March 16, 2006

Dr. Dade W. Moeller
Former President
Health Physics Society
257 River Island Road
New Bern, North Carolina 28562

Dear Mr. Moeller:

Thank you for appearing before the Committee on Environment and Public Works on Wednesday, March 1, 2006. We appreciate your testimony in our effort to examine the status of the Yucca Mountain Project. Your testimony was helpful and we know that your input will prove valuable as the Committee continues its work on this important issue.

Enclosed are questions that have been submitted by Senators Inhofe and Jeffords for the hearing record. Please submit your answers to these questions by 2 pm Friday, April 7, 2006 to the attention of Alex Herrgott, Senate Committee on Environment and Public Works, 410 Dirksen Senate Office Building, Washington, D.C. 20510. In addition, please provide the Committee with a copy of your answers via electronic mail to Alex_Herrgott@epw.senate.gov. To facilitate the publication of the record, please reproduce the questions with your responses.

Again, thank you for your assistance. Please contact Andrew Wheeler on the majority staff at (202) 224-6176 or Mary Frances Repko with the minority staff at (202) 224-6938 with any questions you may have. We look forward to reviewing your answers.

Sincerely,

James M. Inhofe
Chairman

James M. Jeffords
Ranking Member

Health Physics Society – Questions from Senator Inhofe (03/01/06 Hearing)

1. Is it possible to quantify radiation risk at 350 millirem per year, which is the EPA proposal?

2. Is it fair to extrapolate the effects of instantaneous high levels of radiation doses to low level exposure over an individual's lifetime?

3. What are your views on EPA's proposed rule and does it protect public health and safety? Is it overly conservative, not protective, or just right?

4. Is regulating to one million years necessary to protect public health and the environment?

<u>Dade Moeller –Senator Jeffords</u>

1. In your written testimony, I was interested to see that you endorse temporarily storing spent nuclear fuel at the Yucca Mountain site for approximately 100 years. Congress has tried in the past to approve interim storage but has failed because of fears that the storage would become permanent and that the financial and political investment at the site would prevent an independent evaluation of the project as a long term repository. As a radiation health specialist, what do you see as the health benefits of interim waste storage at Yucca Mountain?
2. In your proposal, you also state that during the proposed 100 year storage period, many significant technological developments will occur which could change the best approach for the final disposal of radioactive waste. Given that these new reprocessing technologies are unproven and, if viable at all, are still potentially 20 60 years away, can we say anything today about the health effects of the radiation these technologies will produce?

April 7, 2006

Dade W. Moeller, Ph.D., CHP
President Emeritus
Health Physics Society
257 River Island Road
New Bern, North Carolina 28562

The Honorable James M. Inhofe, Chairman
The Honorable James M. Jeffords, Ranking Member
Committee on Environment and Public Works
United States Senate
Washington, D.C. 20510

Dear Senators Inhofe and Jeffords:

Thank you for expressing your appreciation for my testimony before the Committee on Environment and Public Works on March 1, 2006, as your committee examines the status of the Yucca Mountain project. I am very pleased you believe my testimony was helpful and will be beneficial to the committee staff.

I am very appreciative also of the follow up questions you forwarded to me. They are very important to the future of the Yucca Mountain project and I am pleased to be able to provide further input on these issues.

I have enclosed my responses to your questions. In addition, during the hearing Senator Boxer posed a question regarding a statement attributed to Dr. Thomas Cochran of the Natural Resources Defense Council in which I gave a preliminary response but which required more study for a complete answer. I have enclosed my detailed response to Senator Boxer's question with this letter. Finally, I consider that some of the scientific principles provided in response to questions from Senator Inhofe have a profound implication on the ruling of the Court of Appeals on the EPA proposed standards and I have taken the liberty to share my view on this issue in a separate enclosure to this response. I hope this material will be helpful to you and your staffs.

On behalf of the Health Physics Society, I am honored to have been asked to assist you in this important and challenging task facing the Committee. Please do not hesitate to contact the Health Physics Society, or me, at any time you believe we can be a resource on any radiation safety issue.

Sincerely,

Dade W. Moeller, Ph.D., CHP

Enclosures

cc: Senator Barbara Boxer

RESPONSES TO QUESTIONS FROM SENATOR INHOFE

1. Is it possible to quantify radiation risk at 350 millirem per year, which is the EPA proposal?

Summary Response

It is not possible to quantify the radiation risk at any level of radiation exposure for a population 10,000 to 1 million years from now, which is the time period for which the EPA proposal is applicable. This is due to the fact that there is no technical basis for forecasting the causes of death among, and the life spans that will be experienced by, the affected groups. Without this, and related information, the risk estimates cannot be quantified and any proposed dose rate limit is meaningless. This point is so important to the evaluation of the EPA proposal for Yucca Mountain that I have covered this is a separate enclosure to this submittal titled "Implications of Risk Quantification on the Ruling of the Court of Appeals."

Risk coefficients exist for quantifying the health effects (i.e., fatal cancers) that may occur in a large existing population exposed to 350 millirem (mrem) per year. The resulting estimates, however, incorporate so many assumptions that they are highly uncertainty and, as noted above, they are applicable only to populations with today's (i.e., known) cancer rate experience and human life spans. As for the range of the uncertainties, the Health Physics Society (HPS, 2004) cautions that the "Estimation of health risk associated with radiation doses that are of similar magnitude as those received from natural sources should be strictly qualitative and encompass a range of hypothetical health outcomes, including the possibility of no adverse health effects."

Introduction

There are multiple factors that must be considered in estimating the risks of radiation exposures. The more important of these are discussed below.

<u>Quantifying Risk</u>

Lifetime risk estimates are developed through the science of epidemiology. Fundamental to this process is the comparison of the health outcomes of a group of people, exposed to higher doses, to the health outcomes of a similar group (i.e., similar age, gender, nationality, cancer rates, etc), exposed to lower doses. After accounting for all potentially confounding factors, increases in the number of cases of illness and death that occur in the exposed group, as compared to the non-

exposed, or less exposed (control) group, are attributed to the radiation exposure. It is important to recognize, however, that this is the observed increase in the risk for the exposed group at the time the comparison was made. To obtain the lifetime risk estimate, the observed difference must be projected to a time when everyone in both the exposed and control groups has died. This is particularly significant in terms of the survivors of the atomic bombings in Japan. In that case, only slightly more than half of the original atomic bomb survivors had died by 2005, 55 years after they were exposed (NRC, 2006, page viii). In order to project the health effects to the end of their lives, assumptions must be made about the relationship between radiation induced, and "naturally occurring" cancers, and the projected life spans of the people remaining in the study. Since the risk estimates currently available are applicable only to populations with known cancer rates and life spans, it is not appropriate to apply these estimates to populations who will be living 10,000 to 1 million years from now, the reason being that it is not scientifically possible to project the baseline cancer rates, or the extent of the life spans that populations will be experiencing, three or four decades from now, much less 10,000 to 1,000,000 years from now.

The problem of transferring risk coefficients derived from the Japanese atomic bomb survivor data to a population far into the future is more completely examined in the enclosure to this submittal, titled "Implications of Risk Quantification on the Ruling of the Court of Appeals."

Perspective on 350 millirem per year

Although the current risk estimates cannot be responsibly used to predict risks to populations at the time the EPA proposed dose rate limit of 350 mrem (0.350 rem) per year would apply, they can be used to provide perspective on the health impacts on current populations that might be affected by radionuclide releases from the proposed repository. Assuming that the Amargosa Valley population was exposed at this rate throughout an average lifetime of 70 years, their total dose would be:

$$(0.350 \text{ rem/year})\ (70 \text{ years}) = 24.5 \text{ rem} = 0.245 \text{ Sv}.$$

In this regard, it is important to note that this is higher than 0.1 Sv (10 rem), the minimum dose for which the BEIR VII committee states that fatal cancer risks can be estimated without unacceptable statistical limitations (NRC, 2006, page 7). Assuming a population consisting of 50% men and 50% women, the applicable fatal cancer risk coefficient would be 570×10^{-4} per Sv. (NRC, 2006, Table ES-1, page 15). On this basis, the estimated percentage of the Amargosa Valley population that might incur excess fatal cancers would be:

$$(570 \times 10^{-4} \text{ per Sv})\ (0.245 \text{ Sv}) = 0.014 = 1.4\%.$$

For a population the size of that residing in the Amargosa Valley (about 1200 people; Rautenstrauch et al., 2003), this would mean that the estimated number of excess deaths due to radiation-induced cancer could be:

$$(1200)\ (0.014) = \sim 17.$$

Because the exposed population is so small, this estimate should probably be expressed as representing something in the range of perhaps 10 to 20 deaths. Since these would be expected to occur, if at all, over the 70 year lifetime of this population group, the average number of excess deaths would range from perhaps one every 7, to one every 3.5, years. The implications of this are discussed in the response to question #2 below. Concurrently, this same population group would be expected to suffer a total of 245 fatal cancers, or about 3 to 4 deaths per year, in the absence of the postulated doses due to radionuclide releases from the proposed repository (NRC, 2006, Table ES-1, page 15).

2. Is it fair to extrapolate the effects of instantaneous high levels of radiation doses to low level exposure over an individual's lifetime?

Summary Response

No, it is not, the key words being "over an individual's lifetime." Although risk models for fatal cancer have been developed for extrapolating the health effects of radiation exposures involving high doses received at high dose rates to those involving low doses received at low dose rates, the estimated health effects (for example, the number of fatal cancers that might result) can be expressed only for the affected population as a whole. They cannot be expressed in terms of the impacts on individual members of that group. At the same time, it must be recognized that estimates based on these processes are reasonably accurate only if the population group, being evaluated, is large, i.e., numbering in the tens of thousands. Compounding the situation is that assessments of health effects that involve either small population groups, or small doses will, in general, not be meaningful due to the lack of statistical rigor.

Even when the potentially affected population group is relatively large, the interpretation of the risks is not easy. This is well demonstrated by the information provided in the BEIR VII report (NRC, 2006). Within a group of 100,000 members of the U.S. population, for example, even in the absence of additional exposure from

the proposed repository, there will be, on average, about 20,420 cancer deaths due to natural causes. If each member of this population group is exposed to an average dose of 1 rem over his/her lifetime, one can statistically estimate that an additional 57 of them may die from cancer. No method is available, however, to differentiate which members of this population will be among the 20,420 who will die from cancer due to "natural causes," or will be among the 57 additional members who may die due to the added average dose of 1 rem. Also of note is that, in this example, the increase in the estimated cancer deaths, due to the radiation exposure, is less than 0.3% of what otherwise would have occurred.

3. What are your views on EPA's proposed rule and does it protect public health and safety? Is it overly conservative, not protective, or just right?

Summary Response

On the basis of my review and analysis, I conclude that, considering the significant sources of conservatisms in the dose estimates, the calculated risks, and their associated uncertainties, the proposed EPA dose rate limit would be fully protective of public health and safety. Please note, however, the caveats in the separate set of comments on the "Implications of Risk Quantification on the Ruling of the Court of Appeals."

Technical Basis

The approach adopted by EPA, in establishing the 350 mrem per year dose rate limit, was in accord with the guidance provided by the International Commission on Radiological Protection (ICRP), an organization in which members of the Health Physics Society continue to be active participants. One of the guidelines recommended by this organization for judging the acceptability of dose rate limits for members of the public "is to base the judgement on the variations in the existing level of dose from natural sources. This natural background may not be harmless, but it makes only a small contribution to the health detriment which society experiences. It may not be welcome but the variations from place to place (excluding the large variations in the dose from radon in dwellings) can hardly be called unacceptable." (ICRP, 1991, paragraph 190, pages 44-45).

Nonetheless, the ICRP certainly did not have in mind that this guidance would be used to establish a dose rate limit for a time-period 10,000 to one million years from now. Although, on the basis of my review and analysis, I concluded that the proposed EPA dose limit would be fully protective of public health and safety, that

conclusion was made in the context of the conditions that exist today. Since it is impossible to predict the characteristics (particularly the lifestyles and fatal cancer rates) of populations who will live so far into the future, I also concluded that any dose rate limit that would be developed and recommended on the basis of today's society is essentially meaningless. Other aspects related to this subject are discussed in the response to question #4 below.

Discussion of Uncertainties

While, in view of the conclusions stated above, comments on other aspects of this question would appear to be superfluous, it should be noted that there are considerable uncertainties in the dose rates from each of the components of natural background. In terms of radon, alone, these include relatively large uncertainties in the measured values of the radon concentrations, due to the presence of thoron (which interferes with the radon measurements); the status of the equilibrium of the radon decay products; the fraction of the decay products that are unattached; and the assumed residence time indoors. In fact, it is estimated that the combined uncertainty accompanying the radon dose estimates can be as high as 150% (Moeller and Sun, 2006). Two questionable procedures applied by EPA in the assessments, on which their recommended dose rate (350 mrem y^{-1}) was based, were (1) the use of generic, rather than site-specific data, for estimating the dose rate in both Nevada and Colorado; and, (2) basing the difference in the dose rate in the region with a "high" natural background rate, versus that with in the Amargosa Valley, on the average for the State of Colorado versus the average for the State of Nevada, extrapolated to be representative of the Amargosa Valley. Both Colorado and Nevada obviously have regions with natural background dose rates that are higher than the state-wide average.

To provide an independent review and evaluation of the EPA estimate, an associate and I compared the average natural background dose rate in the Amargosa Valley to that for Leadville, CO. These two communities were selected since they are in the same general region of the U.S.; they are of comparable size; and in both cases site-specific data were available for the conducting the evaluations. Interestingly, the estimated difference in the natural background dose rates in the two communities was almost 400 mrem (4.00 mSv) per year, almost 15% higher than the EPA estimate. One of the primary reasons for the higher estimate is that the EPA contractor overlooked the fact that more than 90% of the population of the Amargosa Valley live in mobile homes which, due to their construction and placement a foot or more above the ground, have indoor radon concentrations that are less than those outdoors (Moeller and Sun, 2006).

Discussion of Conservatism

Also to be considered in answering a question of this nature are the significant conservatisms that are incorporated into the methodologies used in documenting compliance with the dose rate limit. According to the regulations of the U.S. Nuclear Regulatory Commission (USNRC, 2001), the person on whom compliance with the regulations will be based is an adult. Under these conditions, the dose assigned to an intake of a radionuclide is that which will be imparted to the exposed person during the 50 year time-period following ingestion. Due to their nature, a majority of the more important radionuclides in high-level radioactive waste, that have the potential for release from the proposed repository, have long radioactive half-lives combined with long biological retention times in the body. For these reasons, the NCRP has estimated that many of the exposed people will not live long enough to receive their full 50-year dose commitment. In fact, the NCRP estimates that the average adult, who is exposed under these conditions, will receive less than half of the estimated committed dose (NCRP, 1993, Section 6.1, page 25). For these radionuclides, which include ^{226}Ra, ^{237}Np, ^{239}Pu, and ^{241}Am, this means that the calculated dose will be less than half of that which will occur.

It has been a long-standing policy of the ICRP and NCRP that radiation exposures from naturally occurring sources (other than those that are technically enhanced) are not to be included in assessments for compliance with regulations. In contrast, EPA requires that any naturally occurring radium in the ground water being consumed by the residents of the Amargosa Valley must be included as a source of dose in the determination of compliance. EPA also requires that the U.S. Department of Energy (DOE), for purposes of determining compliance, must assume that the “reasonably maximally exposed individual” (RMEI) resides 18 km south of the border of the proposed repository, an area that is currently not inhabited. The Amargosa Valley, which is the most probable location of the primary population group that could potentially be exposed through releases from the proposed repository, is located some 35 km south of the proposed repository.

Another source of conservatism is the assumption by DOE that an aquaculture farm, shut down some 5 years ago but a significant potential source of increased intake of ^{14}C, is still operating. Still another conservatism is the failure to account for the fact that, although the primary radiation exposures due to the operation of the proposed repository will be through the ingestion of radionuclides, studies show that the health effects per unit dose, due to radionuclides non-uniformly distributed within the body, are significantly less than those for comparable doses from external sources of exposure (Bair, 1997). These, and other assumptions, lead to an estimated overall factor of conservatism of 10 in the dose rate estimates (Moeller and Ryan, 2006).

4. Is regulating to one million years necessary to protect public health and the environment?

Summary Response

No. Regulating to one million years becomes unnecessary if the technological and policy changes suggested in my testimony are adopted. In fact, if the proposed changes are implemented, the nature and toxicity of the waste requiring disposal will be such that it will only need to be monitored for a period of 300 to 500 years, at most. Our goal has been to present a plan that will provide a mechanism for ending the ongoing legislative wrangling. It will accomplish this by producing a waste that is far less toxic than that which otherwise will need to be disposed. Also not to be ignored is that the proposed technological changes will eliminate any need for establishing a dose rate limit from 10,000 to one million years.

In any discussion of this nature, it is important to keep in mind the genesis of the controversy. It occurred as a result of the ruling of the United States Court of Appeals (issued on July 9, 2004) that the "10,000-year compliance period selected by EPA violates section 801 of the Energy Policy Act (EnPA) because it is not, as EnPA requires, 'based upon and consistent with' the findings and recommendations of the National Academy of Sciences." In essence, the court ruled that the EPA's standard as of that time was "arbitrary and capricious" under the Administrative Procedure Act, and it was incumbent upon EPA to establish a dose rate limit extending beyond 10,000 to one million years. That ruling had nothing to do with science.

Technical Benefits of the Proposed Approach

The fundamental change in the suggested approach is that the nation's high-level radioactive waste be placed in interim storage at the existing Yucca Mountain facility for a period of 100 years. This will provide a "window" for DOE to reconsider its present approach not only in the management and treatment of its high-level waste, but also to dramatically change the conditions under which it will need to be disposed. The primary technical benefits can be summarized as follows:

1. This "window" would enable DOE to take advantage of new and ongoing technological developments in the physical and chemical processing of spent nuclear fuel. One example, already demonstrated at the laboratory level, has been shown to yield an increased effectiveness in the separation of the transuranic radionuclides (for example, ^{237}Np, ^{239}Pu, and ^{241}Am) from the fission products. This

would produce a waste with a significantly reduced toxicity. In fact, after a decay period of about 350 years, its toxicity would be no higher than the original ore that was strip-mined to obtain the uranium that, after being used as a source of power for the reactors, produced the spent nuclear fuel that, after being processed, yielded the waste. This comparison is based on the assumption that the original ore contained a uranium concentration of 0.2%, that is, it was what is called a relatively low grade of ore. If the ore was of a higher grade, the difference in toxicity would be even more dramatic. After 1,000 years decay, the waste would have decayed to where the toxicity would be no higher than about 10% of that of 0.2% ore. Particularly noteworthy is that, while the uranium ore, when mined, was at or near the surface of the earth, the waste resulting from reprocessing would have been vitrified and buried in thick metal containers more than 600 feet beneath the surface of the earth.

2. The resumption of fuel processing would reduce the thermal heat load of the waste being placed in the proposed repository, thus yielding benefits in terms of reduced impacts on the surrounding geological structures. Equally important, it would eliminate the concerns related to criticality.

3. While the above discussion involves primarily technical issues, the suggested approach would have a significant bearing on the environmental health issues related to the disposal of high-level radioactive waste. The basis for this statement is that the recommended actions, if adopted, would essentially remove the need to consider a regulatory dose rate limit for more than perhaps 400 or 500 years after the waste were placed in the proposed repository. From a technical standpoint, it would enable DOE not only to remove the more toxic long-lived materials from the waste, prior to placing it in the proposed repository, but it would enable the un-used uranium and newly produced plutonium to be reclaimed and used as fuel in generating additional electricity in nuclear power plants. This suggested approach would also conserve our uranium resources and significantly reduce, as noted earlier, the toxicity of the waste.

4. Nonetheless, it is important to recognize that implementation of this proposal would require a full-scale safety review of all of its associated ramifications. A common error, in the adoption of what appear to be promising new approaches, is the failure of those implementing the suggestions to review and evaluate their full range of implications. These would include the impacts of the suggested changes on the challenges that must be solved in handling and vitrifying the waste, similar challenges in converting the transuranic radionuclides into fuel for use in commercial nuclear power plants, and safety considerations associated with transporting the waste to the storage facility. Also to be considered is the fact that, while the newer chemical technologies (a primary example being the UREX + Process developed at

the Argonne National Laboratory East), has been proven at the laboratory scale, the upgrading of this process into an industrial scale operating facility would require considerable effort and time, the latter being perhaps as much as 10 to 30 years.

Policy Implications of the Proposed Approach

From a policy standpoint, the proposed approach has far-reaching implications, many of which would be extremely beneficial to the United States' energy program and associated industries. For example:

1. Achieving a satisfactory solution for waste disposal problem would reduce our dependence on foreign oil, because it would enable us to move forward in generating copious supplies of electricity through the application of nuclear energy.

2. A satisfactory solution to the waste disposal problem would reduce our discharges into the atmosphere of the gases that cause global warming.

3. The resumption of spent fuel reprocessing would significantly reduce the amount of waste requiring transportation and disposal. At the same time, however, this could present challenges in terms of handling and transporting the waste. This and other potential ramifications would need to be given careful consideration.

4. The 100 year storage/monitoring period would enable the DOE staff to document more fully the adequacy of the capabilities of that facility for the "disposal" of high level waste. This would, in turn, provide additional assurance that the proposed facility would operate as anticipated, as well as an opportunity to incorporate beneficial changes in its design.

6. Finally, the proposed policy would enable the Federal government to accept responsibility for high-level waste as mandated in the 1992 Nuclear Waste Policy Act.

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RESPONSES TO QUESTIONS FROM SENATOR JEFFORDS

1. In your written testimony, I was interested to see that you endorse temporarily storing spent nuclear fuel at the Yucca Mountain site for approximately 100 years. Congress has tried in the past to approve interim storage but has failed because of fears that the storage would become permanent and that the financial and political investment at the site would prevent an independent evaluation of the project as a long term repository. As a radiation health specialist, what do you see as the health benefits of interim waste storage at Yucca Mountain?

This question involves multiple considerations. As noted in the written testimony that we prepared, approval of the proposal for storing the high-level waste for 100 years in the Yucca Mountain facility would need to be accompanied by a number of safeguards. First, the waste would need to be stored in a manner so that it could be monitored continuously to warn of any failures in the waste canisters or any other components of the system. To ensure that corrective measures could readily be implemented, if necessary, the waste would also need to be stored so that it can be retrieved, and the defects or sources of the failures remedied. At the same time, all the data on the performance of the system would need to be made available. In fact, arrangements should be considered for having a team of independent, technically qualified, members of the U.S. Nuclear Regulatory Commission (USNRC, 2000) staff (referred to, in the case of commercial nuclear power plants as onsite "resident inspectors") be stationed at the Yucca Mountain facility to observe operations on a full time basis.

<u>Benefits of 100 Year Storage Period</u>

In terms of the factors on which responses are requested, the benefits of the 100 year storage period would relate to potential developments in two specific areas. One would be methods for the cure and/or prevention of diseases that are directly related to the effects of radiation exposures. Obviously, the most important such disease would be cancer. The second benefit would be improvements in the development of chemical technologies for separating the transuranic radionuclides from the spent nuclear fuel. Since it appears more appropriate, the latter topic will be discussed in the response to question #2.

In terms of medical technologies, it should be noted that progress in developing methods for the cure and/or prevention of a variety of cancers is moving ahead at a rapid pace. For example, a recent article in U.S. News & World Report, describes a new vaccine that "may rid the world of cervical cancer." (Fischman, 2006). Similar

progress is being made in developing vaccines for other types of cancer. Should these and related developments be successful, they would completely change the degree of protection required for the disposal of high-level radioactive wastes.

Supporting the importance of such developments, in terms of how the detrimental effects of cancer are viewed, is the following statement of the National Council on Radiation Protection and Measurements (NCRP, 1995):

> "One of the most important factors likely to affect the significance of radiation dose in the centuries and millennia to come is the effect of progress in medical technology. Medical progress achieved during the past several decades has reduced the risk of premature death and increased the average age of the population, leading to a relative increase in diseases prevalent in the elderly, *e.g.*, cancer." … "At some future time, it is possible that a greater proportion of somatic diseases (diseases such as cancer) caused by radiation will be treated successfully. If, in fact, an increased proportion of the adverse health effects of radiation prove to be either preventable or curable by advances in medical science, the estimate of long-term detriments may need to be revised as the consequences (risks) to future populations could be very different." (NCRP, 1995, Report No. 121, Section 4.2.2.3).

<u>Cautionary Notes</u>

In this regard, however, it is important to note that, even if a method for curing or preventing cancer is developed, this will not eliminate the health concerns of radiation. One of the remaining concerns will be the potential for hereditary effects. In this case, however, the concern appears to be even less. After a detailed review and evaluation of the latest information on human genetic disease and the mechanisms of radiation-induced genetic mutation, the BEIR VII committee concluded that the application of a new approach to genetic risk estimation leads the committee to conclude that:

> "At low or chronic doses of low-LET irradiation, the genetic risks are very small when compared to the baseline frequencies of genetic disease in the population." (NRC, 2006, page 12).

Another potential concern would be mental retardation. This effect, which is of concern in terms of exposures to the children of mothers during pregnancy, has been shown to be primarily of importance for exposures that occur during the period from 8 weeks to 15 weeks after conception. A similar but smaller effect has also been detected following exposures that occur during the period from 16 weeks to 25

weeks (ICRP, 1991, paragraph 92, page 23). In terms of the proposed Yucca Mountain repository, however, the concern should be small. As noted in the BEIR VII report, these effects occur only “at high doses.” (NRC, 2006, page 1). Any effects that might be anticipated, due to operations in the proposed Yucca Mountain repository, would be extremely small.

Other Potential Health Benefits of Interim Storage

Another benefit is that the suggested 100 year storage period would enable the U.S. Department of Energy (DOE) to incorporate new technological developments into the repository design while, at the same time, gather additional data to enhance their documentation that the proposed facility will perform as they anticipate, and to identify design and procedural changes that would further improve the retention of the waste.

Another advantage, which certainly has a strong relation to public health and safety, is that the storage of the spent nuclear fuel and high level waste in a single centralized and geologically safe facility, rather than at about 100 interim nuclear waste disposal facilities (about 70 of which are at commercial nuclear power plant sites) throughout the country, would vastly increase the level of protection against potential human intrusion, terrorist attacks, as well as against the impacts of large aircraft crashes, whether deliberate or accidental. Another advantage is that the capabilities for security protection, as well as the ability to correct any failures in the waste canisters, would be vastly superior to those that could be provided at each of the 100 existing storage sites.

The Nuclear Waste Management Organization (NWMO, 2005), created by the Canadian Government in 2002 under the Federal Waste Act, is following a similar approach. Their time frame for completion of a repository, however, is significantly longer (300 years) as compared to the 100 year time frame suggested for the United States. So as to avoid storage of the waste at multiple individual reactor sites, Canadian authorities are also moving forward with plans for the development of a centralized facility for interim storage of the waste.

2. In your proposal, you also state that during the proposed 100 year storage period, many significant technological developments will occur which could change the best approach for the final disposal of radioactive waste. Given that these new reprocessing technologies are unproven and, if viable at all, are still potentially 20 60 years away, can we say anything today about the health effects of the radiation these technologies will produce?

While newly developed reprocessing technologies should not be applied without careful review and evaluation, there appear to be multiple benefits in the resumption of the reprocessing of spent nuclear fuel. Several of these are discussed below:

1. Although proven only at the laboratory scale, the UREX + Process (developed at the Argonne National Laboratory East) for removing the transuranic radionuclides (^{237}Np, ^{239}Pu, and ^{241}Am) from spent fuel, appears especially promising. Because the degree of separation is more efficient than was available with previous technologies, the toxicity of the waste thus produced would be orders of magnitude less than that of spent nuclear fuel.

2. Once removed, the highly toxic transuranic radionuclides could be used as fuel in commercial nuclear power plants and, through this process, converted into shorter lived fission products that would, in general, be far less toxic.

3. Another potential public health benefit would be that the application of these new techniques would reduce the volume of the waste that would need to be handled, transported, and disposed. While this would also involve other considerations, the potential benefits are promising.

4. The high-level radioactive waste, produced through the application of the improved separation techniques, would yield a much reduced heat load. This would significantly improve the performance of the proposed repository. Although these changes would not necessarily yield an immediate health benefit, they would certainly do so in terms of the long-term performance of the proposed repository and its projected health impacts on future generations.

<u>Other Considerations</u>

As question #2 reminds us, it will be necessary to expand the capabilities of the UREX + Process so that is can be applied on an industrial scale. Nonetheless, its effectiveness in separating the transuranic radionuclides from the fission products has such promising benefits that I believe that DOE would be remiss not to undertake this effort. Although this could require as much as 10 to 30 or more years

to accomplish, the suggested 100 year storage period should provide the time necessary to accomplish this goal. When considered in conjunction with the potential reductions in health effects (described in the response to question #1), this technology would certainly appear worthy of exploration.

At the same time, however, it must be acknowledged that the resumption of chemical processing and the implementation of the suggested new approach is not a one-way street. While it is anticipated to have multiple benefits, a change in any component of the waste disposal system will have impacts on other components. For this reason, the suggested changes will need to be implemented in a prudent and cautious manner. While there will undoubtedly be some surprises, the long-term benefits are considered to be well worth the effort.

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RESPONSES TO QUESTION FROM SENATOR BOXER

Prelude: Near the conclusion of the Hearings, Senator Barbara Boxer asked Dr. Moeller to comment on a report by Dr. Thomas B. Cochran, of the Natural Resources Defense Council, that included the statement that a lifetime dose at a rate of 350 mrem per year would create "a one in five risk" of fatal cancer for the general population, and "a one in four risk" for women. In so doing, Dr. Moeller addressed the following question.

1. Is a "one in four risk" of fatal cancer for a woman exposed to 350 millirems per year of cancer acceptable?

The thrust of the response provided by Dr. Moeller was as follows:

Senator Boxer, your estimate from Dr. Tom Cochran, whom I know very well, sounds to me to be high. But to answer your question, if indeed his calculations were correct and a dose rate limit of 350 millirems a year would create a one chance in four of a woman dying of cancer during her lifetime, "that would be totally unacceptable. No one would approve that."

Additional Assessments

Subsequent to the hearings, the following review and evaluation of the risk of such a lifetime dose rate for women has been estimated. The results are as follows.

According to the BEIR VII committee, which, under the auspices of the National Research Council, has just completed a detailed review and evaluation of the latest information on the health effects of ionizing radiation, the risk to women of fatal cancer due to exposure to ionizing radiation is 660×10^{-4} Sv^{-1} (NRC, 2006, Table ES-1, page 15). Assuming a woman were to receive a lifetime (70 years) radiation dose at a rate of 350 mrem per year, her total dose would be:

$$(350 \text{ mrem/year})\ (1 \text{ rem}/1000 \text{ mrem})\ (70 \text{ years}) = 24.5 \text{ rem}.$$

Since 24.5 rem is equal to 0.245 Sv, the estimated increase in fatal cancer risk that a group of women so exposed would incur would be:

$$(660 \times 10^{-4}\ Sv^{-1})\ (0.245\ Sv) = 0.016 = 1.6\%.$$

That is to say, under the stipulated conditions, 1.6% of the women so exposed could die of cancer.

The risk estimated by Dr. Cochran (one chance in four) is equivalent of 25%. This is a factor of:

$$(25\%) \div (1.6\%) = 15.6.$$

times the estimate based on the latest guidance provided by the BEIR VII committee.

Conclusion:

On the basis of these analyses, one can conclude that the risk estimated by Dr. Cochran, due to a total dose of 0.245 Sv, vastly exceeds the amount that such a dose would be expected to create. For purposes of perspective, it might be noted that the "natural" risk of fatal cancer among women residing in the United States is 19.78% (NCI, 2005). Rounding this off to 19.8%, the total risk of fatal cancer to a group of women, under the presumed circumstances, would be:

$$(19.8\%) + (1.6\%) = 21.4\%.$$

On this basis, even the estimated risk of fatal cancer due to a postulated dose of 0.245 Sv, combined with that due to the "natural" background risk, would be less than the "one chance in four" risk ascribed by Dr. Cochran to the postulated dose alone.

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Implications of Risk Quantification on the Ruling of the Court of Appeals

Introduction

On July 9, 2004, the United States Court of Appeals ruled that the "10,000-year compliance period selected by EPA violates section 801 of the Energy Policy Act (EnPA) (U.S. Congress, 1992) because it is not, as EnPA requires, 'based upon and consistent with' the findings and recommendations of the National Academy of Sciences." (U.S. Court of Appeals, 2004) This being the case, the Court ruled that it was incumbent upon EPA to establish a dose rate limit extending from 10,000 to one million years. In contrast, close examination reveals that the recommendation of the National Research Council Committee on Technical Bases for Yucca Mountain Standards (NRC, 1995, pages 6-7) stipulated that the "assessment be conducted for the time when the greatest risk occurs …" Compliance with the ruling of the Court would, therefore, require that the EPA proposed *dose rate limit* be converted into an equivalent limit in terms of *risk*. This can be accomplished only if data on the health effects (cancer risks) per unit of radiation exposure to a *future* U.S. population, anticipated to exist 10,000 or more years from now, can be estimated. The ramifications of such a task are discussed in the sections that follow with the conclusion that the risk cannot be estimated. The implications of how the scientific issues discussed below impact the implementation of the ruling of the Court of Appeals is strictly that of Dade W. Moeller.

Sources of Information on Radiation Risks

Radiation health-effects experts world-wide agree that the primary sources of data on the cancer related risks of ionizing radiation are those generated through the epidemiological studies of the survivors of the World War II atomic bombings in Japan.

Transfer of Risk Estimates to the U.S. Population

Although the Japanese data are comprehensive, they are directly applicable only to the population group that was exposed at the time of the bombings. They cannot be applied, without modification, to the U.S., or any other population, particularly for interpreting the health effects from potential radionuclide releases from the proposed Yucca Mountain high-level radioactive waste repository. Even more importantly, they cannot be applied under any conditions for assessing the risks of exposures that occur 10,000 to 1 million years into the future. This is due to a host of reasons, the most prominent of which can be described as follows:

- The exposures in Japan involved relatively high doses received at high dose rates. In contrast, potential radionuclide releases from the proposed repository will involve low doses received at low dose rates. This is important because the health effects, per unit dose, received at low rates are less than those received at high dose rates. This difference is taken into account through the application of what is called a Dose and Dose Rate Effectiveness Factor (DDREF).

- The *baseline* risks for specific cancers within a population play a dominant role in terms of the magnitude of the excess cancer risks due to radiation exposures. Since the baseline risks for specific cancers within the U.S. population are not the same as those for the Japanese population, there are country-to-country, or *spatial*, differences in the risks of cancer in different body organs.

- The characteristics of the U.S. population in the *future* will be different than they are today. This means that there will be *temporal* differences in the risks of cancer in different body organs, per unit of dose – now as contrasted to the future.

Challenge #1: Converting Health Effects of High Dose and Dose Rates to Low Dose and Dose Rates

Based on extensive reviews and evaluations, the International Commission on Radiological Protection (ICRP, 1991, paragraph B62, pages111 - 112), and the National Council on Radiation Protection and Measurements (NCRP, 1993, Section 7, page 29), have recommended that, for the evaluation of the health effects (per unit dose) of low dose and dose rate exposures, the estimated risks (increased cancers) observed among the Japanese a-bomb survivors be divided by a factor of 2.0. As noted above, this is known as the dose and dose rate effectiveness factor (DDREF). Although the BEIR VII committee recommended a value of 1.5 for DDREF (NRC, 2006, page 274), the value being almost universally applied today is 2.0.

Challenge #2: Transfer of Risk Estimates to the U.S. Population

Once the health risks have been modified, taking into account the dose and dose rates, the next step is to interpret (or translate) the risks from the radiation exposures that were observed among the Japanese population, to those that would be anticipated for people *currently* living in the United States. To accomplish this task, it is necessary to account for critical differences in the characteristics of the populations in the two countries.

Epidemiologists use the term, “risk,” for describing the excess health effects (e.g., cancer incidence and mortality) observed in populations who have been exposed to radiation. One methodology that has been developed for this purpose is the Excess *Relative Risk* (ERR) model. The basis for this model is that the excess risk of developing a specific cancer, due to radiation exposure, is assumed to be proportional to the baseline risk, and that the proportionality (percentage increase) due to a unit dose of radiation will be the same for the U.S. population as for the Japanese population.

Data show that the baseline risks for cancers of the colon, lung, female breast, and male prostate are higher in the U.S. population than in Japan. In contrast, the baseline rates for cancers of the stomach and liver are higher in Japan (NRC, 2006, pages 269 and 275). In applying the concept of proportionality, it is assumed that if a given radiation exposure increases the baseline risk of a specific cancer in the Japanese population by 10%, it will do likewise in the United States population. In a sense, this implies that the higher rates of colon, lung, female breast, and male prostate cancers in the United States mean that the U.S. population is more susceptible to these cancers. That being the case, they will similarly be assumed to be more susceptible to these same cancers, if exposed to radiation. Extending this concept, if vaccines (similar to that for cervical cancer) are developed for preventing additional types of cancers, and their baseline rates are reduced, then the probability of those cancers being caused as a result of being exposed to radiation will be similarly reduced. That is, if a vaccine reduces the baseline rate for a specific cancer, it will be assumed to reduce the probability that radiation will cause that same cancer.

Further complicating the transfer of data from one population to another is that the lifestyles and baseline cancer rates in populations do not remain constant with time. This was exemplified by the changes that occurred in the rates for cancers of the stomach, colon, lung, and female breast, among the Japanese population during the period from 1950 to 1988. This was attributed to the fact they were becoming more “westernized.” (NRC, 2006, page 268).

Challenge #3: Transfer of Risk Estimates to Future U.S. Populations

In contrast to the discussion above, the ruling by the Court of Appeals stipulated that a dose rate limit be established for the time-period from 10,000 to one million years after closure of the proposed repository. Again, it is important to note that, while the National Research Council Yucca Mountain Committee (NRC, 1995) recommended that compliance be assessed on the basis of the time of "greatest risk," the Court stipulated that EPA promulgate a dose rate limit for purposes of determining compliance. The only way that a dose rate limit, regardless of its magnitude, has any relevance is if the risk of cancer, associated with that dose rate limit, can be quantified. As noted above, this depends on a host of characteristics of the presumed future population. Only after those characteristics have been defined, can such a transformation be made. That this will be a daunting task is exemplified by the example, discussed immediately above, of the impacts of "westernization" on the Japanese population. This occurred during a period of less than 4 decades. Currently, there is no scientific basis for projecting the changes that will occur during time-periods ranging from 10,000 to one million years.

Since there are multiple characteristics that determine the risks of cancer among exposed members of a population, and many of these are organ specific, this means that a host of characteristics, lifestyles, medical practices, and other factors, within the postulated *future* population must be specified. The examples that follow illustrate the magnitude and challenges of this task. :

- Cancer screening approaches, such as colonoscopies, during which pre-cancerous lesions can not only be detected, but also removed, thus reducing the incidence of colon cancer. *Note*: Such a statement presumes that colonoscopies will still be the common among populations living 10,000 to a million years from now! The same general concept applies to the other examples that follow.

- Procedures for vaccinating children for chronic hepatitis B, since such a practice reduced the incidence of liver cancer. In contrast, the increasing rate for Hepatitis C, for which a vaccine does not exist today, may lead to an increase in liver cancer.

- The age at which women have their first child – the younger the age the less risk they have of developing breast cancer in the future.

- The racial composition of the population. African-American men, for example, have higher rates of prostate cancer. In a similar manner, genetic susceptibility to cancer is different for various races.

Since, as noted, the National Research Council Committee (NRC, 1995, pages 6-7) recommended that "compliance assessment be conducted for the time when the greatest risk occurs …," it will be necessary to convert the EPA 3.5 mSv (350 mrem) per year dose rate limit (EPA, 2005) into an equivalent risk rate limit. If this is to be accomplished in any reasonably accurate manner, it will be necessary to know the baseline rates for all types of cancer at that time. This, in turn, will require having accurate information not only on the information listed above, but also on:

- How long members of the exposed population are anticipated to live – the risk of cancer increases with longevity, as well as the distribution of the population by age, since the susceptibility to cancer varies with age.

- Projections of future developments of cancer preventive therapies – most especially vaccines for cancers in specific body organs.

- The anticipated exposure of the population group to other carcinogens, such as tobacco.

In short, data will be needed on their age distribution, life spans, baseline cancer rates, exposures to other carcinogens, and dietary habits. In addition, it would require an accurate projection of the status of medical care, medical technology (including the availability of artificial lungs, stomachs, livers, etc.), and multiple other items of information relative to the postulated *future* population.

Conclusions and Commentary

The recommendation of a dose rate limit, without the ability to estimate the risk that it would represent, would provide essentially no benefit in terms of protecting future population groups. Unless the items of information enumerated above can be made available, it will not be possible to provide a useful dose rate limit. Since the data are not available (and cannot be projected), one can only conclude that it is not scientifically possible for EPA to respond to the ruling of the Court in any meaningful manner.

What the Circuit Court failed to recognize is that the time of "greatest risk" will not necessarily coincide with the time of "peak dose." The relationship between dose and risk is not linear with time, especially when dealing with tens of thousands to a

million years. The time of peak dose could, in reality, occur at a time of minimum risk.

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