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Comments on the U.S. Environmental Protection Agency's Proposed Rule for the Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada Submitted on Behalf of the Institute for Energy and Environmental Research

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The following are the comments on the U.S. Environmental Protection Agency's proposed rule for the public health and environmental radiation protection standards for the high-level waste repository proposed for construction at Yucca Mountain[1], henceforth referred to as the "proposed rule", on behalf of the Institute for Energy and Environmental Research (IEER). Based upon the analysis and comments presented below, it is our conclusion that the proposed rule should be rejected as insufficiently protective of the public health. The following comments contain specific criticisms of the proposed rule issued by the EPA as well as IEER's recommendations for a more equitable and scientifically justifiable regulatory standard.

Summary of Main Findings:

It is our conclusion that the proposed rule is the worst radiation protection rule that has ever been proposed given that it is the first rule that actually implies a massive increase in the level of cancer risk. We have identified a number of areas in which the proposed rule is seriously deficient, including:

A. Relaxation of radiation protection standards for future generations who will not benefit from nuclear power plants that produced the waste is contrary to basic ethics, cost-benefit analysis principles, and internationally accepted radiation protection guidelines, including for radioactive waste. These widely accepted guidelines include those by the International Atomic Energy Agency and the International Commission on Radiological Protection and radiation protection authorities in other countries. This has been recognized by scientific bodies, including the National Academy and in the past by the EPA.

B. Indoor radon is a technological artifact and not part of natural background. Excluding the indoor radon component, but retaining all other aspects of the EPA proposed rule, would lower the limit from 350 mrem to approximately 100 mrem per year.

C. The Toxic Substances Control Act recognizes that indoor radon is an artifact of building construction and sets a long-term goal of reducing radon levels indoors to those experienced outdoors. Hence, including the present level of indoor radon in natural background is contrary to the intent of this law.

[1] EPA 2005

D. No country has proposed a standard as lax as that proposed by the EPA. No other standard that has been proposed for times beyond 10,000 years would allow such lax long term rules.

E. The proposed peak dose limit would pose a lifetime cancer incidence risk of 1 in 36 for the general population and 1 in 30 for women. EPA has previously stated that even 1 in 250 lifetime risk is unacceptable from a single facility.

F. The use of the median to set a dose limit from a combined distribution is inappropriate. The best estimate of the mean dose (give all uncertainties) would be considerably higher than the median. The 95th percentile dose of about 2 rem per year would create a lifetime fatal cancer risk for women of about 1 in 10 and a cancer incidence risk of about 1 in 5. This would make the proposed standard statistically about like Russian roulette rather than a radiation protection rule at least for some people.

G. The proposed standard is not in conformity with Executive Order 13045 for the protection of children because it fails to account for the disproportionate risk from radiation for exposures early in life.

IEER recommends that the EPA issue a final standard for the Yucca Mountain repository that includes the following elements:

1. The annual dose limit for all pathways should be between 10 and 25 millirem and should remain constant in time over the period of geologic stability at the site.
2. A separate sub-limit of 4 millirem per year to the most exposed organ from the drinking water pathway should be included over the entire period of geologic stability.
3. The radiological impacts on children should be explicitly considered in the Department of Energy's performance assessments in order to ensure that they are not disproportionately affected by the repository.
4. The impacts of future changes in climate should be taken into account explicitly in the DOE's performance assessments including the consideration of periodic cycling through different climate states on the performance of the isolation system.
5. The standard should recognize that the uncertainties in the estimated doses will increase with time and that the uncertainties beyond 10,000 years will become very significant. In this regard, therefore, we propose that the EPA adopt the French approach to waste repository standards[2] in which the doses beyond 10,000 years are calculated using scientifically reasonable, but highly conservative choices for the important parameter values in order to increase confidence that the ultimate impacts from the repository will be less than those predicted.

Section One – Setting the "Acceptable" Level of Risk for Distant Generations:

The U.S. Environmental Protection Agency's proposed Yucca Mountain standard is the worst radiation protection rule that has ever been proposed by a regulatory body given that it is the first rule that would codify the acceptability of a massive increase in the risk of cancer from the exposure to anthropogenic radiation. It also represents the largest lifetime cancer risk that has knowingly been proposed for members of the general public, especially women, by the US government. Over the last five decades, radiation protection standards for the public have been progressively tightened because, as more information has been gained, the risks of exposure to radiation have been recognized to be higher and higher. This trend continues to this day. For example, the BEIR VII report from the U.S. National Academy of Sciences published in 2005 reports cancer incidence risks per unit of exposure that are more than one-third larger than the values reported by the EPA in its Federal Guidance Report 13 published in 1999.[3]

As summarized by the National Research Council in its 1995 *Technical Bases for Yucca Mountain Standards*, dose limits for exposure to radiation from a single source in Nuclear Regulatory Commission and Environmental

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[2] Règle Nº III.2.f

[3] NAS/NRC 2005 p. 28 and EPA 1999 p. 182

Protection Agency regulations are typically in the range of 15 to 25 millirem per year. This range corresponds to an excess annual risk of developing a fatal cancer of approximately 8.6×10^{-6} to 1.4×10^{-5}, while the risk of developing a cancer irrespective of its lethality would be approximately twice these values.[4] Lower annual dose limits have been set in certain circumstances (for example a dose limit of 10 millirem per year from airborne radionuclides except radon is included in the National Emission Standards for Hazardous Air Pollutants and a 4 millirem per year dose limit for beta/gamma emitters in drinking water is included in the National Primary Drinking Water Standards). However, higher dose equivalents corresponding to an annual fatal cancer risk of up to 4×10^{-4} have been included in regulations and recommendations for exposure to indoor radon levels and for mill tailings.[5] The National Research Council committee also noted that "the risk equivalent of the dose limits set by authorities outside the United States is also in the range of 10^{-5} to 10^{-6} per year (except for exposure to radon indoors or releases from mill tailings)" and that "[t]his range is a reasonable starting point for EPA's rulemaking."[6]

The Yucca Mountain standard that EPA is now proposing, however, includes the following two-tier dose limit

> Compliance will be judged against a standard of 150 microsievert per year (15 millirem per year) committed effective dose equivalent at times up to 10,000 years after disposal and against a standard of 3.5 millisievert per year (350 millirem per year) committed effective dose equivalent at times after 10,000 years and up to 1 million years after disposal.[7]

The 350 millirem per year dose limit is 14 times higher than the dose limit contained in NRC regulations governing the disposal of low-level radioactive waste and more than twenty times higher than the dose limit previously proposed by the EPA as being protective of the public health (i.e. 15 millirem per year). Using the risk factors from the National Academy of Sciences BEIR VII report, we find that the excess cancer risk for an individual that would be exposed to 350 millirem per year over a 70 year lifetime would be more than 1 in 36. The risk to women from this level of exposure would be even greater, approximately 1 in 30. These risks are unacceptably high. As discussed in section three below, the EPA's choice of the median dose for determining compliance with the 350 millirem per year dose limit means that the upper bound doses actually received could be significantly higher.

In attempting to answer the question of what level of risk is acceptable, we must bear in mind the following central feature of the problem; namely that spent nuclear fuel is generated from nuclear power plants that provide us, the present generation, with electricity, and therefore we are getting the benefits from nuclear power, but the costs associated with the impacts of spent fuel disposal will be borne by generations far into the future. In fact, the peak impacts are not expected to occur for tens to hundreds of thousands of years. The implicit ethic in the EPA's proposed relaxation of the standard from 15 millirem to 350 millirem per year at 10,000 years is that the present generation should get all the benefits and pay the least costs, but generations far into the futures should get none of the benefits and pay the heaviest costs. This is undemocratic, unethical, and against any reasonable social norms. It is also against any reasonable concept of cost-benefit analysis.

It is therefore imperative that whatever the level of radiation dose is ultimately set that it should not increase over time. At worst it should stay constant and at best it should get more stringent. We recognize that making the level of protection provided to future generations more stringent than currently accepted radiation protection norms would be a difficult exercise. Therefore we accept that a standard for radiation protection for Yucca Mountain from now until the peak dose should be uniform and should reflect the level of radiation protection that we expect today. This principle is a generally accepted tenet of many radiation protection schemes that have been proposed by both national and international bodies. For example, in its 1999 *Radiation Protection Recommendations as Applied to the Disposal of Long-lived Solid Radioactive Waste,* the International Commission on Radiological Protection concluded that

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[4] Despite the higher cancer incidence risk estimates contained in the BEIR VII report, its average fatal cancer risk estimate is approximately equal to that used in the EPA Federal Guidance Report 13 due to the BEIR VII committee's assumptions regarding improved survival rates for cancer. (NAS/NRC 2005 p. 28 and EPA 1999 p. 179) From a public health perspective the correct value to consider is the risk of developing cancer not just the risk of dying from cancer.

[5] NAS/NRC 1995 p. 50

[6] NAS/NRC 1995 p. 5

[7] EPA 2005 p. 49014

> The principal objective of disposal of solid radioactive waste is the protection of current and future generations from the radiological consequences of waste produced by the current generation. However, permanent total isolation is not likely to be achievable and some fraction of the waste inventory may migrate to the biosphere, potentially giving rise to exposures hundreds or thousands of years in the future. Doses to individuals and populations over such long time-scales can only be estimated and the reliability of these estimates will decrease as the time period into the future increases. **Nevertheless, the Commission acknowledges a basic principle, that individuals and populations in the future should be afforded at least the same level of protection from actions taken today as is the current generation.**[8]

The ICRP went on to note that

> Nevertheless, the Commission recognises a basic principle that individuals and populations in the future should be afforded at least the same level of protection from the action of disposing of radioactive waste today as is the current generation. **This implies use of the current quantitative dose and risk criteria derived from considering associated health detriment.** Therefore, protection of future generations should be achieved by applying these dose or risk criteria to the estimated future doses or risks in appropriately defined critical groups.[9]

In its 2005 draft Safety Standard entitled *Geological Disposal of Radioactive Waste*, the International Atomic Energy Agency included the following among their nine "Principles Of Radioactive Waste Management"

> *Principle 4: Protection of future generations*
> **Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today**
>
> *Principle 5: Burdens on future generations*
> Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.[10]

A number of other examples of the acceptance of this principle can be found. For example, in her presentation to the National Research Council committee, Margaret Federline [of the U.S. Nuclear Regulatory Commission] spoke about a "societal pledge to future generations" that would "provide future societies with the same protection from radiation we would expect for ourselves."[11] Michael P. Lee and Malcolm R. Knapp of the Office of Nuclear Material Safety and Safeguards in the U.S. Nuclear Regulatory Commission have stated that "[a] basic premise here [in defining an adequate level of safety] is that the standards should ensure that future generations are afforded the same level of protection we are afforded today."[12] Sören Norrby, the director of the Office of Nuclear Waste in the Swedish Nuclear Power Inspectorate, has stated that

> **One principle that is generally accepted is that we should offer the same level of protection to future generations as we require today.** The effects in different time frames must then be evaluated, and should in principle cover time periods during which the waste remains hazardous.[13]

Finally, Allan Duncan, the head of the Radioactive Substances Function at the U.K. Environment Agency, has noted that

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[8] ICRP 81 p. 13 (emphasis added)
[9] ICRP 81 p. 23
[10] IAEA 2005 p. 43 (emphasis added)
[11] NAS/NRC 1995 p. 56
[12] NEA 1997 p. 48
[13] NEA 1997 p. 22 (emphasis added)

For the purpose of implementing Government policy on radioactive waste management, and after extensive consultation, the environment agencies have prepared Guidance on Requirements for Authorisation of Disposal Facilities on Land for Low and Intermediate level Radioactive Wastes. Amongst other things this Guidance sets out principles and requirements for disposal of low and intermediate level wastes in the first instance but it has regard to the presence of long-lived radionuclides in the wastes and so, in due course, will be broadly applicable also to the disposal of high level wastes.

The essential principles are as follows:

…

Principle No. 2 - Effects in the future

Radioactive wastes shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.[14]

In the past, the EPA has been extremely specific about what it believes to be the level of risk from exposure to anthropogenic radiation that is acceptable today. In an April 1997 statement on the Nuclear Regulatory Commission's standard governing licensing termination which set a 25 millirem per year dose limit with the potential for exposures to go up to 100 millirem per year under certain conditions, Ramona Trovato, the Director of the EPA's Office of Radiation and Indoor Air, concluded that "a cancer risk of 1 in 250" would be "simply unacceptably high."[15] The EPA's statement went on to conclude that

> This draft rule [from the Nuclear Regulatory Commission] would not ensure adequate protection of the public health and the environment. It would not provide the public the level of protection from residual radioactive materials from NRC licensees that they are afforded for other environmental pollutants under EPA's remediation programs, including those that involve radioactive materials.[16]

An August 1997 memorandum from Stephen D. Luftig, the Director of EPA's Office of Emergency and Remedial Response, and Larry Weinstock, the Acting Director of the EPA's Office of Radiation and Indoor Air, reiterated these conclusions and included an analysis which stated that the 25 to 100 mrem per year dose limit proposed by the NRC was considered to "present risks that are higher than levels EPA has found to be protective for carcinogens in general and for radiation, in particular, in other others contexts."[17]

In setting previous regulatory standards, the EPA has repeatedly taken the position that a lifetime incremental risk greater than 1 in 10,000 would be unacceptable. This level of "acceptable" risk has been codified in the National Emission Standards for Hazardous Air Pollutants, the National Primary Drinking Water Standards, and the guidelines for cleanup of sites under the Comprehensive Environmental Response, Compensation, and Liability Act.[18] In addition, the draft federal radiation protection guidance proposed by the EPA on December 24, 1994 also specified a goal of limiting the lifetime risk from exposure to cancer to less than 1 in 10,000.[19] Finally, this level of "acceptable" risk is implicit in the use of the 15 millirem per year dose limit for Yucca Mountain during the first 10,000 years.

This issue was also addressed the National Research Council in its 1995 analysis of the Yucca Mountain standard. The NRC committee stated that

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[14] NEA 1997 p. 61 (emphasis in the original)
[15] Trovato 1997 p. 4
[16] Trovato 1997 p. 11-12 (emphasis in the original)
[17] Luftig and Weinstock 1997 Attachment B p. 7
[18] Fed Reg April 21, 2000 p. 21580, Fed Reg December 7, 2000 p. 76710 and 76716, Fed Reg March 8, 1990 p. 8716, Fed Reg December 15, 1989 p. 51655 to 51657, 51670, 51677, and 51688, and 40 CFR 300 2005 p. 70
[19] Trovato 1997 p. 5 and Fed Reg December 23, 1994

> Whether posed as "How safe is safe enough" or as "What is an acceptable level of risk?", the question is not solvable by science alone. The rulemaking process, directly involving public comment to which an agency must respond, is an appropriate method of addressing the question of an appropriate level of protection. Accordingly, we do not directly recommend a level of acceptable risk. We do, however, describe the spectrum of regulations already promulgated that imply a level of risk, all of which are consistent with recommendations from authoritative radiation protection bodies.
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> For example, EPA has already used a risk level of 5 x 10^{-4} health effects in an average lifetime, or a little less than 10^{-5} effects per year, assuming an average lifetime of 70 years, as an acceptable risk limit in its recently published 40 CFR 191. This limit is consistent with other limits established by other U.S. nuclear regulations, as shown in Table 2-4 [not shown]. In addition, the risk equivalent of the dose limits set by authorities outside the United States (shown in Table 2-3) [not shown] is also in the range of 10^{-5} to 10^{-6}/yr (expect for exposure to radon indoors or releases from mill tailings). This range could therefore be used a reasonable statting point in EPA's rulemaking.[20]

The tables cited in the NRC report show that the highest level of "acceptable" risk relates to the EPA's recommendations for the indoor radon level which result in an annual risk of 4 x 10^{-4} (about twice the annual risk of developing a fatal cancer from exposure to 350 millirem per year).[21] This fact is noted by the EPA in the proposed Yucca Mountain standard. The proposed rules states that

> The concentration at which EPA recommends action be taken to mitigate exposures is 4 pCi/l, which translates roughly to 800 mrem/yr. The Agency further recommends that homeowners consider taking action only if the measured concentration is between 2 and 4 pCi/l (i.e., above 400 mrem/yr).[22]

However, as the proposed rule goes on to clearly state

> It should be understood that this recommendation [regarding the mitigation of indoor radon] is not based solely on risk, but considers factors such as the voluntary nature of the exposure, the application to private property, and the capabilities of mitigation technology.[23]

Thus, the recommended action levels for indoor radon, which takes these multiple factors into consideration, is not a valid comparison for the determination of what constitutes an acceptable level of risk being imposed involuntarily on distant generations that gain no benefit either individually or societally from the exposures. The far more generally applied level of "acceptable" risk of 10^{-5} to 10^{-6} should serve as the basis for determining whether future generations are being given at least the same level of protection as is considered acceptable for the present generation. This choice is consistent with the conclusions of both the International Commission on Radiological Protection and the International Atomic Energy Agency which have both recommended using a risk equivalent of 10^{-5} per year as a reference value in setting limits for the geologic disposal of high-level waste.[24]

As noted above, the level of risk corresponding to the proposed 350 millirem per year dose limit would be far higher than what the EPA has previously considered to be acceptable in other contexts involving involuntary risks from exposures to carcinogens, including radiation. In attempting to address this conflict the proposed rule notes that

> It is clear that we struggled to reconcile the competing claims of confidence in projections and intergenerational equity. We sought an approach that would account for what we see as potentially

[20] NAS/NRC 1995 p. 49
[21] NAS/NRC 1995 p. 5, 43-46, and 50 and NAS/NRC 2005 p. 28
[22] EPA 2005 p. 49038
[23] EPA 2005 p. 49038
[24] ICRP 81 p. 23 and IAEA 2005 p. 11

> unmanageable uncertainties, but did not depart from levels of risk that are considered protective today.[25]

And later that

> We believe the circumstances involved in today's proposal are significantly different from the situations addressed under Superfund or any other existing U.S. regulatory program, and that it should be clear that comparisons between the two are inappropriate.
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> …Rather, in establishing a standard to apply to the RMEI over unprecedented times, we believe it is reasonable to consider exposures incurred routinely today by people in other locations, which in our view do not "pose a realistic threat of irreversible harm or catastrophic consequences" to those people.[26]

However, comparisons between these regulatory frameworks are not only appropriate, but clearly inline with the international consensus regarding the need to protect future generations to at least the same level that we protect the present one. While there is ongoing debate over how to best implement this goal, there is broad agreement over the need to adequately implement it. The existence of large uncertainties in repository performance at long times is not a valid argument for relaxing the level of protection afforded to future generations. The 1 in 71 lifetime risk of death from cancer (1 in 62 for women) that would accompany exposure to 350 millirem per year, should certainly qualify as a "realistic threat of irreversible harm" under any reasonable interpretation. The rejection by the EPA of the international consensus regarding the appropriate level of protection to be afforded future generations (such as by its assertion that "there is no clear consensus regarding the extent of the claims held by future generations on the current generation"[27]) is a serious problem with the proposed rule. A dose limit that does not increase with time is a necessary element of any final standard issued by the EPA.

Section Two – The Inclusion of Radon with "Natural" Background Radiation:

In the proposed Yucca Mountain standard, the EPA states that

> For purposes of this discussion, natural background radiation consists of external exposures from cosmic and terrestrial sources, and **internal exposures from indoor exposures to naturally-occurring radon**. Altitude and geology are two of the primary variables accounting for regional variations; however, there can be tremendous fluctuation even within a city or county, primarily due to variations in radon emissions.[28]

The inclusion of indoor radon levels as part of "natural background radiation" is not scientifically correct and fails to take into account both the letter and the spirit of current U.S. law (see below). This inappropriate inclusion of radon has led the EPA to draw erroneous conclusions regarding the regional variation in background exposures as part of the proposed rule.

The "average annual effective dose equivalent to individuals in the U.S. population" as estimated by the National Council on Radiation Protection and Measurements includes 200 millirem from radon and its decay products and 100 millirem from other sources such as cosmic rays and the ingestion of primordial radionuclides.[29] The DOE has estimated that the exposure of people in the Amargosa Valley is equal to the average exposure reported by the NCRP, while the EPA has estimated a higher radon dose of 250 millirem per year.[30]

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[25] EPA 2005 p. 49032
[26] EPA 2005 p. 49038
[27] EPA 2005 p. 49036
[28] EPA 2005 p. 49037 (emphasis added)
[29] NCRP 93 p. 59-60
[30] EPA 2005 p. 49037

The exposure to indoor radon, which accounts for two-thirds of the average population exposure in the United States, is, however, a result of human activities and not a result of natural processes alone. As noted by the National Research Council in 1999

> Many human activities – such as mining and milling of ores, extraction of petroleum products, use of groundwater for domestic purposes, and **living in houses** – alter the natural background of radiation either by moving naturally occurring radionuclides from inaccessible locations to locations where humans are present or by concentrating the radionuclides in the exposure environment.[31]

The National Research Council considered indoor radon to be a "technologically enhanced naturally occurring radionuclide [TENORM]."[32] The treatment of other TENORM from a radiation protection standpoint is thus illustrative in the present context. For example, playground equipment and fences contaminated with TENORM waste from the oil industry containing radium has been found at a number of locations in Mississippi and Louisiana. Earlier, a Federal Court held Chevron Oil liable for damages to workers at a salvage company for Chevron's failure to conduct adequate inspections of the equipment and to warn the workers about the possible risks.[33] Exposure to these TENORM materials were not considered to be natural background exposure despite the fact that the radionuclides involved were all naturally occurring. The EPA has itself referred to indoor radon as a technologically enhanced naturally occurring radionuclide and has highlighted the mechanisms by which the construction of homes and other buildings cause radon to build up to higher levels than would be experienced outside.[34] Because this exposure to indoor radon is a result of human activity, it is scientifically incorrect to combine it with the exposure to unavoidable background sources such as cosmic rays. Comparing indoor radon to background radiation is like comparing taking a shower to getting wet from rain.

Further, the inclusion of doses from indoor radon by the EPA in the proposed rule ignores the fact that, since 1988, it has been an explicit long-term goal in U.S. law to reduce exposures to indoor radon to the level of outdoor radon. Specifically, the Toxic Substances Control Act states that

> The national long-term goal of the United States with respect to radon levels in buildings is that the air within buildings in the United States should be as free of radon as the ambient air outside of buildings.[35]

It is reasonable to assume that this goal could be met within the next few hundred years as the building stock in turned over and that, therefore, long before 10,000 years, the average population exposure to the US population will have been reduced to something closer to 100 millirem per year from its current value of 300 millirem per year. Thus the inclusion of radon doses in the proposed rule appear to be inconsistent with both the spirit and the letter of this section of the law.

Following the passage of the section of the Toxic Substances Control Act in which the "national long-term goal" was set forth, the NCRP issued a report on radon control technologies in which they concluded that

> The information presented in this report shows that there is a variety of methods available for the control of radon inside houses. All systems can be effective when properly installed, but the best performance is achieved by active soil ventilation techniques. For new houses being planned or under construction, the installation of barriers between the soil and the house can be very effective. Properly done, this approach will solve the problem for the duration of the use of the house.[36]

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[31] NAS/NRC 1999 p. 1 (emphasis added)
[32] NAS/NRC 1999 p. 1-3 and 19-22
[33] EPA 2000 p. 37
[34] EPA 2000 p. 35-40, EPA 2001 p. 14-16, and EPA 2003 p. 2
[35] 15 USC 2661
[36] NCRP 103 p. 60

The EPA is aware of this legally mandated goal, and, since 1994, has published technical advice for how to limit radon levels in new and existing homes as well as in new schools and other large buildings.[37] In fact, the EPA's 2005 *Citizen's Guide To Radon: The Guide To Protecting Yourself And Your Family From Radon* notes that

> Radon reduction systems work and they are not too costly. Some radon reduction systems can reduce radon levels in your home by up to 99%. Even very high levels can be reduced to acceptable levels.[38]

Already, people living in well-constructed buildings on upper floors are exposed to indoor radon at a level that is not significantly different from outdoor levels.

Significantly, the exclusion of indoor radon from the assumed background radiation level is consistent with the recommendations of the International Commission on Radiological Protection. In its 1990 recommendations, the ICRP excluded the contribution from indoor radon in its choice to use 100 millirem per year as the typical average "annual effective dose from natural sources."[39] The ICRP was even more explicit in its view on this matter in its draft 2005 recommendations. In this report the ICRP stated that

> The Commission considers that the annual effective dose from natural radiation sources, and its variation from place to place, is of relevance in deciding the levels of maximum constraints that it now recommends. The existence of the natural background of radiation does not provide any justification for additional exposures, but it can be a benchmark for judgement about their relative importance and the need for action. **The Commission uses the background dose without the radon contribution because that component is significantly enhanced by human activities and is thus subject to recommendations from the Commission for its control at home and at work.[40]**

The Commission went on to caution that "[e]xposures that are within the natural background range are legitimate matters for concern, sometimes calling for significant action."[41]

There is no scientific or legal basis for the EPA to consider exposures to indoor radon as part of natural background radiation. The proposed rule has not cited any and has not addressed legal and scientific view to the contrary. The final rule should exclude the contribution of indoor radon from its discussion and use a reasonable value for natural background radiation of about 100 millirem per year as estimated by the National Council on Radiological Protection for the U.S. population and in line with the recommendations of the International Council on Radiological Protection for a global average. The use of 100 millirem would also be consistent with the estimated exposure from non-radon sources for people living in the Amargosa Valley reported by the DOE. The existence of this background radiation does not provide a justification for any increase in the allowable level of exposure for this or future generations.

Section Three – Statistical Considerations:

The EPA has proposed that the 15 millirem per year dose limit for the first 10,000 years be measured against the "arithmetic mean" of the projected doses while the 350 millirem per year dose limit for the period between 10,000 to 1 million years would be measured against "the median of the distribution of projected doses."[42] The use of the median dose for times beyond 10,000 years means that half of the calculated doses from the DOE models would be greater than 350 millirem per year, while the other half will be less that 350 millirem per year. As the EPA has noted, the distribution in the projected doses results from the uncertainties involved in the assumptions in the model

[37] See for example EPA 1994, EPA 2001, and EPA 2003
[38] EPA 2005b p. 3
[39] ICRP 60 p. 45
[40] ICRP 2005 p. 41
[41] ICRP 2005 p. 42
[42] EPA 2005 p. 49041 to 49046

of the system's performance. In light of those uncertainties, it is quite likely that significant portions of the population at the time of peak dose could experience doses far higher than 350 millirem per year. In fact, previous assessments of the Yucca Mountain site conducted by the National Academy of Sciences, Sandia National Laboratories, and the Electric Power Research Institute estimated peak doses on the order of several rem to several tens of rem or more were possible.[43]

The EPA has justified the use of the median by saying that it does not want the high values of dose to affect what it calls the "central tendency" of the distribution. Specifically, it notes that

> In fact, for early occurrences of disruptive events (human intrusion or igneous intrusion), DOE assessments show that at some periods of time the arithmetic mean of the projected doses can exceed the 95th percentile of the distribution of TSPA [Total System Performance Assessment] results.[44]

However, what the proposed rule dose not accurately take into account is that over the time periods of actual interest to the standard (i.e. less than 10,000 years and between 100,000 and 1 million years) the projected dose distributions are well behaved with the 95th percentile larger than the mean which is, in turn, larger than the median of the distribution.[45] Specifically, for times less than 10,000 years the peak 95th percentile dose for the proposed action is more than seven times higher than the peak mean dose while for times out to one million years the peak 95th percentile dose is more than four times higher than the peak mean dose. Reading off the graphs of projected doses in the DOE Final EIS, we can also estimate that the peak median dose at long times will be about a factor of three or four less than the mean.[46]

The well behaved nature of the distributions of projected doses over both short and long times is due to the fact that the peak doses are not dominated by "disruptive events," but by the natural processes of water infiltration, waste package corrosion, and radionuclide transport to the biosphere.[47] There is thus no scientific justification for accepting the use of the mean for times less than 10,000 years as representative while rejecting the mean dose at very long times. This conclusion is supported by the ICRP's *Radiation Protection Recommendations as Applied to the Disposal of Long-lived Solid Radioactive Waste*, which states that

> As general guidance, the Commission considers that its recommendations on the estimation of exposures in Publication 43 [*Principles of Monitoring for the Radiation Protection of the Public*] apply. **The Commission therefore continues to recommend that exposures should be assessed on the basis of the mean annual dose in the critical group**, i.e. in a group of people representative of those individuals in the population expected to receive the highest annual dose, which is a small enough group to be relatively homogeneous with respect to age, diet, and those aspects of behaviour that affect the annual doses received.[48]

In making use of different statistical measures for the dose limits, the proposed rule increases the disparity between the level of protection provided to distant generations compared to the present generation. Already the 350 millirem per year dose limit for times greater than 10,000 years is more than 23 times the 15 millirem per year dose limit for times less than 10,000 years. Taking into account the additional difference introduced by the choice of statistical measures would make the long-term dose limit about 70 times or more greater than that which is considered acceptable today. We recognize that the process of calculation is probabilistic and, therefore, there cannot be guarantees for everyone in the literal sense. But, if a statistical approach is used for the long-term, there is a strong case to be made that, whatever the value of the standard, the part of the probability distribution for the dose limit should not be the median or even the mean, but the 95th or 99th percentile, so that the vast majority of the population can be assured of protection. We recognized that the DOE projections of dose estimates are the result of Monte Carlo realizations and do not directly represent doses to fractions of the population. However, if the median of such

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[43] SDA 1995 p. 9
[44] EPA 2005 p. 49043 to 49044
[45] DOE FEIS 2002b p. I-77 to I-78
[46] DOE FEIS 2002b p. I-48 to I-49 and I-77 to I-78
[47] DOE FEIS 2002 p. 5-19 to 5-20 and 5-23
[48] ICRP 81 p. 14 (emphasis added)

realization is 350 mrem per year, the uncertainties in the parameters will create a significant likelihood that a large portion of the population will be exposed to more than that, and some exposed to much more. Given that the uncertainties at the high end of the doses are significant, the mean exposure could be much higher, perhaps several times higher, that the median. Hence, while considerably less than half the exposed population would be expected to be exposed to levels several times higher than 350 mrem/year, the risks to them would be very high indeed.

The large uncertainties at the high end can be interpreted as representing a significant chance that a small proportion of the population would be exposed to high levels or that there is a small chance that large numbers of people could be exposed to them at the time that the highest doses would occur. The interpretation would depend on the specifics of the scenarios that are being run. For instance, a 95 percentile value of peak dose of about 2 rem per year, which can be inferred from official DOE and contractor estimates,[49] could create great risk a small minority of exposed people. For women exposed to this level of radiation it would create lifetime fatal cancer risks would 1 in 10 and incidence risk would be about 1 in 5. This would make the proposed standard statistically about like Russian roulette rather than a radiation protection rule at least for some people. On the other hand, it can be interpreted as a small chance of creating very large risks for large numbers of exposed people, which is also unacceptable.

The final standard that is adopted by the EPA should not be set in a manner that would likely result in a significant portion of the population getting doses higher than the specified limit, particularly when the risks from such exposures are as unacceptably high as those in the rule currently proposed by the EPA. Proper standards should be set in a manner that reasonably insures protection of the entire population.

Section Four – The Treatment of Climate Change:

Over the timescales under consideration for geologic disposal of spent nuclear fuel, the climate at the Yucca Mountain site will be expected to pass through a number of natural climate cycles as well as experience the impacts of anthropogenic climate change due to the buildup of greenhouse gases in the atmosphere. As described by the Department of Energy in 2002

> Estimates of future climatic conditions are based on what is known about the past, with consideration given to climate impacts caused by human activities. Calcite in Devils Hole, a fissure in the ground approximately 40 kilometers (25 miles) southeast of Yucca Mountain, provides the best-dated record of climate changes over the past 500,000 years. The record shows continual variation, **often with very rapid jumps**, between cold glacial climates (for the Great Basin, these are called pluvial periods) and warm interglacial climates similar to the present. Fluctuations average 100,000 years in length.[50]

However, despite this record of past climate changes stretching back half a million years (including evidence for “very rapid jumps” between different states), the EPA’s proposed rule states that

> We are proposing today that DOE, based on past climate conditions in the Yucca Mountain area, should determine how the disposal system responds to the effects of increased water flow through the repository as a result of climate change. **We believe that the nature and extent of climate change can be reasonably represented by constant conditions taking effect after 10,000 years out to the time of geologic stability.** We are proposing to explicitly require that DOE assume water flow will increase as a result of climate change. We leave it to NRC as the licensing authority to specify the values to be used to represent climate change. However, we expect that a doubling of today’s average annual precipitation beginning at 10,000 years and continuing through the period of geologic stability would provide a reasonable scenario, given NAS’s statements regarding potential effects on recharge. NRC could also use the range of projected precipitation values for different climate states and specify a reasonable long-term average precipitation based

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[49] A number of official dose calculations are reproduced in SDA 1995, p. 9. See, for instance, the 1994 Sandia probabilistic results for peak dose.
[50] DOE FEIS 2002 p. 5-12 (emphasis added)

> on the duration of each climate state over the period of geologic stability. We believe that either approach will allow for a reasonable estimate of how water will impact the site without subjecting the assessments to speculative assumptions that may well be unresolvable, while providing a reasonable indicator of disposal system compliance.[51]

This treatment of climate change in the EPA's proposed rule is scientifically incorrect, will tend to underestimate the impacts from the disposal of spent fuel in the repository, and does not appear to be consistent with the recommendations of the 1995 National Research Council review as required by federal law.

In the executive summary to its *Technical Bases for Yucca Mountain Standard*, the NRC committee stated that

> We further conclude that the probabilities and consequences of modifications by climate change, seismic activity, and volcanic eruptions at Yucca Mountain are sufficiently boundable that these factors can be included in performance assessments that extend over this time frame [one million years].[52]

Later in the report, the NRC committee elaborated on the treatment of climate change that it felt should be included in the performance assessments and noted that

> Recent research has indicated that the past 10,000 years are probably the only sustained period of stable climate in the past 80,000 years. Based on this record, it seems plausible that the climate will fluctuate between glacial and interglacial states during the period suggested for the performance assessment calculations. Thus, the specified upper boundary, or the physical top boundary of the modeled system, should be able to reflect these variations (especially in terms of ground water recharge).[53]

Thus, the use of a constant value as proposed by the EPA would not be consistent with the NRC committee recommendations that the "probabilities and consequences" of future climates changes are sufficiently well understood to allow the "variations" in water infiltration to be taken into account. In fact, the DOE performance assessments as presented in the *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* published in 2002 already explicitly took into account the variation in future climate changes in its prediction of doses out to one million years.[54]

Beyond the issue of whether the proposed rule is consistent with the recommendations of the National Research Council as required, the use of a constant or average infiltration rate for the period from 10,000 to one million years is not scientifically valid and would not accurately represent the impacts of climate change on the performance of the repository. The response of the geologic system to increases in available water is not a simple linear one in which increased infiltration rates lead to a proportional increase in water flux through the repository. As summarized by Jane Long of the University of Nevada, Reno and Rod Ewing of the University of Michigan in 2004

> At present, there is no accepted conceptual model that explains the travel times and can consequently be used to infer the flux. If climate change were to produce a larger influx of water, saturation in the mountain could increase. Permeability under any proposed model increases nonlinearly with saturation. **Small increases in percolation flux could significantly increase fluid flow through the repository horizon. This nonlinear response is one of the greatest challenges in predicting the behavior of hydrologic systems over long periods.**[55]

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[51] EPA 2005 p. 49060 (emphasis added)
[52] NAS/NRC 1995 p. 9
[53] NAS/NRC 1995 p. 78
[54] DOE FEIS 2002 p. 5-23 to 5-27
[55] Long and Ewing 2004 p. 376-377 (emphasis added)

This issue of a non-linear response for the transport of water through the unsaturated zone at Yucca Mountain is well recognized and has been discussed by independent scientific bodies for at least a decade. In 1995 the National Research Council noted that

> Change to a cooler, wetter climate at Yucca Mountain would likely result in greater fluxes of water through the unsaturated zone, which could affect rates of radionuclide release from waste-forms and transport to the water table. Little effort has been put into quantifying the magnitude of this response, but a doubling of the effective wetness, defined as the ratio of precipitation to potential evapotranspiration, might cause a significant increase in recharge. An increase in recharge could raise the water table, increasing saturated zone fluxes.[56]

In a subsequent review, another National Research Council committee concluded that

> Models of varying complexity have been developed for preferential flow, but their adequacy for field-scale application requires further testing…. This issue is of particular concern in the fractured vadose zone because of the inherently nonlinear nature of processes involved. As flow conditions change, different flow and transport mechanisms, not represented in the model, may become important, leading to large errors in predictions.[57]

Similar concerns were raised by the Nuclear Waste Technical Review Board, a scientific advisory body created as part of the 1987 amendment to the Nuclear Waste Policy Act whose members are nominated by the National Academy of Sciences and appointed by the President. In their 1997 report to Congress, the Board noted that

> With increased precipitation and, therefore, increased net infiltration, the fraction of the total flux seeping into the drifts could increase nonlinearly. Thus, a future change to higher-precipitation conditions could cause a more than proportional increase in seepage into drifts and adversely affect repository performance.[58]

The issue of climate changes is of significant importance to the predicted long-term performance of the repository. The Total System Performance Assessment presented by the Department of Energy in its 2002 Final EIS for Yucca Mountain included a consideration of the transitions between future climate states, and found that the resulting dose predictions were also cyclical and that "[t]he multiple peaks occurring 200,000 years or more after repository closure are driven by transitions between climate states."[59] For a sense of the scale of these cyclical changes, the difference between the highest peak dose and the lowest value before the next peak in the DOE predictions was roughly a factor of ten (see the figure below).

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[56] NAS/NRC 1995 p. 91
[57] NAS/NRC 2000 p. 39-40
[58] NWTRB 1998 p. 38
[59] DOE FEIS 2002 p. 5-25

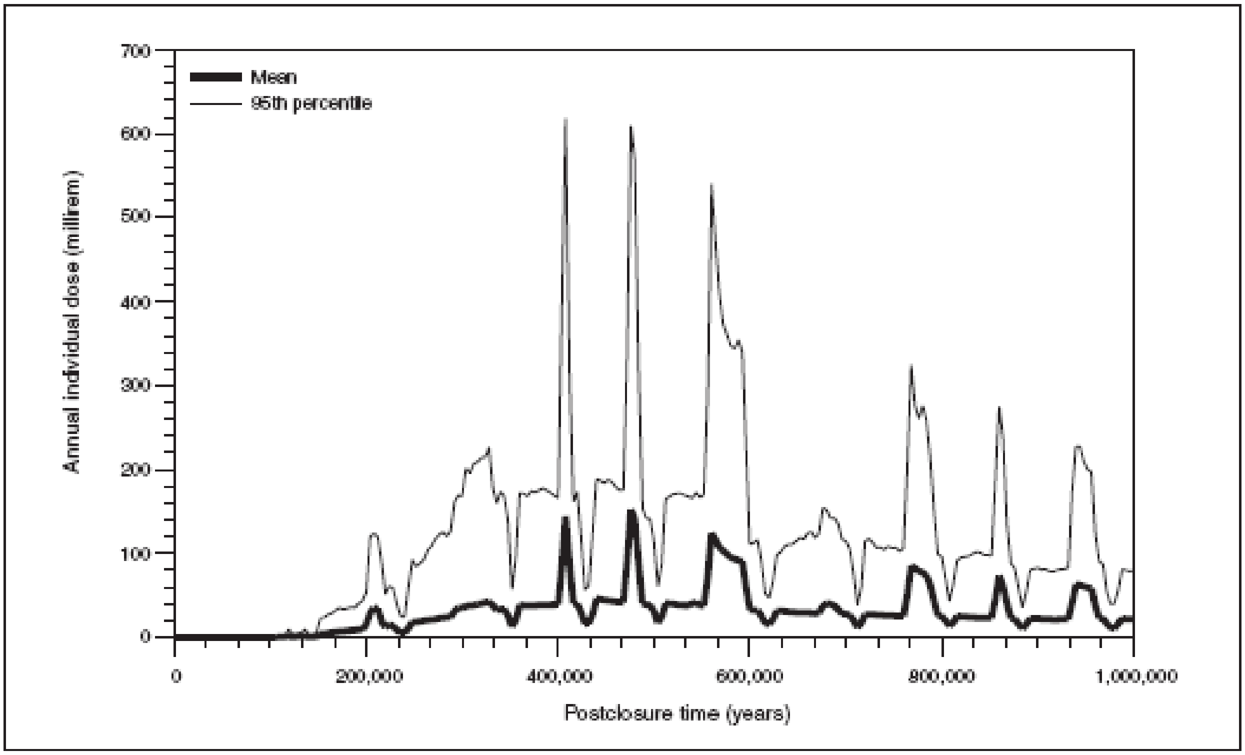

Figure 5-4. Mean and 95th-percentile (based on 200 simulations of the total system performance, each using random samples of uncertain parameters) annual individual dose at the RMEI location during 1 million years after repository closure for the nominal scenario under the high-temperature repository operating mode.

(Figure taken from the *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* [DOE FEIS 2002 p. 5-26])

Not unexpectedly, the DOE found that "[t]he peak annual individual dose usually coincided with the occurrence of a wetter climate period."[60] The use of a constant climate state over the period beyond 10,000 years as proposed by the EPA would washout the important impacts brought about by the changes between climate states and would tend to underestimate the actual peak dose that would be expected from the repository. This underestimation would, along with the use of the median dose, lead to even larger risks for distant generations being possible under the proposed rule. This would further aggravate the issues of intergeneration equity discussed in section one. The final rule issued by the EPA should require the DOE to explicitly consider the long-term fluctuations in climate and to use conservative assumptions about the timing and duration of wetter climate states given the non-linear response of the transport models and the large influence of climate on the long-term performance of the Yucca Mountain repository.

Section Five – The Continued Relaxation of Radiation Protection Standards at Yucca Mountain:

The relaxation of all radiation protection norms to well above anything now permitted, as proposed by the EPA for the period beyond 10,000 years, would be the third time that very major changes have been made to regulations in order to make it more possible to license a repository at Yucca Mountain once analyses came to light that indicated that such a repository could not be licensed under the then existing rules. This count does not include the wholesale abandonment of research on all other potential repositories locations in 1987 to focus solely on Yucca Mountain.

[60] DOE FEIS 2002 p. 5-26

The first time that existing standards and regulations were abandoned to accommodate the development of the Yucca Mountain repository was in relation to the EPA's carbon-14 emissions rules for high level waste disposal.[61] The EPA standard, originally promulgated in the 1980s, was to apply to all high level waste repositories, and included limits on carbon-14 emissions, among other radionuclides. Following the promulgation of this rule, a scientist at Lawrence Livermore National Laboratory realized that because Yucca Mountain was an unsaturated repository in porous rock that it might not be able to meet the carbon-14 emission standard.[62] The EPA constituted a subcommittee of its Radiation Advisory Committee to review the matter. One of the present authors, Dr. Arjun Makhijani, was on that subcommittee which reached a consensus conclusion that

> [I]t is not possible on the basis of presently available information to predict with reasonable confidence whether releases from an unsaturated repository would be less than or greater than the Table 1 (40 CFR 191) release limits. (The Table 1 Release limit is one-tenth of the inventory.)[63]

Instead of maintaining the rule for all repositories and trying to find a better site, Congress decreed that there should be a new rule for Yucca Mountain alone.[64] We call this the "Double Standard" standard.

The second time that radiation protection rules were relaxed was when the NRC abandoned its rules for the performance of the engineered barriers and the geologic setting in which they were to be placed.[65] Under the original rules the engineered barriers were to play an important role in preventing the release of significant amount of radionuclides, only for the first one thousand years. Beyond that period the geologic setting was to play the central role in preventing the radionuclides from reaching the human environment in significant quantities. In 1999 the Department of Energy presented five graphs to the Nuclear Waste Technical Review Board in order to illustrate the role of each element in the isolation system and its importance in determining the ultimate doses received by the public.[66] (See Attachment 1) From the information presented in these graphs, it was clear that the only element in the isolation system which plays a central role in meeting the proposed standard of 15 mrem within the first 10,000 years is the engineered waste canisters. The geologic setting of Yucca Mountain is shown to be practically useless in containing the radionuclides either before or after 10,000 years. Under the original Nuclear Regulatory Commission rule, Yucca Mountain could not have been licensed just as it would likely not have been licensed under the earlier EPA rule covering carbon-14 emissions. Again, instead of abandoning Yucca Mountain and finding a new repository location that could meet the then existing requirements, the NRC relaxed its regulations to what we now have which is to require the DOE to show only a "total system performance assessment." In this method of performance assessment, the performance of the repository can depend on just one element of the isolation system even if every other element is essentially non-performing. That is the case for Yucca Mountain as can be seen from the DOE's own figures from their 1999 presentation.

Hence a very critical system, estimated to cost between $60 and $100 billion is being built without any significant backup protection for the environment as part of its design. This is contrary to common sense and elementary engineering principles for complex, important systems which generally seek to rely on the principle of defense-in-depth. The proposed exposure limit of 350 millirem per year for times beyond 10,000 years, which is well beyond any established radiation norm, is therefore the third time that standards would be greatly relaxed in order to try and accommodate the licensing of a repository at Yucca Mountain. If a repository at Yucca Mountain, or any other site, cannot meet scientifically reasonable and socially acceptable performance criteria than it should be abandoned in favor of a more suitable site. The continued relaxation of regulatory requirements does not serve the public interest and should have no part in the final rule as adopted by the EPA.

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[61] 40 CFR 191
[62] Van Konynenburg 1991
[63] EPA 1993 p.2
[64] 42 USC 10141
[65] 10 CFR 60, 1984
[66] DOE 1999, and reproduced from Science for Democratic Action v.7, no.3, May 1999, pages 12-13.

Section Six – The Risks to Children:

Our final comment on the proposed rule relates to the following claim made by the EPA in its discussions of the standard's compliance with relevant Executive Orders:

> This proposed rule is not subject to Executive Order 13045 [Protection of Children from Environmental Health & Safety Risks] because it is not economically significant as defined in Executive Order 12866, and **because the Agency does not have reason to believe the environmental health risks or safety risks addressed by this action present a disproportionate risk to children**. The public is invited to submit or identify peer-reviewed studies and data, of which EPA may not be aware, that assessed results of early life exposure to radiation.[67]

It stretches credulity to believe that the EPA is unaware of the international scientific consensus that children, and particularly female children, are at significantly greater risk from radiation exposure compared to adults. Following the 1986 Chernobyl disaster there was finally a widespread recognition within the radiation protection community of the need to accurately determine the doses that are received by children from internally deposited radionuclides. The efforts undertaken in the wake of this accident were integrated with ongoing efforts of the International Commission on Radiological Protection leading to the development of age specific dose conversion factors for ingestion and inhalation.[68] These dose models were published between 1989 and 1996 as a series of five ICRP reports that reveled that, for many radionuclides, children can receive higher doses than adults for the same level of ingestion or inhalation.[69] These dose models have been adopted by the European Union's European Basic Safety Standards and the International Atomic Energy Agency's International Basic Safety Standards.

Following the publication of these ICRP reports, the EPA's 1999 Federal Guidance Report 13 included a discussion of the heightened cancer risk from radiation with decreasing age at exposure.[70] The CD supplement to Federal Guidance Report 13 issued by the EPA in 2002 included an extensive database of both dose and risk coefficients for ingestion and inhalation showing a heightened risk to children from exposure to many radionuclides.[71] Finally, the BEIR VII Committee has published the most up to date review of the available scientific information, and has made specific recommendations regarding age specific risk coefficients for exposure to low-level radiation. The figure below shows the rapid rise in risk with decreasing age at exposure as estimated by the U.S. National Academy of Science.[72]

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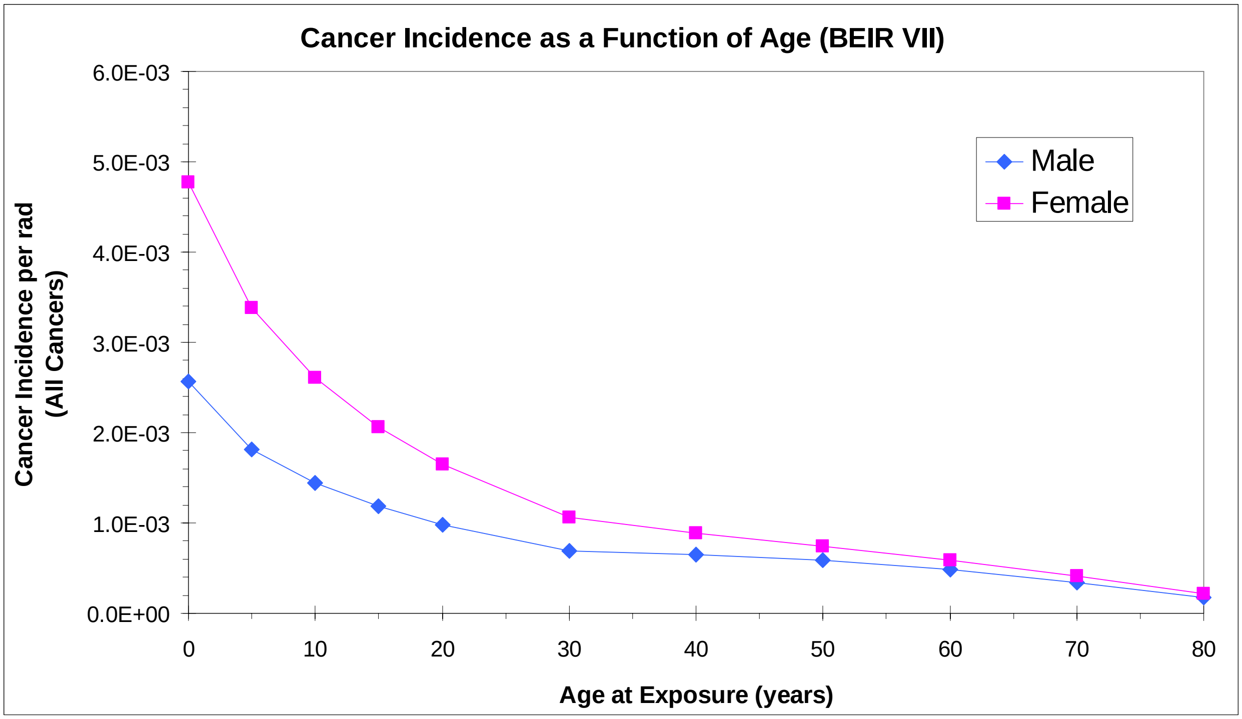
[67] EPA 2005 p. 49062
[68] ICRP 2005 and NCRP 128 p. 3 and 9
[69] ICRP 56, ICRP 67, ICRP 69, ICRP 71, and ICRP 72
[70] EPA 1999 p. 174-178
[71] EPA 2002
[72] NAS/NRC 2005 p. 550



To illustrate the conclusions of the BEIR VII committee in another way, we note that the risk of developing cancer for a child between 0 and 10 years old is more than two-and-a-half times the risk to a 25 year old adult from the same level of exposure. Finally, the disparity between the risk to men and women also grows more significant at younger ages as can be seen quite easily from the above figure.

The final rule should explicitly acknowledge the firmly grounded scientific consensus that children are, in fact, disproportionately at risk from exposure to radiation and reevaluate its compliance with Executive Order 13045 which states that

> A growing body of scientific knowledge demonstrates that children may suffer disproportionately from environmental health risks and safety risks. These risks arise because: children's neurological, immunological, digestive, and other bodily systems are still developing; children eat more food, drink more fluids, and breathe more air in proportion to their body weight than adults; children's size and weight may diminish their protection from standard safety features; and children's behavior patterns may make them more susceptible to accidents because they are less able to protect themselves. Therefore, to the extent permitted by law and appropriate, and consistent with the agency's mission, each Federal agency:
>
> > (a) shall make it a high priority to identify and assess environmental health risks and safety risks that may disproportionately affect children;
>
> and
>
> > (b) shall ensure that its policies, programs, activities, and standards address disproportionate risks to children that result from environmental health risks or safety risks.[73]

[73] Executive Order 1997 p. 19885

Section Seven – IEER's Proposal for a Final Rule:

The Institute for Energy and Environmental Research recommends that the final rule as adopted by the EPA should include, at a minimum, the following elements:

1. The annual dose limit for all pathways should be between 10 and 25 millirem and should remain constant in time over the period of geologic stability at the site. This would be consistent with an implementation of the international consensus that future generations should be protected to at least the same level as is considered acceptable today.
2. A separate sub-limit of 4 millirem per year to the most exposed organ from the drinking water pathway should be included over the entire period of geologic stability. This would be consistent with the previously expressed EPA views that groundwater must be "protected as a natural resource" from radiological impacts and that "protecting ground water used as drinking water is a human health issue."[74]
3. The radiological impacts on children should be explicitly considered in the Department of Energy's performance assessments in order to ensure that they are not disproportionately affected by the repository. This would be consistent with the intent of Executive Order 13045 to protect the health of children regardless of whether or not the Yucca Mountain repository is considered "economically significant as defined in Executive Order 12866."
4. The impacts of future changes in climate should be taken into account explicitly in the DOE's performance assessments including the consideration of periodic cycling through different climate states. This would be consistent with the 1995 recommendations of the National Research Council as required by law.
5. The standard should recognize that the uncertainties in the estimated doses will increase with time and that the uncertainties beyond 10,000 years will become very significant. In this regard, therefore, we propose that the EPA adopt the French approach to waste repository standards[75] in which the doses beyond 10,000 years are calculated using scientifically reasonable, but highly conservative choices for the important parameter values in order to increase confidence that the ultimate impacts from the repository will be less than those predicted.

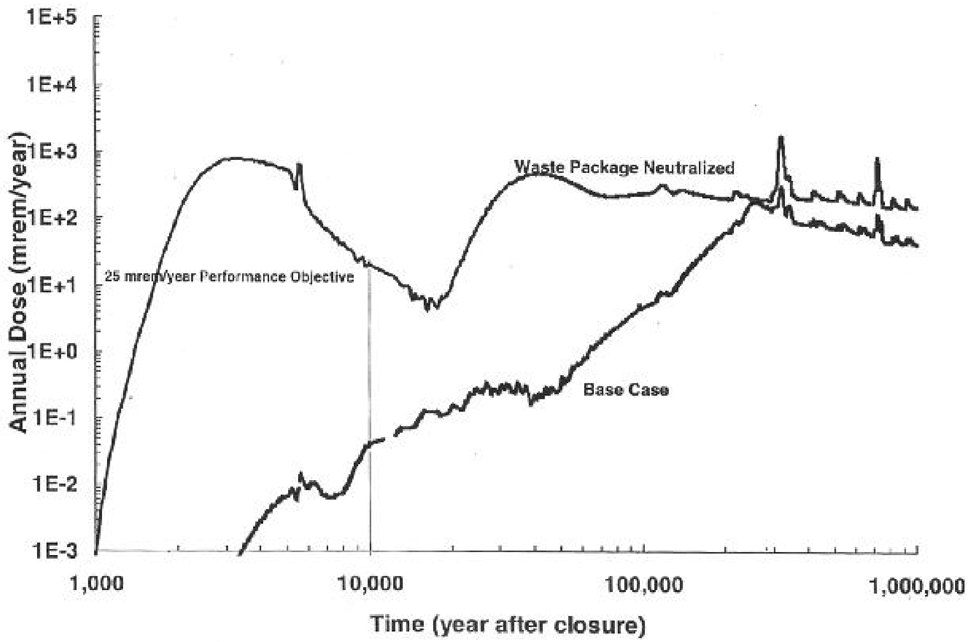
In contrast to the EPA proposed rule, the rule that we propose is in conformity with the NAS 1995 report, with international radiation protection guidelines, with cost-benefit principles, intergenerational equity, and the history and science of radiation protection. It also addresses the issue that uncertainties grow over the long term making a statistical approach more in the long-term more difficult and questionable. By adopting an approach of choosing fixed but conservative parameter values, a statistical approach is avoided, making the long-term result more robust than is obtained by the method suggested by the EPA.

[74] Trovato 1997 p. 8-9

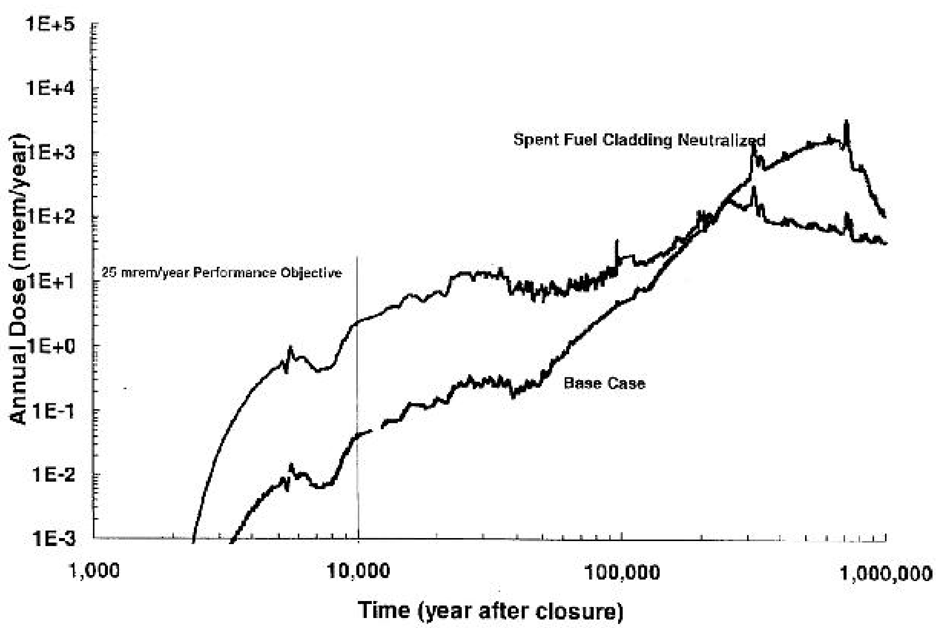
[75] Règle Nº III.2

Attachment 1. Department of Energy Graphs as Presented to the Nuclear Waste Technical Review Board in 1999

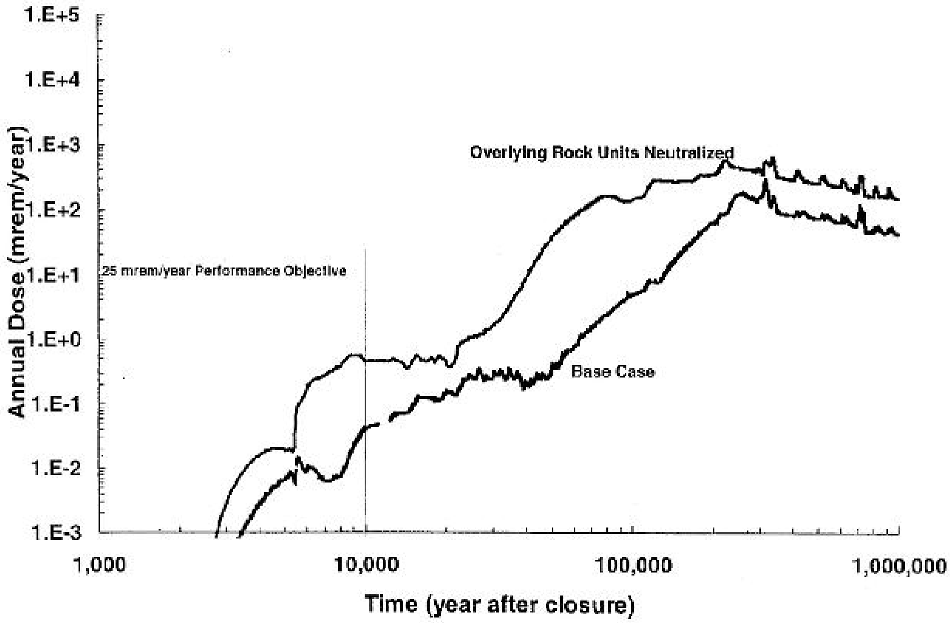
Graph A: Neutralize Waste Package



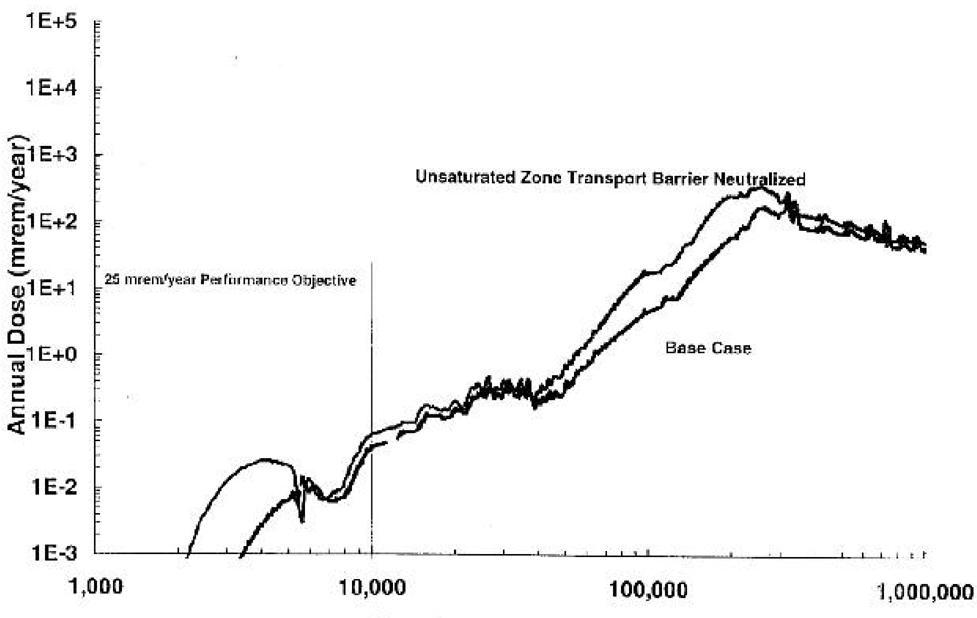
Graph B: Neutralize Spent Fuel Cladding



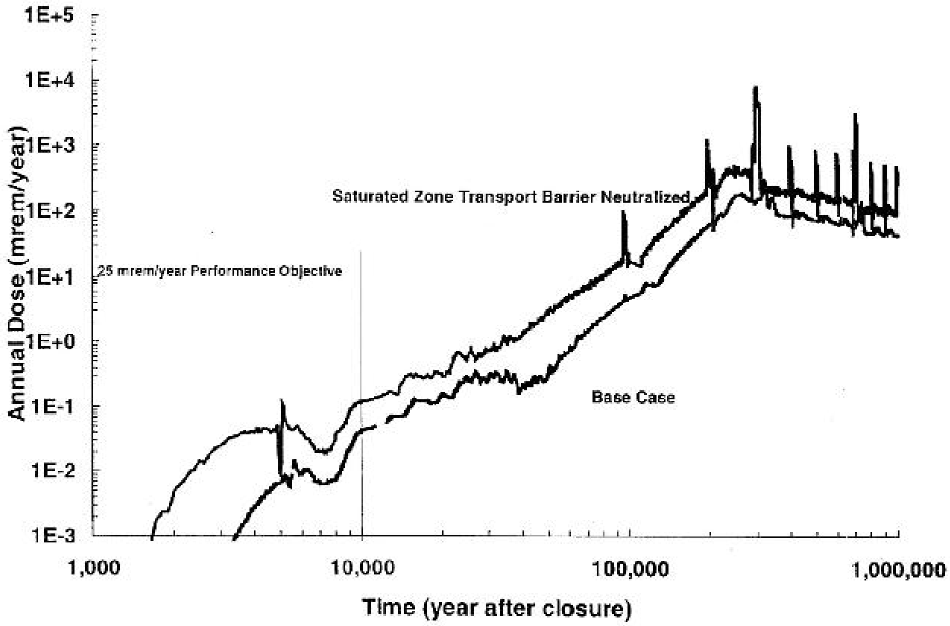
Graph C: Neutralize Overlying Flow Barriers



Graph D: Neutralize Unsaturated Zone Transport Barrier



Graph E: Neutralize Saturated Zone Transport Barrier



Source for all graphs: U.S. DOE Office of Civilian Radioactive Wate Management, "NWTRB Repository Panel meeting: Postclosure Defense in Depth in the Design Selection Process," presentation for the Nuclear Waste Technical Review Board Panel for the Repository, January 25, 1999.

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