.[4] INL has suggested reverting to the historic public dose limit of 500 mrem (1959-1977) and removing ALARA as a regulatory requirement.[5] Optimization practices are generally still assumed to occur, just within the scope of individual plant procedures rather than a federal requirement.

This paper specifically analyzes the implications of increasing the allowable public dose limit from 100 mrem/year to 500 mrem/year and removing or modifying ALARA as a regulatory requirement. These proposed changes could alter facility design requirements, licensing processes, plant operations, and radiation protection programs.

Methodology

The Linear No Threshold (LNT) model assumes that no level of radiation exposure is safe. The prevailing use of the LNT model and the requirement to achieve ALARA exposure causes licensees to implement a wide range of values for radiation protection in excess of NRC standards (See Figure 2).

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https://www.nrc.gov/docs/ML2519/ML25191A324.pdf; and reproduced from Exhibit 3-5 in Department of Energy Occupational Radiation Exposure Reports 2018 and 2023, https://www.energy.gov/sites/default/files/2020/01/f70/2018_Occupational_Radiation_Exposure_Report_0.pdf.

[3] National Council on Radiation Protection and Measurements, Ionizing Radiation Exposure of the Population of the United States, NCRP Report No. 160, https://ncrponline.org/publications/reports/ncrp-report-160/.

[4] Seel, PJ and Adam Stein. Breakthrough Institute. *Drawing the Line: The Linear No-Threshold Model, and When are Doses Too Small to Matter?* 2025, https://thebreakthrough.org/issues/energy/drawing-the-line.

[5] Kanter, Seth et al. Idaho National Lab. *Reevaluation of Radiation-Protection Standards for Workers and the Public Based on Current Scientific Evidence*. 2025, https://www.osti.gov/biblio/2584359.

Revising regulations for a risk-informed approach, where requirements are scaled commensurate with the level of risk, will entail lower regulatory hurdles, fewer inspections, and lower costs. Plants, for example, will have lower expenditures on their Radiation Protection Programs, and less will be spent on inspections.

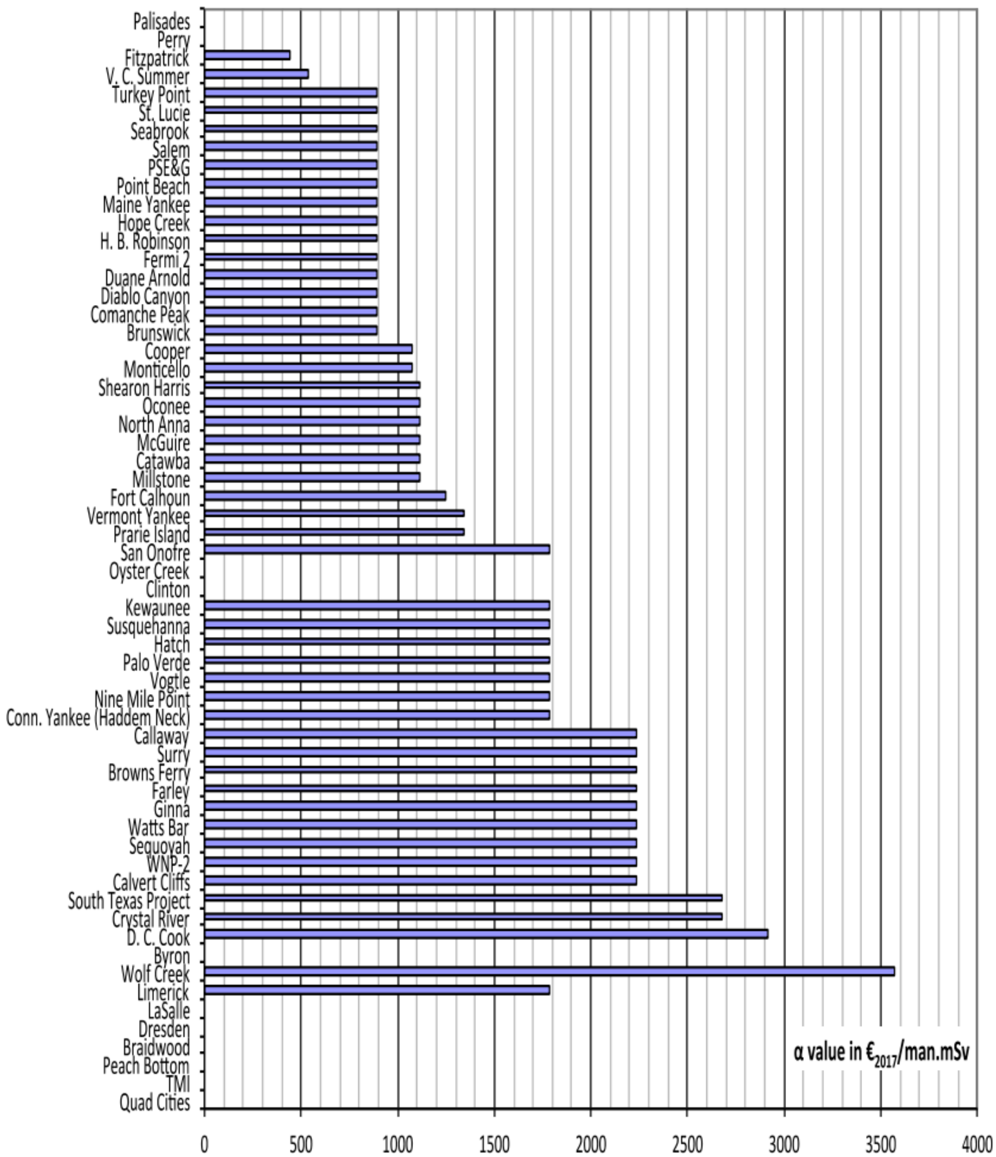

Figure 2. *Monetary value used for radiation reduction programs in Euro/man.mSv reported by U.S. nuclear power plants as of 2015.*[6,7]

[6] For reference, collective radiation dose is expressed in person-millisieverts (man·mSv), where 1 man·mSv = 0.1 person-rem. Values expressed in euros per person-millisievert (€/man·mSv) are therefore equivalent to approximately $11,100 per rem for €1,000/man·mSv, using an exchange rate of €1 ≈ $1.11 (2015 exchange rate).

[7] See, Nuclear Energy Agency Information System on Occupational Exposure, Survey on the Values and Uses of the Monetary Value of the Man.Sievert (in 2017), ISOE European Technical Centre - Information Sheet No. 61, 2018, Page 8,

Model and Data

The analysis develops a bounding range for potential cost reductions using the best publicly available nuclear power plant cost values and deployment scenarios published in an Idaho National Laboratory (INL) report.[8] This report also provides the cost and deployment values used in the Annual Technology Baseline, which is widely used by researchers and energy system professionals.[9] An additional scenario was created to reflect current federal goals and policy by scaling deployment curves from the Idaho National Laboratory study as needed.

The model uses cost data as collected in the INL report. Four types of reactors were included: a large PWR, a small modular PWR, a sodium fast reactor, and a high-temperature gas-cooled reactor, each with a 25% market share with respect to capacity in all the scenarios. The scenarios modeled have a base scenario assuming 0.5 GW of new nuclear deployment will be completed by 2030 from the two ARDP projects (TerraPower Natrium and X-Energy XE-100). The 2030 scenario assumes ten large PWRs (AP 1000s) under construction by 2030 and operational by 2037. In Table 1, the capacity associated with all deployment scenarios is based on INL's capacity projections plus the 2030 base scenario. The 300 GW by 2050 scenario is scaled accordingly to meet the administration's goal.

Table 1*. Deployment scenarios through 2050 of new nuclear power plant construction in gigawatts (GW) of capacity.*

Year	INL Conservative	INL Moderate	INL Advanced	300 GW by 2050
2030	2	2	2	2
2035	7	9	20	29
2040	13	19	68	97
2045	16	27	134	191
2050	22	44	210	300

All the scenarios assume regulatory change. The capital costs are calculated based on the assumption that regulations will change due to risk-informed radiation standards. Therefore, the operational costs calculated do not include reductions for new plants to avoid double-counting because those costs would not be incurred under the new regulations.

https://isoe-network.net/publications/pub-resources/pub-info-sheet/etc-information-sheets/etc-61/3848-etc-61/file.html.

[8] Abou-Jaoude, et al., Gateway for Accelerated Innovation in Nuclear, *Meta-Analysis of Advanced Nuclear Reactor Cost Estimations*, 2024, https://doi.org/10.2172/2371533.

[9] National Renewable Energy Laboratory, *Annual Technology Baseline*, 2024, https://atb.nrel.gov/electricity/2024/nuclear.

Capital Costs

Costs to comply with regulatory requirements are embedded in the design and operation of a nuclear power facility. New plants, not existing ones, will see the cost savings from changing designs. Some capital costs can be reduced by adjusting the design to reflect a 500 mrem/year public exposure standard. Opportunities for cost reductions would primarily come from reduced shielding, redesigning plants to be above-grade instead of underground, or eliminating some effluent recapture systems.

ALARA is an operational program, not a design principle. Many designs still consider how to reduce exposure to workers, for example, by routing piping separately from worker pathways. However, the cost difference, if any, is difficult to estimate and outside the scope of this study.

The savings to the total cost were calculated as a percentage of Overnight Capital Cost (OCC) by adjusting the values under the "Structures and Improvements" and "Capitalized Pre-Construction Costs" categories. The model assumes a 5.65% WACC[10] and a 7-year construction period.

Cost scenarios were developed to represent the potential for each reactor type. More mature designs, such as the AP1000, are less likely to undergo significant redesign and relicensing efforts. Cost reductions are considered for multiple designs across low, mid, and high cases.

Table 2. *Percentage reductions for Capitalized Pre-Construction Costs based on cost scenarios.*

Scenario	HTGR	SFR	SMR PWR	Large PWR
Low	0%	0%	0%	0%
Mid	5%	5%	5%	5%
High	10%	10%	10%	10%

Capitalized Pre-Construction Costs include pre-application engagement, licensing, siting, and other costs occurring before the issuance of the construction permit. Structures and Improvements potentially include a reduction in steel, concrete, shielding, and other materials, plus any labor resources; the bulk of the savings from design choices occur in this category. We assume reductions of 0 to 10% in the former category and 0 to 20% in the latter.

[10] See, National Renewable Energy Laboratory, *Annual Technology Baseline*, 2024, https://atb.nrel.gov/electricity/2024/nuclear. Real WACC under nuclear reductions in steel, concrete, shielding, and other materials, plus ar Market Factors is used.

Table 3. *Percentage reductions cost scenarios for Structure and Improvements by design.*

Scenario	HTGR	SFR	SMR PWR	Large PWR
Low	5%	5%	0%	0%
Mid	10%	10%	7%	5%
High	15%	15%	20%	8%

Operation Costs/Radiation Protection Costs

The two ALARA modification options are modeled as a single scenario. Cost savings will be primarily from low doses, up to 100 mrem/year, and covered by both options. Worker doses at the high level of the ALARA range will continue to be addressed by plant operational procedures.

For the existing fleet, data on direct radiation program costs is not available and considered business-sensitive information. Estimated reductions in radiation exposure are also not available to estimate costs based on willingness-to-pay or $/person-rem values in regulatory guidance. To estimate current costs, expert solicitation was used to estimate the portion of non-fuel operating costs attributable to radiation protection programs and personnel, resulting in values of 2%, 5%, and 15% for low, mid, and high costs, respectively (see Table 4 below). Values for non-fuel operating expenses from the Energy Information Administration (EIA) from 2014-2024 were averaged to reduce uncertainty.[11] The EIA data is provided in mills/kWh and was converted to a per-reactor cost based on a capacity factor of 93% and an assumed capacity of 1000 MW per reactor.

Additional reductions in costs were assumed by lowering the amount paid by the licensees in annual license costs to the NRC. This covers the portion of fees that goes to inspectors, the Radiation Protection Office, and inspection processes.

Limitations

There are significant limits on available technical design and high-fidelity cost information. Most cost values are top-down extrapolations from historical data or bottom-up economic estimations based on broad material content and lack clarity on production costs, profit margin compared to quoted values, and other factors. Differences in costs are likely to exist across markets and states, depending on market structures or if the reactors were owned and/or operated by non-utilities. Additionally, it was outside the scope of this analysis, and beyond the

[11] Energy Information Agency, Table 8.4. Average Power Plant Operating Expenses for Major U.S. Investor-Owned Electric Utilities, 2014 through 2024 (Mills per Kilowatthour), https://www.eia.gov/electricity/annual/html/epa_08_04.html.

data available, to recalculate all shielding values and determine which specific structures could be redesigned and to what extent.

The model brings in scenarios based on the most recent deployment and cost studies and national policies. Scenarios are projections, and, as such, are limited in their predictive knowledge. The model uses four reactor designs in the deployment scenarios; the reality is that there could be many more reactor designs being deployed over the next 25 years, and those deployments are unlikely to be evenly distributed across the designs.

The model assumes ranges of acceptance and implementation of new regulations. It does not estimate the cost of re-design engineering or regulatory work to implement physical or licensing changes. Very little information is publicly available for the licensee's radiation protection program costs, as such information is kept proprietary by operators, utilities, and the Institute of Nuclear Power Operations (INPO).

Results

Based upon the FY2025 Final Fee Rule, the total annual fee per license is $5,645,000 for operating reactors.[12] This amount represents the full cost of NRC licensing and oversight activities allocated to each operating unit. However, the NRC does not provide a public breakdown of how these fees correspond to specific regulatory or technical programs. As a result, it is not possible to isolate the portion of the annual fee attributable solely to radiation protection activities, including the inspections, documentation reviews, and other related program oversight. Such limitations constrain the extent to which annual licensing fees can be used to estimate regulatory cost reductions from modifying dose limits and ALARA. Therefore, the analysis focuses on categories where cost drivers can be more clearly identified and quantified.

Table 4 shows the potential operational cost savings (avoided costs) if ALARA is removed or limited to a range, public dose limits are increased, and associated regulatory limits are updated accordingly. The potential savings from radiation protection programs range from $1.7 to $13 million per GW. These costs likely fluctuated over time as regulatory person-rem guidance has changed, prevailing wages for the workforce have increased, and opportunities to reduce worker exposure have changed.

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[12] U.S. Nuclear Regulatory Commission, FY 2025 Final Fee Rule Work Papers, https://www.nrc.gov/docs/ML2512/ML25129A153.pdf

Table 4. *Savings on annual operational costs by removing or modifying ALARA, increasing public dose limits, and associated regulatory limits (in millions USD).*

Avoided Cost Scenario	Portion of Non-fuel Operating Costs	Annual Cost per GW	U.S. Commercial Units (94)
Low	2%	1.7	163
Mid	5%	4.3	406
High	15%	13.0	1218

If regulatory costs are removed, the operational costs of advanced fossil-fuel plants could serve as a floor for nuclear power plant costs. According to EIA data,[13] non-fuel operating costs for fossil fuel plants are 40-50% lower than those incurred by nuclear plants. The assumption that removing or setting a lower threshold for ALARA could reduce operating costs by 2-15% is well within reasonable bounds.

Data for plant- and country-specific radiation protection plans were compiled from a report by the Information System on Occupational Exposure (ISOE).[14] ISOE contacted the INPO and nuclear power plants directly to ask about expenditures on radiation protection. On average, expenditures at U.S. nuclear power plants were much higher than in other countries, ranging from $5,000/person-rem to $80,000/person-rem in 2017 dollars.

For comparison, Japan spends as little as $5,000/person-rem (€445/man.mSv); France, $7,303/person-rem (€650/man.mSv); and Switzerland, $3,607/person-rem (€273/man.mSv).[10] This suggests that costs related to radiation protection programs in other countries could have significantly reduced costs while still meeting radiation protection limits.

Savings Scenarios and Outcomes: New Construction and Current Fleet

Due to the limitations of the model, there was no accurate estimation of cost savings solely related to ALARA, nor solely related to increasing the public dose limit for projected scenarios. For the existing fleet, increasing the public dose limit does not provide extra savings from the

[13] Energy Information Agency, Table 8.4. Average Power Plant Operating Expenses for Major U.S. Investor-Owned Electric Utilities, 2014 through 2024 (Mills per Kilowatthour), https://www.eia.gov/electricity/annual/html/epa_08_04.html.

[14] Nuclear Energy Agency Information System on Occupational Exposure, Survey on the Values and Uses of the Monetary Value of the Man.Sievert (in 2017), ISOE European Technical Centre - Information Sheet No. 61, 2018, https://isoe-network.net/publications/pub-resources/pub-info-sheet/etc-information-sheets/etc-61/3848-etc-61/file.html.

structures and systems because those were already constructed. Therefore, the existing fleet savings are only from removing or modifying ALARA.

Results in Table 5 were calculated using the savings for each design type times the number of reactors needed for each deployment scenario in 2050.

Table 5. *Savings from the capital cost of new construction based on deployment scenarios and cost scenarios (in millions USD).*

New Construction Scenario	INL Conservative	INL Moderate	INL Advanced	300 GW by 2050
Low	219	437	2,088	2,971
Mid	1,405	2,809	13,379	19,067
High	2,980	5,960	28,396	40,480

Table 6 lists the calculated operational cost savings based on the cost and deployment scenarios based on Table 4. Specifically for Table 6, cost savings were calculated by annualized savings times 25 years.

Table 6. *Cumulative savings from the operational cost of the current fleet based on deployment scenarios and cost scenarios (in millions USD).*

Existing Fleet Savings Scenario	Savings to 2030	Savings to 2050
Low	813	4,065
Mid	2,030	10,152
High	6,091	30,456

When accounting for the already existing fleet, reductions in operating expenditures further increase the cost savings. As shown in Table 7, the total savings significantly increased when accounting for savings across the existing fleet. Table 7 shows the overall savings combining the results in Table 5 and Table 6.

Table 7. Combined savings from the capital cost of new construction and the operational costs from the current fleet, based on deployment scenarios and cost scenarios (in millions USD).

Combined Cost Scenario	INL Conservative	INL Moderate	INL Advanced	300 GW by 2050
Low	4,284	4,503	6,153	7,037
Mid	11,557	12,961	23,531	29,219
High	33,436	36,416	58,852	70,936

Capital reductions are made assuming the regulations are changed, and therefore, operational costs do not include reductions for new plants, because if there are avoided costs, it is not clear what those costs would be. New deployments cannot accrue savings for costs they never incurred.

Conclusion

The results show that raising the dose limit to 500 mrem/year and modifying or removing ALARA could yield potentially significant savings for future nuclear power plants on the order of $16 billion through 2050 if current federal deployment goals are met, with a range of $200 million to $40 billion. Combined with the savings from the current fleet, total savings can range from $4 billion to $70 billion.

Significant uncertainties exist due to data availability, deployment outcomes, and future regulatory implementation. A bounding approach was used to account for uncertainties rather than ignore them.

These first-order bounding estimates are dependent on financial estimates, assumptions that licensees will adjust internal practices to reflect regulatory revisions, and continued federal support and goals to achieve deployment scenarios. However, this analysis indicates there is potential for significant savings for nuclear power facilities and, ultimately, for ratepayers.